

*Technology options for feeding 10 billion people*

**Interactions between climate change & agriculture  
and between biodiversity & agriculture**

Annexes



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**Annexes**

IP/A/STOA/FWC/2008-096/Lot3/C1/SC5-SC9

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## **AUTHORS**

Underwood, E.; Poláková, J.; Kretschmer, B.; McConville, A.J.; Tucker, G.M. - IEEP  
Dooley, E.; Naumann S.; Frelih-Larsen, A. - Ecologic Institute  
Berman, S.; Sarteel, M.; Tostivint, C. - BIO Intelligence Service  
van der Grijp, N.M. - Institute for Environmental Studies, VU University  
Maxted, N. - School of Biosciences, University of Birmingham

## **STOA RESEARCH ADMINISTRATOR**

Lieve Van Woensel  
Science and Technology Options Assessment (STOA)  
Directorate for Impact Assessment and European Added Value  
DG Internal Policies, European Parliament  
Rue Wiertz 60 - RMD 00J012  
B-1047 Brussels  
E-mail: [lieve.vanwoensel@ep.europa.eu](mailto:lieve.vanwoensel@ep.europa.eu)

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This document contains the annexes of the study titled 'Interaction between climate change & agriculture and between biodiversity & agriculture'.

## **Abstract**

There will be rising global demand for food and energy from the land over the coming decades resulting from population growth and economic development. This will coincide with the need to adapt agriculture to increasing climate-related threats (which will probably outweigh opportunities in Europe), whilst decreasing the impact of agricultural emissions on climate change. At the same time, biodiversity losses due to intensive agricultural practices and abandonment of biodiversity-rich farming are expected to continue. The long-term sustainability of farming is being undermined by trends such as soil degradation, declines in pollinators, the loss of natural biological control of pests and diseases, and the loss of plant and animal genetic diversity. Substantial changes in agricultural systems are required in Europe to ensure rapid reductions in agricultural emissions of greenhouse gases, as well as effective adaptation to climate change and strengthened biodiversity conservation. This report describes a range of practices and developments in agriculture that could sustainably increase agricultural productivity whilst contributing to climate change mitigation and adaptation, and providing biodiversity benefits. Policy could play a larger role in supporting innovation and development in the full range of agricultural systems in Europe and in the use of certain wastes and residues for energy purposes. The report provides a set of recommended options for incentivising beneficial actions, constraining unsustainable practices, and promoting innovative options whilst ensuring environmental safeguards for new technologies that might have unwanted negative impacts on biodiversity.

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*For further information about IEEP, see our website at <http://www.ieep.eu> or contact any staff member.*

*London Office*

15 Queen Anne's Gate

London, SW1H 9BU

Tel: +44 (0) 20 7799 2244

*Brussels Office*

Quai au Foin, 55

Hooikaai 55

B- 1000 Brussels

Tel: +32 (0) 2738 7482

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Poláková J, Naumann S, Dooley E., and Freluh-Larsen A.

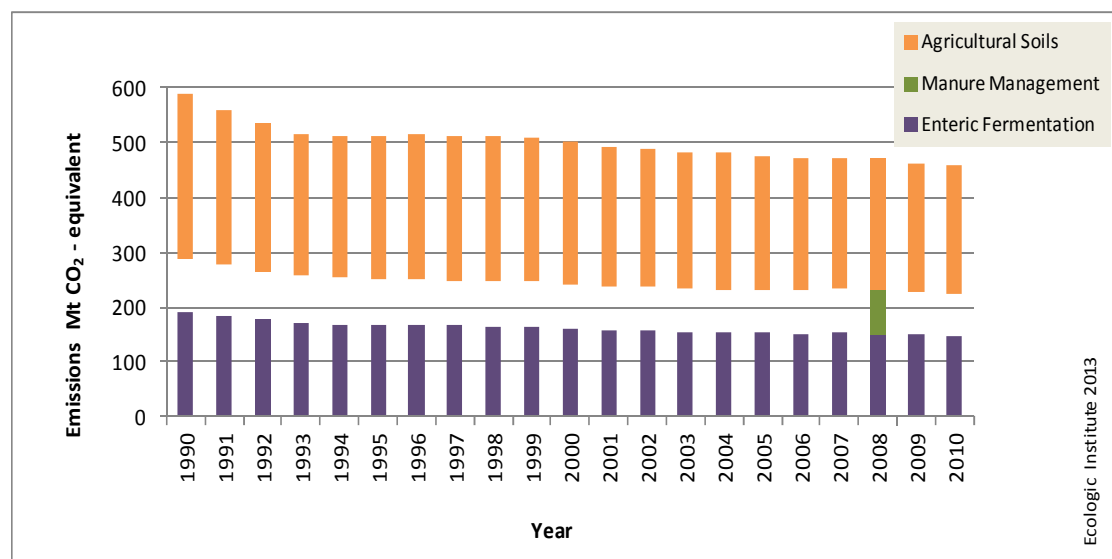
### **2.1. Greenhouses gases and their sources and trends**

Despite the reductions of the last two decades, the agricultural sector still accounts for 9.8 per cent of greenhouse gas (GHG) emissions in the EU-27 (Figure A2-1) (EEA, 2012).<sup>1</sup> Depending on environmental and climatic conditions, the relative economic importance of agriculture, and the prevailing farming systems, the agricultural share of emissions within national totals varies considerably in individual Member States (Figure A2-2).

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<sup>1</sup> Emissions from land use, land use change and forestry are not taken into account in the calculation. Reference year is 2010.

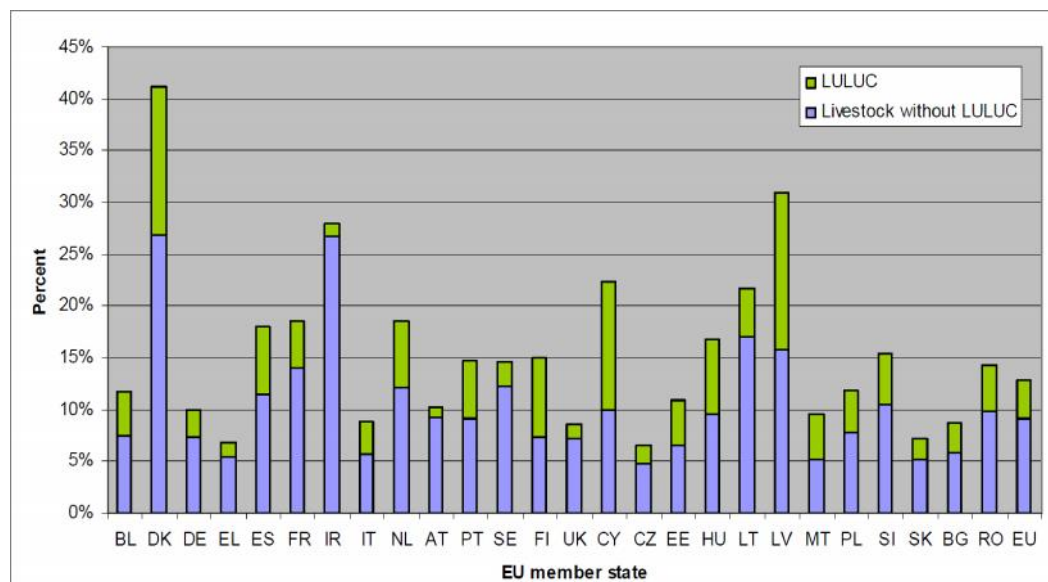
**Figure A2-1 GHG emissions from the EU agricultural sector between 1990 and 2010**



Source: own elaboration based on data from (EEA, 2012)

Note: Data include emissions from agricultural soils, manure management and enteric fermentation

**Figure A2-2 GHG balance of livestock production per Member State in relation to total national GHG emissions**



Source: (Leip et al, 2010)

Note: GHG data for livestock production are based on life cycle assessment modelled by CAPRI; total GHG data are based on National Inventories for UNFCCC reporting.

## 2.4 Other aspects of the European food chain: dietary change

In addition to measures directly targeting agriculture itself, there are other means of reducing emissions from the food chain as a whole, including in the processing and distribution components and in changing dietary patterns (see Figure A2-3).

A recent study on changes in dietary choices concludes that a completely vegetarian diet in the EU could lead to a maximum reduction in emissions of 266 Mt CO<sub>2</sub> eq. per annum, of which 209 Mt CO<sub>2</sub>-eq would occur within the EU. A slightly lower reduction would be expected from a shift to a “healthy diet”, involving lower calorie intake and more fruit and vegetables than the current diet, ie a reduction of emissions of 195 Mt CO<sub>2</sub>-eq, of which 200 Mt CO<sub>2</sub>-eq in the EU. A shift to a diet with a day without animal proteins would achieve a reduction of 50 Mt CO<sub>2</sub>-eq, of which 39 Mt CO<sub>2</sub>-eq would be in the EU. These calculations do assume however that all consumers switch to a given diet (Faber et al, 2012).

Another study concludes that potential reductions in food waste and change in dietary choice to reduce meat consumption in Europe would reduce the overall GHG impact of the EU livestock sector more profoundly than mitigation efforts at farm level (Bellarby et al, 2013). See Figure A2-4 for details of estimated reductions.

Barriers to changes in dietary choice include a range of behavioural factors, such as lack of consumer knowledge on the impacts of food, varied cultural traditions that affect the customary diet, habitual behaviour (Faber et al, 2012). Policies to address these barriers might include meat or animal protein taxes and awareness raising campaigns (eg mass media campaigns, school-based interventions, food product labelling) (Bellarby et al, 2013; Caspari et al, 2009; Faber et al, 2012; Poláková et al, 2013b). Data on the effectiveness of these potential policies are scarce, so evaluating them is difficult. Faber et al (2012) estimate that a full policy package could reduce the climate impact of the EU diet by about a quarter.

**Figure A2-3 Emission reductions from mitigation options in the livestock sector**

Description	Emission savings in Mt CO <sub>2</sub> e per year	Emission reduction in%*	Reduction in consumption in%
<b>Production related mitigation options</b>			
Choice of production system to grass-fed beef	12–26	2–4	X%
Grassland management	4–10	1–2	0
<b>Consumer-impacted mitigation options</b>			
Eat no beef from South America	22–31 <sup>†</sup>	3–5	4
Eat no meat from European beef suckler herd	67–94	10–14	32–45
One less serving of milk or 20 g less cheese (per week)	15–19	2–3	4
<b>Waste reduction (waste rate of 2.4–3.9%)</b>			
Waste minimization	56–115	8–17	0
Anaerobic digestion of unavoidable waste	14–22	2–3	0
<b>Technical approaches</b>			
Anaerobic digestion of all food waste	46–71	7–11	0
Combined techno-fixes	51–60	8–9	0
<b>Totals<sup>‡</sup></b>			
No reduction in consumption <sup>§</sup>	101–207	15–31	0
Additional reduction in consumption <sup>¶</sup>	216–377	33–57	32–45

\*From a scenario II (Weiss & Leip, 2012) total adjusted to 2007 of 661 Mt, the total level of emissions from meat produced in Europe with LUC.

<sup>†</sup>Range is from without LUC to with LUC.

<sup>‡</sup>*Low* estimates do not include waste reduction, but digest all food waste, *high* estimates are a combination of high levels of waste minimization and anaerobic digestion of unavoidable waste at a waste rate of 3.9% (reduced from 12.5%); furthermore, other low/high estimates are utilized where available.

<sup>§</sup>Only technical approaches are used – also see note <sup>‡</sup> in regard to waste; furthermore, only grassland management is included under ‘production-related emissions’ as a change to a grass-fed system would likely indirectly result in an unknown level of reduction in consumption.

<sup>¶</sup>To the total mitigation potential with no reduction in consumption, mitigation options are added that do result in a reduction in consumption listed under ‘Consumer-impacted mitigation options’ as well as the choice of production system.

Source: (Bellarby et al, 2013)

**Figure A2-4 Impact of reductions in consumption of livestock products by European consumers**

Action	Livestock sector	Total Mt product	Total savings of CO <sub>2</sub> e emissions in Mt per year	Change in consumption per person g (%) per week
Eat no beef from South America*	Beef import	0.3	22–31	–12 (–3.5)
Eat no meat from European beef suckler herd <sup>†</sup>	Beef suckler	2.6–3.7	67–94	–106 to 149 (32–45)
One less serving of milk or 20 g less cheese (per week) <sup>‡</sup>	Dairy	6.6	9–11	–200 (–4.3)
A reduction in dairy products (reducing the dairy herd would also decrease the amount of meat) <sup>‡</sup>	Beef dairy	0.3	6–8	–12 (–3.5)

\*Range given for beef raised on historic grassland and partly on newly deforested land.

<sup>†</sup>Assuming that between 32 and 45% of European beef is produced from suckler herds at a replacement rate of 33% and 20%, respectively (see section 2.1), with a higher carbon footprint of 25.5 kg CO<sub>2</sub>e kg<sup>–1</sup> product (Table 8).

<sup>‡</sup>Range given for scenario I–II according to Weiss & Leip (2012).

Source: (Bellarby et al, 2013)

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## **ANNEX TO CHAPTER 3 MANAGEMENT ACTIONS IN EU AGRICULTURE FOR MITIGATION AND ADAPTATION AND THEIR RELATIONSHIPS TO INCREASED FOOD PRODUCTION**

Poláková J, Naumann S, Berman S., Dooley E., and Freluh-Larsen A.

Detailed analysis of management actions that could help European agriculture respond to climate change.

### **Livestock management**

#### *Description of key management actions*

1. Optimising manure application: Shallow incorporation, spreading, broadcasting; deep incorporation, injection; avoiding application in autumn and winter (results in higher use efficiency of N manure), avoiding application on slopes
2. Improved manure processing: including the introduction of anaerobic digestion for methane recovery from manure for biogas for energy
3. Optimising manure storage and improving outdoor storage: Covered storage in tanks, reducing surface area; composting; passively aerated compost; reducing airflow; lowering pH; cooling
4. Feeding techniques to improve digestive nutrient capture, changes to livestock diets: For example, adjusting the protein supply in terms of nitrogen to the nutritional demand of cattle, pigs and poultry to reduce nitrogen content in animal manure.
5. Adjust dietary intake by livestock or manipulate the rumen to address enteric fermentation
6. Improved livestock breeding: Robust species, species with increased productivity
7. Improvement of animal rearing conditions/ animal health and welfare: For example, control of disease and infections, adjusting shading, air conditioning and sprinklers to cool livestock and turning livestock out to pasture earlier.

Table A3-1 Key actions for climate change mitigation and adaptation in livestock management

Actions	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity	Costs of the technology	Main studies
	Mitigation	Adaptation	Benefits	Trade-offs			
1. Optimising manure application	Many application possibilities are available for manure, with best practices requiring even application, quick incorporation into soils, far from water bodies, on dry soil, etc. Such practices will reduce CO <sub>2</sub> and N <sub>2</sub> O emissions	Not identified	Reduces nitrate leaching and thus water pollution Reduces odours Manure application increases SOM in soils with beneficial impacts for water retention and soil biodiversity	Possible trade-offs with ammonia volatilisation (trans boundary air pollution issues) and pollution transfer from air to soil	<b>+</b> Similar to optimised mineral fertiliser application	<b>Moderate</b> Equipment and training for farmers may increase costs, but efficient application reduces input losses and may result in yield increases.	(Flynn et al, 2007); (Baltic deal, 2012)
2. Improved manure processing (including introduction of anaerobic digestion for methane recovery from manure for	Reduces CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O emissions through various techniques, including methanisation, slurry acidification, etc.	Can reduce dependency to fossil fuel energy (eg for heating farm buildings)	Reduces the volume of substrate to put on land, with possible effects on machinery fuel use	Possible increase in other emissions (N,P) if no post-processing, as it concentrates the substrate	<b>+</b>	<b>High</b> High capital investment in equipment, but multiple benefits from reduced energy use, fuel for spreading on land, storage	(Béline et al, 2004); (Martinez et al, 2009); (Hjorth et al, 2010)

Actions	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity	Costs of the technology	Main studies
	Mitigation	Adaptation	Benefits	Trade-offs			
biogas energy)						costs, and potential reuse of by-products (eg, replace straw for cattle stalls)	
3. Optimising manure storage and improving outdoor storage	Much of the emissions from manure derive from storage. Better management can decrease emissions of CH <sub>4</sub> and N <sub>2</sub> O	Not identified	Benefits for soil and air quality	Not identified	0	<b>Moderate - High</b>  Investment in new storage equipment can require large capital costs.	(Flynn et al, 2007) (Baltic deal, 2012)
4. Feeding techniques to improve digestive nutrient capture, changes to livestock diets	Ensuring that the animal feed mineral content is adapted to what the animals can digest; to avoid losses in manure and slurry allows to reduce emissions of CH <sub>4</sub> , N and P from livestock	Not identified	Reduces nitrate leaching and therewith also water pollution. Feeding low crude protein to pigs may reduce nitrogen outputs by 20 to 50% and reduce water intake and the volume of slurry.	Not identified	+	<b>Moderate</b>  Cost of the feed additives, know-how, information, and research to identify best techniques.	(Relandeau, Van Cauwenberghe, and Le Tutour, 2000); (AEA, 2008); (Dourmad, Rigolot, and Jondreville, 2009); (Ecologic, 2010);



Actions	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity	Costs of the technology	Main studies
	Mitigation	Adaptation	Benefits	Trade-offs			
			More efficient use of resources				
5. Adjust dietary intake by livestock or manipulate the rumen	Reduces CH <sub>4</sub> emissions from the rumen by 10-25% (genetic modification of rumen microflora); by 10-15% (bovine somatotropin, BST, and bovine growth hormone, BGH); 10-25% (Ionophores).	Not identified	Not identified	Not identified	+	<b>High</b> High cost for genetic engineering options, research, and hormone intake options, which may be unacceptable for farmers and/or consumers.	(AEA, 2008)
6. Livestock breeding <sup>2</sup>	Cattle selected for high productivity can produce 8-11% less CH <sub>4</sub> (in terms of dietary gross energy) than animals selected in	Better adapted livestock breeds will be more resilient to the changing climate	Not identified	Not identified	+	<b>Moderate</b> Time to breed and select livestock through further research, trade-offs with other	(AEA, 2008)

<sup>2</sup> Livestock breeding and its effect on agricultural productivity is the focus of STOA Study 2.

Actions	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity	Costs of the technology	Main studies
	Mitigation	Adaptation	Benefits	Trade-offs			
	a pasture system.				situation related impacts)	selection traits, and GM techniques all incur costs. Low acceptability.	
7. Improvement of animal rearing conditions/ animal health	Not identified	Reduced pest/disease risk	Not identified	Not identified	<b>+</b> May increase survival rate and health of animals.	<b>Moderate</b> Farmers may incur time, labour, and capital costs compared to factory farms, but reduce costs from diseases and pests.	(AEA, 2008); (Ecologic, 2010)

### ***Priorities for mitigating climate change from livestock management.***

This table (Table A3-1) lists an important group of actions that target the reduction of enteric CH<sub>4</sub> emissions by improving animal performance; the reduction of CH<sub>4</sub> emissions by improving feeding practices; the reduction of CH<sub>4</sub> emissions from manure and the reduction of N<sub>2</sub>O emissions from manure. These actions are also linked to the reduction of non-CO<sub>2</sub> emissions from grazed pastures (see below).

Some technologies, such as the use of nitrification inhibitors in manure management, may have very high costs. It is also of note that certain manure treatments technologies may be implemented at various levels, for example methane recovery by anaerobic digestion on farm is possible, but bigger installations that group several farmers may be more cost-efficient.

In prioritising the mitigation activities for livestock farming it is important to avoid pollution transfers. Trade-offs exist between air and water pollution, as well as between different pollutants. For example, reducing emissions to air often increases the risk of nitrate leaching to water and the reduction of CH<sub>4</sub> emissions by methane recovery from manure by anaerobic digestion increases the concentration of N and P in the residues that are often spread on land, unless post-processed, leading to an increased risk of these pollutants leaching. A comprehensive assessment of the impacts is therefore needed in particular situations.

Several potentially highly effective mitigation strategies for reducing the GHG emissions associated with the EU livestock sector require action beyond the farm gate and include information campaigns addressing consumer behaviour and change in diet.

### ***Priorities for adapting livestock management to climate change.***

The improvement of animal rearing conditions, improved manure processing and treatment and livestock breeding could all help livestock farms adapt to climate change. Improved animal rearing conditions could reduce the pressure of diseases and pests expected to increase with climate change. Use of methane recovery from manure could be used for heating or cooling farm buildings and could thus reduce the footprint associated with fossil fuel energy. Better adapted livestock breeds could be more resilient to the changing climate. All these mitigation actions would incur moderate capital costs, time and labour but could have a positive impact on future productivity of farms. Actions to increase resilience of livestock to frequent variations in climate will also be important; this can be achieved by selection of better adapted species and breeds, with or without genetic engineering.

## **Grazing land and pasture management**

### *Description of key management actions*

8. Reducing and optimising use of fertiliser
9. Maintenance of permanent grasslands/ pasture: Maintaining 'permanent pasture' or land used to grow grasses or other herbaceous forage that has not been included in crop rotation of the holding for five years or longer.
10. Optimising grazing intensity (length and timing of grazing to avoid overgrazing): refraining from grazing during wet periods; applying rotational grazing: animals are regularly moved between pasture areas in such a way as to avoid damage to the turf and optimize forage growth.
11. Grassland renewal: Actively improving the composition of grassland eg by controlled deferred grazing, overseeding and resowing.
12. Establishing shelterbelts: A barrier of trees or shrubs. The term 'field shelterbelt' is used to distinguish between rows of trees or shrubs on agricultural fields from those planted in other ways: around farmyards or livestock facilities (farmstead shelterbelts), on marginal lands to change land use or in block plantings to provide woodlots

Table A3-2 Key actions for climate change mitigation and adaptation in grazing land and pasture management

	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity of agriculture	Costs of the practice	Main Studies
	Mitigation	Adaptation	Benefits	Trade-offs			
8. Reducing and optimising use of fertiliser	May reduce CO <sub>2</sub> from soils by 78 k tCO <sub>2</sub> eq <sup>3</sup> ; soil C accumulation rate on extensified areas: 1.02%/year; reduced indirect CO <sub>2</sub> emissions from lower fertiliser requirements	Reduces threat of leaching into water bodies	Reduction of residual soil nitrate available for leaching in autumn; for a long-term reduction in soluble P loss	Not identified	<b>-/+</b> Depending on the crop type, a drop in crop yield is expected (due to reduced agricultural input).  Likely to be positive if optimised in longer term	<b>Low</b>  Farm costs can be reduced by purchasing less agricultural input.  But there can be opportunity cost associated with lower agricultural product produced	(Flynn et al, 2007); (AEA, 2008); (Koleva and Schneider, 2009); (Ecologic, 2010);
9. Maintenance of permanent grasslands/pasture	High carbon sequestration rate: up to 10 t CO <sub>2</sub> /ha per year (over a period of 10 years)	May increase water holding capacity; benefits especially in areas prone to flooding.	May reduce nitrogen and phosphorus leaching, and prevent soil erosion	Not identified	<b>+/-</b> Depends on counterfactual and balancing grass with crop	<b>Low</b>  Opportunity costs	(Osterburg et al, 2009); (MARS, 2009) (Ecologic, 2010);
10. Optimising grazing intensity	Can influence the amount of carbon accrual in soils; carbon	Depending on local conditions (change in growing season,	Reduces soil erosion; reduces nitrate leaching due to manure	Higher use of energy for food and concentrates	<b>+</b>	<b>Low - Moderate</b>  Costs for fertiliser can be	(Flynn et al, 2007); (Smith et al,

	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity of agriculture	Costs of the practice	Main Studies
	Mitigation	Adaptation	Benefits	Trade-offs			
(length and timing of grazing to avoid overgrazing)	sequestration rate on optimally grazed pasture: CO <sub>2</sub> : 0.11 – 0.81 CH <sub>4</sub> : 0.02 – 0.00 [MtCO <sub>2</sub> eq./year]	rainfall patterns), grazing patterns may need to be adjusted to maintain productive capacity of grassland.	distribution across growing pastures; benefits biodiversity	Higher CH <sub>4</sub> emission from stored manure		decreased. Increased costs for: bringing more food to the stable; applying more animal manure (costs for work and machinery); enlarging manure storage capacity; more fodder conservation and concentrates.	2008)
11. Grassland renewal	Yes	Not identified	Reduces soil erosion	Not identified	+	(if it involves ploughing and reseeded)	(Flynn et al, 2007); (Smith et al, 2008)
12. Establishing shelterbelts	Creating below- and above-ground biomass (sequestering carbon) in case of establishing hedges	Reduce risks for soil and wind erosion	Provides protection from heat and wind for livestock and can increase the heat units in	Not identified	+	<b>Low - Moderate</b>	(Wall and Smit, 2005); (Iglesias et al, 2007b)

	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity of agriculture	Costs of the practice	Main Studies
	Mitigation	Adaptation	Benefits	Trade-offs			
	or lines of trees.		adjacent fields Can provide wildlife habitat				

### ***Priorities for mitigating climate change from grazing land and pasture management***

There are two key approaches to mitigating emissions through soil and land management in grasslands. The first is to protect the valuable carbon stocks where they exist. The second is to reduce N<sub>2</sub>O emissions from application of fertiliser, drainage and cultivation.

The actions with the highest overall potential for soil carbon sequestration are the maintenance of permanent grasslands/pasture and the avoidance of overgrazing leading to erosion of peatlands (Smith et al, 2008; Worrall et al, 2011a; Worrall et al, 2011b). Protection and maintenance of permanent grassland can prevent the release of GHG emissions up to 10 tonnes of CO<sub>2</sub> equivalent per hectare per year (Osterburg et al, 2009).

It is worth noting that there may be some conflict between the retention of permanent pasture to conserve stocks of soil carbon and measures to reduce the GHG emissions from livestock by adjusting their diet and rearing conditions, manure storage etc. There may be a complex trade-off between these two strategies, with different approaches being appropriate in different circumstances.

In highly productive grasslands, the reduced use of fertilizers and their optimal application are critical for abating N<sub>2</sub>O emissions from soils, as well as presenting a significant opportunity to reduce the CO<sub>2</sub> footprint associated with their production (Bellarby et al, 2013; DEFRA, 2008; UNFCCC, 2008). Avoiding the drainage of organic soils and ensuring low soil disturbance and permanent vegetation cover by carefully controlled grazing can also reduce N<sub>2</sub>O emissions. IPCC-derived literature continues to emphasise the important co-benefits provided for soil fertility and soil workability, water-holding capacity, nutrient cycling, and a range of other positive soil attributes through these mitigation actions aimed primarily at reducing GHG emissions eg(Smith, 2012).

### ***Priorities for adapting grazing and pasture management to climate change***

Depending on local conditions (change in growing season, rainfall patterns), grazing patterns may need to be adjusted to reduce the risk of effluent pollution and maintain productive capacity of grassland. Changing crop and grazing zones to reflect shifts in climatic conditions, eg maize expansion northward in Europe, has high potential to reduce crop losses and grassland damage (Olesen et al, 2012).

### ***Potential interactions between adaptation measures for livestock production and for grazing and pasture management***

Shifts in crop and grazing zones may facilitate changes in livestock management systems. For example a switch from grass-based systems to those based on fodder maize may well have a positive impact on production, but it could adversely affect climate change mitigation by driving the conversion of grassland to cropland. Reducing the area of permanent pasture may also have adverse consequences for climate change adaptation since it increases water holding capacity, thereby improving adaptive capacity of farms and wider rural areas in areas prone to flooding, or where the total amount and frequency of intense precipitation is expected to increase.



## Cropland management

### *Description of key management actions*

13. **More catch crops / green manure / winter cover / less fallow:** The provision of temporary vegetative covers between agricultural crops, which is then ploughed in to the soil.
14. **Diversified crop rotations:** Inclusion of different crop types in crop rotations (growing various crops on the same piece of land in a planned sequence).
15. **Adding legumes/N-fixing crops to rotation or undersowing:** Adding nitrogen-fixing crops, such as beans, peas, soya, Lucerne, to rotations of cereals. Legumes can be included into cereal rotations as a separate crop, as a second crop (when the land would otherwise be bare fallow) or under the major crop.
16. **Intercropping:** Growing two or more different crops alongside each other, for example, combining a fast growing crop with a slow growing crop.
17. **Zero tillage:** zero till (no-till) is a way of growing crops without disturbing the soil. This practice involves leaving the residue from last year's crop undisturbed and planting directly by drilling seeds through the residue.
18. **Conservation / reduced tillage:** Reduced tillage differs from zero tillage (in that the soil is still tilled, but is disturbed less. Reduced / conservation tillage can take many forms including ridge tillage, shallow ploughing and scarification of the soil surface. Can also include timing of tillage ploughing), such as spring ploughing instead of autumn ploughing.
19. **Restrictions on agricultural activities on slopes:** Prohibiting or limiting planting on sloped cropped land, eg contour ploughing, or excluding the growing of row crops, such as maize, potatoes, sugar beet, and sunflowers on slopes.
20. **Crop residue management in-field:** Residue incorporation, where stubble, straw or other crop debris is left on the field, and then incorporated when the field is tilled.
21. **Reducing or optimising the use of fertilisers:** Optimising the rate, placement and timing of fertiliser; using fertilisers with added nitrification inhibitors and slow release fertilisers; reducing the amounts of mineral fertilisers below the economic optimum.
22. **Precision agriculture:** a farming system that focuses on the precise application of fertilisers at the right time of the crop development as well as controlled application of pesticides only in case of attacks by pests, based on detailed mapping of fields and the use of GPS technology.
23. **Planting of hedgerows:** Establishing a living fence of shrubs or trees in, across, or around a field to delineate field boundaries.
24. **Establish buffer strips:** Strips of vegetation established along the banks of a water body.
25. **Reintroducing/ maintaining terraces:** Bench, channel, narrow and broad based ridge terracing reduce the length of slope on a hillside.
26. **Grass in orchards and vineyards:** Growing grass primarily for seasonal protection and soil improvement on orchards and vineyards to reduce exposure of bare soil
27. **Replacing annual with perennial/ permanent crops:** Replacing annual with perennial crops (for example, transition from row crops to perennial grasses represents an agricultural best management practice capable of increasing carbon sequestration.
28. **Replacement of synthetic pesticide treatments with natural treatments:** Natural treatments aim at using biological control organisms (insects, acarids, micro-organisms) to fight the development of specific crop predator (mainly pests).
29. **Integrated farming:** A whole farm approach to farm management, seeking to provide efficient and profitable production

30. **Organic farming:** Producing crops and animals without the use of synthetic inputs (such as manufactured pesticides and artificial fertiliser) or genetically modified organisms, recycling wastes as nutrients, using nitrogen fixing plants, rotational farming systems and year-on-year mono-culture, and under high animal welfare standards.
31. **Use of adapted plants and plant varieties:** Planting adapted crops/varieties, and planting mixtures of different species (eg for pastures) and species genotypes
32. **Improved pest strategies/ integrated pest management:** Setting up integrated pest management with additional checking systems to reduce the required amount of pesticides, and national pest management surveillance
33. **Modifying sowing dates:** Modifying sowing date to match season conditions (for example temperature and rainfall) to crop characteristics
34. **Extended use of biochar:** Applying biochar (Terra preta) to the soil to condition it. It is charcoal (organic material) created by pyrolysis of biomass.
35. **Establishing more firebreaks:** Gaps in vegetation are cleared or burnt under controlled conditions to prevent the spreading of wild fires or bushfires
36. **Plant breeding and genetic modifications:** Breeding crop varieties that are better adapted to more difficult environments (changing climate). It is also possible to use genetically improved crop species to be drought-tolerant or change their seasonal patterns (eg to be planted earlier or later to avoid heat waves).

Table A3-3 Key actions with co-benefits for climate change mitigation and adaptation in croplands

Actions	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity	Costs of the practice	Main Studies
	Mitigation	Adaptation	Benefits	Trade-offs			
13. Catch crops; winter cover; green manure; less fallow	Adds carbon to soils and may increase plant-available N, thereby reducing N <sub>2</sub> O emissions; Reduced indirect CO <sub>2</sub> emissions from mineral fertiliser requirements; CO <sub>2</sub> : 9.7 <sup>1</sup> , N <sub>2</sub> O: -3.8 [MtCO <sub>2</sub> eq./year]	Improved soil structure, water infiltration and water holding capacity and pest resilience; benefits for countering the effects of increased weather extremes and variability.	Reduces run-off and erosion; improves soil structure, thus increasing infiltration and trapping nutrients; reduces N leaching.	Reduced fallow periods can lead to C losses; Some catch crops can lead to a decrease in N uptake by following cereals; May increase soluble P.	<b>+</b> Improved water holding capacity may increase crop yield; but may not improve productivity if they mean higher cost.	<b>Low</b> Generally low cost for the catch crop, but money is saved through decreased nitrogen fertiliser requirements.	(Freibauer et al, 2004); (Flynn et al, 2007); (Frelil-Larsen et al, 2008); (Smith et al, 2008); (Smith and Olesen, 2010); (Olesen et al, 2011)
14. Diversified crop rotations	Can increase carbon sequestration (through increased organic matter – more carbon allocation below ground). CO <sub>2</sub> : 0.77 <sup>1</sup> , N <sub>2</sub> O:	Reducing pest and pathogen risks; preserving/improving productive capacity of soils. Improved soil structure,	Reduces runoff and erosion; reduces chemical inputs and pesticide leaching; improves soil quality and moisture efficiency; benefits	N fixation requires energy and water. This might lead to less water being available for subsequent	<b>+ / -</b> Improved productivity in medium term but may reduce less productive in the short term than	<b>Low</b> Requires additional skills, time and material investment in the short-term. For long diversified	(Flynn et al, 2007); (Frelil-Larsen et al, 2008); (Olesen et al, 2011)

Actions	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity	Costs of the practice	Main Studies
	Mitigation	Adaptation	Benefits	Trade-offs			
	0.27 [MtCO <sub>2</sub> eq./year]	enabling better water absorption and water holding capacity, can reduce impacts from flooding and droughts.	to biodiversity and water.	crops.	monocropping	rotations, investments may be more significant.	
15. Adding legumes/N-fixing crops to rotation or undersowing	Reduced indirect CO <sub>2</sub> emissions from mineral fertiliser requirements; increased SOC.  CO <sub>2</sub> : 10.6 <sup>1</sup> , N <sub>2</sub> O: 0.2 [MtCO <sub>2</sub> eq./year]	Contributing to optimum crop growth and efficient nutrient management; reducing risk for leaching of N	Improves soil fertility; benefits to biodiversity and water.	Legume-derived N can also be a source of N <sub>2</sub> O.	<b>+</b>  Generally positive but may not be as productive as high fertiliser application	<b>Low</b>	(Flynn et al, 2007); (Frelil-Larsen et al, 2008); (Smith et al, 2008) ; (Olesen et al, 2011)
16. Intercropping	Tree/crop systems under agroforestry practice are capable of sequestering carbon (C) in the standing biomass and soil (see also	Increased water retention and soil moisture; improved shading, thus strengthening resilience against weather extremes.	Can enhance use and capture of nutrient resources; can improve biodiversity by providing habitats for an increased number of species	Not identified	<b>+</b>  There may be some competition for water, nutrients and light between the crops which	Higher management costs.	(FAO and IAEA, 2008); (Gama-Rodrigues, 2011); (Béduneau and Gabory, 2012); (Chiti et al, 2012)

Actions	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity	Costs of the practice	Main Studies
	Mitigation	Adaptation	Benefits	Trade-offs			
	"Agroforestry")				reduces the yields of one or other.		
17. Zero tillage	<p>Improves C storage/increases SOC in arable soils.</p> <p>CO<sub>2</sub>: 19.9<sup>1</sup>, N<sub>2</sub>O: -0.5 [MtCO<sub>2</sub> eq./year]</p> <p>Depending on soil and climate in some areas reduced tillage may increase or reduce N<sub>2</sub>O emissions or have no measurable influence.</p>	<p>May reduce soil erosion and soil compaction; increase water holding capacity; thus strengthening resilience against weather extremes.</p>	<p>Benefits water infiltration and water conservation; decreases total P concentrations in surface run-off in the short-term; improves soil quality; benefits to biodiversity benefits to energy conservation</p>	<p>May increase fungal problems (and reduce yield); denitrification may increase as soil is less aerated and more compacted; may increase need for herbicides due to reduced mechanical weeding; can increase soluble P in the long-term.</p>	<p><b>+/-</b></p> <p>Can reduce cultivation costs (including energy), but may be associated with difficult weed control</p>	<p><b>Low</b></p> <p>Requires the use of specialized machinery</p>	<p>(Flynn et al, 2007); (Frelh-Larsen et al, 2008); (Smith et al, 2008)</p>

Actions	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity	Costs of the practice	Main Studies
	Mitigation	Adaptation	Benefits	Trade-offs			
18. Conservation / reduced tillage	Ditto	Ditto	Ditto	Ditto	+/- Ditto	Low Ditto	(Flynn et al, 2007); (Hawkins, 2007); (Frelil-Larsen et al, 2008); (Smith et al, 2008); (FAO, 2011);
19. Restrictions on agricultural activities on slopes (eg contour ploughing)	Reduces soil erosion and surface runoff, thereby reducing soil CO <sub>2</sub> emissions.	Essential for reducing soil erosion and avoiding topsoil loss, leading to the preservation of soil productivity.	Benefits soil quality and stability; preventing increase in fertiliser use compensating topsoil loss	Not identified	- Minor productivity decrease due to higher cost of contour ploughing	Low	(ahu and Ecologic, 2007); (FAO, 2011);
20. Crop residue management in-field	Incorporation of stubble, straw or other vegetative material can improve carbon sequestration.  For no removal: CO <sub>2</sub> : 8.5t, N <sub>2</sub> O: - 1.3	Improves soil structure, improves water holding capacity, and depending on timing of removal, can protect from soil erosion.	Benefits water conservation; improves soil quality; benefits soil biodiversity;	May conflict with efforts to use residues as biomass for energy production; risk of N <sub>2</sub> O emissions outweighing	+ Maintaining soil fertility and structure by returning crop residues	Low No large costs are associated with leaving residue on the field (but high investment costs associated with purchasing new machinery,	(Flynn et al, 2007); (Smith et al, 2008); (Smith & Olesen, 2010)

Actions	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity	Costs of the practice	Main Studies
	Mitigation	Adaptation	Benefits	Trade-offs			
	<p>[MtCO<sub>2</sub> eq./year]</p> <p>For composting and returning: CO<sub>2</sub>: 1.8<sup>1</sup>, N<sub>2</sub>O: 0.64</p> <p>[MtCO<sub>2</sub> eq./year]</p> <p>Reduced indirect CO<sub>2</sub> emissions from mineral fertiliser requirements.</p>			improvements in C storage when select residues with high N content		when the measure is combined with reduced/zero tillage)	
21. Reducing or optimising use of fertiliser and pesticides	<p>Potential reduction of CO<sub>2</sub>: 78 k tCO<sub>2</sub>eq<sup>3</sup></p> <p>Soil organic content accumulation rate on extensificated areas: 1,02%/year</p> <p>Reduced indirect CO<sub>2</sub> emissions from lower mineral fertiliser requirements.</p>	<p>Reduce threat of N and P leaching.</p> <p>Reduced pesticide use can avoid higher environmental costs of pesticide applications expected under climate change.</p>	<p>Reduction of residual soil nitrate available for leaching in autumn; for a long run reduction in soluble P loss.</p>	<p>Depending on the crop type, a drop in crop yield is expected (due to reduced agricultural input).</p>	<p><b>+/-</b></p> <p>Depending on the crop type, a drop in crop yield is expected (due to reduced agricultural input); likely to be positive if optimised in longer term</p>	<p><b>Low</b></p> <p>Farm costs can be reduced by purchasing less agricultural input.</p> <p>But there can be opportunity cost associated with lower agricultural product produced.</p>	<p>(Flynn et al, 2007); (AEA, 2008); (Koleva &amp; Schneider, 2009) ; (Ecologic, 2010)</p>

Actions	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity	Costs of the practice	Main Studies
	Mitigation	Adaptation	Benefits	Trade-offs			
22. Precision agriculture	<p>Reduces soil emissions of N<sub>2</sub>O, NH<sub>3</sub> and CO<sub>2</sub> through the reduction in fertiliser use up to 30% (but may require more passages and thus fuel use)</p> <p>Increases the efficiency of resources use (fertiliser and pesticides), and thereby indirect CO<sub>2</sub> emissions for their production</p>	Allows for a more efficient use of resources.	Reduces nitrate leaching (and thus eutrophication); reduces impacts from pesticides on wildlife (e.g. pollinators)	Easy to implement on large farms but not on small ones.	<p><b>+</b></p> <p>Higher yields, better resource efficiency</p>	<p><b>Low - High</b></p> <p>Capital equipment costs vary; costs of training and info for the farmer to implement effectively; potential yield reductions in short term causing income loss.</p> <p>Savings in fertiliser applied, fuel, labour, and machinery depreciation</p> <p>Currently mostly used in N and W Europe, eg by about 10% farmers in</p>	(Flynn et al, 2007); (Iglesias et al, 2007b); (Reichardt et al, 2009); (Reichardt and Jürgens, 2009); (Pölling et al, 2010)



Actions	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity	Costs of the practice	Main Studies
	Mitigation	Adaptation	Benefits	Trade-offs			
						Germany.	
23. Planting of hedgerows	Increase carbon storage in above-ground biomass. Abatement: 76 kt CO <sub>2</sub> -eq/yr (scenario: 2008-2050) <sup>3</sup>	Provide windbreaks and habitats for eg insects and birds which help to control pest and disease. Can provide shading to livestock.	Reduce soil erosion and run-off. sediment transport; reduces runoff velocities, allowing for increased infiltration of soluble nutrients and pesticides	Not identified	<b>+/-</b> Minor negative effects if production removes land from production; minor positive effect through increased pollination and avoided crop damage from wind breaks	<b>Moderate</b> Establishment and maintenance costs. Increased costs of operating with smaller fields if new boundaries established	(Iglesias et al, 2007b); (AEA, 2008); (Farmer et al, 2008)
24. Establish buffer strips	Only if woodland buffers or hedges are created (thus creating below- and above-ground biomass)	Can reduce soil erosion through extreme rainfall; reduce leaching; improve water retention and thus reduce peak flows; provide additional habitat for beneficial	Reduces soil erosion and run-off, thus reducing eutrophication risk; decrease thermal stress for the aquatic environment; benefits to aquatic environments; can be used to grow	Not identified	<b>-</b> Minor negative impacts due to loss of production	<b>Moderate</b> Due to minor loss of production Harvesting biomass from the buffer zone could offset the costs.	(van den Broek et al, 2007); (Hoffmann et al, 2009); (Somma and et al, 2013)

Actions	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity	Costs of the practice	Main Studies
	Mitigation	Adaptation	Benefits	Trade-offs			
		insects; thus reducing pest and disease risk.	energy crops				
25. Reintroducing / maintaining terraces	Reduces soil erosion thereby reducing CO <sub>2</sub> emissions from soil	Reduced erosion risk significantly helps to reduce the risk of landslides and downstream flooding, reducing also peak flows.	Reduced sediment overflow; reduced nutrient overload in water bodies and eutrophication; improved water quality and water infiltration	Not identified	<b>+</b> If allows previously uncropped land to be farmed and maintains soil structures	<b>High</b> Costs of labour are associated with constructing and maintaining terraces.	(Ecologic, 2010); (FAO, 2011)
26. Grass in orchards and vineyards	Reduces soil erosion and increases C sequestration on cropland; may increase SOM. CO <sub>2</sub> : 1.8 <sup>1</sup> , N <sub>2</sub> O: 0.3 [MtCO <sub>2</sub> eq./year]	Permanent soil cover is particularly important in areas prone to erosion and desertification	Benefits water quantity and quality and reduces run-off; reduced chemical inputs benefit pollination	May increase pest risk and the depletion of soil moisture	<b>0</b>	<b>Low (- Moderate)</b> The measure requires additional time investments, but the benefits outweigh these costs.	(Flynn et al, 2007)
27. Replacing annual with perennial/permanent	Improved soil carbon allocation. For permanent crops:	Improved soil structure and water holding capacity reduces from extreme	Can reduce soil erosion and run-off; may improve biodiversity; may reduce pesticide	Not identified	<b>+/-</b> (Depends on crops chosen and which other	<b>Variable</b>	(Flynn et al, 2007); (Frelih-Larsen et al, 2008)

Actions	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity	Costs of the practice	Main Studies
	Mitigation	Adaptation	Benefits	Trade-offs			
crops	CO <sub>2</sub> : 1.69-3.04 <sup>2</sup> N <sub>2</sub> O: 2.30 <sup>2</sup> , NH <sub>3</sub> : 0.02 <sup>2</sup> [MtCO <sub>2</sub> eq./year]	weather events.	inputs		corps are displaced)		
28. Replacement of synthetic pesticide with natural treatments	Decreased need for fossil fuel leading to an indirect reduction of CO <sub>2</sub> emissions due to energy savings	Avoiding increased environmental costs of the projected increase of pesticide applications under climate change.	Decreased negative impacts on soil of pesticides, insecticides, acaricides, and nematicides.	Not identified	<b>-/+</b> Likely neutral or negative in short term, but positive in long term	Low	(Koleva & Schneider, 2009); (Ecologic, 2010); (FAO, 2011)
29. Integrated farming	Can reduce need for fossil fuels to run equipment and produce synthetic fertilisers, thereby reducing GHG emissions.	Integrated irrigation and rain fed production can reduce impact of drought.	Benefits soil protection and can reduce water pollution and water abstraction. Can also benefit biodiversity.	Easy to implement on large farms but not on small ones.	<b>-/+</b> Likely neutral or negative in short term, but positive in long term	Not identified	(Berry et al, 2005); (Bianchi et al, 2006); (Ecologic, 2010)
30. Organic farming	May improve carbon sequestration: 1.156 kg CO <sub>2</sub> -	Better water holding capacity and more stable output in areas	Can reduce water pollution. Can also have benefits on biodiversity, and	Not identified	<b>-/+</b> Likely neutral or negative in short	Not identified	(Hirschfeld et al, 2009); (Ecologic, 2010); (Moriondo et al,

Actions	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity	Costs of the practice	Main Studies
	Mitigation	Adaptation	Benefits	Trade-offs			
	eq/ha; may reduce indirect CO <sub>2</sub> emissions from production of mineral fertiliser and pesticides. However, there may be CO <sub>2</sub> emissions associated with production of imported soy concentrate as for organic feed.	prone to drought than in conventional systems.	air pollution due to reduced emissions; high level of animal welfare and health		term, but positive in long term		2010) (FAO, 2011); (Olesen et al, 2011)
31. Improved pest strategies/ integrated pest management	Not identified	Avoiding increased environmental costs of the projected increase of pesticide applications under climate change	Reduces impacts on soil from pesticide use and water pollution; may have indirect benefits for biodiversity	Physical barriers to pest invasion, such as row covers or plastic-lined trenches, require energy use for the production.	+	<b>Moderate - High</b>	(Iglesias et al, 2007b); (AEA, 2008); (Ecologic, 2010); (FAO, 2011); (Olesen et al, 2011)

Actions	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity	Costs of the practice	Main Studies
	Mitigation	Adaptation	Benefits	Trade-offs			
32. Modifying sowing dates	Not identified	Improved resilience against projected increase in summer temperatures and reduced summer precipitation, and to make the most use of winter precipitation.	May lead to more efficient water use if planting is shifted to earlier dates; incorporating crop residues or mulch/compost as soil cover after earlier harvest could help with soil moisture and organic matter.	Not identified	+/- May be short term decrease in production but long term increase through longer growth phase and decreased risk from water stress. However, with faster crop maturation in warm climates less grain may be produced; there is also risk of damages through late frosts. <sup>3</sup>	Not identified	(Zebisch et al, 2005); (Rosenzweig and Tubiello, 2007); (AEA, 2008); (FAO, 2011); (Olesen et al, 2011); (Hjerp et al, 2012)
33. Use of biochar	Long-term effect on sequestration	Enhances retention of	Can increase soil fertility and	Not identified	Not identified Can increase	<b>Low</b> The cost of the	(Verheijen et al, 2009);

<sup>3</sup> Winter cereal should be sowed later than currently customary, to avoid damages through a late onset of the cold phase, which is important for development (Zebisch et al, 2005).

Actions	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity	Costs of the practice	Main Studies
	Mitigation	Adaptation	Benefits	Trade-offs			
	of carbon in soils is uncertain.	water in soils, thus reducing vulnerability to droughts	enhance retention of water in soils		soil fertility and raise agricultural productivity. But there is also risk of accelerated decomposition of SOM, thus potential to both harm crop productivity in the long term due to loss of SOM.	material and its incorporation into the soil, but in comparison to other soil additives may be more cost competitive.	(Vermeulen et al, 2010);  (Desbarats et al, 2012)
34. Establishing more firebreaks	Not identified	Reduced crop damage from forest fires during summer drought.	Not identified	Not identified	<b>+/-</b>  Can reduce area of land for production but may prevent fire and thus improve stability of output	<b>Low (- Moderate)</b>	(Iglesias et al, 2007b)
35. Use of adapted	Incidental benefits to carbon	Adapted plants and varieties	Crops can be selected for several	Unintended negative	<b>+</b>	<b>Low</b>	(World Bank,

Actions	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity	Costs of the practice	Main Studies
	Mitigation	Adaptation	Benefits	Trade-offs			
plants and plant varieties	sequestration by reduced pressure on land for farming as a result of improved productivity	will effectively respond to the local conditions and be more resilient to gradual climate changes.	traits, including beneficial to water (stress-tolerant, or varieties with earlier maturation periods that are harvested before low flows in summer). May benefit biodiversity.	effects: eg crops selected to be tolerant to water stress are fully irrigated as the yield under full irrigation is higher (or is believed to be higher) than with low irrigation.		Locally adapted crops are not always available.  Savings from less input costs and higher income potential from yield increases	2009)
36. Plant breeding and genetic modifications	Incidental benefits to carbon sequestration by reduced pressure on land for farming as a result of improved productivity	Adapted plants and varieties will effectively respond to the local conditions and be more resilient to gradual climate changes.	Crops can be selected for several traits, including beneficial to water (stress-tolerant, or varieties with earlier maturation periods that are harvested before low flows in summer). May benefit	Unintended negative effects: eg crops selected to be tolerant to water stress are fully irrigated as the yield under full irrigation is	+	<b>High</b>  Varieties from private research more costly but yield stability or increase and climate or pest resilience may result in higher income. Added costs of time and resources to	(FAO, 2007); (Freluh-Larsen et al, 2008); (AEA, 2008); (Vermeulen et al, 2010); (Antoniou et al, 2012); (EASAC, 2013)

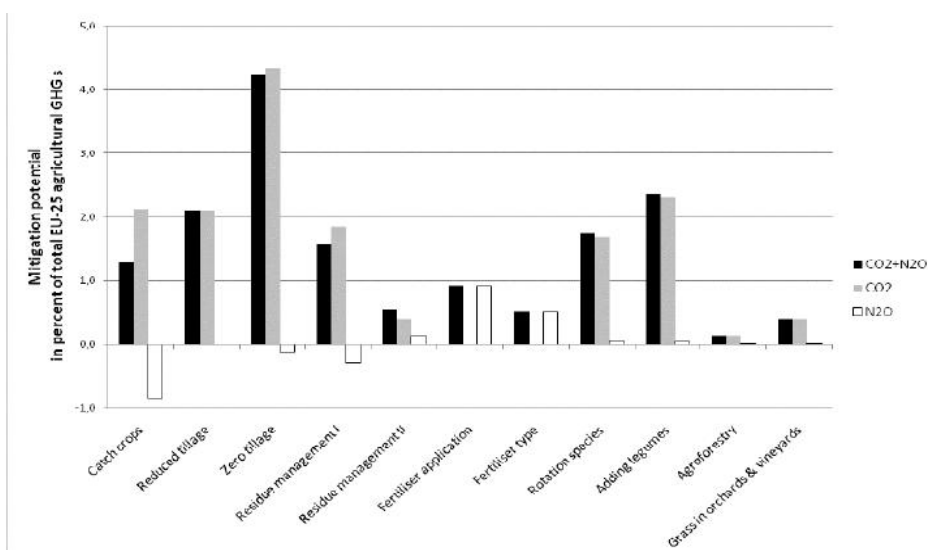
Actions	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity	Costs of the practice	Main Studies
	Mitigation	Adaptation	Benefits	Trade-offs			
			biodiversity.	higher (or is believed to be higher) than with low irrigation.		get approvals and inputs required for optimal performance.	



### Priorities for mitigating climate change from crop production

Zero tillage has been modelled as having the highest technical mitigation potential for reducing CO<sub>2</sub> emissions from soils in EU croplands, followed by rotation with legumes or N-fixing crops, minimum tillage, incorporation of residues (eg straw) and addition of organic matter (eg compost)<sup>4</sup>, crop rotations, and vegetative cover or cover crops. Precision farming and practices involving optimised fertiliser application and fertiliser type are the measures with the largest positive effect on N<sub>2</sub>O emissions from croplands (Figure A3-1). It is also a priority in terms of economical mitigation potential (Moran et al, 2008).

**Figure A3-1 Technical mitigation potential of selected soil management actions**



Note: Mitigation potentials calculated by MITERRA-Europe for CO<sub>2</sub> (grey) and N<sub>2</sub>O (white), both in Mt CO<sub>2</sub>-eq per year (for the EU-27), are divided by the total agricultural emissions of the EU-25 in 2004 (EEA data, quoted from Fuentes 2007). The black columns represent the sum of CO<sub>2</sub> and N<sub>2</sub>O mitigation potentials in relation to total emissions.

Source: (Lesschen et al, 2008)

A range of soil management actions deliver mitigation benefits by reducing soil erosion and thus the amount of soil swept away, resulting in lower rates of soil organic carbon loss. The maintenance of permanent vegetation cover and ensuring contour ploughing on slopes are critical actions in this respect, but farmers are often unwilling to adopt these measures voluntarily and they are not effectively enforced through GAEC cross-compliance (Diaz-Chavez et al, 2013; Martínez Raya et al, 2006a; Martínez Raya et al, 2006b; Martínez-Mena et al, 1999).

Soil erosion can also be reduced by maintaining tree or vegetation cover and root systems. Buffering against wind and water erosion can be provided by the use of cover crops, intercropping, permanent crops, zero or reduced tillage, terracing and agroforestry (Gay et al, 2009; Lal, 2012). These

<sup>4</sup> Note that the improved residue management and incorporation of organic matter results has important co-benefits besides the maintenance of SOM and stabilisation of carbon stocks, ie it also facilitates lower levels of leaching of reactive nitrogen than in artificial fertilisers, with benefits for biodiversity (Crews and Peoples, 2004).

management practices have a high potential for economical mitigation since the benefits often exceed the costs of inputs, labour, and the opportunity costs of restricted production in certain areas.

Reduced use of mineral fertilisers and pesticides can also reduce the costs for external inputs and increase the relative benefits of those actions.

For all soil management actions, identification of appropriate location for their implementation will determine the magnitude of their impact on the climate. The zones where there is high risk of release of GHG emissions or big potential for delivering sequestration benefits should be a priority. Such zones include on the one hand soils depleted of soil organic carbon both in cropland and grazing areas, or affected by soil erosion, salinisation, or soils otherwise degraded, and on the other hand soils rich in organic carbon stocks, particularly peatlands (Gay et al, 2009; Lal, 2012; Poláková et al, 2013a; Schils et al, 2008).

### ***Priorities for adapting crop management to climate change***

Improved soil management in croplands can increase resilience against climate change, though the individual actions will vary in terms of their cost-effectiveness.

Incorporating certain cropland management practices, such as catch crops or winter cover, diversified crop rotations, legumes or N-fixing crops in rotations, intercropping, permanent or perennial crops, grass in orchards and vineyards, and crop residue management, into farming systems can offer large potential benefits for the conservation of soils and water at low costs. These practices can improve the soil structure, water infiltration and retention capacity, and root cover, thus reducing the risks of water and wind erosion from intense weather events, improving resilience to droughts, and reducing the scale of flooding. In all these ways they can also help sustain agricultural productivity in the face of climate change.

Different actions may be needed to achieve different adaptation objectives in different regions. In some cases water retention for soil moisture to reduce impact of droughts may be more important than water retention to protect against flooding (Olesen et al, 2011). Actions to increase the resilience of crops to frequent variations in weather conditions will be important in other situations. Zero and reduced tillage offer potentially high adaptation benefits due to the protective layer retained over the soil. Although they may require upfront costs due to equipment investments, they can produce net savings as they result in less fuel and labour costs (Schoumans et al, 2011). Restrictions of agricultural activities on slopes and terracing present very high potential to prevent erosion but introduce costs through labour and opportunity costs.

Introducing irrigation to supplement rainfed production reduces drought risk, but may be potentially costly, inefficient, and cause salinization, depending on the type of irrigation and soil type (Baldock et al, 2000; Iglesias et al, 2007a). Reduction of mineral fertilizers and pesticides through precision agriculture, biological control and organic farming may save input costs but may incur increased labour costs.

Adjustment of sowing dates is a highly effective adaptation activity already practiced by farmers in Europe due to changing weather patterns, such as the reduced risk of spring frosts (Olesen et al, 2012). Planting of adapted crops and varieties, selection of better adapted crop species and varieties (with or without the use of genetic engineering) and diversification of the crops are key technologies.

### ***Co-benefits for adaptation and mitigation from crop production***

Such co-benefits can be delivered particularly through land management actions aimed at reducing soil erosion, limiting the leaching of nitrogen and phosphorus, conserving soil moisture, using appropriate crop species or varieties, modifying the microclimate and avoiding the cultivation of new land (Poláková et al, 2013b; Smith & Olesen, 2010). Organic farming has certain merits for adaptation over conventional agriculture due to its use of crop rotations, and in many cases its better soil water holding capacity and higher yields under extreme conditions than conventional systems (FAO, 2010; Tuomisto et al, 2012). Generally however the yields and thus absolute levels of production in organic systems are lower.

Soil management practices can produce a number of synergies for climate change mitigation and adaptation. The specific outcomes are dependent on regional conditions, the type of farming systems and the manner in which these practices are implemented. Not all mitigation measures do automatically produce co-benefits for adaptation and vice versa. Examples include grass in orchards/vineyards, which can compete for water and catch crops that may reduce the water available for subsequent crops and thus negatively affect yields. Afforestation measures, when poorly planned, can also result in increased demands for water by trees (compared to non-irrigated arable crops).

## **Land use change and other land based management**

### *Description of key management actions*

37. Peatland and wetland restoration (rewetting of organic soils): Undoing drainage of peatlands eg by blocking drainage pipes
38. Afforestation of cropland/ Woodland creation: Process of converting open land into a forest by planting trees or their seeds.
39. Conversion of arable land to grassland in high risk areas
40. Shift crop and grazing zones: Shifting areas geographically, following the creation of new conditions determined by a changing climate.
41. Agroforestry (farmland trees): Production of livestock or crops on land that also grow trees, either for timber or firewood or another tree product
42. Extensification / deintensification: eg late mowing and extensive grazing in grasslands.
43. Set aside: Removing land from agricultural production
44. Restoring river patterns; restoring natural aquatic ecosystems and riparian forests

**Table A3-4 Key land use change and other land based management actions with co-benefits for climate change mitigation and adaptation**

Action	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity	Costs of the practice	Main studies
	Mitigation	Adaptation	Benefits	Trade-offs			
37. Peatland and wetland restoration (rewetting of organic soils)	Reductions up to 28,2-30,5 Mio. t CO <sub>2</sub> eq ha <sup>-1</sup> yr <sup>-1</sup>	May reduce water flow speed, important for flood protection. May improve groundwater recharge, important for drought management.	Reduces soil erosion risk; support to biodiversity.	Restoring a high water table may release CH <sub>4</sub> soil emissions in the beginning.  Potential loss of productive land and resulting loss of income	-	<b>Low - High</b>  Costs are highly site-dependent and vary greatly, may involve minor costs of phasing out of inappropriate burning/grazing, to moderate costs for removing drain grips; to high costs for constructed wetlands <sup>5</sup> .	(Flynn et al, 2007); (Osterburg et al, 2009); (Flessa et al, 2012); (Wichtman n and Joosten, 2007)
38. Afforestation of cropland/ Woodland	Potential to improve carbon sequestration, depending on climate: 0,17- 0,53 t CO <sub>2</sub> -eq. ha <sup>-1</sup>	Enhanced resilience to flooding.	Reduce soil erosion and run-off; decreased N	Depending on type, design, and management, woodland	-  (Depends on counterfactu	<b>Moderate - High<sup>6</sup></b>  The main costs involve land purchase and	(Ecologic, 2010); (Smith et al, 2008)

<sup>5</sup> The cost of constructing wetlands per ha per year has been cited to range from €245-850 up to €10,360 per ha converted. Within the larger estimate, 16% of the costs stemmed from lost agricultural production, 24% from administrative costs, and 60% from construction costs. Constructed wetlands require further maintenance due to the deposition of sediment and organic matter.

<sup>6</sup> The annualised specific cost of converting arable land to forest is found to be 84-150 €/ha (at 2007 price levels). The cost-efficiency indicator for this land conversion was 280-490 €/kg P.

Action	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity	Costs of the practice	Main studies
	Mitigation	Adaptation	Benefits	Trade-offs			
creation	yr <sup>-1</sup>		leaching to the groundwater; reduced P load; may increase biodiversity.	creation can have negative effects on groundwater recharge due to the generally larger water demands of trees versus non-irrigated arable crops.	al and crop types replaced)	planting; low maintenance costs.	
39. Conversion of arable land to grassland in areas of high soil risk	Accrual of soil carbon due to avoided soil erosion; may reduce N <sub>2</sub> O emissions from lower N inputs in grasslands.	Mitigate floods by restoring the hydrological cycle of drainage basins	Reduce nutrient, pesticide, and sediment runoff; benefits to biodiversity by developing species-rich grasslands.	Management of grasslands for high biodiversity potentially incompatible with management for maximum profit.	- (Depends on counterfactual and crop types replaced)	<b>High</b> Relatively expensive. Financial benefits may be complicated to appraise. Investment costs include seed planting.	(Smith et al, 2008); (Alonso et al, 2012); (Walker et al, 2004); (De Deyn et al, 2011); (Török et al, 2011)
40. Shift crop and grazing zones	Not identified	Reduced likelihood of crop loss and grassland damage due to changing		May not always be effective in avoiding the negative effects of droughts or floods on crop	Unclear	<b>Moderate</b>	(Rosenzweig & Tubiello, 2007); (Iglesias et al, 2007b)

Action	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity	Costs of the practice	Main studies
	Mitigation	Adaptation	Benefits	Trade-offs			
		climatic conditions.		and livestock production.			
41. Agroforestry (farmland trees)	Increased carbon sequestration: CO <sub>2</sub> : 0.63 <sup>1</sup> N <sub>2</sub> O: 0.02 [MtCO <sub>2</sub> eq./year]	Multiple rows of trees or shrubs can serve as shelterbelts or windbreaks and provide protection for livestock and crops.	Reduces wind erosion, protects growing plants, improves moisture use efficiency; could improve biodiversity.	Not identified	<b>+/-</b> Can increase number of products from land but with some trade-offs. Depends on counterfactual and type of product replaced.	<b>Moderate</b> Capital investments for tree purchase and planting; savings through reduced heating costs for farm buildings; decreased fertiliser use.	(Flynn et al, 2007); (Smith et al, 2008)
42. Extensification / deintensification of agricultural management	CO <sub>2</sub> : 1.69 – 3.04 <sup>2</sup> N <sub>2</sub> O: 2.30 CH <sub>4</sub> : 0.02 [MtCO <sub>2</sub> eq./year]  Soil sequestration rate on extensified areas: 1,02%/year	Not identified	May benefit soil quality; biodiversity; water quality	Not identified	<b>-/+</b> Likely neutral or negative in short term, but positive in long term	<b>Moderate</b>	(Flynn et al, 2007); (Glendining et al, 2009); (Marriott et al, 2009)
43. Set aside	Reduced use of pesticides and fertilizers, with direct	Not identified	Benefits biodiversity (e.g. re-	Not identified	<b>-</b> Lost	<b>Moderate</b> Opportunity cost;	(Flynn et al, 2007); (Boellstorff

Action	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity	Costs of the practice	Main studies
	Mitigation	Adaptation	Benefits	Trade-offs			
	and indirect emission savings: <u>in dry climates</u> by 3.93 (-0.07-7.9) t CO <sub>2</sub> -eq. ha <sup>-1</sup> yr <sup>-1</sup> with decreased N <sub>2</sub> O emissions of 2.3 (0.0-4.6) t CO <sub>2</sub> -eq. ha <sup>-1</sup> yr <sup>-1</sup> <u>in moist climates</u> 5.36 (1.17-9.51) t CO <sub>2</sub> -eq. ha <sup>-1</sup> yr <sup>-1</sup> with decreased N <sub>2</sub> O emissions of 2.3 (0.0-4.6) t CO <sub>2</sub> -eq. ha <sup>-1</sup> yr <sup>-1</sup>		establishing soil biota); rebalancing soil nutrients		production	reduced income	and Benito, 2005); (Firbank et al, 2003);



### ***Land use change priorities for mitigating climate change***

The mitigation benefit of rewetting organic soils under peatland and wetland restoration actions significantly exceeds the benefit of all other potential mitigation actions, with up to 30 million tonnes of CO<sub>2</sub> equivalent emission reductions annually (Flessa et al, 2012; Joosten and Clarke, 2002). The cost effectiveness of restoration actions varies from very low to high. Afforestation has been shown by modelling to be a potentially cost-effective technique (McKinsey&Company, 2009). However, the choice of species and location of new planting needs to be environmentally optimal to avoid negative impacts on water availability through increased absorption and transpiration. Rewetting of fertile, lowland peatland soils will usually lead to a loss of agricultural production, though experimental work is showing that it is possible to grow novel crops on re-wetted peat, a technique known as paludiculture (Wichtmann & Joosten, 2007), and so keep these areas in some kind of production.

### ***Land use change priorities for adapting agriculture to climate change***

Agroforestry is defined as a form of land use that combines trees with crops on the same plots. It appears to have a certain potential to help agriculture adapt to climate change without loss of productivity, whilst also producing other co-benefits. A study by the French Government's Ministry of Agriculture concluded that agroforestry had the potential to increase the total production of biomass per unit area, improve soil condition and nutrient availability, reduce nitrogen leakage, enhance drought tolerance and sequester additional carbon (Liagre et al, 2012).

The highly selective use of afforestation may help agriculture adapt to climate change, though there will be local losses of production in the areas afforested. A review for the UK Environment Agency (Halcrow Group Limited, 2008) found evidence that well-managed forests can help reduce local flooding and peak flows for smaller, more frequent events but not for extreme events at the catchment scale.

The same review found growing evidence that the restoration or establishment or protection of riparian and floodplain woodland can attenuate flood propagation through increased hydraulic roughness, reduced flood flows and increased downstream time to peak.

Any afforestation needs to be carefully planned in terms of site and species to provide the optimal range of environmental benefits. This can help avoid negative impacts on water tables and soils that occurred through inappropriate afforestation in the past.

## **Energy efficiency actions and renewable energy use**

### *Description of key management actions*

45. Energy efficient equipment: Increasing energy efficiency for example, for heating, field operations, ventilation, lighting, air circulation, as well as reducing the usage of farm equipment and tractors and/or using smaller tractors with a longer lifetime.
46. Adoption of green building schemes for farm buildings/greenhouse buildings, and use of renewable energy: Schemes to make buildings 'greener' are available and can apply to farm buildings, and renewable energies can be adopted on the farm territory (eg heat pumps)
47. Reducing machinery fuel use: Reduced machinery fuel use through for example the elimination of tillage operations, reduction of irrigation, use of lighter machinery and use of more energy efficient machinery. Usage of biodiesel or other biofuels instead of petroleum products.
48. Processing of agricultural and forest residues for energy
49. Installation of infrastructure for renewable energy

Table A3-5 Key energy efficiency actions for climate change mitigation on farms and in rural areas

Action	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity	Costs of the practice	Main studies
	Mitigation	Adaptation	Benefits	Trade-offs			
45. Energy efficient equipment	Reduces CO <sub>2</sub> emissions	Not identified	Not identified	Not identified	<b>0</b> No impact on agricultural productivity per se	<b>Moderate</b> Upfront investment costs, but expected to lead to farming cost reductions for energy consumption	(Ecologic, 2010); (UNFCCC, 2008)
46. Efficiency of farm buildings/greenhouses	Reduces CO <sub>2</sub> emissions.	Not identified	May involve reduced water use.	Not identified	<b>0</b> Ditto	<b>High</b> Upfront capital investment, but expected to lead to farming cost reductions for energy consumption	(Ecologic, 2010)
47. Reducing machinery fuel use	Reduces CO <sub>2</sub> emissions	Not identified	Depends on the type of action, eg for no tillage see above.	Depends on the type of action, eg for no tillage see above.	<b>0</b> Ditto	<b>Low</b> Less fuel costs but potential yield losses if eg weed increases in no tillage are not handled properly or more herbicide is needed	(UNFCCC, 2008)
48. Processing of agricultural and forest residues for	Reduces CO <sub>2</sub> emissions; reduces	See study 5	See study 5	See study 5	See study 5	See study 5	See study 5

Action	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity	Costs of the practice	Main studies
	Mitigation	Adaptation	Benefits	Trade-offs			
energy <sup>7</sup>	dependency on fossil fuel.						
49. Installation of infrastructure for renewable energy (solar, wind, geothermal)	Reduces CO <sub>2</sub> emissions; reduces dependency on fossil fuel.	Not identified	Depends on the type of installation	Not identified	<b>0</b> No impact on agricultural productivity per se	<b>High</b> Upfront capital investment, but renewable energy sources would eliminate costs for energy and offer potential alternative income stream from excess sold to grid	(UNFCCC, 2008)

<sup>7</sup> Study 5 provides an assessment of the potential for producing bioenergy from agricultural sources with low environmental impacts such as waste and residues.

### ***Priorities for climate change mitigation through energy efficiency in agriculture***

These mitigating actions may be divided into three groups. The first group focuses on reducing CO<sub>2</sub> emissions through increased energy efficiency, for example by ensuring that machinery is more fuel-efficient, and that buildings, greenhouses and equipment are energy efficient. These measures may reduce running costs and have other co-benefits. Farm building modernisation aimed at energy efficiency may sometimes also provide benefits in terms of hygiene and/or animal welfare.

The second group of mitigating actions focuses on the processing of agricultural and forest residues for energy. This can be an effective mitigation strategy, although care is needed to avoid conflicts with other aspects of mitigation (such as the incorporation of straw into soils to maintain stable SOM levels, see study 5).

The third group focuses on the replacement of electricity/heating systems on farms with systems based on renewable energy (solar and wind power, geothermal). This can be an effective mitigation strategy, though it has high capital costs.

For most of the measures in the second and third groups, bigger installations, serving a group of users at local level, are likely to be more cost-effective smaller installations on each individual farm. Increasing energy efficiency and generating renewable energy on farms may also help agriculture adapt to climate change by reducing the impact on farmers of rising energy prices and future levies on fossil fuels.

## Sustainable water use and other key actions for adaptation to climate change

### *Description of key management actions*

50. Precision irrigation: Technologies to target and vary water inputs to the crop according to its actual needs, at the right time and with precise amounts of water.
51. Reconstruction and upgrading of drainage infrastructure: Some of the drainage systems used today may be outdated and need improvement through reconstruction.
52. Mulching, or protective film covering: Mulching is the practice of leaving eg crop residues, wood chips or other materials on agricultural soils. Protective film covering (plastic film or other materials) can be placed on bare soil or around crops to regulate temperature and moisture.
53. Improvements in irrigation equipment: Improved design of the water-supplying devices to increase water efficiency.
54. Reuse of greywater on farms; rainwater harvesting: Grey water or other less polluted effluents can be collected and treated so that the water may be reused on the farm.
55. Improved irrigation scheduling: Tools are available to schedule and fine-tune the timing and amount of water applied to crops, depending on the weather, soils, crops, etc.
56. Reconstruction of outdated rural water supply networks: Leakages and evaporation from water supply networks leads to inefficiencies. Better efficiency can be achieved, for example through canal lining, low pressure piping systems or channel automation
57. More effective water regulation and allocation: At national, regional or river basin level, rules to allocate water must take into account the needs of all stakeholders, prioritising the uses to ensure sustainable and equitable use of water
58. Water footprinting, water auditing and water labelling: These instruments may help consumers make sustainable choices.
59. Extended water pricing and metering: Water pricing is a mechanism to clarify the value of water for users. Trading is an economic mechanism to allocate water use.
60. Defences against floods and extreme events (hails etc): Dykes and other types of grey infrastructure in flood-prone areas divert water away from the river network. Preventing mechanisms can mitigate the adverse effects of extreme events (hail, winds, flooding)
61. Establishing disaster information systems and monitoring: For example, national and subnational early warning and information systems; Disaster Information Management Systems the European Drought Observatory
62. Establishing insurance schemes: Insurance schemes to compensate for losses due to climate or weather extremes

**Table A3-6 Key management actions for sustainable water use and water efficiency and other actions for adaptation to climate change on farms and wider rural areas**

	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity	Costs of the practice	Main studies
	Mitigation	Adaptation	Synergies	Trade-offs			
Sustainable water use and water efficiency							
50. Precision irrigation	Possible indirect impact from reduced energy use to pump and transport water (but potentially increased energy through pressure in pipes and monitoring systems).	Increases the efficiency of water use; may reduce exposure to droughts if in total in the water basin water use decreases.	Improves crop water efficiency thus improving crop productivity; reduces pressure on water bodies, reduces water related soil erosion and runoff.	Some evidence shows that increased water efficiency leads to increased area under irrigation at a landscape level and zero effect on total water use.  Not applicable for all crops on all soils.	<b>+</b>  Likely sustainability issues if irrigation is used to continue production as a result of climate shift.	<b>Moderate - High</b>  Relatively high costs for equipment and technical capacity building of farmer required for optimal implementation, but higher profits for farmers potentially from lower quantity of water needed. It requires precise knowledge (meteorology, soil humidity etc.)	(Fereres and Soriano, 2007);  (Candela et al, 2008);  (Hassanpour aghdami et al, 2010)
51. Reconstruction and upgrading of drainage infrastructure	For some crops, e.g. for rice, efficient drainage and intermittent irrigation may reduce CH4 emissions.  Effect on N2O emissions is highly	Drainage systems allow monitoring of water tables and may ensure more efficient water use; however may reduce ecosystem resilience on naturally	Variable	May reduce groundwater table, increase salinization; sustainability issues in relation to naturally waterlogged soils ie peats	<b>+/-</b>  Likely neutral or positive in short term, but may be negative in long term	<b>Moderate</b>  Cost of the sub-soiling and drainage materials, labour, and maintenance. Certain increases in yields and fewer energy costs, but runoff of nutrients through drainage may	(Baldock et al, 2000);  (Vermeulen et al, 2010)

	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity	Costs of the practice	Main studies
	Mitigation	Adaptation	Synergies	Trade-offs			
	variable, from positive in soils where anaerobic conditions exist, to highly negative if reconstruction leads to increase in area under drainage, thus inducing powerful emissions from the mineralization of peat content.	waterlogged soils, eg peats.				incur significant pollution costs.	
52. Mulching or protective film covering	Minor benefits to carbon sequestration where biomass is left on cropland	Reduces need for irrigation by reducing evaporation; reduces soil erosion and run-off.	Efficient use of inputs and reduction of weed. May reduce pressure on water bodies; and increase soil organic matter in case of mulching.	In case of covering crops, there may be disadvantages for biodiversity and ecosystems. May be fungal issues.	<b>+</b> Potential benefits for plants (temperature, moisture, pest, etc.) in case of covering crops, where crops are disadvantaged by frost or wind	<b>Low</b> Minimal costs of the materials and their placement. Savings from less irrigation, more efficient chemical use, and higher yield potential from reduced climate-related losses.	(Fernández et al, 2001)
53. Improvements in irrigation	More efficient irrigation systems reduce the need for	Drip irrigation may increase the efficiency of water	May reduce pressure on water bodies, and	Risk that the surface of irrigated	<b>+</b> Could have impacts on	<b>Moderate - High</b> Relatively high costs for equipment and	(Hawkins, 2007); (BIO



	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity	Costs of the practice	Main studies
	Mitigation	Adaptation	Synergies	Trade-offs			
equipment	energy.	use, and better crop productivity.	indirect impacts to biodiversity; may reduce water related soil erosion and run-off.	agriculture increases and total water use remains the same rather than reducing	sustainability	technical capacity building of farmer required for optimal implementation, but higher profits for farmers potentially from lower quantity of water needed.	Intelligence Service, 2012)
54. Re-use of greywater on farms; rainwater harvesting	Minor negative impact in the short term due to energy requirements	May increase the availability of water for irrigation and provide for stable productivity.	Reduces pressure on water bodies; reduces indirect impacts to biodiversity; improves efficient use of resources through reduced treatment; may reduce eutrophication and accumulation of heavy metals in water bodies	Possible environmental issues depending on level of treatment.	+	<b>Moderate</b> Capital cost of the water collection and storage and movement. Higher profits potentially from productivity increases and reduced crop losses in dry conditions. Unclarity about health and safety issues.	(Kathijotes, 1999); (MED WWR WG, 2007); (BIO Intelligence Service, 2012)
55. Improved irrigation scheduling	More efficient irrigation systems reduce the need for energy	Reduces the amount of water used for irrigation.	Reduces pressure on water bodies and indirect impacts to biodiversity	Reduced efficiency in case of heavy droughts	0	<b>Moderate</b> Costs to train farmer to maximize effectiveness of the tool; investment costs in equipment if not already in place; but more efficient use	eg IRRINET system

	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity	Costs of the practice	Main studies
	Mitigation	Adaptation	Synergies	Trade-offs			
						of water so potentially higher profits.	
56. Reconstruction of outdated rural water supply networks	Minor energy/ CO2 saving by more efficient supply systems and less water being pumped.	May reduce water losses from transport, and improve water availability in farms.	Potential water savings at EU level have been estimated to up to 25% of water used for irrigation; reduced pressure on water bodies; lower risk for intrusion of pollutants into the irrigation systems.	May reduce availability of water that leaked in ecosystems and groundwater bodies, with possible impacts on biodiversity	0	<b>High</b> Capital costs of the water infrastructure	(WssTP, 2010); (BIO Intelligence Service, 2012)
57. More effective water regulation and allocation	Possible indirect effect	Improves water management and allocation.	Reduces pressure on water bodies and indirect impacts to biodiversity.	Difficulty in prioritising water uses; risk of illegal abstraction.	0	<b>Moderate</b> Administrative and research costs	(BIO Intelligence Service, 2012)
58. Water footprinting, auditing and labelling	Possible indirect effect	Possible indirect effect	Possible indirect effect on reduced pressure on water bodies	Unclear issues in metrics and methodologies to be used	0	<b>Moderate</b> Administrative and research costs; Low understanding of labels by consumers	(RPA and Cranfield University, 2010)

	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity	Costs of the practice	Main studies
	Mitigation	Adaptation	Synergies	Trade-offs			
59. Extended water pricing and water metering	Possible indirect effect	Possible indirect effect on water management through economic allocation of water	May reduce pressure on water bodies	Not identified	0	<b>Moderate</b> Administrative and research costs	(Arcadis et al, 2012)
Hazard management							
60. Defences against floods and extreme events (hails etc)	Minor negative impact from energy use for the construction of the defences	May protect crops from impacts of extreme events, thus reducing vulnerability to extreme events.	May reduce soil erosion and crop damage in case of floods.	May have catastrophic results if mismanaged; may have negative impacts to biodiversity	<b>+</b> Likely neutral or in short term, but may be positive in long term	<b>High</b> Investment costs in materials for erecting defences, but reduced losses from weather events.	(FAO, 2011); (AEA, 2008);
61. Establishing disaster information systems and monitoring	Not identified	Contributes to disaster preparedness and risk mitigation. May develop expertise in disaster prevention.	Possible indirect effect through anticipation of droughts.	Not identified	0	<b>Moderate - High</b> High costs for establishing detection system with equipment and capacity building, but potential losses averted are high and spread across a wide range of stakeholders.	(Rogers and Tsirkunov, 2010)
62. Establishing insurance schemes	Not identified	Possible indirect effect by compensating	Not identified	Difficulty of assessing ex-ante environmental	0 Risk of encouraging	<b>High</b> Costs from enrolling in schemes and limited	(Ecologic, 2010); (Vermeulen

	Potential climate benefits		Other environmental benefits and trade-offs (eg water, soil, biodiversity)		Effect on productivity	Costs of the practice	Main studies
	Mitigation	Adaptation	Synergies	Trade-offs			
		losses from climate changes		and economic effects	farmers to avoid risk management	insurance sum; potentially high costs from uncompensated losses without insurance; high cost verification.	et al, 2010); (BIO Intelligence Service, 2011)

### *Priorities for climate change adaptation through water management*

The table lists a number of actions that can improve water management and so reduce exposure to scarcity and droughts. The table includes actions that aim to reduce losses, increase efficiency of use, and make use alternative water sources.

The technologies available include improvements in water infrastructures, mulching and soil coverage, efficient irrigation systems such as sprinklers or drip irrigation, precise irrigation management, such as precision or deficit irrigation, and water harvesting (collection & storage of rainwater, or storage of river water in the winter for use in the summer).

The report presents evidence that climate change is likely to expose agricultural production to increased risk from a range of sources. The listed actions could help farmers cope with these risks in three ways:

- By averting the risks
- By anticipating the risks, gaining time to deploy control measures to reduce their impact
- By helping recovery after the risk has materialised

Extreme weather events are a major category of increased risk to which agriculture is likely to be exposed. Flood defences that can avert the risk of flooding are a good example of the first kind of action. The second kind of action encompasses a mix of technologies including early-warning systems to anticipate when impacts are likely to occur, monitoring systems to evaluate what could be done, and actions to control the impact, such as hail nets or frost protection techniques. The third kind encompasses measures such as subsidised insurance schemes that encourage resilience after the impact. It is however important that farmers are not encouraged to ignore the need to take steps to avert, anticipate or control risks.

Increased pest and disease pressure are another likely category of increased risk. The response needs to include continued strict hygiene management to avert the risk, but also early-warning systems to anticipate the risk and allow the use of a precision agriculture approach to control these risks. Early warning systems can allow medicines to be administered or pesticides applied only when and if they are needed, using the most appropriate molecules. In this way the greatest degree of control can be achieved at the lowest cost and with the least environmental impact.

It is apparent from the actions listed in Table A3-6 that one important adaptation measure will be to increase what could be called “knowledge-based agriculture” (World Bank, 2009). This includes better information about the climate, to schedule irrigation and anticipate and mitigate potential impacts from extreme events (e.g. hail, floods), and about early-warning signs, for example to anticipate pest and disease risks. Systems to monitor widespread disasters also form a part of such knowledge base. Precise knowledge is also required to refine the use of inputs to cultivation, whether in terms of water quantities (precision irrigation) or pesticides and fertilisers (precision agriculture), so that the right amount of the right substance is provided at the right time and in the right conditions.

### 3.5 Enabling mechanisms and policy measures

**Table A3-10 Overview of opportunities in key Pillar 2 measures for support to actions for climate change mitigation and adaptation**

RDP measures	Domain	Examples of technologies and actions that can be supported
Capital investments to infrastructure		
Article 18: Investments in physical assets	Crop use and crop management	Precision agriculture;
	Livestock management	Optimising manure storage and improved outdoor storage; Introduction of biogas plants (using manure) on farm; Improvement of animal rearing conditions/ animal health;
	Sustainable water use and water efficiency	Precision irrigation; Reconstruction and upgrading of drainage infrastructure; Protective film covering; Improvements in irrigation equipment; Re-use of grey water on farms; Rainwater harvesting; Installation of water meters
	Energy efficiency and use of renewable energies	Energy efficient equipment; Efficiency of farm buildings/greenhouse buildings; Processing of agricultural and forest biomass for energy; Installation of infrastructure for renewable energy;
Article 19: Restoring agricultural production potential damaged by natural disasters	Sustainable water use and water efficiency	Reconstruction and upgrading of drainage infrastructure; Reconstruction of outdated rural water supply networks;
	Hazard management	Defences against floods and extreme events; Establish disaster information systems and monitoring;
Article 21: Basic services and village renewal in rural areas	Livestock management	Introduction of biogas plants (using manure) at local level;
	Sustainable water use and water efficiency	Rainwater harvesting; Reconstruction of outdated rural water supply networks; Irrigation scheduling;
	Energy efficiency and use of renewable energies	Efficiency of farm buildings/greenhouse buildings; Processing of agricultural and forest biomass for energy; Installation of infrastructure for renewable energy (solar, wind, geothermal, etc).
Soil and land management actions		
Article 21: Basic services and village renewal in rural areas	Land based actions	Wetland and peatland restoration; restoring river patterns; restoring natural aquatic ecosystems and riparian forests
Article 23	Land use change	Afforestation of cropland/Woodland creation;
Article 24	Land use change	Agro-forestry
Article 29	Cropland management	Catch crops/ green manure/ less fallow/ winter cover; Diversified crop rotations; Adding legumes/ N-fixing crops to rotation or undersowing; Intercropping; Zero tillage; Conservation/ reduced tillage; Restrictions on agricultural activities on slopes; Crop residue management; Reduced use of fertiliser and pesticides; Planting of

		hedgerows; Establish buffer strips; Reintroducing/maintaining terraces; Grass in orchards and vineyards; Perennial/ Permanent crops; Establish firebreaks; Modifying sowing dates; Improved pest strategies/integrated pest management; Replacement of synthetic pesticide with natural treatments; Integrated farming;
	Grazing land and pasture management	Optimising grazing intensity; Maintenance of permanent grasslands/pastures; Grassland renewal; Establishing shelterbelts;
	Land use change and cross-cutting actions	Wetland restoration; Conversion of arable land to grassland; Extensification/ de-intensification of production; Set-aside

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## **ANNEX TO CHAPTER 5(a) TYPOLOGY OF AGRICULTURAL HABITATS ACCORDING TO LINKS BETWEEN FARMING PRACTICES AND BIODIVERSITY**

Tucker, Graham M. & Underwood, Evelyn

European agricultural ecosystems can be broadly classified according to their original vegetation and degree of agricultural improvement, intensification and specialisation (although it should be noted that some agricultural modifications can be gradual, and development pathways vary across Europe) (Oppermann et al, 2012; Poláková et al, 2011). The main types are described in Table A5-1 and below:

### *Natural habitats*

The remaining natural habitats in Europe, such as montane grasslands, blanket bogs, tundra, semi-desert, salt steppes and coastal marshes, have a very high value for biodiversity, as they contain near natural communities and vegetation, many of which are restricted to such habitats. Agricultural activities such as grazing, mowing, cultivation or drainage will damage these species. However, many of these habitats are maintained through grazers that have been semi-domesticated, such as reindeer, or by feral descendants of domestic livestock, such as the wild goats and sheep on Mediterranean islands.

### *Extensive livestock systems - semi-natural pastures and meadows (including silvo-pastoral, rough grazing, and litter meadows)*

Much of the biodiversity on European farmland depends on extensive grazing systems (Doxa et al, 2010; Marriott et al, 2009; Pykälä, 2003; Van Teeffelen et al, 2008). Shepherds have traditionally been responsible for the maintenance of large areas of mountain, boreal and coastal habitat in Europe, and the shepherd's and shepherd dog's ability to protect their flock is also vital for the co-existence of livestock grazing and large carnivores such as bears, wolves and lynx (Oppermann et al, 2012). Extensive livestock grazing is on the decline in the EU due to farmland abandonment, but low intensity livestock systems still occupy around 15% of the EU's agricultural land, as well as large areas of rough grazing that are not included in the agricultural statistics. In Western Europe, traditional livestock systems usually include all-year grazing on permanent pastures. In Central Europe, traditional livestock systems involved summer grazing on summer pastures, and hay making on lowland and river floodplain meadows. In winter, the livestock are kept indoors and fed on the hay and other dried forage. In mountainous areas, livestock are traditionally moved to mountain pastures for the summer, a practice known as transhumance, and the lower grasslands are primarily used for hay. Some meadows were established in order to harvest litter for animal bedding (Küster and Keenleyside, 2009). Eastern and Southern European farmland has retained much more biodiverse grassland than Western Europe eg (Báldi et al, 2013).

Semi-natural grasslands and grazed scrub and heath host species-rich vegetation communities, with up to 80 plant species per m<sup>2</sup>; some species are restricted to such habitats and dependant on specific agricultural practices (Veen et al, 2009), including many grassland butterflies (van Swaay et al, 2006), amphibians (Temple and Cox, 2009a) and reptiles (Rödder and Schulte, 2010; Temple and Cox, 2009b) that are now threatened in Europe. The vegetation is maintained through extensive grazing and/or mowing for hay or litter, at a point in the vegetation cycle that allows plants to flower and set seed. Some meadows have traditional irrigation systems, which can increase habitat diversity, but the habitats are usually highly sensitive to agricultural activities such as fertilisation or irrigation. Agro-silvo-pastoral systems are traditional high nature value agricultural systems in many countries (Bergmeier et al, 2012), including boreal wood pastures, dehesa and montado, English parks and



forests, and traditional orchards, where the long continuity of management has created a very rich plant diversity which depends on the continuation of the partial tree cover (Aavik et al, 2008).

However, in some Member States, rough grazing land also includes areas of degraded species-poor grazing that has resulted from overgrazing of heath and scrub or drainage of wetlands.

### *Extensive arable-pastoral systems*

Extensive arable systems are now very rare in Europe, mainly dry cereal production ('pseudosteppe') in Spain, Portugal and southeast Europe. They are linked to extensive grazing systems with shepherded sheep grazing on the fallow fields and crop residues (Caballero and Fernández-Santos, 2009). The systems use little to no fertiliser, pesticides or irrigation, and are characterised by sparse crops, diverse crop rotations, high proportion of fallow, and patches of semi-natural vegetation (Bota et al, 2005). They support a number of threatened species, especially birds such as the Great Bustard (*Otis tarda*) and Lesser Kestrel (*Falco naumanni*) (Bota et al, 2005; Pain and Pienkowski, 1997; Tucker and Evans, 1997), rare arable weeds such as Spreading Hedgeparsley (*Torilis arvensis*) and Whiskered Brome (*Bromus grossus*), and varied vegetation in the fallow fields.

### *Traditional and extensively managed permanent crops*

Traditional (high stem) permanent crops include old olive groves, vineyards, and nut groves in southern Europe, and fruit orchards in all parts of Europe. There has been a large loss of these crop systems (eg Duarte et al, 2008), but they may still occupy 2 to 3% of Europe's agricultural land, particularly in the Mediterranean. Trees may be very old, providing a good habitat for bats, birds, insects, lichens and bryophytes, and animals and plants also find habitats in features such as terraces, walls, ditches or ponds (Davy et al, 2007; Steffan-Dewenter and Leschke, 2003; Verhulst et al, 2004). Mediterranean permanent crops provide vital overwintering habitat for large numbers of frugivorous and insectivorous birds from central and northern Europe (Rey, 2011). The ground vegetation is often semi-natural and grazed or mown and hosts rare and endangered plant species (Bruggisser et al, 2010; Steffan-Dewenter & Leschke, 2003), although some are kept bare. Some bare patches provide good foraging and insect habitats (Schaub et al, 2010), but large-scale cultivation leads to soil erosion (Gómez et al, 2011).

### *Improved grassland systems*

Agriculturally improved grassland covers around 15% of the EU's agricultural land (ie half of the permanent grassland area). Farming in Ireland, Spain, Luxembourg, Austria, Portugal, Slovenia and the UK is dominated by grassland systems. Improved grassland generally has very low biodiversity, with ten or fewer plant species in the sward<sup>8</sup>. Flowering plants (except clover)<sup>9</sup> are generally regarded as weeds, but provide important food resources for insects and birds in otherwise barren habitats. Biodiversity in field margins and boundary habitats is often also relatively low because of the high intensity of fertiliser and other inputs used. Some improved grassland provides forage and habitat for overwintering birds such as geese and swans.

<sup>8</sup> principally improved cultivars of Ryegrass (*Lolium perenne*), Cocksfoot (*Dactylus glomerata*), and White Clover (*Trifolium repens*)

<sup>9</sup> such as Creeping Buttercup (*Ranunculus repens*), Dandelion (*Taraxacum officinale*), Creeping Thistle (*Cirsium arvense*) or Chickweed (*Stellaria media*)

***Intensive arable systems***

Arable land covers over 60% of the EU's agricultural area<sup>10</sup>, and is a large part of the landscape in most Member States (except Scandinavia and mountain regions). Intensive arable systems are generally very low in biodiversity. Any semi-natural vegetation patches, even small areas such as hedges or ditches, contribute a large proportion of the biodiversity present (Drapela et al, 2008; Hendrickx et al, 2007; Kivinen et al, 2006). Crops vary in the amount of biodiversity they harbour - although this also depends on the management. Oilseed rape crops, for example, are often hotspots of insect diversity - although it is argued that this has a negative impact on the pollination of semi-natural vegetation (Diekotter et al, 2010; Holzschuh et al, 2011). Arable crops and stubble provide habitat and food resources for some animals and birds if the management is not too intensive; for example the European Hamster (*Cricetus cricetus*) only occurs in productive arable areas.

***Intensive permanent crops***

Intensively managed permanent crops are grown on around 5% of the EU's agricultural area. These vineyards, olive groves and fruit plantations are generally poor in biodiversity, and specialisation in these crops reduces biodiversity at the landscape scale (Zimmermann et al, 2010). Drainage, irrigation, and intensive management of the ground vegetation substantially reduce biodiversity (Allen et al, 2006). Crop plants are kept in dwarf form and replaced before they can become old enough to provide good habitats. High levels of pesticide use reduce invertebrate populations and therefore also other wildlife.

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<sup>10</sup> The utilised agricultural area (UAA) is the total arable land, permanent grassland, land used for permanent crops and kitchen gardens. The UAA excludes unutilised agricultural land, woodland and land occupied by buildings, farmyards, tracks, ponds, etc.

**Table A5-1 A broad field-scale typology of agricultural habitats according to the main links between farming practices and biodiversity in the EU, and the impacts of farming practises on biodiversity**

The table below lists the distinct types of agricultural ecosystem in Europe based on their original vegetation and degree of agricultural improvement, intensification and specialisation (although some agricultural modifications can be gradual, and development pathways vary across Europe). However, it is important to note that this is a field-scale typology, and when viewed at landscape scale, the relationship with biodiversity also varies according to 1) the spatial scale of the fields and farming system (eg from very small-scale strip farming, to enclosed fields or extensive unenclosed landscapes); 2) the presence and ecological quality of field boundary habitats (eg hedges and ditches, uncropped strips) and other non-farmed habitat features (eg trees and ponds); 3) landscape diversity, in terms of: composition (ie habitat and boundary types); structure (ie scale of fields and other elements); and interactions with other habitat types other than farmland (eg forests, wetlands, urban areas).

Source: Adapted from Poláková et al (2011); <sup>a</sup> adapted from van Swaay *et al* (2006) using updated annexes from Butterfly Conservation Europe (<http://www.bc-europe.org/upload/Butterfly%20habitats%20-%20Appendix%201.pdf>); <sup>b</sup> (Temple & Cox, 2009a); <sup>c</sup> (Temple & Cox, 2009b). Note: Habitat divisions for each taxa group reflect the habitat types distinguished in the available data.

	Permanent grasslands and other grazed habitats				Crops							
	Natural habitats	Semi-natural habitats		Improved grassland		Cultivated			Permanent			
		Pastures	Meadows	Organic	Conventional	Extensive	Organic	Intensive	Extensive	Organic	Intensive	
Vegetation and biodiversity importance	Near natural species & communities (montane grasslands, blanket bogs, tundra, semi-desert, salt-steppes, coastal marshes). Very high	Species-rich, native species (dry grasslands, shrublands, pastoral woodlands, floodplain meadows and upland meadows)  Very high biodiversity value, these habitats tend to be species-rich and declining; some species are restricted to such habitats and dependant on specific agricultural practices (incl. 25 European HD Annex II butterfly species <sup>a</sup> , 5		Often dominated by non-native grasses; organic: may have higher plant diversity  Moderate, species diversity is much reduced compared to natural and semi-natural habitats, but some species of conservation importance use such habitats, sometimes in important numbers		Dry cereal production ('pseudo-steppe') in Iberia & SE Europe. High, such habitats are now rare and support some threatened species (esp birds). varied	Arable farmland with Monocultures of cultivars at field-scale. Low, especially in intensive farmland dominated landscapes, but biodiversity levels can be enhanced by appropriate measures			Old olive groves, vineyards and orchards in S Europe . Moderate to high, such habitats are declining and support some threatened species	Typical fruit and nut systems in most of Europe. Low, especially in intensive farmland dominated landscapes, but biodiversity levels can be enhanced by appropriate measures	

	Permanent grasslands and other grazed habitats					Crops					
	Natural habitats	Semi-natural habitats		Improved grassland		Cultivated			Permanent		
		Pastures	Meadows	Organic	Conventional	Extensive	Organic	Intensive	Extensive	Organic	Intensive
	biodiversity value, many species are restricted to such habitats	<i>European threatened amphibians<sup>b</sup>, 4 European threatened reptiles<sup>c</sup></i>				vegetation in fallow fields					
Grazing / mowing	Grazing and mowing is normally not required to maintain habitat, and may be detrimental to sensitive species. Low grazing	Extensive grazing is normally the prime factor that maintains the habitat, appropriate grazing also increases botanical diversity, and associated fauna	Habitat created by & dependent on mowing for hay at appropriate times	High grazing densities and/or cutting for hay or silage. Outdoor grazing can provide benefits, especially for invertebrates and birds	Grazing levels are often too high to maintain plant diversity and associated fauna; can provide feedings benefits for birds, but high nest losses from trampling	Crop residues and fallow land are often grazed. Grazing of fallows and stubbles is important for biodiversity	Temporary grasslands usually cut for silage and grazed	Temporary grasslands usually cut for silage, often no grazing with animals	Traditional orchards, olive groves etc may be grazed. Grazing of fallows and stubbles is beneficial for biodiversity. Some mowing for hay, which can increase biodiversity	None	

	Permanent grasslands and other grazed habitats				Crops							
	Natural habitats	Semi-natural habitats		Improved grassland		Cultivated			Permanent			
		Pastures	Meadows	Organic	Conventional	Extensive	Organic	Intensive	Extensive	Organic	Intensive	
	levels due to low productivity			Mowing is normally for silage and is early and frequent, reducing plant and animal diversity, and causing high losses of ground nesting birds, but losses can be reduced by wildlife friendly cutting			Temporary grasslands are sometimes grazed, but stocking levels too high to maintain plant diversity and associated fauna; can provide feedings benefits for birds, but high nest losses from trampling. Mowing of temporary grasslands is normally for silage and is early and frequent, reducing plant and animal diversity, and causing high losses of ground nesting birds, but these can be reduced by wildlife friendly cutting					
Cultivation & planting	Never - destroys the habitat	None or very infrequently - normally causes significant damage, restoration can be difficult or impossible		Many are occasionally re-sown (< 5 years) - Cultivation and reseeded of grasslands results in loss of semi-natural elements and much reduced biodiversity, recovery is possible if seedbanks remain but is slow		Annual or frequent cultivation used to control weeds etc, damages soils and reduces biodiversity. In extensive and organic systems rotations and fallow periods are used to maintain soil fertility and condition. In intensive arable rotations are variable, often only break crops or repeat cropping. Rotations, especially those that contain fallow, increase crop diversity, which provides more options for species in terms of food and breeding habitat. Fallow land also reduces cultivation frequency and associated soil impacts, and can also provide good breeding habitats for birds due to the lack of farming operations.			Very infrequent; trees may be very old in traditional orchards and olive groves			
Drainage	Drainage is highly damaging,	Drainage is highly damaging, but some habitats require or benefit		Some habitats may benefit from appropriate hydrological management eg to allow winter		Unmanaged	Drained and/or irrigated if necessary		Unmanaged	Sometimes irrigated	Often irrigated	

	Permanent grasslands and other grazed habitats					Crops					
	Natural habitats	Semi-natural habitats		Improved grassland		Cultivated			Permanent		
		Pastures	Meadows	Organic	Conventional	Extensive	Organic	Intensive	Extensive	Organic	Intensive
	and hydrological management is not normally necessary.	from appropriate hydrological management eg to allow winter flooding, or high water tables		flooding, or high water tables							
Irrigation		Irrigation not normally carried out	Traditional irrigation systems can increase habitat diversity	Traditional irrigation systems can increase habitat diversity, modern systems leads to significant intensification and associated significant detrimental impacts		Irrigation normally destroys the habitat if carried out	Irrigation leads to significant intensification and associated significant detrimental impacts		Irrigation normally destroys the habitat if carried out	Irrigation leads to significant intensification and associated significant detrimental impacts	
Fertiliser	Never - Fertilisation usually destroys the habitat	Usually none	None or occasional organic manure or nutrient rich flooding	Regular use of organic manure	Regular fertiliser use and/or organic manure.	Occasional use, dung from livestock. Absence of use helps support biodiversity	None, other than livestock manure	High annual NPK use	Occasional use. Low rates of fertiliser use may reduce plant diversity	None, other than livestock manure. Use of manure may provide some benefits	High amounts used annually. Fertiliser use has little impact due to highly artificial nature of the vegetation
		High rates of artificial fertiliser, slurry and farmyard manure use reduces plant diversity and associated fauna.					Very high rates of artificial fertiliser, slurry and farmyard manure use reduces plant diversity and associated fauna, and creates vegetation that is often too tall and dense for birds to nest and feed in				
Pesticides	Never	Very rarely		Organic crop protection methods sometimes	Occasionally as needed. Herbicide use has	Not normally used, but major impacts if	Organic compounds used occasionally	Used annually, primarily prophylactically. Pesticide use has	Pesticides not normally used, but major impacts if they	Organic compounds used occasionally,	Pesticide use has significant impacts on

	Permanent grasslands and other grazed habitats				Crops						
	Natural habitats	Semi-natural habitats		Improved grassland		Cultivated			Permanent		
		Pastures	Meadows	Organic	Conventional	Extensive	Organic	Intensive	Extensive	Organic	Intensive
				used, usually with few significant impacts	significant impacts on many species as a result of direct toxicity and indirect impacts from the disruption of food webs	they are	lly, with similar biodiversity impacts to other pesticides	significant impacts on many species as a result of direct toxicity and indirect impacts from the disruption of food webs	are	with similar biodiversity impacts to other pesticides	many species as a result of direct toxicity and indirect impacts from the disruption of food webs

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## ANNEX TO CHAPTER 5(b) IMPACTS OF FARMING PRACTICES ON BIODIVERSITY

Underwood, Evelyn & Tucker, Graham M.

### 5.3 Negative impacts of agricultural practices on biodiversity in agricultural systems

Farming practices profoundly affect biodiversity, but practices differ amongst ecosystem types and also vary in terms of intensity. As a result some practices can be beneficial or detrimental to biodiversity depending on the intensity and the vegetation type. For example, optimal levels of grazing help maintain semi-natural habitats, but over and under-grazing can be damaging. Some practices, such as conventional tillage, pesticide use, drainage and irrigation, and the use of artificial fertilisers, nearly always result in less biodiversity.

The following overview assesses the impact of each practice on biodiversity, although in reality the practices are linked in a sequence of farmland intensification. For example, grassland drainage to create drier ground allows vehicle access so that fertilisers, herbicides and pesticides can be used, and on suitable ground the grassland may then be ploughed up and reseeded, allowing higher stocking levels and the cutting of grass for silage. It is based on Poláková et al (2011) and evidence from a range of studies (Aebischer et al, 1999; Billeter et al, 2008; Donald et al, 2001; Donald et al, 2006; Hendrickx et al, 2007; José-María et al, 2010; Liira et al, 2008; Pain and Pienkowski, 1997; Stoate et al, 2001; Stoate et al, 2009; Sutcliffe and Kay, 2000; Tucker and Evans, 1997; van Swaay et al, 2006; Wilson et al, 2009).

It should be borne in mind that other factors that are not directly related to agriculture are also contributors to biodiversity changes in farmland habitats, such as high predator densities, alien invasive species, hunting, disturbance, collisions with vehicles and power lines, external pollution sources, impacts on species whilst on migration, or in wintering or breeding grounds, and climate change.

It is also important to note that fragmentation from urbanisation and other infrastructure developments, as well as climate change, will exacerbate all expected pressures on agricultural habitats and species (EEA and FOEN, 2011; IEEP & Alterra, 2010).

#### 5.3.1 Changes in farming landscapes that result in loss of biodiversity on farmland

##### *Loss of natural and semi-natural habitats, including semi-natural grassland*

The largest impact of agricultural change on overall biodiversity in the landscape comes from the loss of semi-natural habitats (Billeter et al, 2008). Many species only occur on farmland if the population is regularly replenished from semi-natural habitat refuges, which have to be present at a sufficient density for that species (Bergman et al, 2004; Kivinen et al, 2006; Le Féon et al, 2010; Oeckinger and Smith, 2007). In particular, the loss of extensively grazed semi-natural grassland is a major factor in the loss of biodiversity in Europe's agricultural landscapes (EEA, 2010), particularly the abandonment of extensive livestock systems on montane pastures and meadows, and areas with poor soils and harsh climates (Dover et al, 2011; Laiolo et al, 2004). Cessation of mowing for just a few years reduces hay meadow plant species richness (Baur et al, 2006; Dover et al, 2011). Eight European grassland butterfly species have suffered precipitate population declines as a result of the loss of semi-natural grassland habitat, particularly wet grassland (EEA, 2013).

Mountainous and hilly areas are particularly at risk from abandonment (Keenleyside & Tucker, 2010). The limited availability and cost of skilled shepherds is now a widespread problem throughout many regions of South and Eastern Europe with common land grazing (García-González, 2008).

### *Loss of mixed farming and diversity in farm systems*

Landscape-scale diversity is important because species often have a range of resource requirements (Guerrero et al, 2012; Newton, 2004). Habitat heterogeneity at both field and landscape scale is generally associated with species richness (Siriwardena et al, 2012), and is crucial for the maintenance of many species meta-populations, such as butterflies (Oliver et al, 2010). The loss of structural and ecological heterogeneity in the landscape results in reduced breeding and feeding options for animals, and reduced ecological connectivity amongst habitat patches (Doxa et al, 2012). Farming landscapes dominated by intensive arable cropping have markedly lower weed species diversity than complex landscapes that contain a range of 'refuge' habitats for weed species, such as field margins, fallows, grassland and garden land (Roschewitz et al, 2005).

Mixed farms with arable and livestock now make up only 13% of European farms (Eurostat, 2012a), a dramatic decline. Specialisation means the loss of grassland on arable farms and of arable land on livestock farms. In improved grassland-dominated landscapes, even small patches of intensive arable farmland can be highly beneficial in terms of increasing bird diversity (Robinson et al, 2001), and the same applies to patches of grassland in arable landscapes (Piha et al, 2007; Westbury et al, 2011). For example the Skylark (*Alauda arvensis*) requires a variety of crops within its territory if it is to successfully fledge more than one brood in a season, as is required to maintain populations (Chamberlain et al, 1999). This is because crops that are suitable for first broods become too tall for breeding, so they require less dense and tall crops for subsequent broods, such as spring-sown crops or semi-natural grassland (Guerrero et al, 2012). Hares (*Lepus europaeus*) benefit from increasing habitat heterogeneity especially in intensively managed and homogenous farmland landscapes, and from mixed farms with grassland and arable (Smith et al, 2004; Vaughan et al, 2003).

### *Removal of habitat features including boundary habitats and other patches of semi-natural vegetation*

Farmland features such as hedgerows, trees, ponds, ditches, stone terraces and uncropped areas with patches of rough grass or scrub provide important habitat in many farmland landscapes. They provide important structural diversity to the farmland landscape, and provide cover and food resources, eg for bats (Frey-Ehrenbold et al, 2013) and birds (Newton, 2004; Siriwardena et al, 2012). Typically their greatest value is in enabling some species of forest, wetland, scrub and rocky habitats to exist in otherwise agricultural dominated areas, thereby greatly increasing between-habitat and overall landscape-scale diversity. Ditches with vegetated margins and farmland ponds are key biodiversity hotspots in farm landscapes (Aavik and LIIRA, 2010; Davies et al, 2008). Shrubs in grasslands provide refuges and food sources for invertebrates and birds (Söderström et al, 2001) with consequent benefits for plant reproduction through their dispersal of seeds and pollination services (Pihlgren and Lennartsson, 2008).

Many farm habitat features that were traditionally managed as part of the farm are suffering from abandonment. Abandonment of terraces in Mediterranean countries has resulted in widespread soil erosion and associated biodiversity loss (Bellin et al, 2009; Dunjo et al, 2003; García-Ruiz and Lana-Renault, 2011).

The removal or excessive management of hedgerows and boundary features can have significant impacts, especially in areas that lack other non-farmed habitats (Batáry et al, 2010). Linear habitat strips and patches facilitate the movement of some species (García-Ruiz & Lana-Renault, 2011) through what would otherwise be a hostile landscape (Davies and Pullin, 2007). However, boundary habitats and linear elements do not compensate for the loss of semi-natural habitats, as they mostly support disturbance tolerant generalist species, which are quite common and widespread (Liira et al,

2008). It is also important to point out that some species of extensive open farmed landscapes, such as steppe grasslands and moorlands, are detrimentally affected by the introduction of trees and boundary features (Chiron et al, 2010; Wolff, 2005). This is because many of these species avoid enclosed landscapes.

### 5.3.2 Farming practices that are detrimental to biodiversity on grassland

#### *Grassland drainage*

Drainage of grasslands leads to the loss of shallow pools and ditches, less winter flooding and lower groundwater levels, and changes the vegetation composition. This can result in the loss of important wet grassland habitats, which may support wintering water birds and provide suitable breeding habitat for birds on lowland river and coastal floodplains (Newton, 2004). Butterfly species are particularly affected by the drainage of wet grasslands across Europe (van Swaay et al, 2006; WallisDeVries and van Swaay, 2009). Many of the invertebrates that form a major part of bird diets on wet grassland are highly sensitive to drought, and are thus more vulnerable to population crashes on drained grassland, resulting in impacts on bird populations (Pearce-Higgins, 2010). However, ditches can provide some compensatory aquatic habitat. There is evidence that fields under open drainage provide better bird habitat than fields with subsurface drainage (Marja et al, 2013). Subsurface drainage can increase subsoil erosion, resulting in negative impacts on aquatic biodiversity (Bilotta et al, 2008).

#### *Ploughing and re-seeding of grasslands*

After drainage (where necessary) and fertilisation the next step in agricultural improvement of grasslands is usually ploughing and reseeded. Grasslands are typically sown with a few selected grass cultivars, such as *Lolium* spp (sometimes with clover) that through breeding programmes are adapted to high nutrient conditions. This clearly has a profound impact on the vegetation and knock-on impacts on the whole ecosystem. It further reduces plant species diversity (and associated animal communities), increases the density and growth rates of the grassland, and impacts soil biodiversity.

#### *High grazing densities*

Intensive grazing reduces the heterogeneity of plant vegetation and decreases invertebrate species richness (Kruess and Tschardt, 2002; WallisDeVries et al, 2002). High stocking rates can lead to soil compaction, which reduces permeability for roots, water and oxygen and destroys the micro- to macro-aggregate structural diversity that maintains soil life. This can lead to declines in earthworms and other soil invertebrates, which in turn exacerbates soil compaction effects. Soil compaction can have impacts on invertebrate feeding birds, as a result of reduced soil invertebrate populations, but also reduced accessibility due to less penetrable soils (McCracken and Tallowin, 2004). High grazing rates in wet conditions can also lead to poaching of the grass surface, which increases soil erosion.

#### *Cutting for silage and other mechanical operations*

Most former hay meadows and many pastures are now primarily used for silage production, under which the grass is intentionally cut before seeding to maximise its nutritional value. This results in a significant loss of biodiversity as later cutting for hay allowed plants to flower and seed and under typical low nutrient conditions plant and associated invertebrate diversity was very high. The absence of seed food resources also has impacts on seed-eating birds (Buckingham et al, 2006; Buckingham et al, 2010; Vickery et al, 2001). The loss of grazing livestock from grassland converted to silage production is detrimental for biodiversity because animal dung (particularly from cattle)

supports invertebrates, some of which are important prey for several species of bat (Wickramasinghe et al, 2003) and many birds (Vickery et al, 2001).

The early cutting of silage is a major problem for ground-nesting birds, which results in very low rates of breeding success for many species (Oppermann and Spaar, 2003). Intensively managed grasslands also require a variety of frequent mechanical operations, including fertiliser spreading, topping of vegetation as weed control, and rolling. These operations are so frequent that there is insufficient time for birds to breed in between, and therefore egg and chick mortality rates are so high that such grasslands become sink habitats, ie they attract ground-nesting birds but breeding success is lower than mortality rates (Buckingham et al, 2006).

Modern mechanised hay harvesting generally removes grass over large land areas simultaneously, which results in the instantaneous and complete destruction of habitats for invertebrates and birds and also synchronises sward regrowth across the whole area, reducing habitat heterogeneity and affecting those species that require patches of bare ground or short swards (Cizek et al, 2012). Modern farm machinery also directly kills most small animals that cannot get away in time, such as grasshoppers, bees, amphibians and some late breeding birds (Humbert et al, 2009); this has been a key cause of the decline in the population of the Corncrake (*Crex crex*) (Orbicon, Écosphère, ATECMA, Ecosystems LTD, 2009).

#### *Livestock anti-parasitoids and pharmaceuticals*

Livestock medicines are generally not completely eliminated in animals, as they are bioactive substances, acting highly effectively at low doses and excreted after a short time of residence. They are therefore transmitted to the environment through faeces and urine. Thousands of tonnes of **antibiotics** may be excreted by animal husbandry per year (Kemper, 2008). Although antibiotic use has declined since the prohibition of growth promoters in the EU in 2006<sup>11</sup>, they are found in soils and the aquatic environment (though most antibiotics in water originate from human sewage rather than livestock) (EEA, 2011). Many antibiotics are adsorbed in soil, but little is known about their impacts on soil functions. The increase in use of **avermectins** and other drugs against parasites of livestock is negatively affecting invertebrates in dung, and the birds and bats that feed on them (Beynon, 2012; Floate et al, 2005; Hutton and Giller, 2003; Vickery et al, 2001).

#### *Use of fertilisers on grassland*

The use of artificial fertilisers (typically nitrogen in grasslands, and nitrogen, phosphorus and potassium on other crops) to increase biomass production is almost universal in non-organic improved grasslands and crops in Western Europe (Box A5-1). Central and Eastern European grasslands in contrast are rarely fertilised and retain much more biodiversity (Báldi and Batáry, 2011).

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<sup>11</sup> Regulation (EC) No. 1831/2003 of the European Parliament and of the Council of 22 September 2003 on Additives for Use in Animal Nutrition.

**Box A5-1 Nitrogen surpluses from fertiliser use in the EU**

The EU-27, with 7% of the global population, uses 13% of the world's nitrogen (N) fertiliser and 10% of manure N excretion, and is facing severe detrimental effects of nitrogen losses to the environment (Dise, 2011; EEA, 2007). Average N fertiliser consumption in the EU-15 has declined since 2002, but is increasing in the EU-12, so that average use per ha is now fairly similar across the EU<sup>12</sup>. An indication of the pressure of fertiliser use on the environment is shown by nitrate concentrations in rivers and lakes<sup>13</sup> and coastal waters<sup>14</sup>. Overall, average concentrations have declined by 11% since 1992, but they are still enough to cause eutrophication problems in many of Europe's lakes and coastal waters<sup>15</sup>. Concentrations are still highest in lowland Western Europe and the Czech Republic, but notably Estonia, Lithuania, and Slovenia are increasing their nitrate leaching to water.

The gross nitrogen balance indicator<sup>16</sup> measures the surplus or deficit of nitrogen on agricultural land in different parts of the EU. Most EU countries have a nitrogen surplus in excess of 40kg/ha, meaning that more nutrients are added than are needed by crops, though there has been a gradual decline in surpluses in the EU-15 over the last 20 years (OECD, 2013). Notably, Denmark and Belgium have halved their average surplus since 1990 but are still at over 80 kg/ha.

Another indicator is Nitrogen Use Efficiency (NUE), which is the N output in useful products as a percentage of the total N input (including mineral fertiliser and biological fixation, but not manure and excrements and atmospheric deposition). NUE varies from 63% in Hungary to 15% in the Netherlands (Sutton et al, 2013); this means that in the Netherlands in 2008, 85% of the nitrogen was lost as gas emissions (NH<sub>3</sub>, N<sub>2</sub>O, NO<sub>x</sub>, N<sub>2</sub>) or as N leached to water.

Fertiliser application causes changes in species composition because plants of natural and semi-natural habitats have generally evolved in low nutrient conditions and are out-competed by the few species that are able to take advantage of the high nutrient levels. Consequently, even low levels of fertiliser use degrade the quality of such habitats (Cop et al, 2009; Zechmeister et al, 2003). Significant regular fertiliser use therefore results in grass dominance and reduced plant species diversity, leading to the conversion of semi-natural habitats into agriculturally improved grassland. For example, in the UK the use of inorganic nitrogen on grassland has doubled since the 1950s (Vickery et al, 2001), and an average of only three broad-leaved species are found where nitrogen inputs exceed 75 kg/ha/yr (a currently quite average fertilisation rate on grassland in the UK<sup>17</sup>) (McCracken & Tallwin, 2004). Furthermore, this process becomes increasingly irreversible as a result of the accumulation of nutrients in the soil and gradual die-off of the former semi-natural habitat's seed bank.

<sup>12</sup> FAOSTAT <http://faostat3.fao.org/home/index.html>

<sup>13</sup> <http://www.eea.europa.eu/data-and-maps/indicators/nutrients-in-freshwater/nutrients-in-freshwater-assessment-published-3>

<sup>14</sup> <http://www.eea.europa.eu/data-and-maps/indicators/nutrients-in-transitional-coastal-and/nutrients-in-transitional-coastal-and-4>

<sup>15</sup> <http://www.eea.europa.eu/data-and-maps/indicators/chlorophyll-in-transitional-coastal-and/chlorophyll-in-transitional-coastal-and-3>

<sup>16</sup> <http://www.eea.europa.eu/data-and-maps/indicators/agriculture-nitrogen-balance/agriculture-nitrogen-balance-assessment-published>

<sup>17</sup> The average N fertilisation rate on UK grasslands is currently around 60 kg/ha/yr. It should be noted that this is part of an on-going decline – in the 1990s it was 130 kg/ha/yr.

See [http://www.ukagriculture.com/farming\\_today/fertiliser\\_data.cfm](http://www.ukagriculture.com/farming_today/fertiliser_data.cfm)

Declines in plant species diversity from eutrophication result in knock-on declines in some invertebrate groups, including mites (Acari), springtails (Collembola) flies (Diptera), beetles (Coleoptera), damselflies and dragonflies (Orthoptera), and millipedes and centipedes (Myriopoda) (Nagy, 2009). Fertiliser creates dense fast growing homogeneous grass swards which are unsuitable for birds such as the Skylark (*Aluda arvensis*) and Lapwing (*Vanellus vanellus*) to nest in and interfere with foraging efficiency and prey availability (Donald et al, 2002; Wilson et al, 2009).

Earthworms and other soil invertebrates may benefit from moderate fertiliser applications, especially farmyard manure (Vickery et al, 2001). But high nitrogen levels from excessive use of fertiliser and manure lead to increasing mineralisation of organic carbon in the soil, which destroys organic matter and reduces soil biodiversity.

### **5.3.3 Farming practices that are detrimental to biodiversity in arable and perennial systems**

#### *Change from spring cropping to winter cropping, loss of stubble fields and fallow*

The widespread switch from spring to winter cropping of cereals across Northern Europe is associated with a switch from overwintered stubble with spring ploughing to late summer ploughing after harvest. Additionally, the increased efficiency of harvesting operations has resulted in less split grain for food. Cereal stubble in autumn and winter is a key food resource for farmland birds and mammals (Geiger et al, 2010a), and the loss has contributed to their decline (Chamberlain et al, 2000; Newton, 2004; Whittingham et al, 2005). In spring, the winter crop is already too tall and dense for successful breeding (Donald et al, 2002). The switch to winter cereals in Denmark also led to a dramatic decline in the weed flora (Hald, 1999).

#### *Tillage and other soil cultivation practices causing loss of soil organic matter and erosion*

Ploughing and other tillage operations result in the direct mortality of soil invertebrates and disruption of the soil ecosystem (Roger-Estrade et al, 2010). This leads to reduced earthworm and other soil invertebrate populations (Nieminen et al, 2011; Postma-Blaauw et al, 2012), which in turn reduces food availability for soil-invertebrate feeding birds (Tucker, 1992). Deep tillage (15cm or more) destroys bee nests and European Hamster (*Cricetus cricetus*) burrows (La Haye et al, 2010; Rouston and Goodell, 2010). Tillage also disrupts fungal networks and reduces the quantity of fungi in soil. The impacts of regular cultivation on soil biodiversity, combined with the soil's exposure, also reduce organic matter and degrade soil structure, reducing soil biodiversity. This can have impacts on a variety of ecosystem services including the ability of the soil to produce crops and sustain livestock, resist wind and water erosion and absorb and retain water. Cultivation also leads to significant carbon losses.

However, if tillage operations are carefully timed and combined with use of ground cover crops, sufficient inputs of organic matter such as manure, and crop rotations, plant roots can penetrate deeply, soil decomposers are aerated, and soil can recover. Tillage and other soil cultivation practices are particularly damaging if they create bare soil that is vulnerable to erosion, for example by ploughing against instead of along the contour, or by creating a hard 'pan' layer which stops water infiltration and drainage.

#### *Irrigation*

Modern irrigation systems are generally only used on the most productive or potentially productive croplands. As such farmland is generally very low in biodiversity in comparison with other European agricultural systems, the introduction of irrigation results in only moderate additional biodiversity



impacts<sup>18</sup> (Reidsma et al, 2006). However, the introduction of irrigation in dry arable or permanent crop systems is associated with the intensification of other agricultural practices, the combined effect of which is detrimental to biodiversity. For example, the introduction of irrigation in extensive cereals in Spain has been shown to result in severe declines in farmland bird species (Brotons et al, 2004; Ursúa et al, 2005). Trickle irrigation of permanent crops such as olives or citrus, for example in Crete, Apulia in Italy and Andalusia in Spain, is associated with soil erosion and salinization, which has an indirect impact on soil biodiversity and weed diversity (European Commission, 2010). Salinisation - the accumulation of soluble salts of sodium, calcium, potassium and magnesium in soil - is the result of mis-managed irrigation and/or poor drainage, and creates toxic conditions for many soil organisms, resulting in a deterioration or loss of soil functions (Lomolino, 1994).

#### *Use of artificial fertilisers on cropland*

Fertiliser use on crops strongly decreases weed diversity, and also has a strong negative impact on plant diversity in field margins, particularly on rare arable weeds (Kovács-Hostyánszki et al, 2011b). High fertiliser inputs tend to favour bacterial decomposition, which quickly exploits readily available nutrients and easily digestible organic compounds, and so 'burns up' soil organic matter. Conversely, application of manure, or other organic matter sources, tends to lead to larger and more diverse soil communities and more fungi, which can break down complex compounds such as lignin and cellulose and create long-lasting soil organic matter (humus) (Sradnick et al, 2013). Reactive nitrogen leaches more rapidly from artificial fertilisers than from manure and plant matter (Tuomisto et al, 2012), and nitrogen and phosphate in run-off from agricultural fields leads to eutrophication of streams, ponds and rivers, as well as any habitats that are flooded by ditch or river water, which has a strongly negative effect on biodiversity (Dise, 2011).

#### *Use of pesticides (insecticides, herbicides, fungicides, and rodenticides)*

Pesticides are used on most intensely cultivated crops (herbicides, insecticides, and fungicides) and most improved grasslands (mainly herbicides) (see Box A5-2). Most cereal and maize cropping in the EU relies heavily on the use of herbicides for weed control. Around a third of the maize area<sup>19</sup> is treated with insecticides delivered as a seed treatment, soil insecticide or a foliar application, and nearly all maize seed is treated with fungicide (Meissle et al, 2010). Insecticide and fungicide use is particularly high on fruit and vegetable crops. Certain approved products (eg sulphur) are used on some organic farms, particularly on vineyards.

<sup>18</sup> (except compared to the intensive lowland arable systems of Northwest Europe)

<sup>19</sup> Eg 50-60% of maize in Hungary and 32-42% of maize in France receives insecticides. Seed treatment with neonicotinoid insecticides (e.g. thiamethoxam, tefluthrin, clothianidin) ranges from 20% in Southwest Poland and Békés region to 100% in the Ebro valley.

**Box A5-2 Pesticide use in Europe**

Overall pesticide use in Europe is steadily increasing, with decreases in fungicide use countered by increases in herbicide use (Eurostat, 2007). By weight, over half of pesticide use goes on fruit and vegetables, particularly fungicide use in vineyards (in 2003 25% of the total volume of pesticides was inorganic sulphur). Nearly half goes on arable crops, mainly herbicides on cereals and maize. However, weight is not a good measure of the environmental impact of pesticide use, as fungicides and herbicides are much bulkier than insecticides, but not necessarily more damaging to biodiversity. Some pesticides are bulky but environmentally relatively benign, such as sulphur, whilst others are used in low doses but have significant environmental impacts, for example atrazine, which persists in the soil for up to 100 days and in groundwater for decades<sup>20</sup>.

Pesticide active ingredients are therefore classified according to their environmental impact, combining data on eco-toxicity, persistence and environmental characteristics (Eurostat, 2012b) (see Box 3-7). In addition, pesticide impacts are strongly affected by the method of use; ie applied volume, application method and timing, and interaction with crop variety and soil type. The real risk of pesticide use is therefore calculated by multiplying the environmental impact rating of the active ingredient with data on the use (ie dose per ha, type of crop, time and method of application) taking into account influencing environmental factors (eg see the Environmental Yardstick for Pesticides in the Netherlands<sup>21</sup>).

There is currently no agreed EU-wide indicator for the environmental impact of pesticides and a lack of harmonised data on pesticide use (Calliera et al, 2013), though the EU research projects HAIR<sup>22</sup> and FOOTPRINT<sup>23</sup> have developed proposals and tools for aggregated pesticide risk indicators. The widely used Environmental Index Quotient (EIQ), developed by Cornell University, has established EIQ values for pesticide active ingredients incorporating data regarding mode of action, plant surface residue half-life, soil residue half-life, toxicity to indicator organisms (including bees, birds, fish, and beneficial organisms), and ground-water/run-off potential. EIQs range from over 80 for the insecticides disulfoton (a systemic seed and soil treatment used on potatoes, fruit trees, beets, hops and other crops in the EU) and fipronil (used in many EU Member States to treat sunflowers and maize<sup>24</sup>). In contrast, flonicamid, a relatively new insecticide now widely used to control aphid on potatoes, wheat and fruit trees, has an EIQ of only 8.67<sup>25</sup>. This means disulfoton and fipronil are assigned over 10 times greater impacts on birds and beneficial insects than flonicamid.

Farmers are continually adapting and changing the pesticides they use, but new regulations are currently driving a faster rate of change. In 2009, a new EU pesticide regulation<sup>26</sup> defined a positive list of approved 'active substances' at EU level, leaving Member States to license pesticide formulations on the basis of this list. Around 60% of the more than 800 'active substances' (chemical ingredients of pesticides) that were available for use in 2000 have already been withdrawn from the European market. Around 31 are being reviewed in the next years, including glyphosate and 2,4-D.

<sup>20</sup> For this reason, atrazine has been withdrawn from the market in the EU since 2005

<sup>21</sup> <http://www.milieumeetlat.nl/en/home.html>

<sup>22</sup> HAIR: <http://www.hair.pesticidemodels.eu/home.shtml>

<sup>23</sup> FOOTPRINT: <http://www.eu-footprint.org/ppdb.html>

<sup>24</sup> [http://ec.europa.eu/food/plant/protection/evaluation/existactive/list1\\_fipronil\\_en.pdf](http://ec.europa.eu/food/plant/protection/evaluation/existactive/list1_fipronil_en.pdf)

<sup>25</sup> [http://ec.europa.eu/food/plant/protection/evaluation/newactive/technical\\_review\\_flonicamid.pdf](http://ec.europa.eu/food/plant/protection/evaluation/newactive/technical_review_flonicamid.pdf)

<sup>26</sup> Regulation (EC) No 1107/2009 of the European Parliament and of the Council of 21 October 2009 concerning the placing of plant protection products on the market and repealing Council Directives 79/117/EEC and 91/414/EEC

The requirements of the Water Framework Directive may also trigger restrictions if some pesticides cannot be kept out of water courses (particularly the herbicides propyzamide, carbetamide, and chlorotoluron, and the molluscicide metaldehyde). There are contrasting trends in the consumption of pesticides and their use across countries in Europe, and it is difficult to determine the full extent of pesticide impacts in the EU due to the lack of consistent EU-level data and long-term studies. However it is likely that removal of the most toxic pesticides from the market will result in a small reduction in impacts.

Pesticides have direct impacts on biodiversity as a result of their intended toxicity to pests, but also have effects on non-target species. Evidence strongly suggests that the use of broad-spectrum pesticides has been a key factor in the decline of non-crop plants (ie weeds), many invertebrate groups and some birds in arable farmland habitats across much of Europe (Boatman et al, 2004; Campbell et al, 1997; Geiger et al, 2010b; Potts, 1997; Stoate et al, 2001).

**Insecticides** are known to have negative effects on non-target insects, a particular concern with regard to impacts on bees and other pollinators, food for bird chicks, butterflies, and natural predators of crop pests. Most insecticide sprays only reach some of the organisms in a field, as some can usually hide<sup>27</sup>, and populations recover between sprays, but insecticides used in a systemic way as seed dressings present new risks because the insecticides are taken up in the plant and are present in plant tissues as the plant grows, and in the soil and on other plants (see Box 5-3). Four systemic insecticides have now been restricted for three years to only non-flowering crops, greenhouse crops and winter cereals<sup>28</sup>, because of concern for their impact on honey bees that forage in these treated crops (EFSA, 2013a; EFSA, 2013b; European Commission, 2013), and on bumblebees (Gill et al, 2012; Kindemba, 2009; Whitehorn et al, 2012). A recent report for the European Parliament concluded that '*Chronic exposure of honeybees to sub-lethal doses of neonicotinoids can also result in serious effects, which include a wide range of behavioural disturbances in bees, such as problems with flying and navigation, impaired memory and learning, reduced foraging ability, as well as reduction in breeding success and disease resistance*' (Grimm et al, 2012). As further discussed in section 3.5 this may have contributed to significant declines in bee populations in the EU.

**Acaricides** and **molluscicides** have a range of non-target effects. Metaldehyde and methiocarb – two commonly used molluscicides - are highly toxic to small mammals such as hedgehogs and wood mice (Brooks and Crook, 2002). Molluscicides are widely used – in the UK alone over 250 million tonnes are used annually, particularly on wheat (Brooks & Crook, 2002).

**Fungicides** can persist in soil for many months and so can have serious chronic effects on soil organisms (see Box A5-3). Many fungicides are washed into streams and are toxic to amphibians (Brühl et al, 2013), fish and other aquatic life. Fungicides based on copper are highly toxic to aquatic organisms especially fish.

<sup>27</sup> except species that are particularly active at the time when the insecticide is applied, for example bumblebees in the early morning

<sup>28</sup> Commission Implementing Regulation (EU) No 485/2013 of 24 May 2013 amending Implementing Regulation (EU) No 540/2011, as regards the conditions of approval of the active substances clothianidin, thiamethoxam and imidachloprid, and prohibiting the use and sale of seeds treated with plant protection products containing those active ingredients. <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2013:139:0012:0026:EN:PDF>, and Standing Committee on the Food Chain and Animal Health vote on fipronil 16 July 2013 [http://europa.eu/rapid/press-release\\_IP-13-708\\_en.htm?locale=en](http://europa.eu/rapid/press-release_IP-13-708_en.htm?locale=en)

The impacts of **herbicides** in reducing weed populations is known to be the most important factor affecting invertebrates in herbicide management systems, with an established correlation between phytophagous invertebrates and weed abundance (Hawes et al, 2003). This has substantial knock-on impacts on food webs, competitors and parasites that affect the entire ecosystem of intensively managed farmland habitats. UK studies have documented long-term declines in arable weeds (such that they are now extremely rare) and many insect groups in intensively managed farmland (Aebischer, 1991; Potts et al, 2010). Herbicide drift is also significantly reducing field margin plants (Robinson and Sutherland, 2002), with loss of flower resources causing declines of pollinators (Brittain and Potts, 2013; Kovács-Hostyánszki et al, 2011a) and farmland butterflies (Frampton and Dorne, 2007a).

Farmland **invertebrate** populations, including beetles, wasps, flies, bugs and mites, are reduced across European agricultural landscapes because of pesticide use (Geiger et al, 2010b). Early-season insecticide applications against sucking pests damage predator populations (through both direct effect of insecticide and indirect effect of lack of food), and lead to pest resurgence due to the lack of biological control (Desneux et al, 2007). Spiders and harvestmen are highly sensitive to some pesticides such as pyrethroids and are also indirectly affected by insecticide and herbicide drift onto field margins (Drapela et al, 2008; Haughton et al, 2001; Pekár, 2012).

Farmland **birds** are negatively affected by the loss of invertebrate food sources and broad-leaved weeds, for example the Grey Partridge (*Perdix perdix*) (Potts, 1997; Sánchez-Bayo et al, 2013; Vickery et al, 2009), the loss of seed food resources on grassland, arable and field margins eg Corn Bunting (*Miliaria calandra*) (Boatman et al, 2004) and due to insecticide applications during the breeding season eg Yellowhammer (*Emberiza citronella*) (Morris et al, 2005; Newton, 2004). Birds also suffer sublethal effects from exposure to pesticide sprays, and from eating pesticide treated seed (especially organophosphate or carbamate insecticides) (Prosser and Hart, 2005). The decline of farmland invertebrates has also decreased **reptile** (Temple and Cox, 2009) and **bat** food resources (Temple and Terry, 2007; Wickramasinghe et al, 2003).

A recent study (Brühl et al, 2013) into the effects of four commonly used pesticides<sup>29</sup> on **amphibian** populations revealed acute mortality. At the recommended application rates the pesticides resulted in 40% to 100% mortality of European Common Frogs (*Rana temporaria*) after only seven days. At only 10% of the recommended rate the pesticides still caused a 40% mortality rate. Amphibians, the most threatened and rapidly declining vertebrate group in Europe, are particularly vulnerable to pesticide toxicity due to their permeable skin and a life-style that encompasses terrestrial and aquatic phases. No risk assessment for amphibians is required for the registration of a pesticide product despite 32 of the 75 European amphibian species being associated with arable land (Fryday and Thompson, 2012).

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<sup>29</sup> The study tested the herbicides bromoxynil-octanate and fenoxaprop-P-ethyl, the fungicide spiroxamine and the insecticide dimethoate.

**Box A5-3 Persistence of pesticides in the environment**

Persistence describes the ability of a pesticide active ingredient to retain its molecular integrity and thus its toxicity in the environment<sup>30</sup>, and is determined by its rate of **degradation** and its degree of **mobility** in soil, water and air. The persistence of pesticides is expressed in terms of half-life, or the time necessary to break-down half of the original quantity of pesticide originally applied.

Pesticides are **degraded** by light (photodegradation), by pH, or by other soil or water factors (chemical degradation), and by bacteria and other micro-organisms (microbial degradation). Some pesticides remain toxic or increase toxicity when degraded into smaller molecules (metabolites). Some fat-soluble pesticides can accumulate within the bodies of animals (known as **bio-accumulation**), and poison the animal's predators, including insectivores such as amphibians, reptiles, shrews, bats and birds, as well as these predator's predators - notably, the organochlorine pesticides have persisted in food chains for many decades after their use was stopped, eg (Kean et al, 2013). Pesticides can also persist in soil - for example, vineyard soils often contain quite high levels of persistent pesticides (Komárek et al, 2010).

Pesticide **mobility** is affected by volatilization, water solubility and leaching or run-off, adsorption to soil particles and soil erosion, and uptake by plants (Arias-Estévez et al, 2007). All pesticide application methods result in some of the pesticide dispersing into the air, soil, weeds, field margins or water. Pesticides that are applied as granular or liquid soil treatments (generally before sowing or together with the seed) are generally designed to remain active in the soil for part or most of the crop growing season by binding to soil particles, and can spread with soil surface run-off or wind erosion of soil. When pesticides are applied as a seed treatment or coating, sowing the treated seeds creates dust containing high concentrations of pesticides, which lands on soil and field margins (Krupke et al, 2012), though dust can be substantially reduced with new technology<sup>31</sup>. When pesticides are applied as a foliar spray, a certain proportion drifts away and lands on the soil or field margins without reaching the crop plants. Pesticide that lands on foliage is also washed off into soil or dissipates into air (volatilization).

Water-soluble pesticides are likely to pass into the soil matrix, either **running off into surface waters** (through soil pipes or on the soil surface) or **leaching into groundwater**. The slower the degradation of the pesticide, the more likely it is that it will pollute groundwater or have persistent effects in aquatic habitats. For example, whilst the fungicide mancozeb (in the same way as other EBDC group fungicides) is rapidly broken down in soil, its metabolite ETU is more persistent and highly toxic to aquatic life such as amphibians<sup>32</sup> (DG SANCO, 2013; Shenoy et al, 2009). Some pesticides are strongly **adsorbed onto soil** organic matter, and can remain in the soil for long periods until they are broken down by microbes or run-off with soil erosion. For example, glyphosate is readily adsorbed onto soil particles, preventing most of the pesticide from leaching into water, even though it is highly water soluble. It is considered to have a half-life (ie half of total degraded) in soil of around 20 days, but degradation is actually very variable (Borggaard and Gimsing, 2008). Nevertheless, it is also frequently detected in surface waters, reflecting its widespread use (Horth and Blackmore, 2009). Some adsorbed pesticides are inactivated but others retain their toxicity, for example if they are eaten by soil organisms.

Most pesticides work as **contact pesticides**, meaning that insects and other organisms are directly affected if the pesticide gets onto their bodies and enters the cuticle or skin, or through eating leaf

<sup>30</sup> <http://www.eionet.europa.eu/gemet/concept?ns=1&cp=6131>

<sup>31</sup> <http://seedgrowth.bayer.com/index.php?id=29>

<sup>32</sup> <http://www.epa.gov/espp/litstatus/effects/redleg-frog/2011/mancozeb/assessment.pdf>

material coated in pesticide or contaminated soil. Contact insecticides act usually in single exposures (eg through spray droplets, pulse contamination after spraying) and have the highest effects immediately after application (Sánchez-Bayo et al, 2013).

**Systemic pesticides** are fundamentally different because they are taken up by the plant and enter all plant tissues, with the water-soluble active residues present within tissues, or soil, for the whole growing season (Sánchez-Bayo et al, 2013). Insects and other organisms can therefore be directly affected by consumption of plant tissues containing the pesticide, including sap (phloem), leaves, roots, pollen, nectar, and guttation fluids, or by eating contaminated soil. Therefore, organisms take up systemic insecticides constantly over long periods, resulting in their highly effective pest control, but also in increasing and cumulative toxicity to non-target organisms. Sucking insects and mites are generally most exposed as the concentration is highest in the phloem. Organisms that feed on treated seed or on seedlings are also highly exposed to toxic effects, including ladybird larvae (Moser and Obrycki, 2009) and birds (Prosser & Hart, 2005). Systemic pesticides are also taken up by weeds growing in or near crop fields and are present in sap, pollen, and nectar (Krupke et al, 2012). For example, Green Lacewing are poisoned in this way by neonicotinoids (Rogers et al, 2007). They may also accumulate in aquatic habitats (van Dijk et al, 2013). Systemic pesticides include insecticides (eg neonicotinoids), fungicides (eg difenoconazole), and herbicides (eg glyphosate).

## 5.7 Agricultural practices that maintain and increase biodiversity in agricultural systems

This section lists farming practices and actions that have been shown to increase biodiversity at the farm scale and field scale in Europe (Cooper et al, 2009; Olmeda et al, 2013; Poláková et al, 2011; Wilson et al, 2009). These actions primarily aim to maintain and provide suitable habitats for breeding and feeding, abundant food resources for animals and limit mortality factors (such as from machinery, pesticides and livestock trampling). For each farming practice, the evidence for benefits to biodiversity and for multiple ecosystem services benefits is described.

It should be noted that the overview is influenced by the bias in published literature. A review of research on the effectiveness of integrated farm management, organic farming and agri-environment schemes as interventions for conserving biodiversity in temperate Europe showed a strong bias to publications relating to the impact of field margin measures, followed by hedgerows and set-aside (Randall and James, 2012). A range of other measures, including pond management or undersown cereals, are hardly documented at all. There is also a strong bias towards impacts on invertebrates and farmland birds, with very few studies that examine impacts on amphibians or reptiles.

It is also important to bear in mind that many research publications report only numbers of foraging animals, for example bees, and not data that can be used to infer a population level effect (Dicks et al, 2010). For wide-ranging animals such as birds, bats, butterflies and bees, it is possible that the research only measures a redistribution of individuals in the landscape in response to resource patches, such as flower-rich field margins or hedgerows, and does not reflect an increased reproductive rate (Feber et al, 2007; Power and Stout, 2011; Westphal et al, 2009). More generally, species richness and/or abundance does not necessarily reflect a positive impact on critical specialist species, and may actually hide a decline in specialist species through increased biotic homogenisation (Filippi-Codaccioni et al, 2010). Also, effects of local management interventions vary greatly in relation to landscape complexity (Concepción et al, 2012).

### 5.7.1 Farmland management options

#### *Protection, restoration and management of semi-natural habitats and species*

Natural and semi-natural habitats are of the highest conservation importance and maintain many threatened species (Beaufoy et al, 2011; Pardini and Nori, 2011). For example, the long-term stability of pollinator populations depends on patches of semi-natural habitat in farmland (Garibaldi et al, 2011).

The maintenance of permanent grasslands also provides other ecosystem services: it increases soil organic matter levels, storing carbon, and can increase water holding capacity which can provide flood prevention benefits in areas prone to flooding (Pilgrim et al, 2010; Powlson et al, 2011). The protection and restoration of peatlands and other organic soils is particularly important for climate change mitigation as drained organic soils are major sources of greenhouse gas emissions.

#### *Establishment or restoration of farmland habitat features (hedges, shelterbelts, woodland patches, terraces, farm ponds, stone walls etc)*

Farmland features, including hedges, ditches, terraces, trees, stone walls, stone heaps, and rock outcrops, are key breeding and feeding habitats for many species on farmland (eg Siriwardena et al, 2012). Old trees, and particularly veteran trees that have holes and deadwood, are key habitats and refuges for numerous invertebrate species, as well as birds, bats and other mammals (Davy et al, 2007). Ponds are key elements of biodiversity at the landscape level in Europe's agricultural areas, particularly for the presence of rare species (Davies et al, 2008). Trees in agricultural landscapes, and

other farmland features, are also important elements of ecological corridors that enable species movements through farmland landscapes in response to changing conditions (Manning et al, 2009).

Hedges or lines of trees also create above and below-ground biomass that stores carbon, protect livestock from heat and wind (Iglesias et al, 2007; Wall and Smit, 2005), and can increase grass growth through the increased water retention of shaded areas, particularly early in the season.

Farmland features are protected under CAP cross-compliance rules in many Member States and/or registered under the direct payment system. Agri-environment schemes help maintain 41% of hedgerows and 24% of dry stone walls in England (Natural England, 2009), and hedgerow and ditch management under agri-environment has been shown to increase bird populations in some regions (Davey et al, 2010).

#### *Farm woodland management and creation, maintenance of agro-silvo-pastoral systems, agroforestry*

Traditional agro-silvo-pastoral systems in Europe, such as dehesa, montado, wooded meadows and pastures, parklands and old orchards, are highly valuable habitats for threatened species, and restoration and maintenance can restore species richness (Bergmeier et al, 2012; Losvik and Hjelle, 2010; Pardini & Nori, 2011). In Spain, agri-environment schemes and other measures are promoting the regeneration of oaks in dehesa (Pereira and da Fonseca, 2003; Plieninger and Schaar, 2012).

Afforestation of agricultural land with native species can enhance biodiversity on degraded, species poor arable land and rough grassland, by protecting soil and creating woodland habitat, or it can destroy biodiversity if carried out on species-rich semi-natural grassland or scrub, by shading out biodiverse grassland communities (Bremer and Farley, 2010; Buscardo et al, 2008). A way to encourage species-rich natural regeneration of woodland is to plant woodland islets (sparsely spaced patches of small densely planted native shrubs and trees), which act as kernels for woodland species dispersal but also maintains some open habitat (Rey Benayas and Bullock, 2012).

Agroforestry (using tree cropping, alley cropping, shelterbeds or hedgerows on cropland) can increase biodiversity in intensive arable areas by protecting soil biodiversity and introducing permanent tree habitats for some bird and mammal species already present on farmland (Burgess, 1999; Rigueiro-Rodríguez et al, 2009), but does not always contribute to increasing overall species richness.

In the UK, the area of farm woodlands has increased from 280,000 ha in 1981 to 700,000 ha in 2008 as a result of agri-environment schemes and other measures (Quine et al, 2011).

#### *Actions to protect and promote the use of crop and livestock genetic diversity and crop wild relatives*

The conservation and use of livestock genetic diversity is an important component of agrobiodiversity conservation in itself, but also helps the conservation of biodiversity-rich farming, as traditional breeds are often best suited to maintaining semi-natural habitats. For example, in Hungary Mangalitsa pigs, Racka sheep and other native breeds are being increasingly farmed and used for the maintenance of semi-natural habitats.<sup>33</sup> The increasing popularity of premium beef from Aberdeen Angus cattle in the UK has increased populations to 11% of registered cattle, maintaining grazing on rough pasture including many protected areas<sup>34</sup> (DEFRA, 2013). The establishment of protected areas for crop wild relatives would also help protect other threatened species (Kell et al, 2012).

<sup>33</sup> [http://www.nytimes.com/2009/04/01/dining/01pigs.html?pagewanted=all&\\_r=0](http://www.nytimes.com/2009/04/01/dining/01pigs.html?pagewanted=all&_r=0)

<sup>34</sup> <http://www.grazinganimalsproject.org.uk/>



*Integrated Farm management / Integrated Production / Precision agriculture / Organic management*

Integrated production and integrated farm management encompass a wide range of management practices and grades of intensity, but are generally characterised by lower fertilizer use and a greater reliance on balancing nutrient cycles at farm level through mixed farming, use of green manures, leys, open-air grazing, and by lower pesticide use through the use of integrated pest management (Berry et al, 2005).

Precision agriculture also involves reductions in fertiliser and pesticide use and more efficient use of irrigation. In general, the higher levels of soil organic matter and lower nitrogen inputs result in a more complex and diverse soil life, and fewer negative off-farm effects from nitrogen run-off and soil erosion (although there is a great deal of variation between individual farms).

Organic management uses no artificial fertilizer and a very restricted list of pesticides, relying instead on animal manure, mulches, green manure crops, and non-chemical IPM and IWM strategies.

These farming strategies all have in common that they generally increase input use efficiency and reduce nitrogen and phosphorus losses (see Box A5-4) (although some organic farms with high stocking densities and poor management may have high nutrient run-off from livestock manure).

**Box A5-4 Increasing fertiliser use efficiency and halting nitrogen and phosphorus losses**

The EU has a series of policies to reduce nitrogen (N) emissions and leaching, including the Nitrates Directive, the Thematic Strategy on Air Pollution, and the National Emission Ceiling Directive. These policies all demand substantial action from the agricultural sector. Actions that reduce N outputs include 1) balanced fertilisation (fertiliser use that does not lower crop yields<sup>35</sup> but that decreases N leaching losses to below the NVZ<sup>36</sup> target level), combined with improved crop and manure management; 2) low-protein animal feeding, combined with improved herd management; and 3) ammonia emissions abatement measures, including improved manure application and storage (Oenema et al, 2009).

A study estimated that strict and uniform implementation of balanced fertilisation in all NVZs would increase the EU's Nitrogen Use Efficiency (NUE) by 16%, and if all these actions were implemented all over the EU, NUE would increase by 25%, while ammonia emissions decrease by 31% and N leaching by 41% (Oenema et al, 2009). This would have substantial benefits for biodiversity, but would also involve substantial costs for the farming sector, particularly to reduce ammonia emissions. Balanced fertilisation is by far the most effective and cost-efficient action in terms of N loss reductions, but would require a substantial scaling up of training, incentives and enforcement, as well as new policy tools for non-NVZ areas (Velthof, 2009). Denmark has been notably successful in implementing balanced fertilisation, increasing NUE and reducing N losses (Smith et al, 2007).

Organic farming systems are characterised by higher weed diversity and abundance, particularly in field centres, higher invertebrate abundance (such as bees and butterflies), and greater structural diversity of fields and non-crop habitats (Boller et al, 2004; Gabriel et al, 2006; Gabriel et al, 2009; Gabriel et al, 2010; Gibson et al, 2007; Hole et al, 2005; Holzschuh et al, 2008; Krauss et al, 2011;

<sup>35</sup> although there may be an increased risk of reduced yields under favourable growing conditions when N demand of crops are relatively high (Oenema et al, 2009)

<sup>36</sup> NVZ = nitrate vulnerable zone, in which nitrate concentrations entering groundwater and surface waters must be reduced to less than 50 mg NO<sub>3</sub><sup>-</sup> l<sup>-1</sup>. Overall, 46% of the EU is NVZ; some Member States, such as Denmark and Germany, have designated their whole land area as NVZ; others such as Poland have designated only 10% or less.

Norton et al, 2009; Petersen et al, 2006; Power & Stout, 2011; Smith et al, 2010; Taylor and Morecroft, 2009; Winqvist et al, 2011). Organically managed olive groves have higher spider abundance than comparable conventionally managed sites (Cardenas et al, 2006). The use of organic manure instead of conventional fertiliser has a positive effect on pest abundance, but also on the abundance of invertebrate natural enemies of pests (Garratt et al, 2011) (except beetles, notably carabids, which show mixed responses to extensification of management (Clough et al, 2007; Cole et al, 2005; Flohre et al, 2011)).

Organic farms have a greater impact on species abundance and richness in intensively farmed landscapes when measured against comparable conventional farms eg (Rundlöf et al, 2008). However, few studies demonstrate increased species diversity at the landscape scale as well as the farm scale (eg Clough et al, 2007).

## 5.7.2 Grassland management options

### *Extensive grassland management, mixed stocking, mosaic / rotational grazing*

Lower grazing densities and cessation of fertilisation on grassland can rapidly increase invertebrate populations (Kruess & Tscharntke, 2002), and over the longer-term leads to an increase in plant species richness. Mixed stocking encourages a diverse sward structure on land grazed by both sheep and cattle, benefiting breeding birds, such as the increased abundance of meadow pipits in upland grassland subjected to mixed, low intensity grazing (Evans et al, 2006; Wilson et al, 2009). Maintaining heterogeneity requires variation in the type and intensity of management actions within a habitat, for example different grazing intensities across time or space, varying stock type, or staggered mowing in strips or blocks. Restricting grazing times and seasons is important to avoid livestock trampling causing soil compaction on waterlogged soils, or soil erosion through excessive sward damage.

Grazing levels have very varied impacts on species and biodiversity, and need to be locally adapted, according to trade-offs between species, and carefully monitored on low productivity soils (Báldi et al, 2005; Buckingham et al, 2006; Tahmasebi Kohyani et al, 2008). Different livestock have different impacts on vegetation, and also interact with wild grazers such as deer or rabbits (Albon et al, 2007). Suitable grazing densities on semi-natural grassland can vary from a maximum of 2.5 LU/ha/yr<sup>37</sup> on manure-fertilised pastures, to less than 0.1 LU/ha/yr on sandy and dry grasslands (Olmeda et al, 2013). However, nutrient levels in fertilised grassland only fall slowly after fertilisation is stopped, and reducing grazing density in an intensively managed farm landscape may not increase biodiversity without other actions to reduce soil fertility.

Extensification of grazing by lowering livestock densities and changing livestock type led to increases in plant diversity in Scotland, though the change was slow (whereas abandonment led to rapid decrease followed by stabilisation) (Marriott et al, 2009). Grassland extensification significantly increased species richness and abundance of bees and insect-pollinated plants in Switzerland, but not in the Netherlands where bee populations are much smaller (Kohler et al, 2006). Restoration of grazing on abandoned farms in Finland was able to recover most of the species richness, but the recovery of rare species needs more targeted measures (Pykälä, 2003). Reduced livestock stocking densities and field boundary enhancements failed to increase hare densities in Ireland, whilst strongly increasing rabbit and fox densities, which may graze sensitive plant species or predate ground-nesting birds (Reid et al, 2007).

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<sup>37</sup> One livestock unit (LU) per hectare (ha) per year (yr) is equivalent to the grazing of one dairy cow, 1.3 horses, 3.85 pigs, or around 6 sheep or goats, [https://en.wikipedia.org/wiki/Livestock\\_grazing\\_comparison](https://en.wikipedia.org/wiki/Livestock_grazing_comparison)

*Meadow management (late cutting, restricted or no fertilisation, use of low mortality mowing techniques etc)*

Traditional hay meadows are key habitats for many rare and endangered invertebrate species, including butterflies, grasshoppers, and bees. Abandonment and lack of management is threatening the biodiversity of many hay meadow areas (Veen et al, 2009). Under some conditions it is possible to maintain species diversity by grazing instead of mowing (Dolek and Geyer, 1997). Adapted mowing techniques and equipment, (including higher cutting height, leaving uncut refuges, use of fauna-friendly cutter bar and avoiding use of conditioner), can significantly reduce invertebrate mortality during mowing (Humbert et al, 2010).

Plant species richness on UK northern meadows was maximised through grazing during spring and autumn, a mid-July hay cut and low levels of inorganic fertiliser (Jefferson, 2005). The diversification of mowing regimes (mosaic mowing, temporary fallows, sequential mowing) in the Czech Republic has increased arthropod diversity in hay meadows (Cizek et al, 2012). Unfertilized meadows in Switzerland were visited by a greater species richness and abundance of wild bees than adjacent intensively managed fields (Albrecht et al, 2007; Knop et al, 2006), but extensification of UK southern meadows had no effect on wild bees (Potts et al, 2009), which had a low abundance, indicating that bees require additional measures to promote floral abundance.

Brown Hare (*Lepus europaeus*) densities in Switzerland are related to the extent of extensively managed hay meadows (Zellweger-Fischer et al, 2011). In Scotland, targeted agri-environment schemes that include delayed mowing of silage grassland (plus unharvested crop patches sown annually with a cereal-rich seed mix) have significantly increased Corn Bunting (*Emberiza calandra*) populations (Perkins et al, 2011).

*Restoration and management of wetlands and humid grassland*

Management of wet grassland requires the restoration of a high groundwater level, achieving grazing levels that avoid compaction, and using suitable grazing stock that is adapted to the conditions. The sward structure and tall grass cover is particularly influential on the breeding success of different wader bird species (O'Brien, 2001; Weiss et al, 1999). Restoration requires scrub clearance followed by the reintroduction of mowing, burning and/or grazing (Middleton et al, 2006).

Restored wet meadows have increased breeding populations of a range of bird species in Italy and Denmark (Wilson et al, 2009). Restored grazing of coastal meadows combined with pond restoration substantially increased breeding populations of *Bufo viridis* in Denmark (Rannap et al, 2004). Increased mixed stock grazing and late cutting of coastal grassland in Estonia increased breeding populations of Ruff, Garganey, Black-tailed Godwit, Yellow Wagtails and other birds. Restoration management of wet grassland in the UK is reversing declines in rare plant species (Swetnam et al, 2004). Traditional late cutting and grazing on re-created floodplain meadows on ex-arable land in the UK resulted in the re-establishment of most key grassland plant species, though it did not restore the typical plant community assemblage (ie relative abundances) (Woodcock et al, 2011). The provision of wet features on grassland in the UK (flooded ditches and pools) increased Lapwing (*Vanellus vanellus*) chick foraging rates and body condition (Eglington et al, 2010).

*Field margins adjacent to intensive grassland*

Field margins adjacent to grass fields increase invertebrate diversity and abundance, particularly when left uncut or cut late and unfertilized (Haysom et al, 2004; Woodcock et al, 2007), although dense grass cover on unmown strips was shown to inhibit bird foraging and carabid beetle activity (Cole et al, 2007).

**5.7.3 Cropland management options (arable and permanent crops)***Conversion of arable land to species-rich grassland*

Conversion of arable land to grassland or fodder crops with restricted mowing and management have resulted in increased populations of Little Bustard (*Tetrax tetrax*) (RSPB and Birdlife International, 2011). Recreation of grassland by hay spreading on arable land has produced plant and invertebrate-rich communities, although they do not always resemble original communities (Woodcock et al, 2008).

*Integrated Pest Management (IPM), Integrated Weed Management (IWM)*

IPM/IWM is the integrated management of pest/weed populations at acceptable levels for a healthy crop using a carefully considered balance of biological, technical and chemical methods that cause the least possible disruption to the biological control provided by the agro-ecosystem, and prevent the evolution of resistant pests/weeds<sup>38</sup>. Pesticide use is limited to the strict minimum necessary to maintain the pest population at levels below those causing economically acceptable damage or loss. The key elements of IPM are therefore prevention, monitoring, and targeted control based on decision thresholds triggered by pest levels.

**Box A5-5 Integrated Pest Management and the Directive on the Sustainable Use of Pesticides**

The EU adopted a Directive<sup>39</sup> in 2009 stipulating the introduction of Integrated Pest Management measures in all Member States. It requires Member States to implement national plans promoting IPM and setting targets to reduce pesticide use, to train and inspect pesticide users, to monitor pesticide use, and especially to implement measures to protect water courses from pesticide pollution. 20 Member States have now produced plans<sup>40</sup>, indicating that training and awareness is improving; however, they lack ambition. Only Denmark sets a quantitative pesticide reduction target, aiming to return to 2000 use levels, and no plans link CAP payments to compliance or explain how CAP resources will be used to increase farm-level IPM capacity<sup>41</sup>.

The new cross-compliance regulations for the Common Agricultural Policy 2015-2020 do not include any reference to farmers' obligations under the Directive; however, Member States are now obliged to provide farmers with advice on Integrated Pest Management through their Farm Advisory Services.

<sup>38</sup> NB The intensive use of introduced biological control agents such as *Trichogramma* wasps or biological control treatments such as virus sprays can have negative impacts on biodiversity as the agents may attack beneficial or valued species such as non-pest butterfly larvae or the eggs or larvae of other predators (through intra-guild predation); however, most of the time they are unlikely to outcompete native biological control agents (Babendreier et al, 2003). The release of new alien species into the environment for biological control can result in unintended negative impacts, and is therefore subject to rigorous risk assessment and regulation in the EU (Bale et al, 2008).

<sup>39</sup> Directive 2009/128/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for Community action to achieve the sustainable use of pesticides

<sup>40</sup> [http://ec.europa.eu/food/plant/pesticides/sustainable\\_use\\_pesticides/national\\_action\\_plans\\_en.htm](http://ec.europa.eu/food/plant/pesticides/sustainable_use_pesticides/national_action_plans_en.htm)

<sup>41</sup> [http://www.pan-europe.info/News/PR/130620\\_letter\\_Borg.pdf](http://www.pan-europe.info/News/PR/130620_letter_Borg.pdf)

Decreasing pesticide impacts (both quantity and types of active ingredient) should restore populations of natural enemies which will act against pests. The challenge is to effectively support the populations of natural enemies so that their recovery is large enough to provide an efficient regulatory service. As natural enemies need shelters, food, reproduction areas and so on, non-crop habitats can play an essential role in maintaining such populations (and other biodiversity as well) (Bianchi et al, 2006; Landis et al, 2005). Natural biological control can be enhanced through unsprayed field margins and diverse weed populations<sup>42</sup> that provide important food and habitat (Landis et al, 2005; Rusch et al, 2013; Schmidt and Tscharrntke, 2005); however finding management options that reliably enhance biological control is not always easy. The conservation of natural enemy species richness can sometimes weaken, or have no effect, on biological control, because biological control agents compete with each other and predate each other (Holland et al, 2012; Straub et al, 2008). On the other hand, diverse biological control agents often work synergistically to enhance control levels, or take over control in different seasons and areas (Tscharrntke et al, 2005).

Lack of pesticide use on organic farms is associated with greater populations of farmland birds in the UK (McKenzie and Whittingham, 2009). Reduced agro-chemical use has showed positive effects on plant biodiversity grassland and birds in arable land across regions in Austria (Wrbka et al, 2008). A meta-analysis of the impacts of restricting pesticide use on crop edges showed that arthropod populations benefited from restricted herbicide use, but that evidence for the impact of excluding insecticide and fungicide use was insufficient (Frampton and Dorne, 2007b).

#### *Diversified crop rotations, including more leguminous crops, fodder crops and green manures / catch crops*

Crop rotation is used to control the build-up of weeds, pests and diseases (using break crops), and to replenish soil fertility and organic matter levels using crops that fix nitrogen (legumes) and/or grass leys with clover. Variation in crop type is of particular importance in promoting landscape-scale diversity, providing a variety of resource requirements for different species. In Scotland, farms with the greatest diversity of crop types and cropping practices at the landscape scale also have the highest species richness of arable weeds (although organic farming was associated with higher weed abundance at the field scale) (Hawes et al, 2010).

In Western Europe, spring-sown crops harbour higher above-ground biodiversity than winter cereals (Twining et al, 2007). Oilseed rape, a typical break crop in a cereal rotation, has a higher weed diversity and abundance than cereals, also offering more food resources to invertebrates and birds (Drapela et al, 2008). The mass flowering provides short periods of abundant nectar and pollen resources; however this is not sufficient to sustain pollinator breeding cycles and could be detrimental to local wild plant diversity by diverting pollinators during critical periods (Diekotter et al, 2010; Holzschuh et al, 2011). Sunflowers, soybean and linseed have the highest potential for biodiversity (BioIntelligence Service, 2010). Root crops generally have a poor biodiversity profile, partly because of the rates of pesticide use and tillage; however, sugar beet offers higher biodiversity because of the difficulty of achieving high rates of weed control. Legume crops such as Lucerne, field peas, field beans (*Faba*), lupins, offer important food resources to birds, invertebrates and other animals, and primary habitat to the European Hamster in Western Europe (*Cricetus cricetus*) (BioIntelligence Service, 2010; La Haye et al, 2010).

#### *Crop genetic diversity*

A genetically diverse wheat crop hosted greater arthropod community diversity than comparable genetically uniform fields (Chateil et al 2013).

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<sup>42</sup> (that do not necessarily cause crop losses)

*Under-sowing spring cereals and grass-clover leys in cereal rotations*

Under-sowing spring cereals with grass and clover fixes soil nitrogen for the following crop, allowing for reduced agrochemical input and benefiting invertebrate populations and thus birds (Atkinson et al, 2002; Hauggaard-Nielsen et al, 2012; Wilson et al, 2009). The lack of subsequent ploughing is known to benefit sawfly (Symphyta) populations (Barker et al, 1999). Grass-clover leys in cereal rotations allow the recovery of soil biodiversity, particularly fungi, nematode and earthworm communities (whilst predatory mite species and enchytraeid worms recover only over longer time periods) (Postma-Blaauw et al, 2012).

*Conservation tillage, zero-till (no-till) and direct drilling (including cover crops, mulching)*

Zero-till increases soil organic matter (SOM), thus improving soil structure and stability, improving soil drainage and water holding capacity (and thus resilience to flooding and droughts), and reducing soil runoff and pollution of surface waters with sediment, pesticides and nutrients (Holland, 2004). A richer soil biodiversity develops that can improve nutrient recycling and this may also help combat crop pests and diseases. The greater availability of crop residues improves food supplies for insects, birds and small mammals.

Conservation tillage also provides many of these benefits, but soil organic matter build up is lower (Koch and Stockfisch, 2006). In France, conservation tillage offered greater resources for insectivorous and granivorous birds than conventional systems (Filippi-Codaccioni et al, 2009).

However, zero-till usually requires the use of broad-spectrum herbicides, so run-off containing herbicide residues can result in increased negative impacts on aquatic biodiversity. It can result in a more diverse weed flora if successful, or a dominance of perennial weeds or persistent weeds such as blackgrass (*Alopecurus myosuroides*) and cleavers (*Galium aparine*) if not. Therefore on some soils periodic cultivation is still necessary. The mulch may promote some pests (eg slugs, cut worms) and fungal diseases. Soil may become compacted, which requires the use of chisel ploughs or subsoilers, and reversion to more intensive tillage causes loss of soil organic matter and sequestered carbon.

*Field margins: grass & shrub buffer strips, flower rich field margins, bird food strips*

Vegetated field margins adjacent to arable fields increase plant diversity, provide important nesting foraging habitat for several bird species (Vickery et al, 2002; Wilson et al, 2009), and provide habitat for small mammals and invertebrates such as grasshoppers and bees (Boatman and et al, 2013; Cole et al, 2007; Marshall et al, 2006).

Arable margins sown with pollen- and nectar-rich wildflowers (particularly legumes) and perennial grasses provide the widest forage for bees and butterflies (Carvell et al, 2007; Pywell et al, 2006). In the UK, the abundance of long-tongued bumblebee species was positively correlated to farms with pollen and nectar-mix field margins at the landscape scale (Pywell et al, 2006). Field margins sown with wild seed mixtures provide good summer foraging and breeding habitat for birds (Weibel, 1998), including owls and raptors, and a year-round supply of seeds supporting high densities of foraging birds in winter and summer (Henderson et al, 2004; Vickery et al, 2009), as shown by the positive effects on grey partridge population as part of integrated management.

Arable field margins with permanent grass vegetation promote soil invertebrate biodiversity (Smith et al, 2008), and were shown to increase natural biological control of aphids in winter wheat in the UK and in cereals in France (Holland et al, 2012). In Finland, the establishment of buffer strips consisting of tall grasses and scrub has positively benefited Whitethroats, Whinchats, Sedge Warblers, and

Common Reed Buntings, despite the primary aim of the scheme being to improve water quality (Brunner and Huyton, 2007).

*Uncropped arable field margins, arable in-field uncropped bird patches, bare patches in permanent crops*

Uncropped cultivated margins on arable land provide habitat for insects and foraging habitat for birds (Boatman & et al, 2013; Wilson et al, 2009), and have proved to be an effective agri-environment measure for arable plants, provided they are not fertilised (Walker et al, 2007). Uncropped cultivated strips have contributed to the conservation of endangered plants and rare beetles on arable land in Germany, whereas in the UK, poor uptake of the agri-environment measure for uncropped cultivated margins (as opposed to sown margins) means that rare arable weeds are not benefiting from conservation (Still and Byfield, 2007).

Bird patches - bare patches left undrilled in the centre of winter or spring-cropped arable fields - have increased populations of Skylarks (*Alauda arvensis*) and Stone Curlews (*Burhinus oedicanus*) in the UK by allowing longer and more successful breeding (Evans and Green, 2007; Morris et al, 2004; Smith et al, 2009). Lapwings benefit from uncropped cultivated land close to wet areas, which provide high quality food for their chicks.

In intensively managed permanent crops (orchards, vineyards, olive groves etc), patches of bare ground provide valuable bird foraging (Schaub et al, 2010) (but see also permanent ground cover below).

*Overwinter stubbles, winter bird crops / summer game crops, cereal-based whole crop silages*

Overwinter cereal stubbles provide important winter foraging habitats for seed eating birds through spilt grain and broadleaved weeds, including Skylark, Greenfinches, Reed Buntings, Linnets, Chaffinches, Yellowhammers, Goldfinches, Pied Wagtails, Grey Partridges, Meadow Pipets and Cirl Bunting (Baker et al, 2012; Bradbury et al, 2004; Wilson et al, 1996; Wilson et al, 2009). In spring, stubble provides breeding habitat for ground-nesting birds (Skylarks and Lapwings). The retention of over-winter stubbles has contributed to increased Cirl Bunting populations in the UK (Peach et al, 2001). In Scotland, targeted agri-environment schemes that include unharvested crop patches sown annually with a cereal-rich seed mix (plus delayed mowing of silage grassland) have slowed the decline of corn bunting populations (Perkins et al, 2011).

Winter bird crops such as kale, quinoa, radish and unharvested cereals support high densities of seed-eating farmland bird species (Henderson et al, 2004). Cereals planted for whole crop silage also provide good bird habitat (Peach et al, 2011). Summer crops planted for food for game such as pheasants and partridge also provides good nesting habitat for other birds (Parish and Sotherton, 2004).

*Set-aside, fallow*

There is strong evidence that the withdrawal of individual fields from intensive agricultural production under the EU set-aside regulations provided important benefits for both foraging and nesting birds (Gillings et al, 2010; Kovács-Hostyánszki et al, 2011c; Whittingham et al, 2005). In the UK, a positive population trend was observed for Lapwings, Skylarks, Stone Curlews and Linnets in areas of large-scale extensification such as set-aside (Henderson et al, 2000). Skylarks particularly benefit from set-aside and summer fallows for nesting (Wilson et al, 2009). Sown fallow tilled plots intended for Stone Curlew (*Burhinus oedicanus*) in UK arable areas also contained greater abundances of other farmland birds of conservation concern, hares and arable weeds (Macdonald et

al, 2012). In Hungary, arable fallows sown with a locally adapted seed mixture significantly increased populations of grasshoppers, bees and butterflies (Kovács-Hostyánszki et al, 2011c).

*Maintenance of permanent species-rich ground cover in perennial crops*

In permanent crops (orchards, vineyards, olive groves etc), permanent ground cover provides vegetation and invertebrate diversity and protection from soil erosion (Allen et al, 2006; Gómez et al, 2011). However, the lower levels of disturbance associated with less mowing can reduce the abundance of some invertebrates (Bruggisser et al, 2010). Extensively managed vineyards provide key habitat for rare plant and animal species such as Wild Tulip (*Tulipa sylvestris*) and Star-of-Bethlehem (*Ornithogalum spp.*), Tree Sparrow (*Passer montanus*), Redstart (*Phoenicurus phoenicurus*), Songthrush (*Turdus philomelos*) (Cremene et al, 2005; Verhulst et al, 2004). Cover crops under olives in Spain increased soil biodiversity long-term compared to herbicide weed control (Moreno et al, 2009).



## ANNEX TO CHAPTER 5(b) REFERENCES

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## ANNEX TO CHAPTER 6(a) GM CROPS IN THE EU NOW AND IN THE FUTURE

Berman, Sandra, Tostivint, Clement & Underwood, Evelyn

This study carried out a review to identify GM crops that might contribute to sustainable agriculture in Europe to 2050, if they were authorised in the EU and commercial and research priorities swung back to GM in Europe.

In order to produce a forecast of what GMOs will be commercialised and used in the future, it is essential to have a look at the global pipeline of new GMOs i.e. events that are between the “early discovery” starting point and the “commercialisation” completion point. Three categories of pipelines can be distinguished according to their proximity to market:

- Commercial pipeline – GM events authorised for marketing and cultivation in at least one country but not yet commercialised (commercialisation only depends on the developer).
- Regulatory pipeline – GM events already in the regulatory process to be marketed and cultivated in at least one country.
- R&D pipeline – GM events not yet in the regulatory process but at earlier stages of development.

### Commercial use of GM crops in the EU and globally

Only two GM crops are currently authorised for cultivation in Europe – insect-resistant Bt maize (MON810) and BASF’s starch-modified Amflora potato. Spain has grown Bt maize MON810 for animal feed since 1998, currently on an estimated 116,306 ha<sup>43</sup> (Ministerio de Agricultura, Alimentación y Medio Ambiente, 2012). Smaller areas of Bt maize MON810 are cultivated in the Czech Republic and Portugal, and less than 1,000 ha in Slovakia and Romania.<sup>44</sup> France and Germany grew Bt maize MON810 during 2006 to 2008.<sup>45</sup> The GM Amflora potato was approved for EU cultivation in March 2010, and grown in Sweden and the Czech Republic in 2010 and 2011. Germany planted one small area in 2010.<sup>46</sup> In 2012 the developer BASF withdrew the crop from the European market, and has since withdrawn the applications for approval of two more GM starch-modified potatoes<sup>47</sup>. Romania grew Roundup Ready soybeans from 2003 to its accession to the EU in 2006 (137,000 ha in 2006), but then (officially) stopped as RR soybeans are currently not approved for cultivation in the EU.

Worldwide, the US currently grows 43% of the area of GM crops, with 19% in Brazil (increasing rapidly), 15% in Argentina, 7% in Canada, 7% in India, and 2% each in China, Pakistan, and Paraguay (James, 2012). Nearly half the GM crop area is herbicide-resistant soybean (mainly in Brazil, the US and Argentina), followed by stacked herbicide-resistant and/or Bt maize (mainly in the US and Brazil), Bt cotton (mainly in India, China, the US, Pakistan), and herbicide-resistant canola (mainly in Canada and the US). The other commercial-scale GM crops are herbicide-resistant alfalfa and herbicide-resistant sugar beet, on the increase in the US and Canada, virus-resistant papaya grown

<sup>43</sup> mainly in Aragon on 41,669 ha, Catalunya on 33,530 ha, and Extremadura on 15,951 ha.

<sup>44</sup> It is possible that GM soy cultivation in Romania continued unofficially until recently, as data collection is very poor [http://www.infomg.ro/web/en/GMOs\\_in\\_Romania/](http://www.infomg.ro/web/en/GMOs_in_Romania/)

<sup>45</sup> In 2008 Germany had 3,171 ha registered to grow Bt maize. <http://www.gmo-safety.eu/basic-info/564.maize-approval-cultivation-coexistence.html>

<sup>46</sup> The cultivation area was only 17 ha, for the purposes of seed multiplication and industrial tests.

<sup>47</sup> Amadea and Modena GM potatoes, see <http://www.basf.com/group/pressrelease/P-12-109>

only in Hawaii, virus-resistant squash (zucchini) in the US, and a virus-resistant bean about to be grown in Brazil.

### **Regulatory pipeline for GM crops in the EU as of May 2013**

Around 25 GM crop applications are currently (early 2013) in the EU authorisation procedure for cultivation (deliberate release) (see Table A6-2 below). The majority incorporate a single herbicide tolerance or insect resistance trait, or have stacked traits (Lusser et al, 2012). The list includes GM maize (MON88017) with resistance to corn rootworm and stem borers combined with herbicide tolerance (Devos et al, 2012). Notably, no wheat varieties are on the list, though new GM varieties are being developed in the US.<sup>48</sup> Due to the current regulatory process and lack of support by Environment Ministers none of these applications have been given final authorisation for cultivation by the European Commission.

Research on GM crops is still on-going in Europe but applications for experimental releases of GM plants are decreasing.<sup>49</sup> About one-third of applications come from universities and public research bodies,<sup>50</sup> but current private sector GM research is aimed at markets where acceptance and market potential are higher than in Europe.<sup>51</sup> BASF has withdrawn its GM starch-modified potatoes (Amadea and Modena) from the European regulatory process and announced in January 2012 that it is stopping GM development in Europe<sup>52</sup>, and Monsanto and Pioneer identify only a limited number of GM crops for commercialisation in Europe.<sup>53</sup> The GMO research and development (R&D) process has taken on average 13 years for current GM crops<sup>54</sup> (McDougall, 2011), with the risk assessment and regulatory process accounting for more than a third of this time. It is therefore unlikely under the current regulatory stalemate that any new GM crops will be authorised in the EU in the next decade (Fresco, 2013; Peng, 2011).

### **R & D pipeline for GM crops globally**

It must be underlined that no recent study could be found that focuses specifically on the R&D pipeline of GMOs intended for Europe. The most recent study with a European perspective provides projections to 2015 (Stein and Rodríguez-Cerezo, 2009). However, it appears that these projections will not be achieved (FAO, 2012). Recent forecasts focus on the short-term – i.e. on GM events in advanced stages of the R&D pipeline and likely to be commercialised in the next five years (FAO, 2012; Lusser et al, 2012). This review therefore looked globally for examples of new GM traits and crops that could be relevant to European agriculture.

New GM traits that have recently been commercialised in other regions or are expected to be commercialised within the next few decades include:

<sup>48</sup> <http://www.guardian.co.uk/environment/2013/jun/22/agriculture-oregon-monsanto-gm-wheat>

<sup>49</sup> In 2012, less than 50 new release applications for GM plants were submitted in the EU whereas over 100 new applications were submitted in 2009. In 2012, 30 of the new applications came from Spain.

<sup>50</sup> [http://gmoinfo.jrc.ec.europa.eu/gmp\\_browse.aspx](http://gmoinfo.jrc.ec.europa.eu/gmp_browse.aspx)

<sup>51</sup> Monsanto declared in early 2012 that it no longer intends to sell MON810 maize in France <http://www.reuters.com/article/2012/01/24/us-gmo-france-monsanto-idUSTRE80N1NI20120124>

<sup>52</sup> See <http://www.basf.com/group/pressrelease/P-12-109>

<sup>53</sup> see [http://www.monsanto.com/investors/Documents/2013/2013.01.08\\_Pipeline\\_Q1FY13.pdf](http://www.monsanto.com/investors/Documents/2013/2013.01.08_Pipeline_Q1FY13.pdf), [http://www.pioneer.com/CMRoot/Pioneer/About\\_Global/our\\_research/pipeline/Pipeline\\_2012.pdf](http://www.pioneer.com/CMRoot/Pioneer/About_Global/our_research/pipeline/Pipeline_2012.pdf)

<sup>54</sup> Based on information provided by six of the industry's largest biotech crop developers.

- **improved nutrient profiles** such as
  - GM high oleic / low linoleic and linolenic soybean<sup>55</sup> grown in the US since 2011
- **altered crop metabolism for industrial products**, such as
  - GM *Eucalyptus* trees with modified cell wall lignin for faster growth near commercialisation in Brazil
  - GM bioethanol-ready maize<sup>56</sup> grown for biofuel in the US since 2012
- **abiotic stress tolerance** including
  - GM drought-tolerant maize (MON87460) grown in the US since 2012
  - GM drought-tolerant wheat, barley and sugarcane, and water use efficient GM cotton field tested in Australia
  - GM freezing-tolerant *Eucalyptus* being field-tested in the USA
  - GM salinity-tolerant *Eucalyptus* being field-tested in Japan
  - GM salt-tolerant wheat and barley field-tested in Australia – the *codA* gene from the soil bacterium *Arthrobacter globiformis* encodes an enzyme in the biosynthetic pathway that produces a molecule that protects cells from desiccation (Khan et al, 2009)
- **disease resistance** traits such as
  - GM powdery mildew resistant wheat field tested in Switzerland in 2010 and 2011<sup>57</sup>
  - GM grapevines resistant to grapevine fanleaf virus through production of a coat protein of the GFLV virus field tested in France<sup>58</sup>
  - GM fungus resistant chestnut trees (designed for release into the wild in the US<sup>59</sup>)
- **nitrogen use efficiency** in
  - GM nitrogen use efficient barley will be field tested in Sweden – it contains two GM genes from *Arabidopsis thaliana* (amino acid transporter genes LHT1 and AAP5) that modify the plant's up-take of amino acids from soil<sup>60</sup>
  - GM oilseed rape and GM rice have been modified similarly by Arcadia Biosciences and are being field tested in the US<sup>61</sup>
- **bioremediation capacity** in
  - GM poplars containing increased levels of glutathione, which binds and inactivates heavy metals such as cadmium, storing them in leaves – field trials are planned in Germany and Russia<sup>62</sup>

<sup>55</sup> DP-305423-1 soybean contains a modified, noncoding omega-6 desaturase gene (*gm-fad2-1*), expressed with a seed-specific promoter, which results in increased levels of monosaturated fatty acids (oleic) and reduced polysaturated fatty acids (linoleic and linolenic).

<sup>56</sup> SYN-E3272-5 maize expresses a thermostable alpha-amylase enzyme (*amy797E*) that is activated when maize enters bioethanol production, making the process more efficient by saving on the need for enzyme addition.

<sup>57</sup> <http://www.konsortium-weizen.ch/>

<sup>58</sup> <http://www.gmo-safety.eu/news/1271.safety-research-public-involvement-france-inra.html>

<sup>59</sup> <http://www.economist.com/news/science-and-technology/21577033-gm-species-may-soon-be-liberated-deliberately-wildwood>

<sup>60</sup> <http://www.gmo-safety.eu/focus/1413.nitrogen-efficiency-genetic-engineering.html>, [http://gmoinfo.jrc.ec.europa.eu/gmp\\_report.aspx?CurNot=B/SE/12/484](http://gmoinfo.jrc.ec.europa.eu/gmp_report.aspx?CurNot=B/SE/12/484)

<sup>61</sup> <http://www.arcadiabio.com/nitrogen>

<sup>62</sup> <http://www.gmo-safety.eu/science-live/305.soil-detoxification-genetically-modified-poplars.html>



One particularly interesting trait is the inclusion of **nitrogen fixing capacity** into non-leguminous crops, which can probably only be achieved through the use of GM technologies because it requires the use of genes from other species. It is unlikely to be near commercial use within the next 15 years (Baulcombe et al, 2009), but rapid progress is being made (Untergasser et al, 2012).

### **Biological novelty, stacked traits, and new breeding technologies**

The GM breeding process enables the introduction of a much wider range of novel traits than conventional breeding, which may deviate substantially (genetically, biochemically, and physiologically as well as in ethical, regulatory, and public perceptions) from what classical, selection-based breeding has achieved, and which therefore pose a new scale of potential risk (Nielsen, 2003). Other new plant breeding technologies also enable the introduction of novel traits (Lusser et al, 2011), and can therefore present many of the same types of possible risks to biodiversity as GM crops (eg Busconi et al, 2012; Krato and Petersen, 2012; Perez-Jones et al, 2010; Peterson and Shama, 2005). They pose a legislative challenge in Europe because their GM or non-GM status is currently not legally defined.

Numerous GM genes can be combined or '**stacked**' in a single plant variety more easily than with conventional breeding, creating novel combinations of traits. In the EU the EFSA guidelines (EFSA, 2010) require separate case-by-case assessments of stacked varieties<sup>63</sup>. There is an on-going debate about whether stacked varieties should be subject to the same or a less rigorous risk assessment than the parent GM varieties (see Box A6-1).

#### **Box A6-1 Environmental risk assessment of stacked GM varieties**

A stacked GM variety is a GM plant in which two or more single GM events have been combined by conventional plant breeding. The major biotechnology companies are increasingly producing GM varieties with combinations ("stacked traits") of already commercialised GM traits (Lusser et al, 2012). For example, SmartStax maize, the result of collaboration between Monsanto and Dow AgroSciences, combines eight GM traits: six for insect resistance (Bt) and two for herbicide tolerance. GM crops in which the genes are stacked by joining together genes or events, so that they do not segregate independently in cross-breeding, require a different kind of assessment (Taverniers et al, 2008).

There are many possible different comparators for conventionally stacked GM plants (EFSA, 2010), as they may be the result of multiple rounds of cross-breeding among many different genotypes and possibly involve several stacked events. Also, (near)isogenic non-GM lines may not exist, because the original crossed lines may be quite different genetically. Choosing the appropriate comparators among the single transformation GM plants and the intermediate stacked events that gave rise to the stacked GM plant under assessment may not be a straight forward action, and the choice of comparator must be justified in the risk assessment.

The risk assessment relies on the previous risk assessments of each individual event (provided they were done for the same use as is proposed in the stacked crop) (Schrijver et al, 2007), but aims to discover (CBD BCH, 2012): 1) whether cross-breeding has resulted in changes to the structure of the GM genes that affect expression, 2) whether expression of the GM traits has changed due to interactions between GM genes, or with the non-GM genetic background, or 3) whether the combination of GM proteins and metabolites affects non-target organisms more strongly than the individual GM traits and products (Raybould et al, 2012). In addition, resistance management

<sup>63</sup> EFSA ERA guidelines (EFSA, 2010) p 22 'It is very unlikely that any scientific rationale could justify the absence of experimental data for ERA, because there would need to be considerable evidence from previous risk assessments to rule out *ab initio* interactions between the events on biota, even if the proteins themselves could be shown not to interact. Furthermore, for cultivation, it should be stressed that consideration of management is essential.'

strategies need to be adapted to the combination of traits. In contrast, the biotechnology industry considers that stacked crops need little if any additional risk assessment data unless it is considered likely that the genes will interact (Pilacinski et al, 2011). Even if no substantial differences are found from this comparison, the combination of different crop management strategies enabled by the stacking could have a significantly different effect on agro-biodiversity than expected from the individual traits.

An expert group convened by the European Commission has evaluated whether eight new techniques<sup>64</sup>, including cisgenesis and intragenesis, constitute techniques of genetic modification and clarified where the resulting organisms fall outside the scope of EU GMO legislation.<sup>65</sup> These techniques are all being used by commercial breeders, with targeted mutagenesis (ODM), cisgenesis/intragenesis, and agro-infiltration already used to produce commercial crops, and ZFN technology, RdDM, grafting on GM rootstocks, and reverse breeding currently used mainly at research level (Lusser et al, 2011)<sup>66</sup>. If these techniques are classified as non-GM in Europe, the most advanced crops could be commercialised in two to three years. The crop/trait combinations likely to be among the first commercial products derived from these technologies include herbicide resistance ('Clearfield') in oilseed rape and maize through ODM; and fungal (potato blight) resistant potatoes, potatoes with reduced amylase content<sup>67</sup>, drought-tolerant maize, and scab-resistant apples (Vanblaere et al, 2011), all through cisgenesis/intragenesis<sup>68</sup>.

It is not clear whether crops produced through **cisgenesis** or intragenesis – gene movement using recombinant nucleic acid transformation between organisms in the same species or species complex<sup>69</sup> – are defined as GM crops or not. Because cisgenesis introduces genes that have been present in the species gene pool for centuries, using promoters and other genetic sequences from the same species, some argue that these crops should not be subject to such strict requirements because their risks can

<sup>64</sup> These are: zinc finger nuclease (ZFN) technology (ZFN-1, ZFN-2 and ZFN-3), oligonucleotide directed mutagenesis (ODM), cisgenesis and intragenesis using recombinant nucleic acid transformation; RNA-dependent DNA methylation (RdDM); grafting of non-GM components onto GM rootstock; reverse breeding; agro-infiltration (agro-infiltration "*sensu stricto*", agro-inoculation, floral dip); and synthetic genomics.

<sup>65</sup> New Techniques Working Group (2012) Final Report, European Commission  
[http://ec.europa.eu/food/plant/gmo/new\\_breeding\\_techniques/index\\_en.htm](http://ec.europa.eu/food/plant/gmo/new_breeding_techniques/index_en.htm)

<sup>66</sup> The EU is currently publishing 45% of all scientific publications on these new techniques, followed by North America (32%); conversely, the majority (65%) of patent applications come from applicants based in the USA, followed by EU based applicants (26%) (Lusser et al, 2011).

<sup>67</sup> Rpi-vnt1.1 potato developed by Wageningen University DuRPH project, to be field tested in Ireland

<sup>68</sup> <http://www.fwi.co.uk/articles/15/12/2012/136656/gm-helping-to-fight-potato-blight.htm>

<sup>69</sup> The European New Techniques Working Group defines these as: "**Cisgenesis** is the genetic modification of a recipient organism with a gene from a crossable – sexually compatible – organism (same species or closely related species). This gene includes its introns and is flanked by its native promoter and terminator in the normal sense orientation. Cisgenic plants can harbour one or more cisgenes, but they do not contain any parts of transgenes or inserted foreign sequences. To produce cisgenic plants any suitable technique used for production of transgenic organisms may be used. Genes must be isolated, cloned or synthesized and transferred back into a recipient where stably integrated and expressed. Sometimes the term cisgenesis is also used to describe an *Agrobacterium*-mediated transfer of a gene from a crossable – sexually compatible – plant where T-DNA borders may remain in the resulting organism after transformation. This is referred to as cisgenesis with T-DNA borders. **Intragenesis** is a genetic modification of a recipient organism that leads to a combination of different gene fragments from donor organism(s) of the same or a sexually compatible species as the recipient. These may be arranged in a sense or antisense orientation compared to their orientation in the donor organism. Intragenesis involves the insertion of a reorganised, full or partial coding region of a gene frequently combined with another promoter and/or terminator from a gene of the same species or a crossable species."

be regarded as comparable to conventionally bred crops (as long as the possibility of unintended genetic effects is considered) (Schouten et al, 2006). Others argue that cisgenic GM crops may still have novel traits in novel settings (Russell and Sparrow, 2008) and that the regulation is therefore warranted. Also, it is argued that public perception would backlash if cisgenic GMOs were deregulated, which could be more costly in the long run (Russell & Sparrow, 2008). EFSA has published a scientific opinion on the risks of cisgenesis and intragenesis, concluding that cisgenetic crops present similar hazards to conventionally bred plants whilst novel hazards can be associated with intragenic and transgenic plants, but that all these breeding methods can produce variable frequencies and severities of unintended effects which need to be assessed case by case (EFSA, 2012a).

**Site-directed nuclease 3 techniques**, including the zinc finger technique (ZFN), allow the integration of gene(s) in a predefined insertion site in the genome of the recipient species. The technique can be used to introduce transgenes, intragenes or cisgenes, so the range of possible risks associated with introduced genes is comparable to GM crops. However, EFSA's scientific opinion on the technology noted that the use of site-directed nucleases can minimize the hazards associated with the disruption of genes or regulatory elements in the recipient genome (compared with most mutagenesis techniques), thus reducing the likelihood of unintended effects (and where such changes occur they would be of the same types as those produced by conventional breeding techniques) (EFSA, 2012b).

### EU Member States bans of GM crops in relation to environmental concerns

There are considerable differences in the attitudes of EU Member States towards the use of GMOs (European Commission, 2011a). In particular, the Commission note the wide range of views on the impact of GM crops on biodiversity (among other matters).

Eight Member States have implemented national bans on GM crop cultivation<sup>70</sup>. Austria, Bulgaria, Germany<sup>71</sup>, Greece, Hungary, Poland<sup>72</sup> and Luxembourg have invoked the "safeguard clause" in Article 23<sup>73</sup> of EU Directive 2001/18/EC as their legal basis to provisionally restrict or prohibit the use and/or sale of MON810 maize and/or Amflora potato on their territory. France's ban uses the "emergency measure" in Article 34<sup>74</sup> of Regulation (EC) 1829/2003<sup>75</sup> after the previous ban was legally challenged.<sup>76</sup> Some examples of Member State concerns are listed in Table A6-1 according to the categories of possible impact on biodiversity used in EFSA environmental risk assessment (EFSA, 2010).

<sup>70</sup> Additionally, the Italian government has requested the EU executive to «suspend the authorisation for cultivation of MON 810 maize seeds in all EU Member States» due to «environmental risks» <http://www.politicheagricole.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/6133>

<sup>71</sup> <http://www.bmelv.de/SharedDocs/Pressemitteilungen/2009/063-AI-Mon810.html>

<sup>72</sup> MON810 maize and Amflora potato, AgraFacts No.01-13 04/01/2013 <http://www.agrafacts.com/Home.html>

<sup>73</sup> This clause specifies that “where a Member State (...) has detailed grounds for considering that a GMO (...) constitutes a risk to human health or the environment, that Member State may provisionally restrict or prohibit the use and/or sale of that GMO (...) on its territory”.

<sup>74</sup> This measure specifies that “where (...) the need to suspend or modify urgently an authorisation arises, measures shall be taken under the procedures provided for in Articles 53 and 54 of Regulation (EC) No 178/2002.”

<sup>75</sup> Regulation (EC) No 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety.

<sup>76</sup> The French ban on MON810 maize cultivation using the “safeguard clause” was declared unlawful by the European Court of Justice in 2011. JUDGMENT OF THE COURT (Fourth Chamber) - 8 September 2011 - In Joined Cases C-58/10 to C-68/10.

<b>Table A6-1</b> Examples of biodiversity-related concerns raised by Member States to justify national bans <sup>77</sup>			
<b>Potential environmental impacts</b>	<b>Specific concern</b>	<b>Member States bans of GM crops</b>	<b>References</b>
A. Risks associated with gene flow and its consequences	<ul style="list-style-type: none"> <li>• Possible gene flow from Bt maize MON810 or HT maize T25 through outcrossing to neighbouring non-modified varieties</li> </ul>	France, Austria – Bt maize MON810  Austria – HT maize T25	78
B. Risks associated with horizontal gene transfer	<ul style="list-style-type: none"> <li>• Possible risks related to antibiotic-resistance marker gene nptII, potential horizontal transfer of nptII gene fragments, potential transfer of nptII gene from Amflora potato to soil bacteria</li> </ul>	Austria, Hungary, Luxembourg – Amflora potato	79
C. Risks associated with resistance evolution	<ul style="list-style-type: none"> <li>• Possible resistance development in target organisms of Bt maize</li> </ul>	Hungary – Bt maize MON810	80
D. Risks associated with non-target impacts on species and ecosystem services	<ul style="list-style-type: none"> <li>• Possible impacts on terrestrial organisms such as Lepidoptera species, ground-dwelling arthropods, Hymenoptera (e.g. honey bees).</li> <li>• Possible impacts on aquatic organisms, in particular aquatic arthropods such as Trichoptera species</li> <li>• Possible impacts on soil organisms such as symbiotic fungal communities, earthworms, nematodes, isopods, springtails</li> <li>• Trophic chain effects on predators or parasitoids</li> </ul>	Austria, France, Greece, Hungary – Bt maize MON810	81
E. Risks associated with changes in crop production practices	<ul style="list-style-type: none"> <li>• Changes in weed management to be expected with introduction of GM HT maize T25</li> </ul>	Austria – HT maize T25	82
Source: Review of Member States justifications of their reasons for the concern that motivated the ban and the European Food Safety Authority response (on the request of the Commission). References in footnotes.			

<sup>77</sup> Does not include national bans of Germany and Bulgaria

<sup>78</sup> (EFSA, 2008a; EFSA, 2008b)

<sup>79</sup> (EFSA, 2012c; EFSA, 2012d; EFSA, 2012e)

<sup>80</sup> (EFSA, 2008c)

<sup>81</sup> (EFSA, 2008a; EFSA, 2008b; EFSA, 2008c; EFSA, 2008d; EFSA, 2012f; EFSA, 2012g; Ministère de l'Agriculture, de l'Alimentation, de la Pêche, de la Ruralité et de l'Aménagement du Territoire, 2012a; Ministère de l'Agriculture, de l'Alimentation, de la Pêche, de la Ruralité et de l'Aménagement du Territoire, 2012b)

<sup>82</sup> (EFSA, 2008b)

## European Commission proposal for socio-economic assessment of GMOs

In an attempt to break the regulatory deadlock for approval of GM crops for cultivation, the European Commission published a proposal for regulatory changes that would allow an individual Member State to ban the cultivation of a particular GM crop on its own territory, based on criteria other than risks to the environment or health, whilst allowing other Member States to make a decision about growing it (see Box A6-2)<sup>83</sup>.

The EU regulatory framework is specific as regards the process of assessing environmental and health risks, for which EFSA provides scientific opinions, but also allows for “other legitimate factors” to be taken into account when making a decision on whether or not to authorise a GM crop for cultivation<sup>84</sup>. The proposal is currently in stalemate at Council, and the Commission is undertaking talks with individual Member State representatives<sup>85</sup>.

The methodological framework for performing socio-economic assessments of GMOs is currently under development, and data gathered from Member States by the European Commission was very heterogeneous (European Commission, 2011a). Regional workshops and national studies have added to the discussion (COGEM, 2009; Greiter et al, 2011; Lusser et al, 2012; Spök, 2010)<sup>86</sup>. France has set up a High Council for Biotechnology which includes an economic, ethical and social committee that supports decision-making<sup>87</sup>. A European Socio-Economic Bureau will be established at the JRC in 2013.

Arguments in favour of implementing a socio-economic assessment for GM crops emphasise that it would make decision-making more robust and more transparent. Whilst Member States must invoke scientific arguments to activate the safeguard clause or other ways of banning GMOs on their territory, decision-making is also influenced by public opinions and other socio-economic arguments. Allowing Member States to invoke such arguments for banning GMO cultivation on their territory may make the process more transparent.

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<sup>83</sup> EC (2010) Commission Proposal for a Regulation of the European Parliament and the Council amending Directive 2001/18/EC as regards the possibility for the Member States to restrict or prohibit the cultivation of GMOs in their territory. COM (2010) 375. European Commission.

<sup>84</sup> Regulation (EC) No.1829/2003 preamble 32 “It is recognised that, in some cases, scientific risk assessment alone cannot provide all the information on which a risk management decision should be based, and that other legitimate factors relevant to the matter under consideration may be taken into account.” The Cartagena Protocol on Biosafety allows for socio-economic considerations in Article 26 (<https://bch.cbd.int/protocol/text/>)

<sup>85</sup> ENDS Europe DAILY Monday 18 February 2013 EC begins talks to unblock GM impasse

<sup>86</sup> EEA workshop Copenhagen, 6 and 7 December 2012 <http://www.umweltbundesamt.at/socio-economics-gmoschemicals/>

<sup>87</sup> <http://www.hautconseildesbiotechnologies.fr/spip.php?rubrique20URL>

**Box A6-2 Proposal for socio-economic assessment of GMOs in the EU**

The European Commission suggests that the socio-economic assessment of GMOs should particularly address the following issues (European Commission, 2011b):

1. Socio-economic impacts associated with effects of GMOs on human health and the environment (as identified by the environmental risk assessment according to Dir. 2001/18/EC). EFSA is responsible for assessing possible environmental and health consequences of adverse effects by GMOs, but Member States could address the economic and socio-economic impacts of such effects, including impacts due to changes in agricultural management (eg changes in tillage activities, use of agrochemicals – fertilizer and pesticides, crop rotation patterns).
2. Socio-economic impacts as regards general environmental policy objectives which are different from those addressed in GMO regulation (Directive 2001/18/EC and Regulation (EC) No 1829/2003) eg maintenance of certain type of natural and landscape features; maintenance of certain habitats and ecosystems (ie preservation of the conservation status quo); maintenance of specific ecosystem functions and services (eg preservation of nature-oriented regions of particular natural and recreational value to citizens); conservation of biodiversity in agricultural and natural ecosystems.
3. Socio-economic impacts associated with the presence of GMOs in other products ie impacts related to: preservation of organic and conventional farming systems; avoiding the presence of GMOs in other products such as particular food products under GM-free schemes; avoiding the distortion of competition in relation to the practicality and cost of the measure laid down in Article 26a for avoiding the unintended presence of GMOs in other products.
4. Socio-economic impacts associated with social policy objectives eg keeping certain type of rural development in given areas to maintain current levels of occupation (such as specific policy for mountain regions); or objectives to support equitable distribution of costs and benefits.
5. Socio-economic impacts on town and country planning/land use
6. Socio-economic impacts on relevant issues of cultural policy e.g. related to preservation of societal traditions in terms of traditional farming methods; or preservation of cultural heritage linked to territorial production processes with particular characteristics.

**Table A6-2 GM crops in the EU regulatory pipeline as of May 2013**

Key: Trait: InsRes = insect resistance; HerbTol = herbicide tolerance (resistance)

The GM crops **in red** are currently in the application process for cultivation in the EU. NB: as of July 2013 Monsanto has announced it will withdraw its applications for deliberate release of five GM maize varieties, one GM soybean and one GM sugarbeet (but not MON810 maize)<sup>88</sup>.

Source: GMO Compass database <http://www.gmo-compass.org/eng/database/plants/>

Crop	Status of application	Event	Company	Trait	Food and Feed	Food processing	Import and	Cultivation
Cotton	Application withdrawn	281-24-236 x 3006-210-23	Dow AgroScience	InsRes		x		
Cotton	Risk assessment report	281-24-236 x 3006-210-23	Dow AgroSciences	InsRes	x	x		
Cotton	Application submitted	281-24-236 x 3006-210-23 x MON88913	Mycogen Seeds/Dow AgroScience	InsRes, HerbTol	x	x		
Cotton	Risk assessment report	GHB614	Bayer CropScience	HerbTol	x	x		
Cotton	Application submitted	GHB614 x LLCotton25	Bayer Crop Science	HerbTol	x	x		
Cotton	Valid authorisation	LL Cotton 25	BayerCrop Science	HerbTol	x	x		
Cotton	Application withdrawn	LL25xMON15 985	BayerCrop Science	InsRes, HerbTol	x			
Cotton	Notified as "existing product" (Application for renewal of authorisation submitted)	MON 1445	Monsanto	HerbTol	x			
<b>Cotton</b>	Application submitted	<b>MON 1445</b>	Monsanto	<b>HerbTol</b>	x	x		x
Cotton	Application withdrawn	MON 15985	Monsanto	InsRes	x	x		
Cotton	Notified as "existing product" (Application for renewal of authorisation)	MON 15985	Monsanto	InsRes	x			

<sup>88</sup> <http://www.reuters.com/article/2013/07/17/us-eu-monsanto-gmos-idUSBRE96G16R20130717>

Crop	Status of application	Event	Company	Trait	Feed	Food and processing	Import and	Cultivation
	submitted)							
Cotton	Application withdrawn	MON 15985 x MON 1445	Monsanto	InsRes, HerbTol	x			
Cotton	Notified as "existing product" (Application for renewal of authorisation submitted)	MON 15985 x MON 1445	Monsanto	InsRes, HerbTol	x			
Cotton	Application submitted	MON 15985 x MON 1445	Monsanto	InsRes, HerbTol	x	x		
Cotton	Notified as "existing product" (Application for renewal of authorisation submitted)	MON 531	Monsanto	InsRes	x			
<b>Cotton</b>	Application submitted	<b>MON 531</b>	Monsanto	<b>InsRes</b>	x	x		x
Cotton	Application submitted	MON15985	Monsanto	InsRes	x	x		
Cotton	Notified as "existing product" (Application for renewal of authorisation submitted)	MON531 x MON1445	Monsanto	InsRes, HerbTol	x			
Cotton	Application submitted	MON88913	Monsanto	HerbTol	x	x		
Cotton	Application submitted	MON88913x MON15985	Monsanto	InsRes, HerbTol	x	x		
Flowers	Risk assessment report	Carnation Moonaqua	Florigene Ltd	modified flower colour			x	
Flowers	Notified as "existing product"	Carnation Moondust	Florigene Ltd	modified flower colour			x	
Flowers	Valid authorisation	Carnation Moonlite	Florigene Ltd	modified flower colour			x	
Flowers	Notified as "existing product"	Carnation Moonshadow 1	Florigene Ltd	modified flower colour				x



Crop	Status of application	Event	Company	Trait	Feed	Food and processing	Import and	Cultivation
Flowers	Authorisation no longer valid	Carnation Moonshadow 2	Florigene Ltd	increased shelf-life				x
Maize	Valid authorisation	1507	Pioneer / Dow AgroScience	InsRes, HerbTol	x			
<b>Maize</b>	Risk assessment report	<b>1507</b>	Pioneer HiBred	<b>InsRes</b>				x
Maize	Valid authorisation	1507 x 59122	Dow AgroSciences / Pioneer Hi-Bred	InsRes, HerbTol	x	x		
<b>Maize</b>	Application submitted	<b>1507 x 59122</b>	Mycogen Seeds (Dow AgroScience)	<b>InsRes, HerbTol</b>	x	x		x
Maize	Valid authorisation	1507 x NK603	Pioneer Hi-Bred / Mycogen Seeds	InsRes, HerbTol	x	x		
<b>Maize</b>	Application submitted	<b>1507 x NK603</b>	Pioneer Hi-Bred	<b>InsRes, HerbTol</b>	x	x		x
Maize	Application submitted	3272	Syngenta Seeds SAS	Altered composition	x	x		
Maize	Valid authorisation	59122	Pioneer Hi-Bred / Mycogen Seeds	InsRes, HerbTol	x	x		
<b>Maize</b>	Application submitted	<b>59122</b>	Pioneer / Mycogen Seeds	<b>InsRes, HerbTol</b>	x	x		x
Maize	Valid authorisation	59122 x 1507 x NK603	Pioneer Hi-Bred	HerbTol	x	x		
<b>Maize</b>	Application submitted	<b>59122 x 1507 x NK603</b>	Pioneer Hi-Bred	<b>InsRes, HerbTol</b>	x	x		x
Maize	Application withdrawn	59122 x NK603	Pioneer HiBred / Mycogen	InsRes, HerbTol	x	x		x
Maize	Valid authorisation	59122 x NK603	Pioneer Hi-Bred	InsRes, HerbTol	x	x		
Maize	Application submitted	98140	Pioneer	HerbTol	x	x		
Maize	Valid authorisation (Notified as "existing product")	Bt11	Syngenta	InsRes	x			

Crop	Status of application	Event	Company	Trait	Feed	Food and processing	Import and	Cultivation
Maize	Risk assessment report	Bt11	Syngenta	InsRes		x		x
Maize	Valid authorisation	Bt11 x GA21	Syngenta	InsRes, HerbTol	x	x		
Maize	Application submitted	Bt11 x MIR162 x 1507 x GA21	Syngenta	InsRes, HerbTol	x	x		
Maize	Application submitted	Bt11 x MIR162 x GA21	Syngenta	InsRes, HerbTol	x	x		
Maize	Application submitted	Bt11 x MIR162 x MIR604 x GA21		InsRes, HerbTol	x	x		
Maize	Risk assessment report	Bt11 x MIR604	Syngenta	InsRes, HerbTol	x	x		
Maize	Risk assessment report	Bt11 x MIR604 x GA21	Syngenta Seeds	InsRes, HerbTol	x	x		
Maize	Application submitted	Bt11 x MIR604 x GA21	Syngenta Seeds	InsRes, HerbTol				x
Maize	Authorisation no longer valid	Bt176	Syngenta	InsRes	x	x		x
Maize	Valid authorisation	GA21	Syngenta Seeds SAS	HerbTol	x	x		
Maize	Application submitted	GA21	Syngenta Seeds SAS	HerbTol	x	x		x
Maize	Authorisation no longer valid	GA21 MON810	x Monsanto	InsRes, HerbTol	x			
Maize	Application withdrawn	LY038	Renessen LLC	Altered composition	x	x		
Maize	Application withdrawn	LY038 MON810	x Renessen LLC	Altered composition, InsRes	x	x		
Maize	Application submitted	MIR162	Syngenta	InsRes	x	x		
Maize	Valid authorisation	MIR604	Syngenta	InsRes	x	x		
Maize	Application submitted	MIR604	Syngenta Seeds	InsRes				x
Maize	Risk assessment report	MIR604 GA21	x Syngenta	InsRes, HerbTol	x	x		
Maize	Renewal of authorisation, risk assessment report	MON810	Monsanto	InsRes	x	x		x
Maize	Renewal of	MON863	Monsanto	InsRes	x			

Crop	Status of application	Event	Company	Trait	Feed	Food and processing	Import and	Cultivation
	authorisation, risk assessment report (Notified as "existing product")							
Maize	Valid authorisation	MON863	Monsanto	InsRes	x	x		
Maize	Valid authorisation	MON863 x MON810	Monsanto	InsRes	x			
Maize	Risk assessment report	MON863 x MON810	Monsanto	InsRes		x		
Maize	Valid authorisation	MON863 x MON810 x NK603	Monsanto	InsRes, HerbTol	x	x		
Maize	Application for renewal of authorisation submitted	MON863 x NK603	Monsanto	InsRes, HerbTol	x			
Maize	Valid authorisation	MON863 x NK603	Monsanto	InsRes, HerbTol	x	x		
Maize	Application submitted	MON87460	Monsanto	drought tolerance	x	x		
Maize	Valid authorisation	MON88017	Monsanto	InsRes, HerbTol	x	x		
<b>Maize</b>	Application submitted	<b>MON88017</b>	Monsanto	<b>InsRes, HerbTol</b>				x
Maize	Valid authorisation	MON88017 x MON810	Monsanto	InsRes, HerbTol	x	x		
Maize	Valid authorisation	MON89034	Monsanto	InsRes	x	x		
Maize	Risk assessment report	MON89034 x 1507 x MON88017 x 59122	Dow AgroSciences, Monsanto	InsRes, HerbTol	x	x		
Maize	Risk assessment report	MON89034 x 1507 x NK603	Monsanto	InsRes, HerbTol	x	x		
Maize	Risk assessment report	MON89034 x MON88017	Monsanto	InsRes, HerbTol	x	x		
<b>Maize</b>	Application submitted	<b>MON89034 x MON88017</b>	Monsanto	<b>InsRes, HerbTol</b>				x
Maize	Valid authorisation	MON89034 x NK603	Monsanto	InsRes, HerbTol	x	x		
<b>Maize</b>	Application	<b>MON89034 x NK603</b>	Monsanto	<b>InsRes, HerbTol</b>				x

Crop	Status of application	Event	Company	Trait	Feed and Food processing	Import and	Cultivation
	submitted						
Maize	Valid authorisation	NK603	Monsanto	HerbTol	x		
<b>Maize</b>	Risk assessment report	<b>NK603</b>	Monsanto	<b>HerbTol</b>	x	x	x
Maize	Valid authorisation	NK603 x MON810	Monsanto	InsRes, HerbTol	x		
Maize	Risk assessment report	NK603 x MON810	Monsanto	InsRes, HerbTol	x	x	
<b>Maize</b>	Application submitted	<b>NK603 x MON810</b>	Monsanto	<b>InsRes, HerbTol</b>			x
Maize	Application submitted	NK604 x T25	Monsanto	HerbTol	x	x	
Maize	Notified as "existing product" (Application for renewal of authorisation withdrawn)	T25	Bayer CropScience	HerbTol	x	x	
Potato	Application submitted	AV43-6-G7	AVEBE	Altered composition	x		x
Potato	Application submitted	BPS-A1020-5	BASF Plant Science	Altered composition	x	x	x
Potato	Valid authorisation	EH92-527-1	Amylogen HB	Altered composition			x
Potato	Valid authorisation	EH92-527-1	BASF Plant Science	Altered composition	x		
<b>Rapeseed</b>	Application submitted	<b>GS40 / 90pHoe6 / Ac</b>	Bayer CropScience	<b>HerbTol</b>	x		x
Rapeseed	Valid authorisation	GT 73	Monsanto	HerbTol		x	
<b>Rapeseed</b>	Application submitted	<b>Liberator pHoe6/Ac</b>	Bayer CropScience	<b>HerbTol</b>	x		x
Rapeseed	Authorisation no longer valid	MS1 x RF1	Bayer CropScience	Male sterility, HerbTol	x	x	x
Rapeseed	Authorisation no longer valid	MS1 x RF2	Bayer CropScience	Male sterility, HerbTol	x	x	x
Rapeseed	Valid authorisation	MS8 x RF3	Bayer CropScience	Male sterility, HerbTol	x	x	
Rapeseed	Application submitted	MS8 x RF3 x GT73	Monsanto / Bayer CropScience	HerbTol	x	x	

Crop	Status of application	Event	Company	Trait	Feed	Food and processing	Import and	Cultivation
Rapeseed	Application submitted	MS8 x RS3		Male sterility, HerbTol	x			
Rapeseed	Valid authorisation	T45	Bayer CropScience	HerbTol	x	x		
Rapeseed	Authorisation no longer valid	TOPAS 19/2	Bayer CropScience	HerbTol	x	x		
Rice	Risk assessment report	LL RICE 62	Bayer CropScience	HerbTol	x	x		
Soybean	Application submitted	MON87769 x MON89788	Monsanto	Altered composition, HerbTol	x	x		
Soybean	Application submitted	305423	Pioneer Hi-Breed	Altered composition	x	x		
Soybean	Application submitted	305423 x 40-3-2	Pioneer Hi-Bred	Altered composition, HerbTol	x	x		
Soybean	Application submitted	356043	Pioneer	HerbTol	x	x		
Soybean	Valid authorisation	A2704-12	Bayer CropScience	HerbTol	x	x		
Soybean	Application submitted	A5547-127	Bayer CropScience	HerbTol	x	x		
Soybean	Application submitted	BPS-CV127-9	BASF Plant Science	HerbTol	x	x		
Soybean	Notified as "existing product" (Application for renewal of authorisation submitted)	MON40-3-2	Monsanto	HerbTol	x			
<b>Soybean</b>	Application submitted	<b>MON40-3-2</b>	Monsanto	<b>HerbTol</b>				x
Soybean	Application submitted	MON87701	Monsanto	InsRes	x	x		
Soybean	Application submitted	MON87701 x MON89788	Monsanto	InsRes, HerbTol	x	x		
Soybean	Application submitted	MON87705	Monsanto	Altered composition, HerbTol	x	x		
Soybean	Application submitted	MON87769	Monsanto	Altered composition	x	x		
Soybean	Valid	MON89788	Monsanto	HerbTol	x	x		

Crop	Status of application	Event	Company	Trait	Feed	Food and processing	Import and	Cultivation
n	authorisation							
<b>Sugar Beet</b>	Application submitted	<b>A5-15</b>	Danisco Seeds / DLF Trifolium	<b>HerbTol</b>	x			x
Sugar Beet	Valid authorisation	H7-1	KWS Saat AG / Monsanto	HerbTol	x			
<b>Sugar Beet</b>	Application submitted	<b>H7-1</b>	KWS Saat AG / Monsanto	<b>HerbTol</b>	x			x

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## ANNEX TO CHAPTER 6(b) THE KINDS OF POSSIBLE IMPACTS OF GM CROPS ON BIODIVERSITY AND CURRENT EVIDENCE OF IMPACTS

Underwood, Evelyn

This annex outlines the potential risks and benefits of GM crops for biodiversity using the seven main headings of environmental risk used in European regulation and risk assessment (EFSA, 2010). It also discusses the current status of scientific evidence for risks and benefits affecting biodiversity with examples from current GM crop use and risk assessments in Europe and elsewhere (Andow and Zwahlen, 2005; Snow et al, 2005). Agronomic, commercial, ethical, or socio-economic risks and benefits are not discussed.

The scientific evidence is ranked according to whether it demonstrates a) risks or benefits with a measurable impact on a biodiversity assessment endpoint; b) risks or benefits that are likely to occur but that have not been associated with a clear negative effect on a biodiversity assessment endpoint; c) risks to biodiversity extrapolated from small-scale test results; d) risks demonstrated in experiments but very difficult to detect in the field, or risks associated with indirect evidence.

The published scientific evidence of the impacts of GM crops on biodiversity is mainly on the current herbicide-tolerance and Bt insect-resistance traits. It should be noted however that the new generation of GM traits poses a much wider range of potential risks to biodiversity than the current generation, and whilst the implications of their use is considered here, so far there is relatively little scientific data on these crops from which to judge impacts.

Risks and environmental benefits associated with **impacts of the specific cultivation, management and harvesting techniques.**

The proven large-scale impacts of current GM crops on biodiversity are mostly related to the **changes in management practices involved**, particularly changed herbicide or insecticide use, reduced till and zero-till practices, and altered crop rotation practices; these risks are similar to the impacts of changes in conventional farming systems. The scale and direction of these impacts depends very much on how farmers manage GM crops, the regulatory restrictions imposed on GM crop management, and how the GM crop system is compared to conventional crop management practices. The agronomic changes associated with GM crop production practices can have positive or negative effects on biodiversity, and the overall impact can vary according to the precise management practices, environment, and landscape context.

Changes in insecticide or fungicide use on GM insect-resistant or disease-resistant crops can be associated with benefits for biodiversity if **insecticide or fungicide use decreases** in frequency and toxicity, particularly if GM crops are used with **integrated pest management**. Changes in insecticide and fungicide use can also release **secondary pests and diseases** from control if they were previously highly controlled by the intensive use of broad-spectrum pesticides, and pesticide use is reduced or changed to chemicals that more narrowly target the primary pest(s). Under reduced pesticide control, the biological control capacity of predators in the crop may not be sufficient to control these secondary pests, which were previously not considered to be a problem, and they may increase in abundance and cause increased crop damage.

Changed management on GM herbicide-tolerant crops can influence biodiversity through 1) the change in herbicide **application and timing**; 2) the change in the **type(s) of herbicide** applied; and 3) associated changes in farming practices including reduced or **no-tillage** and changes in crop rotations or **monoculture**. Changes in herbicide use can be associated with benefits for biodiversity if **herbicide**

**use decreases** in frequency and toxicity and weed populations continue to provide habitat and food resources for wildlife. GMHT crops change the **types of herbicides** used - usually glyphosate (or glufosinate on a small area) combined with a pre-emergence herbicide<sup>89</sup>.

*Evidence: (a) risks or benefits with a measurable impact on a biodiversity assessment endpoint: **Impacts of changed management of GM herbicide-tolerant (GMHT) crops***

The altered herbicide use associated with herbicide-resistant GM crops may **reduce weed populations**, resulting in **reduced populations of weed-associated wildlife** such as seed-eating birds. In the UK, a large farm scale evaluation of four GMHT cropping systems concluded that GMHT oilseed rape and beet crops (but not GMHT maize) reduced the abundance of weeds and associated wildlife compared to the conventional management at that time (Brooks et al, 2003; Brooks et al, 2005; Firbank et al, 2006; Haughton et al, 2003; Hawes et al, 2003a; Heard et al, 2003) (see Box A6-3 for details). As the loss of weed seed and insect food in the agricultural landscape has already had a strongly negative effect on many of Europe's farmland birds (Squire et al, 2003), and as oilseed rape is currently far more important than maize both in area and in the diversity of wildlife it supports in Western Europe (European Commission, 2012; Squire et al, 2003), the negative effect on weeds was considered important enough to conclude that on balance the **GMHT crops would reduce biodiversity**<sup>90</sup> (UK ACRE, 2004; UK ACRE, 2005).

In contrast, research in the US, Canada and South America has come to the opposite conclusion that GMHT crops have increased weed diversity (Gulden et al, 2009; Gulden et al, 2010; Puricelli and Tuesca, 2005; Scursoni et al, 2006; Young et al, 2013). The authors conclude that this is because glyphosate has allowed more broad-leaved weeds to survive and causes greater species richness and evenness than the conventional weed control used in comparable US farming systems. Notably, however, the population of Monarch butterflies in the US Corn Belt is decreasing sharply and a partial cause is the dramatic reduction in its food plant - previously a widespread weed in GMHT maize and soy (Pleasants and Oberhauser, 2013). GMHT crops enable greater flexibility of herbicide use, and this can be implemented in a way that increases in-field biodiversity (eg Dewar et al, 2003) or that significantly decreases it (Strandberg et al, 2005), depending on the timing and frequency of herbicide applications.

**Box A6-3 Do GM herbicide-resistant crops benefit or decrease biodiversity of weeds and associated wildlife?**

GM herbicide-resistant (GMHT) crops allow broad-spectrum herbicides (ie that kill most weeds) to be applied to the crop much later into the growing season and with greater flexibility in timing. The environmental concern is that if GMHT crops have fewer weeds this might mean the crop also has fewer invertebrates that feed on the weeds, and fewer birds that feed on weed seeds, reducing the overall biodiversity in the GM farming system. However, the impacts of changes in herbicide regimes are specific to crop combinations, locations, initial weed density, and other environmental factors, and the impacts on in-field biodiversity therefore vary according to how the crops are managed and what the GM system is compared to.

**GMHT crops reduce in-field biodiversity:** The UK farm-scale evaluations compared the GM

<sup>89</sup> NB: GMHT crops have not resulted in a reduction in the overall weight of herbicides applied (which is increasing), because the average number of applications does not differ greatly from conventional cropping (Benbrook, 2012; Brookes and Barfoot, 2012; Kleter et al, 2007).

<sup>90</sup> Whilst recognising that the GM HT maize had a positive effect compared to atrazine-treated maize

cropping system side-by-side in the same fields as the equivalent non-GM cropping system, with farmers managing the crops in their own way within the recommended management framework (Champion et al, 2003). It is therefore not possible in this study to separate out individual causal factors within the GM system of crop, GM product, herbicide, herbicide application, and environment, but the rigorous, high power experimental design meant that the results are very scientifically robust for the tested cropping systems (Andow, 2003; Perry et al, 2003). The evaluation found that the GMHT glufosinate and glyphosate-resistant beet and oilseed rape had fewer late-flowering (broad-leaved) weeds and weed seeds, and lower numbers of bees, butterflies, and seed-eating beetles (Brooks et al, 2003; Haughton et al, 2003; Heard et al, 2003). The GMHT forage (silage) maize in contrast had higher weed abundance than the non-GM crop comparison - though as the herbicides used have since been banned in the EU, the difference would probably be smaller if compared to today's maize cropping systems (Brooks et al, 2005). The weed seed bank was altered for several years after GMHT cropping ceased (Firbank et al, 2006), and the results were used to extrapolate a probable decline in food resources for farmland birds in GMHT beet and oilseed rape (but not maize) (Gibbons et al, 2006). Detritivore insects feeding on dead plants increased in abundance in GMHT crops (Hawes et al, 2003b), but most insects did not react to the different cropping system (Haughton et al, 2003). Of the three GMHT crops evaluated, oilseed rape is currently by far the most important both in area and in the diversity of wildlife it supports in Western Europe (European Commission, 2012; Squire et al, 2003), and as the loss of weed seed and insect food in the agricultural landscape has already had a strongly negative effect on many of Europe's farmland birds (Squire et al, 2003), the effect on weeds was considered important enough to conclude that on balance the **GMHT crops would reduce biodiversity**<sup>91</sup> (UK ACRE, 2004; UK ACRE, 2005). A different study on GMHT fodder beet demonstrated that when herbicide application recommendations were followed, they had similar results to the UK FSEs, but when glyphosate was applied earlier than recommended the weed diversity and abundance was extremely low (Strandberg et al, 2005). A Spanish field trial of GMHT maize found no links between the abundance of certain insect predators and glyphosate use (Albajes et al, 2011).

**GMHT crops increase in-field biodiversity:** Other studies have concluded that GMHT crops result in an increase in weed diversity. Studies in Canada found that the weed community in GMHT maize and GMHT soybean shifted to fewer broad-leaved annuals and more perennials and grasses, and lower midseason weed ground cover, in both tilled and no-till systems (Gulden et al, 2009; Gulden et al, 2010). A study of GMHT soybean monoculture and GMHT soybean-GMHT maize rotations in Argentina found that under both tilled and no-till systems, regular glyphosate application reduced richness and density of the most competitive weeds, such as early-emergence broad-leaved and grassy annuals, and increased that of the less competitive late-emerging annual broad-leaved weeds, thus increasing overall species richness after glyphosate treatment (Puricelli & Tuesca, 2005). A large-scale US field survey found greater species richness and evenness and proportion of broad-leaved weeds in continuous GMHT monocultures, and less weed diversity in GMHT rotations or non-GM crops (Young et al, 2013). Studies of GMHT soybean on a north-south transect through the US found higher weed abundance and diversity compared to conventional crops when only one post-emergence glyphosate application was made, but no significant difference with two applications (Scursoni et al, 2006). The lower weed control efficacy of the one spray treatment had no effect on yield above latitude 40°N but did affect yields in fields further south. However, most GM HT soybean farmers in the US apply two or more sprays, so this study does not apply widely to the current situation.

<sup>91</sup> Whilst recognising that the GM HT maize had a positive effect compared to atrazine-treated maize

GM herbicide-resistant crops in North America have not reduced the quantity of herbicide used on crops<sup>92</sup>, but have resulted in a large-scale **shift to herbicide use with lower environmental toxicity rating** than previously used herbicide treatments (Brookes & Barfoot, 2012; Kleter et al, 2007; Lopez et al, 2012), because glyphosate is a relatively quick-acting readily degradable herbicide (Borggaard and Gimsing, 2008). However, recent evidence suggests that glyphosate may actually have a higher environmental toxicity than previously considered and that its environmental risk rating should be revised (FoEE, 2013; Helander et al, 2012). Moreover, the lack of weed resistance management associated with GMHT use is resulting in the proliferation of herbicide-tolerant weeds (Duke and Powles, 2008; Owen, 2011; Powles, 2008); already this has resulted in an increase in the volume and environmental impact of herbicide use on GMHT crops in the US and South America (Binimelis et al, 2009; Brookes & Barfoot, 2012; Cerdeira et al, 2011)

At a global scale GMHT crops have facilitated the widespread adoption of **reduced tillage or zero-till farming** systems (Cerdeira et al, 2011; Givens et al, 2009), which are likely to have had large-scale beneficial impacts on soil biodiversity (from increased soil organic matter) and aquatic biodiversity (from reduced soil erosion and associated pollution) (Cerdeira et al, 2011; National Research Council, 2010). Several studies calculate that this has resulted in a large reduction in carbon emissions (reviewed in Brookes & Barfoot, 2012), both due to the increase in soil organic matter and the energy saved by fewer field operations. Today, almost all of the US soybean and cotton area, over 50% of the US maize area, and almost all of the soy area in South America uses GMHT cropping, and a large part of this uses no-till systems. This now poses a dilemma for the control of glyphosate-resistant weeds, which are resulting in the re-introduction of tillage into zero-till systems (Binimelis et al, 2009; Christoffoleti et al, 2008), reducing the beneficial impact. GMHT cropping systems have also facilitated greater use of monoculture cropping and reduced crop rotations (Mortensen et al, 2012), which could be expected to decrease overall farmland biodiversity.

*Evidence: (b) risks or benefits that are likely to occur but that have not been associated with a clear negative effect on a biodiversity assessment endpoint: **Impacts of changed management of GM insect-resistant Bt crops***

GM insect-resistant Bt maize has resulted in large-scale reductions in stemborer pest pressure (Hutchison et al, 2010) and some **reductions in insecticide use** in the US<sup>93</sup>, mainly on sweetcorn rather than field maize (feed maize) as insecticide use on the latter is low<sup>94</sup> (Brookes & Barfoot, 2013). In Spain, a study has estimated that GM Bt maize has reduced the environmental impact of insecticide use by around 40% compared to pre-GM (Brookes, 2009). However, insecticide use against

<sup>92</sup> GMHT crops have not resulted in a reduction in the overall weight of herbicides applied in the US (which is increasing), because the average number of applications does not differ greatly from conventional cropping (Benbrook, 2012; Brookes & Barfoot, 2012; Kleter et al, 2007).

<sup>93</sup> NB Pesticide use data is only gathered systematically in the US, and only once or twice a decade and for a subset of crops. Different authors report different statistics of pesticide use on GM crops, either because of the use of different data or different assumptions in the analysis and modelling. In particular, conclusions about whether GM crops use more or less pesticide than non-GM crops should be treated with caution, since for the US soya and cotton crops (where most pesticide is used) there is no longer a "typical" non-GM crop area for comparison, so comparisons are made either with a modelled counterfactual or to extrapolations of historical data.

<sup>94</sup> Before the introduction of GM Bt maize varieties in the US, no more than 10% of the maize crop typically received insecticide treatments targeted at stalk boring pests (Lepidoptera) and about 30-40% of the crop annually received treatments against corn rootworm (Coleoptera) (Brookes and Barfoot, 2013). Insecticide use against stalk/corn borers is often ineffective so many farmers did not control these pests unless infestation rates were very high.

corn borers is generally low and relatively ineffective, and most farmers in Europe either do not control this pest or use biological and agronomic control methods (Meissle et al, 2011).

In China before the advent of GM Bt cotton, insecticide use had reached a completely unsustainable crisis point of over 20 applications of broad-spectrum (highly toxic) insecticides per crop (Huang et al, 2003). Insecticide use has almost halved, although cotton farmers still seem to be over-using insecticide on GM Bt cotton (Liu and Huang, 2013; Pemsal et al, 2005; Yang et al, 2005a) - unless they have received some training in integrated pest management, in which case they apply significantly less (Pemsal et al, 2011; Yang et al, 2005b). The reduction in insecticide use means that some secondary pests have become more common, particularly mirids (Lu et al, 2010; Wang et al, 2009), but natural predators have also become more common (Lu et al, 2012).

Any reductions in pesticide use can generally be associated with benefits for biodiversity in farmland and aquatic habitats, but impacts have not been quantified. As the use of pesticides is changing rapidly in Europe, GM cropping systems need to be compared to current best practices to demonstrate which has greater impacts (see Chapter 5 for discussion of pesticide use in Europe).

**Evidence: (d) risks associated with indirect evidence: GM cropping is associated with indirect land use change but the biodiversity implications are disputed**

Changes in crop management practices can be associated with **indirect land use change** because the GM crop facilitates expansion into new areas. This can have positive or negative effects on biodiversity depending on the relative benefits of the new cropping system and what it replaces. There is strong disagreement about whether the technology has improved environmental sustainability in South America through the use of no-tillage systems on wind-erosion prone soils (Cerqueira et al, 2011; Christoffoleti et al, 2008) or whether it has driven the negative biodiversity impacts associated with soy expansion (Arima et al, 2012; Pengue, 2005; Zak et al, 2008). Others argue that because GMHT crops are associated with double-cropping and increased yields, they have substantially increased productivity and so prevented land use change (Brookes et al, 2010).

**Risks associated with interactions of the GM plant with target organisms, principally the evolution of resistance in target organisms.**

GM crops designed to improve the management of pests, weeds or diseases, are, like other pest management strategies, associated with the potential risk of resistance evolution<sup>95</sup> in the target pest. The potential biodiversity impacts of resistance evolution are associated with **increased pesticide use and toxicity** to control the resistant pests. Other consequences of resistance evolution include economic and social impacts on farmers who suffer from crop losses and the extra costs and efforts to control the resistant pests.

**Evidence: (b) risks or benefits that are likely to occur but that have not been associated with a clear negative effect on a biodiversity assessment endpoint: Risk management specifications for GM insect-resistant crops are mandatory but not for herbicide-tolerant crops**

Most authorisations of insect-resistant GM crops in the US, Canada and Europe recognise resistance evolution as a significant risk for both agronomic and environmental reasons. As a result, rigorous resistance management measures and monitoring have been required for insect-resistant GM crops

<sup>95</sup> Resistance evolution is the evolution of resistance to the GM trait in the target pests, eg resistance to Bt in Fall Armyworm *Spodoptera frugiperda*.

(particularly Bt maize and Bt cotton) since the first approvals, and are considered to have played an important role in delaying resistance evolution (Huang et al, 2011). However, resistance has developed rapidly in South Africa where the measures were not implemented thoroughly (Kruger et al, 2011a; Van Rensburg, 2007). As a result, South African farmers are increasing their insecticide use on GM maize (Kruger et al, 2011b).

In contrast, the evolution of herbicide-resistant weeds is now posing an increasingly serious agronomic and environmental problem for GM herbicide-resistant crops in the US, Argentina, Paraguay and Brazil (Cerdeira et al, 2011; Duke & Powles, 2008; Mortensen et al, 2012; Owen, 2011; Powles, 2008). The consequences for biodiversity derive from the increased use of herbicides to control resistant weeds that are more toxic and/or more persistent in the environment than glyphosate, such as 2,4-D or dicamba, and/or increases in glyphosate applications (Binimelis et al, 2009; Brookes & Barfoot, 2012; Cerdeira et al, 2011).

### **Possible risks associated with resistance in the new generation of GM traits and crops**

Resistance risks are also posed by virus-resistant and fungal and bacterial disease-resistant GM crops, as viruses and bacteria are notoriously good at obtaining resistance through the acquisition of genetic material. There is still a lack of sufficient knowledge of the breadth and durability of GM virus-resistance under field conditions to be able to predict its stability and necessary risk management measures (Tepfer, 2002; Thompson and Tepfer, 2010).

### **Risks associated with persistence and invasiveness including plant-to-plant gene flow.**

The potential risks to biodiversity associated with GM gene flow are:

- 1) The increased abundance of feral, hybrid or wild GM plants with **increased weediness and invasiveness**, with 1) possible biodiversity consequences in the environments they invade, 2) possible increased pesticide use to control them with associated negative impacts, and 3) in the worst case, displacement of wild species through competition.
- 2) **reduced genetic diversity in wild plant populations**, especially wild crop relatives, due to genetic assimilation of the GM gene and loss of wild genes. In the worst case, if the hybridisation is associated with reduced fitness, the populations might shrink, endangering the wild species (“demographic swamping”). For some, the **presence of the GM gene** in wild species is seen as harmful in itself, without evidence of impacts on genetic diversity or fitness. It is also possible that overall genetic diversity is increased because of the introduction of crop genes into wild populations (Bartsch et al, 1999), yet the **change in the wild population** is still considered to be harmful, for example because of its value as a crop breeding resource (Fénart et al, 2008; Stevanato et al, 2013).
- 3) presence of the GM gene in crop land races or local crop varieties, which can be regarded as a risk to **crop genetic diversity** (as well as being a commercial risk for non-GM growers, particularly certified organic growers).

It is widely recognised that gene flow between most crops and their wild relatives can and will occur if the crop is grown close to related weedy or wild populations (Ellstrand, 2003; Snow et al, 2005), eg oilseed rape, beets and wheat in Europe (Arnaud et al, 2003; Arrigo et al, 2011; Darmency et al, 2009; Fénart et al, 2007). Feral and crop-wild hybrid populations with the GM gene might displace wild species in non-crop habitats through greater persistence in the soil (see Box A6-4) and greater fitness, eg if they are resistant to common diseases or pests (Warwick et al, 2009). Crop-wild hybrids are usually expected to have a lower fitness than wild plants or the crop (Halfhill et al, 2005), but this is often not the case (Snow et al, 2010), or only in the first generation, and the GM trait may tip the



balance towards increased fitness of second and later generations. It has been shown that a GMHT gene persists in crop-wild hybrids despite the absence of herbicide selection pressure and in spite of fitness costs associated with hybridization (Warwick et al, 2008).

#### **Box A6-4 Persistence and fertility of GM plants: seed dormancy and seed production**

**How can GM crops persist?** Plants with the GM gene will persist if they 1) remain as seeds in the field, field margins and other habitats, and grow as volunteers in subsequent crops and/or develop feral populations, and/or if they 2) hybridise with wild relatives and persist in hybrid populations in crop habitats and/or other habitats. Crop management techniques can reduce the frequency of volunteers (Thole and Dietz-Pfeilstetter, 2012), but even if all plants are removed, some will persist from dormant seed (D'Hertefeldt et al, 2008; Lutman et al, 2005; Pekrun et al, 2005). Seed dormancy and a long-lived seed bank can greatly increase population growth rates and persistence times (Claessen et al, 2005a; Claessen et al, 2005b). It is therefore important to check the ability of GM seeds to persist in the soil and remain dormant despite suitable germination conditions<sup>96</sup>. Equally importantly, if the GM crop can produce and release more seeds than the non-GM crop, it may be much more persistent.

**What is the risk to biodiversity of GM seed persistence in the soil?** If GM seeds can persist in the soil over a number of years, they can germinate and spread, carrying the GM trait into subsequent crops and non-crop habitats, and making it more likely that the GM plant will hybridise with wild relatives. Volunteers and feral populations form a 'genetic bridge' to crop-wild hybrids (Reagon and Snow, 2006), and long-lived seed banks can contribute to maintaining crop genes in wild populations (Arnaud et al, 2009), where their traits might have unwanted effects on the wild plants and/or on associated non-target organisms such as pollinators.

**How much persistence do crops have?** Most crops are bred to germinate as soon as they are sown, and some crops show very little dormancy or fertility under European conditions, for example maize. However, some crops have retained dormancy characteristics from their wild relatives, such as oilseed rape, or have been deliberately bred for dormancy, such as potato tubers<sup>97</sup>. Most crops create volunteer and feral populations, and crop volunteers are some of today's commonest arable weeds. Oilseed rape, wheat, and potatoes leave behind as many or more seeds/tubers in the soil than recommended sowing densities, because of the way they are harvested (Warwick et al, 2009) and/or because they have shattering seed pods and small seeds (Dexter et al, 2011; Gulden et al, 2003a).

**What affects seed dormancy?** Seed dormancy is influenced by four factors: 1) genetic characteristics that can be stronger or weaker in different varieties, 2) the influence of environmental factors on seed development on the plant, 3) how quickly the seed is buried in the soil, and 4) the effect of environmental factors on the seed in the soil (Finch-Savage and Leubner-Metzger, 2006). Seeds such as oilseed rape can change their dormancy whilst they develop on the crop or when they are in the

<sup>96</sup> Primary dormancy is an innate characteristic of a seed that stops it germinating during a specified period of time, even if the environmental conditions are favourable for germination. Most cultivated seeds have been bred to lose primary dormancy (except to prevent premature germination before harvesting), so that they germinate without delay after sowing. However, seeds can acquire secondary dormancy as a result of environmental triggers, eg if rape seeds in the soil are exposed to drought stress in the absence of light they acquire secondary dormancy. This means that the seed bank shows discontinuous germination, ie some seeds will germinate more quickly whilst others persist to germinate after many years. This enables the plant meta-population to persist through regular colonisation and regeneration.

<sup>97</sup> Cereal crops have different specific dormancy characteristics that are crucial to seed quality: eg wheat should not sprout before harvest, but barley must continue ripening after harvest in order to be ready for the malting process.

soil, and this can enhance their persistence (Fei et al, 2007; Gulden et al, 2003b; Momoh et al, 2002). Oilseed rape varieties can be selected for low dormancy (Schatzki et al, 2013), but this will generally only reduce the possibility of dormancy to a certain extent (Gulden et al, 2004). In contrast, wheat seeds do not generally develop increased dormancy (Nielson et al, 2009; Willenborg and Van Acker, 2008) (although relatively little is known about the long-term persistence of wheat volunteers).

**Are GM seeds more persistent in the soil than non-GM seeds?** GM modification can cause unexpected alterations in seed characteristics (Shewmaker et al, 2002), but it is expected that most of these will be detected during the environmental risk assessment process. Generally, GM crops can be expected to have similar seed persistence as the non-GM parent crop, unless a cultivar specially bred for lower persistence was used for the GM transformation. GMHT oilseed rape cultivar seeds show no differences in persistence compared to conventional or conventionally herbicide-resistant varieties (Lutman et al, 2005); however feral oilseed rape populations are already known to persist over many years, even decades, and persistence varies greatly between different varieties (Beckie and Warwick, 2010; Lutman et al, 2003a; Pascher et al, 2010). GM stress-tolerant crops may be able to germinate in a wider range of conditions than their non-GM crop parents, increasing the likelihood of populations spreading into new habitats (Warwick et al, 2009).

**Evidence:** (b) risks or benefits that are likely to occur but that have not been associated with a clear negative effect on a biodiversity assessment endpoint: **Gene flow occurs but it is often difficult to clarify or achieve consensus on the actual harm to biodiversity**

So far, gene flow and its consequences have not been actively managed in GM growing countries (other than by the exclusion of certain areas<sup>98</sup>), and GM volunteers, ferals and crop-wild hybrids have not been classed officially as serious environmental problems. Only a few different GM traits and crops are currently widely grown, and one of the principal crops (ie soybean) is not currently (officially) grown near its wild relatives. The GMHT genes from oilseed rape are now relatively widespread in feral and weedy populations in Canada (Beckie & Warwick, 2010; Knispel and McLachlan, 2010), parts of the US (Munier et al, 2012; Schafer et al, 2011), and along transport routes in Japan and Switzerland (Nishizawa et al, 2009; Schoenenberger and D'Andrea, 2012). It is not clear whether the presence of the GMHT gene in feral oilseed rape and crop-wild hybrids is having any noticeable effect on biodiversity. The GM Bt gene is present in maize landraces in Mexico (Piñeyro-Nelson et al, 2008). Opinions differ as to whether this presence negatively affects the genetic diversity of maize (CEC, 2004; Wainwright and Mercer, 2009)<sup>99</sup>, though it can be regarded as compromising the genetic integrity of the landraces (Bellon and Berthaud, 2004; van Heerwaarden et al, 2012). GM Bt genes are present in wild cotton populations in Mexico (Wegier et al, 2011).

However, in one case GM gene flow has resulted in ecological consequences in natural habitats where glyphosate herbicide is an important tool for managing invasive plant species. A GM herbicide-

<sup>98</sup> GM cotton cultivation is prohibited in areas where wild cotton is found in the US (Hawaii, Florida and Caribbean islands), but not in Australia (North) or Brazil (Bahia). In Mexico, GM maize is currently restricted in the south. However, little monitoring of the status of these wild populations is currently carried out.

<sup>99</sup> (CEC, 2004) p 17 'Transgenes are unlikely to displace more than a tiny fraction of the native gene pool, if any, because maize is an outcrossing plant with very high rates of genetic recombination. Instead, transgenes would be added to the dynamic mix of genes that are already present in landraces, including conventional genes from modern cultivars. Thus, the introgression of a few individual transgenes is unlikely to have any major biological effect on genetic diversity in maize landraces.'

resistant variety of Creeping Bentgrass (*Agrostis stolonifera*) was field-tested in Oregon in the US in 2003 on around 162 ha. *Agrostis stolonifera* is a wind-pollinated perennial grass that is very common in lawns, fields, and in the wild across the US and Europe. The grass is considered invasive in wetland habitats in the northern US. Scientists monitored sites around the field trials, and a year later found GM glyphosate-resistant *Agrostis stolonifera* populations at 21 km and 14 km from the trials (Watrud et al, 2004). The field trials were stopped and attempts were made to eradicate the GM grasses, but high frequencies of GM HT grass have been found every year since in an increasingly wide area in Oregon, including river banks up to 3.8 km away that are treated with glyphosate herbicide (Reichman et al, 2006; Zapiola et al, 2007). The GM HT grass has now been shown to have hybridised in the wild with another grass species (*Polypogon monspeliensis*) (Zapiola and Mallory-Smith, 2012). There is concern that it is also hybridising with an invasive grass *Agrostis gigantea*, and that the hybrids will cause problems in protected habitats (Bollman et al, 2012).

It is widely accepted that if GMHT **oilseed rape** (*Brassica napus*) varieties were cultivated on a large scale in Europe, it is highly likely that feral oilseed rape populations and wild relatives will acquire the GM gene, and that the herbicide-resistance trait will persist in some wild populations (Colbach et al, 2005; Colbach, 2009; Devos et al, 2012; EFSA, 2013; Messean et al, 2009; Squire et al, 2011). Feral GMHT oilseed rape and crop-wild hybrids would have a selective advantage where glyphosate herbicide is used to control weeds in ruderal habitats (see Box A6-5), but it is not clear whether this alone would present any additional ecological risks (Collier and Mullins, 2013), and it is also not common for ruderal habitats in Europe to be managed with glyphosate (Cook et al, 2010).

The presence of herbicide resistance in wild populations<sup>100</sup> may not in the end have a very significant impact on biodiversity because invasive plants can always be controlled by other herbicides or mechanical means, and the GM HT trait in oilseed rape does not seem to confer any other fitness benefits or disadvantages (Simard et al, 2005). However, other GM traits in oilseed rape might have greater consequences if they were used on a wide scale in Europe. The GM Bt gene has been shown to increase the fitness of feral oilseed rape plants (Stewart Jr. et al, 1997), non-GM oilseed rape cultivars (Le et al, 2007), and crop relatives under attack by caterpillars in small-scale tests, and caterpillar herbivory has been shown to be a common limiting factor on wild *Brassica* populations (Damgaard & Kjaer, 2009; Vacher et al, 2004).

**Box A6-5 What are the consequences for biodiversity of gene flow from GM herbicide resistant oilseed rape in Europe?**

**What are the pathways of gene flow from GM oilseed rape?** Oilseed rape (*Brassica napus*) is mainly self-pollinated, but generally a proportion of the population is cross-pollinated by wind and insects, which can disperse oilseed rape pollen anywhere from 10m to 1 km from the crop (Cresswell and Hoyle, 2006; Devaux et al, 2005; Hüsken and Dietz-Pfeilstetter, 2007). Oilseed rape also produces plentiful volunteer plants in the following crop (Begg et al, 2006; Mauro and McLachlan, 2008; Simard et al, 2002). *Brassica napus* seeds can develop secondary dormancy (Momoh et al, 2002), so even though feral populations tend to disappear after a few years, the meta-population persists due to long-term seed banks and regular colonisation and regeneration (D'Hertefeldt et al, 2008; Lutman et al, 2003b; Pessel et al, 2001), as well as regular seed inputs from oilseed transport by road, rail and water. Oilseed rape also readily hybridises with a number of wild relatives that occur as weeds in agricultural areas (see Annex 6.2).

<sup>100</sup> Gene flow of herbicide resistance is equally likely from conventionally bred oilseed rape (Krato & Petersen, 2012)

**How likely is gene flow from GMHT oilseed rape in Europe?** In Europe, GMHT oilseed rape has been shown to have transferred the GM herbicide-resistance gene to feral populations even though it has only been grown for a few years in experimental field trials (D'Hertefeldt et al, 2008; Lutman et al, 2005). It is therefore widely accepted that if current GMHT oilseed rape varieties were cultivated on a large scale in Europe, it is highly likely that feral oilseed rape populations and wild relatives will acquire the GM gene, and that the herbicide-resistance trait will persist in some wild populations (Colbach et al, 2005; Colbach, 2009; Devos et al, 2012; EFSA, 2013; Messean et al, 2009; Squire et al, 2011). Feral oilseed rape populations are becoming widespread in Europe in regularly disturbed ruderal habitats including field margins, urban and industrial sites, roadsides, railways, and riverbanks, and they differ genetically from commercial varieties (Crawley and Brown, 1995; Pascher et al, 2010; Squire et al, 2011). Crop-wild hybrids are also likely to be relatively common (Crawley & Brown, 1995; Pascher et al, 2010; Squire et al, 2011). These habitats can be important refuges for threatened arable weeds and other pioneer species in Europe (Fried et al, 2009; Walker et al, 2007)<sup>101</sup>.

**What is the harm to biodiversity from GMHT gene flow?** Feral oilseed rape is not currently considered to be an invasive species, but where glyphosate herbicide is used to control weeds in these ruderal habitats, for example along railway lines (Schoenenberger & D'Andrea, 2012), as well as where glyphosate drift occurs, GMHT feral populations will have a selective advantage (Londo et al, 2010; Watrud et al, 2011), and could develop into a more persistent weed. It is not clear whether this alone would present any additional ecological risks eg (Collier & Mullins, 2013), and it is also not common for ruderal habitats to be managed with glyphosate (Cook et al, 2010). However, it may prove to be difficult to control these populations once established (EFSA, 2013), because oilseed rape benefits from disturbance that removes competitors (Knispel & McLachlan, 2010). The European Food Safety Authority considers that GMHT feral populations are likely to be small and mostly confined to port areas so long as GMHT oilseed rape is not grown in Europe, but does acknowledge that control of feral GMHT populations may require repeated cutting and/or herbicide applications, as well as measures to prevent seed spills (EFSA, 2013).

**Are gene flow risks unique to GMHT oilseed rape?** Herbicide-resistant oilseed rape varieties that have been bred using conventional breeding techniques are now available on the UK seed market<sup>102</sup>. They are resistant to a herbicide mix that contains metazachlor and imazamox active ingredients, considered to have higher environmental toxicity than glyphosate, particularly in water (UK Voluntary Initiative, 2013)<sup>103</sup>. In a field experiment, the herbicide-resistance gene was found to out-cross readily into neighbouring herbicide-susceptible oilseed rape plants, up to a distance of 45m, and the progeny also showed a cross-tolerance to another herbicide, triflurosulfuron-methyl (Krato and Petersen, 2012). It is therefore likely that these oilseed rape varieties will pose some of the same biodiversity risk questions as GMHT oilseed rape. However, because there are no regulatory mechanisms for the (mandatory) monitoring of IMI crops it is highly unlikely that any surveys will take place, and thus gene flow and persistence will go un-noticed.

<sup>101</sup> This is a key difference between European and North American agricultural biodiversity, because in North America most weed and ruderal species are introduced aliens. The US APHIS risk assessment of GM HR canola concluded "Since outcross species are only found in disturbed habitats, transfer of novel traits would not have an impact on unmanaged environments."

<sup>102</sup> The varieties are known as 'Clearfield' and include Clifton CL and DK Imagine marketed by Monsanto. <http://www.farmersguardian.com/home/arable/arable-news/clear-potential-for-improving-osr-weed-control/45237.article>

<sup>103</sup> <http://www.fwi.co.uk/articles/03/08/2010/122636/metazachlor-restrictions-add-a-new-osr-challenge.htm>

Gene flow is also likely from other GM oilseed rape varieties that might be grown in Europe in future, such as Bt canola, which has been shown to have the potential to increase the fitness of fitness of feral oilseed rape (Stewart Jr. et al, 1997) and of crop-wild hybrids under selection pressure (Damgaard and Kjaer, 2009; Vacher et al, 2004).

#### *Possible risks from gene flow of the new generation of GM traits and crops*

Gene flow from conventionally bred crops is already affecting crop wild relatives all over Europe (see Annex 8(b)), but the dominant, single locus pest resistance traits typical of GM crops are more easily transferred than the polygenic traits from most conventional breeding, and their potential impact is greater, because of the way the GM trait can more strongly and directly target a pest than can most conventional breeding technologies (Laughlin et al, 2009). Other than GMHT oilseed rape and GM Bt maize<sup>104</sup>, there are currently no GM crops subject to significant crop-wild gene flow<sup>105</sup> grown at the commercial scale, so there is a corresponding lack of scientific evidence of large-scale impacts on biodiversity.

Many grass and tree species are particularly likely to spread GM genes, as they produce large quantities of wind-spread pollen and cross-breed over large distances, and some can also spread vegetatively (Wang and Brummer, 2012). Avoiding gene flow risks to wild populations of these crops will require careful and rigorous research and management. The example of the establishment of a GMHT grass in the wild and its hybridisation with a wild grass species in the US (after just a few years of field trials) illustrates this (Reichman et al, 2006; Zapiola et al, 2007; Zapiola & Mallory-Smith, 2012). There is concern that it is hybridising with the invasive grass *Agrostis gigantean*, and that the hybrids will cause problems in protected habitats (Bollman et al, 2012).

The new generation of GM crops present a much wider range of potential environmental consequences of gene flow, including the impacts of abiotic stress tolerance and crops producing industrial chemicals. Stress-tolerance traits are likely to influence fitness. For example, it will be important to test the fitness of feral GM freeze-tolerant *Eucalyptus* trees, because these trees are hybrids with one parent species that is already listed as a potentially invasive species in the USA; in addition they are designed to be grown over a wider geographic range than the non-GM crop (Wolt, 2009). GM nitrogen use efficient oilseed rape showed greater seed yield than the non-GM cultivar in tests under a range of soil nitrogen levels (Strange et al, 2008), which could make the crop more likely to establish feral and crop-wild hybrid populations in non-crop habitats where nitrogen concentrations are typically much lower than in crop fields.

GM modification for stress tolerance traits involves changes to genes that regulate other genes, metabolic processes, or membrane structure, rather than producing a GM protein (Cominelli et al, 2012), increasing the difficulty of predicting fitness effects from the genetic structure or phenotype (Chan et al, 2012) – in contrast to the GM Bt protein-producing trait which does not seem to interfere with expression of other genes (Coll et al, 2010). Stress tolerance genes can interact (“cross-talk”), possibly increasing the tolerance of the plant to other stresses (Mittler and Blumwald, 2010). Because the environmental tolerance of the GM crop differs from its non-GM comparators, no direct comparisons are possible. The detection of GM genes within genetically diverse wild plants and crop

<sup>104</sup> GM Bt maize cultivation is now authorised in Mexico, and the biotech companies are waiting for approval of large-scale trials. See <http://www.reuters.com/article/2012/11/23/us-mexico-corn-idUSBRE8AM00O20121123>

<sup>105</sup> The two other principal GM crops – soybean and cotton – are not (officially) grown near their wild relatives

landraces requires more precise methods than for routine crop analysis, and is more prone to failure (Piñeyro-Nelson et al, 2008; Piñeyro-Nelson et al, 2009; Schoel and Fagan, 2009), so gene flow might not be detected until it is at an advanced stage.

#### Risks associated with **effects on biogeochemical processes**

This category includes risks associated with changes in biogeochemical processes such as soil functions, nitrogen cycling, carbon sequestration, and nitrous oxide or carbon dioxide emissions. Adverse effects should be assessed at the field scale and the wider environment. However, it is often very difficult to detect impacts of crop changes on ecological functions in the field, because of the influence of environmental factors (Hönemann et al, 2009; Londoño-R et al, 2013; Rauschen et al, 2010). A key question is whether GM crops have negative impacts on essential soil functions. If a GM crop releases altered chemicals and residues into the soil which can persist and interact with soil organisms, they might affect soil processes. For example, GM Bt maize varieties release quite large quantities of GM Bt toxin into the soil, and the Bt toxins from Bt maize varieties can persist in soil (see Box 6-2-4 for details).

***Evidence: (a) risks or benefits with a measureable impact on a biodiversity assessment endpoint: GM Bt crops have few direct impacts on natural biological control***

GM Bt crops have generally been found to have no significant effects on **natural biological control** agents (predators and parasitoids) in field surveys, but because GM insect-resistant crops are highly effective at reducing the numbers of their target prey, they have fewer parasitoids and predators that are specialised on the target pests (Farinós et al, 2008; Marvier et al, 2007; Poza et al, 2005; Romeis et al, 2006; Wolfenbarger et al, 2008). When both GM Bt and non-GM crop fields are treated with insecticides and compared, no differences in insect and invertebrate populations have been found (Eizaguirre et al, 2006; Wolfenbarger et al, 2008). All predators and larval parasitoids of caterpillars are likely to be exposed to the Bt protein to some extent through their prey (eg Harwood et al, 2005; Obrist et al, 2006a). As many Lepidoptera species are sublethally affected by Bt in some way, their specialist predators and parasitoids may be affected by the low quality of their sick prey (Meissle et al, 2005; Vojtech et al, 2005), as well as being less abundant in the GM crop field because of the lack of prey.

***Evidence: (a) risks or benefits with a measureable impact on a biodiversity assessment endpoint: GM Bt maize affects soil processes but not more than the differences found between crop types, tillage and pesticide use systems***

GM Bt maize has certain impacts on soil organisms, but no impacts on soil functions could be attributed to the GM Bt trait (although many differences between crop varieties have been found) (see Box A6-6). Based on the research so far GM varieties do not have greater negative effects on soil functions than the differences found between different crop types, tillage and pesticide use systems (Birch et al, 2007; Cortet et al, 2007; Griffiths et al, 2007; Icoz and Stotzky, 2008a).

**Box A6-6 Does GM Bt maize affect soil functions and soil biodiversity?**

**Does the Bt protein from GM Bt maize persist in soil?** GM crops can influence soil organisms and their functions through root exudates and through root residues and crop residues during and after the cropping period. Bt maize varieties release Bt protein(s) into soil from root exudates (Saxena et al, 2002; Saxena et al, 2004), and maize residues and their Bt content may remain in the soil for a few months to a year, depending on the environment and soil tillage practice. Different Bt proteins behave differently in soil: in lab tests, the Cry3Bb1 protein from root exudates breaks down over 14-21 days (Icoz and Stotzky, 2008b), whereas the Cry1Ab protein persists for up to 180 days (Saxena and Stotzky, 2001a). Long term studies have found no evidence for the persistence of Bt Cry3Bb1 protein in the soil into the next year (Gruber et al, 2012; Icoz et al, 2008), whereas Bt Cry1Ab persists in soil (Icoz et al, 2008; Zwahlen et al, 2003a). Analytical recovery of the Bt protein Cry1Ab is strongly linked to soil clay content – the more clay, the less of the protein can be recovered (Icoz & Stotzky, 2008a; Saxena et al, 2004).

**Does Bt maize affect soil organisms? Earthworms** are key species for crop residue degradation; they break down a large proportion of the biomass in most agricultural soils, enabling further degradation by other soil invertebrates and microbes. They are also key prey items for many animals, and their potential lifespan often exceeds several years. Earthworms (*Lumbricus terrestris*, *Aporrectodea caliginosa* and *Eisena fetida*) fed on Bt maize residues take up the Bt protein, break down some of it in the gut, and excrete some in their casts (varying with each species) (Ahmad et al, 2006; Emmerling et al, 2011; Schrader et al, 2008; Shu et al, 2011). *Lumbricus terrestris* is rarely found in high numbers in temperate agricultural soils, but *Aporrectodea caliginosa* often comprises a major proportion of the total earthworm biomass (Edwards et al, 2012). One study found weight loss of *L.terrestris* earthworms after 6.5 months of exposure (Zwahlen et al, 2003b), but field surveys of four *Aporrectodea* species and *L.terrestris* have not found any negative fitness effects over 4 years under Bt maize (Zeilinger et al, 2010). **Enchytraeid worms** (*Enchytraeus albidus*) were affected by the nutritional quality of different Bt maize cultivars but not consistently by the Bt trait compared to non-Bt cultivars (Hönemann and Nentwig, 2009). Other soil organisms involved in decomposition take up Bt protein in Bt maize fields, including predatory and seed eating **carabid beetles** (Zwahlen and Andow, 2005), **slugs** and **snails** and their faeces (Kramarz et al, 2009; Zurbrügg and Nentwig, 2009), **woodlice** and their faeces (Clark et al, 2006; Pont and Nentwig, 2005; Wandeler et al, 2002), but no consistent negative fitness effects have been found (Icoz & Stotzky, 2008a). A study found that a **nematode** species reacts to the Cry3Bb1 Bt protein by up-regulating defence genes, but because the concentration of the protein in Bt maize field soil is lower than in the experiment it is expected that it is essentially unaffected (Höss et al, 2011).

**Does Bt maize affect soil ecosystem functions?** Field experiments have not found any consistent effects of the Bt trait on **decomposition** of Bt maize (Zwahlen et al, 2007) - some varieties vary in their lignin content, which affects degradation (Saxena and Stotzky, 2001b), but differences fall within the range of common non-GM maize hybrids (Jung and Sheaffer, 2004; Poerschmann et al, 2008; Zurbrügg et al, 2010). **Microbial activity**, an indicator of soil decomposition and nutrient cycling, can vary significantly in response to a range of environmental pressures and cultivar characteristics, but no studies have linked consistent effects to the Bt trait (Icoz et al, 2008; Icoz & Stotzky, 2008a). Effects have been attributed to differences in the nutritional quality of different Bt maize cultivars (Clark et al, 2006; Escher et al, 2000). Other studies have judged that the negative effects of Bt maize on some micro-organisms at field scale were no greater than the differences found between crop types, tillage and pesticide use systems (Birch et al, 2007; Cortet et al, 2007; Griffiths et al, 2007).

### Risks associated with **interactions of the GM plant with non-target organisms.**

These risks are associated with the characteristics of GM traits, including the fact that the transgenic product is usually expressed in nearly all plant tissues throughout the life cycle of the plant, and that the transgene product is a novel toxic chemical in the plant and crop environment.

The principal biodiversity concerns are that:

- 1) impacts may affect specific **species of conservation concern and/or economic concern or cultural significance** in and around crops (eg butterflies and pollinators, honeybees, silkworms).
- 2) impacts on key species may **disrupt ecosystem functions and services** including biological control (predators and parasitoids) and soil functions (eg degradation, nutrient recycling), resulting in less overall benefit for biodiversity in the agro-ecosystem, and possibly increased agri-chemical use and other practices with known negative impacts (see below).
- 3) impacts on non-target herbivores might make them into **new pests or more damaging pests**, which may trigger the use of more environmentally damaging control methods including increased insecticide use, and might also have consequences for other neighbouring crops.

Non-target impacts could be triggered by a range of **exposure pathways**, including exposure to 1) the growing GM crop and its propagules and exudates eg pollen or root exudates or seed; 2) crop residues and seeds remaining on and in the soil after harvest, and 3) GM plant parts and/or transgenic product(s) that have moved away from the cultivation site. This can include aquatic organisms in streams draining off crop fields ingesting transgenic plant material or transgenic protein (Douville et al, 2007; Douville et al, 2009; Jensen et al, 2010; Tank et al, 2010); animals feeding on stored transgenic grain (Hubert et al, 2008); or pollen drift into field margins and neighbouring habitats (Ludy and Lang, 2006). Another important feature of non-target effects is that they can involve **knock-on food-web effects**, such as effects on predators and parasitoids that are exposed to the transgenic product through their prey or hosts that feed on the GM crop (known as tritrophic exposure), or more complicated linkages. If the prey or host are unaffected by the transgenic product themselves, they may expose their predators or parasitoids over a prolonged period of crop growth, and they may also concentrate the transgenic protein in their bodies to levels higher than those found in the plant tissues. Research on GM Bt crops has elucidated a wide range of exposure pathways by which many non-target organisms come into contact with the GM toxin (see Box A6-7).

#### **Box A6-7 Do the GM Bt insect toxins persist in the environment and in food chains?**

GM Bt proteins have been shown to **accumulate** in invertebrate food chains during the crop growing season, and some invertebrates are able to break down the protoxin into the active toxin form. Although there is little evidence for any consistent effects of the GM Bt trait on non-target organisms other than the target pests (ie either Lepidoptera or Coleoptera for different Bt proteins), this is a cause of continued uncertainty about possible negative effects. The evidence for Bt persistence in soil and soil food webs is described in Box 6-2-4.

GM Bt **exposure pathways** on maize have been examined. Red spider mites (*Tetranychus urticae*) rasp on GM Bt maize plant tissues and can concentrate Bt protein in their bodies, containing up to three times the levels in the leaf (Obrist et al, 2006a). Mites are a common minor pest of maize and other crops across Europe, and form a key component of the diet of many generalist predators. They pass on the protein undigested to their predators. Ladybirds (*Stethorus* sp.) and lacewings (*Chrysoperla*



*carnea*) have been shown to take up the protein in its potentially active form (Obrist et al, 2006b). Ladybirds (*Stethorus punctillum*) digest the protoxin into its active toxin form (Alvarez-Alfageme et al, 2008); inside predatory rove beetles (*Atheta coriaria*) the Bt protein was shown to decay over a period of 24h after exposure (García et al, 2010). No negative effects on fitness of mites or thrips or their predators have been found, and the Bt does not seem to affect the nutritional quality of the spider mite prey (García et al, 2010; Obrist et al, 2006c). Similar results have been found for thrips, common sucking pests on maize leaves. Thrips faeces, which are ubiquitous on infected plants, contain Bt (Obrist et al, 2005), as do slugs and their faeces (Zurbrügg & Nentwig, 2009).

In contrast, current GM Bt maize varieties contain only very low amounts of Bt in the phloem, therefore exclusively sucking insects such as aphids are not exposed to Bt, and neither are their predators and parasitoids (Lundgren and Wiedenmann, 2005; Raps et al, 2001; Romeis and Meissle, 2011). However, GM products can be present in the phloem in other GM crops (Lough and Lucas, 2006; Ramesh et al, 2004).

Streams and ditches running off Bt maize fields in the US are full of maize residues and detritus (Tank et al, 2010), potentially exposing aquatic organisms to low levels of the GM product (Carstens et al, 2012), though the Bt proteins break down quickly in the water once the residues have decomposed (Douville et al, 2005) and impacts on aquatic organisms seem to be mainly due to differences in the nutritional quality and structure of different maize varieties (Jensen et al, 2010).

**Evidence: (c) risks to biodiversity extrapolated from small-scale test results: GM Bt crops may have some effect on non-target Lepidoptera, but have not been found to have significant effects on bees or other non-target organisms**

GM Bt crops produce Bt proteins that target either caterpillar (Lepidoptera) pests<sup>106</sup> or beetle (Coleoptera: Chrysomelidae) pests<sup>107</sup>. Few toxic effects of the GM Bt traits have been found on species other than the target pests (in contrast to the evidence of non-target impacts of GM insect-resistant crops that use protease inhibitor genes) (see below). However, GM Bt maize pollen has been shown to have an adverse effect on the caterpillars of some butterfly and moth species (see Box A6-8). Most GM Bt maize varieties express the Cry toxins in their pollen, and large-scale cultivation of GM Bt maize in Europe could affect Lepidoptera that use maize weeds as larval host plants, because of the way Bt-containing maize pollen coats the weeds during the flowering period.

Numerous Lepidoptera species in Europe rely to some extent on agricultural weeds as larval food plants<sup>108</sup>, and this could affect valued species. Seven European butterfly species<sup>109</sup>, of which three are non-pest species, have been tested for the impact of consumption of Bt maize pollen, and all were found to be affected by Bt pollen (Lang and Otto, 2010). EFSA use a model to estimate the risk of Bt maize pollen for Lepidoptera, based on experimental data of acute mortality (LC50) for two species

<sup>106</sup> Cry1Ab, Cry1Ac, Cry1F, VIP3a

<sup>107</sup> Cry3Bb1

<sup>108</sup> Examples are: *Issoria lathonia* and *Argynnis adippe* on *Viola arvensis*; *Lythria purpuraria* on *Polygonum aviculare*; *Tyta luctuosa* on *Convolvulus arvensis* (Hilbeck et al, 2008).

<sup>109</sup> The tested European Lepidoptera are the main target pests of Bt maize *Ostrinia nubilalis* and *Sesamia nonagroides*, plus the secondary pests *Plutella xylostella*, *Pieris brassicae*, *Pieris rapae*, and *Agrotis segetum* (Felke et al, 2002; Felke and Langenbruch, 2005), and the non-pest species Common Swallowtail (*Papilio machaon* L.), Peacock (*Inachis io*), and Small Tortoiseshell (*Aglais urticae*).

(Felke et al, 2010; Felke & Langenbruch, 2005), and concludes that there is no evidence that any Lepidoptera species fall into the 'extremely sensitive' class that requires risk mitigation measures. The model has been criticised for ignoring the possible impact of sublethal effects, extrapolating data from one GM Bt event to a different one, and making assumptions about maize cultivation periods and butterfly generations across Europe which are subject to considerable uncertainty (Lang et al, 2011). It is difficult to generate the scientific evidence to clearly indicate a quantitative effect of Bt maize pollen on Lepidoptera populations, because of the need to account for all the other factors affecting Lepidoptera populations, many of which are currently in steep decline in Europe (van Swaay et al, 2006; van Swaay et al, 2010).

#### **Box A6-8 Non-target impacts on species of conservation concern: Bt maize pollen and butterflies**

**What is the problem with Bt maize pollen?** Most Bt maize varieties are known to be toxic to butterfly and moth (Lepidoptera) species, as they are designed to target certain Lepidoptera pests, and other non-target Lepidoptera pests are known to be sublethally affected to various degrees. Most Bt maize varieties express the Cry toxins in their pollen, and this can be consumed by the larvae of butterflies feeding on weeds in and around maize fields. Early risk assessments failed to address risks of Bt pollen<sup>110</sup> until Losey et al (Losey et al, 1999) published a laboratory experiment that showed higher mortality of the much-loved Monarch Butterfly (*Danaus plexippus* L.) in the US when exposed to Bt maize pollen on their host plant.

**What biodiversity is possibly at stake in Europe?** Numerous butterfly and moth species in Europe rely to some extent on agricultural weeds as larval food plants<sup>111</sup>. Some of these are considered to be of conservation concern, and may be legally protected. In addition, due to the relatively small-scale nature of European agriculture, maize pollen drift can reach neighbouring non-agricultural habitats and different cropping patterns and varieties mean pollen can be released anytime between June and October (Hofmann 2009 quoted in (Lang & Otto, 2010)). In Austria it has been estimated that 144 butterfly species (around 70% of Austria's total)<sup>112</sup> appear in agricultural landscapes and have larval phases that overlap with maize pollen drift to varying degrees, ranging from 8% to 100% overlap with pollen-shed period (Traxler et al 2005 quoted in (Lang & Otto, 2010)). A two-year field survey of maize fields in Germany found 33 species commonly using field margins (Lang, 2004), and a screening assessment identified 96 species of Macrolepidoptera in Germany that depend on agricultural habitats and overlap with maize pollen (Schmitz et al, 2003).

**What is the evidence?** Seven European butterfly species<sup>113</sup>, of which three are non-pest species, have been tested for the impact of consumption of Bt maize pollen and all were found to be affected by Bt pollen (Lang & Otto, 2010). Common Swallowtail (*Papilio machaon* L.) was tested with event 176 pollen containing Cry1Ab (Lang and Vojtech, 2006), Peacock (*Inachis io*) was tested with event 176 pollen containing Cry1Ab (Felke et al, 2010; Felke & Langenbruch, 2005), and Small Tortoiseshell (*Aglais urticae*) was tested with Bt maize events 176 and Bt11 expressing Cry1Ab (Darvas et al, 2004; Felke & Langenbruch, 2005) and MON89034 × MON88017 pollen containing Cry1A.105 and Cry2Ab2 (Schuppener et al, 2012). The *Inachis io* test found negative effects despite only exposing larvae to Bt

<sup>110</sup> <http://www.epa.gov/oppbppd1/biopesticides/pips/regofbtcrops.htm>

<sup>111</sup> For example *Issoria lathonia* and *Argynnis adippe* on *Viola arvensis*; *Lythria purpuraria* on *Polygonum aviculare*; *Tyta luctuosa* on *Convolvulus arvensis* (Hilbeck et al, 2008).

<sup>112</sup> 144 out of the total 215 Austrian butterfly species (Papilionoidea and Hesperioidea)

<sup>113</sup> The tested European Lepidoptera are the main target pests of Bt maize *Ostrinia nubilalis* and *Sesamia nonagroides*, plus the secondary pests *Plutella xylostella*, *Pieris brassicae*, *Pieris rapae*, and *Agrotis segetum* (Felke et al, 2002; Felke & Langenbruch, 2005), and the non-pest species Common Swallowtail (*Papilio machaon* L.), Peacock (*Inachis io*), and Small Tortoiseshell (*Aglais urticae*).

maize pollen for two days and measuring effects for only 7 days. No other European Lepidoptera species have been tested.

**What is the risk?** EFSA has been asked to assess the risk to European butterflies from Bt maize and has published Scientific Opinions on the Bt maize varieties MON810 and Bt11 (expressing Cry1Ab) and Bt maize 1507 (expressing Cry1F). EFSA use a model to estimate the risk to Lepidoptera according to five sensitivity classes<sup>114</sup>, which are calibrated using the experimental data on LC50 for two species<sup>115</sup> that have been tested on Bt maize event 176 (Felke et al, 2010; Felke & Langenbruch, 2005). EFSA concludes that risk mitigation measures (such as planting a 10m buffer strip of non-Bt maize) are only required where the most sensitive class of Lepidoptera occur at the same time as large-scale Bt maize cultivation and pollen production, but decides there is no evidence that any Lepidoptera species fall into this 'extremely sensitive' class.

**Is the risk adequately assessed?** The EFSA model has a number of weaknesses (Lang et al, 2011). Because of the lack of evidence, the model uses only acute mortality data (ie the dose that kills half the caterpillars after 48 hours feeding), and does not take account of any sublethal effects. However, these could equally have a serious effect on butterfly populations. The model extrapolates the data from event 176 to event MON810 and event 1507 based on estimates of relative toxicity and pollen concentrations. However, Bt Cry1Ab concentration in pollen varies greatly between different cultivars and plant individuals (Nguyen and Jehle, 2007). The model makes assumptions about maize cultivation periods and butterfly generations across Europe, which are subject to considerable uncertainty. A recent study predicts substantial overlap of Peacock larvae with maize pollen in Southern Europe, whilst in Northern Europe the larvae are not likely to be exposed (Holst et al, 2013).

**Would it be possible to discover an effect on butterflies from monitoring Bt maize cultivation?** An analysis of the possibilities for Bt maize-specific butterfly monitoring in Switzerland came to the conclusion that the monitoring will at best detect large effects on ubiquitous butterflies, only detecting changes exceeding 30% in species richness or abundance of the most abundant species, and causalities between changes in butterfly communities and the cultivation of Bt-maize will be difficult to determine due to the high variability of communities and the multitude of influencing environmental factors (Aviron et al, 2009). Butterfly and moth populations are declining across Europe, so it would be a challenge to separate out the Bt maize effect.

**Has Bt maize pollen affected the Monarch Butterfly in the US?** In the US, field experiments with Monarch Butterfly larvae (*Danaus plexippus*) found that continuous exposure to Bt-11 and MON810 maize pollen (both containing Cry1Ab) on host plants negatively affect survivorship and larval development time, as well as body weights of pupae and adults (Dively et al, 2004)<sup>116</sup>. Laboratory and cage tests showed that Monarch butterfly larvae are negatively affected by feeding on Bt (Bt-11) maize anthers containing Cry1Ab (Anderson et al, 2004); and larvae took longer to develop and the pupae weighed less when fed on leaves or host plants dusted with a mixture of Bt anthers and pollen (compared to non-Bt) (Anderson et al, 2005), as a result of food avoidance behaviour (Prasifka et al, 2007). A field experiment also found a negative effect of Bt maize (event 176) pollen containing Cry1Ab on Black Swallowtail larvae (*Papilio polyxenes*) (Zangerl et al, 2001)<sup>117</sup>. The Bt maize event 176

<sup>114</sup> 'below-average', 'above-average', 'highly sensitive', 'very highly sensitive' and 'extremely sensitive'

<sup>115</sup> The Peacock (*Inachis io*) and Diamondback Moth (*Plutella xylostella*) are close to the measure for 'highly sensitive' to Cry1Ab (Perry et al, 2010)

<sup>116</sup> an effect which had not been observed from only 4-5 days of field exposure (Stanley-Horn et al, 2001)

<sup>117</sup> In contrast, Jesse & Obrycki (Jesse and Obrycki, 2002) found no effect of Bt maize pollen from either Bt 11 or event 176 on Milkweed Tiger Moth larvae (*Euchatias egle*).

expresses high concentrations of the Cry1Ab toxin in pollen, and it was withdrawn from the US market by the developers Syngenta in 2002<sup>118</sup> (Oberhauser and Rivers, 2003).

Dively et al. (2004) used the negative fitness effects from the Monarch Butterfly experiments (but not the behavioural effect) to calculate that across the whole US Corn Belt, 2.4% of the population might suffer adverse effects as a result of exposure to Bt maize pollen (mainly to the MON810 variety). They assumed that half of the breeding population was found in the Corn Belt, so the overall risk to the species would be half this. Since then, Monarch Butterfly populations in the US Corn Belt have been shown to be substantially reduced because of the loss of their food plant populations to the use of herbicide-resistant GM maize and soya (Pleasant & Oberhauser, 2013). Because Monarch butterfly populations are also being negatively affected by a range of other simultaneous pressures, it is unlikely that any possible negative effects of Bt maize over the last decade would have been detected.

Small-scale tests with GM Bt crops have not found effects on honey **bees** (Duan et al, 2008; Hendriksma et al, 2012; Huang et al, 2004; Ramirez-Romero et al, 2005; Rose et al, 2007) or bumblebees (Babendreier et al, 2008). The effects of GM Bt maize residues on four **aquatic species** was attributed to differences in the nutritional quality and structure of maize varieties (Jensen et al, 2010).

***Evidence: (c) risks to biodiversity extrapolated from small-scale test results: There is evidence from small-scale tests of non-target impacts of protease inhibitor genes***

In comparison to Bt, GM insect-resistant crops that use **protease inhibitor** genes demonstrate clear non-target impacts on aphids and their parasitoids, bees, and a carabid beetle in small-scale tests (Azzouz et al, 2005; Babendreier et al, 2008; Ferry et al, 2005; Hogervorst et al, 2009; Lövei et al, 2009; Schlüter et al, 2010). These genes have only been commercialised in China as a component of GM insect-resistant Bt cotton, but they are being considered as additions to prolong the usefulness of other Bt crops in the face of pest resistance (Schlüter et al, 2010).

***Evidence: (b) risks or benefits that are likely to occur but that have not been associated with a clear negative effect on a biodiversity assessment endpoint: Secondary pest problems occur on GM Bt crops, but the biodiversity consequences are not clear***

GM Bt crops influence **secondary pests** in various ways, but this will only have consequences for biodiversity if it changes management, for example by increasing insecticide use. For example, some GM Bt maize varieties are more attractive to aphids than the non-GM crop comparison (Faria et al, 2007; Pons et al, 2005), which could have an impact on viral disease infection rates, triggering higher insecticide use (eg seed treatments). The Western Bean Cutworm (*Striacosta albicosta*) is spreading in the US Corn Belt and causing increasing problems on GM Bt maize, as the GM Bt does not control it effectively (Eichenseer et al, 2008). This could be because of the release of the pest from competition with *Helicoverpa zea*, a pest killed by Bt maize (Dorhout and Rice, 2010), but some dispute that this is the main reason for the pest's expansion (Hutchison et al, 2011).

<sup>118</sup> USDA APHIS withdrew the US authorisation for Bt event 176 maize in 2004. In Europe, Bt 176 maize was cultivated in Spain from 1998 until EU authorisation was withdrawn in 2007.

**Possible non-target risks of the new generation of GM crops**

The Bt proteins are relatively large and easily detectable for the measurement of exposure and impacts, but assessing the non-target impacts of future GM crops that do not produce a GM protein is much less clear-cut. The assessment may need to rely on testing impacts on key ecological functions (see above). However, it is often very difficult to detect impacts of crop changes on ecological functions in the field, because of the influence of environmental factors (Hönemann et al, 2009; Londoño-R et al, 2013; Rauschen et al, 2010).

Risks associated with **plant to micro-organism gene transfer**, ie the horizontal transfer of the transgene from the plant into bacteria or viruses or other micro-organisms.

Bacteria are known to frequently acquire and transfer genetic material (DNA or RNA) from other bacteria (known as horizontal transfer). It has also been demonstrated that bacteria can pick up genetic material from plants or from free DNA in the soil (Kay et al, 2002; Nielsen et al, 2000); therefore it is possible that bacteria could acquire transgenes from GM crop cultivation.

*Evidence: (d) risks demonstrated in experiments but very difficult to prove in field: **Horizontal gene transfer has been demonstrated in experiments but is very difficult to detect in the field***

Horizontal gene transfer from GM crops to micro-organisms and consequences for biodiversity have not been conclusively demonstrated in the field (Keese, 2008), but studies have shown the ubiquitous distribution of genetically modified DNA in the soil and water environment and soil and water food webs where GM crops are grown (Douville et al, 2007; Douville et al, 2009; Hart et al, 2009; Nielsen et al, 2007). Current scientific understanding tends to conclude that horizontal transfer from GM crops to bacteria is extremely rare and unlikely to have any adverse environmental consequences, but also recognises the lack of knowledge about genetically modified plant DNA in the environment (EFSA, 2010; Gulden et al, 2005; Keese, 2008; Vries and Wackernagel, 2005), and the technical difficulties to detecting horizontal gene transfer under field conditions (Gebhard and Smalla, 1999). One issue is that bacteria already carry a wide diversity of genetic material conferring resistance to antibiotics (Berg et al, 2005), pesticides, and other agricultural chemicals, and some GM crops carry GM genes derived from common bacteria or virus genes, implying that it is very difficult to separate out the additional impact created by horizontal transfer from GM crops. For example, a study of bacteria in the guts of bees visiting a GM crop found high levels of naturally acquired herbicide-resistance and could not detect any GM DNA transfer (Mohr and Tebbe, 2007).

**Risks associated with effects on human and animal health**

The impacts of GM crops on human and domestic animal health generally only have very indirect consequences for biodiversity, so are not discussed here. GM Bt maize for example can have benefits for health by reducing the levels of mycotoxins in maize grain (Bakan et al, 2002; Bowers et al, 2013; Wu, 2006). GM crops can have indirect effects on wild animal health through the types of non-target impacts and changes in crop management discussed above, for example avoidance of the negative impacts of pesticides on amphibians.

## ANNEX TO CHAPTER 6(b) REFERENCES

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## ANNEX TO CHAPTER 8(a) CROP GENETIC RESOURCES NATIVE TO EUROPE AND THE MIDDLE EAST AND THEIR CROP WILD RELATIVES

Underwood, Evelyn

Table A8-1 describes the status of the crop wild relatives of the principal economically important domesticated food crops that are native to Europe and the Middle East. For each crop it lists the number of crop wild relatives (CWR) native to Europe, some examples of CWR and their conservation status, and the evidence for gene flow between crop and CWR in Europe. It does not include nuts and berries that are only partially domesticated (eg walnut, bilberry), or forage crops such as grasses and legumes.

**Crop Wild Relatives (CWR) native to Europe:** No. of crop wild relatives native to Europe, % **threatened:** proportion of species with an IUCN threat status in Europe (EX, CR, EN, VU, NT) (IUCN, 2012), examples of species and their conservation status according to IUCN (2012). **European conservation status:** EX extinct, CR critically endangered, EN endangered, VU vulnerable, NT near threatened, DD data deficient, LC least concern (IUCN, 2012).

**Main threats:** from IUCN Red List of Threatened Species (Europe) <http://www.iucnredlist.org/initiatives/europe>

**Evidence for crop-CWR gene flow:** evidence for crop-CWR gene flow and hybridisation in Europe (see references listed for details).

Crop species/genus	Common names of crops	CWR native to Europe: no. of species, % threatened, examples and European conservation status	Main threats to CWR	Evidence for gene flow between crop and CWR	References
<i>Triticum aestivum</i> ssp. <i>aestivum</i> <i>Triticum turgidum</i> ssp. <i>durum</i> <i>T. spelta</i>	Bread wheat Durum wheat Spelt wheat	<b>No:</b> 33 CWR species <b>Status:</b> 12.1% of wheat CWR are threatened. Examples (see also barley below): <i>Triticum monococcum</i> ssp. <i>aegilopoides</i> (wild einkorn) <i>Aegilops cylindrica</i> , <i>Ae. geniculata</i> , <i>Ae. neglecta</i> , <i>Ae. triuncialis</i> , <i>Ae. ventricosa</i> , <i>Ae. tauschii</i> (EN), <i>Ae. bicornis</i> (VU) <i>Agropyron cimmericum</i> (EN), <i>A. dasyanthum</i> (EN) <i>Elymus caninus</i>	Severe fragmentation of populations; Coastal habitat destruction due to urbanisation/infrastructure development and tourism, silviculture;	<b>Gene flow:</b> Wild einkorn is hybridizing with cultivated wheat which is likely to be affecting the genetic diversity of wild populations. Spontaneous hybridization with wheat is reported for most of the tetraploid <i>Aegilops</i> species. Substantial gene flow between wheat and the most common <i>Aegilops</i> spp. occurs in the Mediterranean region ( <i>Ae. neglecta</i> , <i>Ae. triuncialis</i> , less with <i>Ae. geniculata</i> ).	(Zaharieva and Monneveux, 2006); (Loureiro et al, 2006); (Arrigo et al, 2011); (Parisod et al, 2013); (Guadagnuolo et al, 2001); (Weissmann et al, 2005);

		( <i>Triticum parvicoccum</i> is presumed extinct)		Hybrids have male sterility, but backcrossing allows introgression. Gene flow with <i>Ae.cylindrica</i> has been demonstrated in Spain. Wheat alleles in <i>Ae.triuncialis</i> and <i>Ae.peregrina</i> populations demonstrate long-term gene flow and introgression. Traces of wheat introgression in <i>Hordeum marinum</i> were found in the field.	
<i>Hordeum vulgare</i>	<b>Barley</b> Malt barleys Whisky barleys Forage barley Bere barley landraces	<b>No:</b> 7 CWR species <b>Status:</b> No barley CWR are threatened. Examples: <i>Hordeum vulgare</i> ssp. <i>agiocrithon</i> , <i>H.vulgare</i> ssp. <i>spontaneum</i> , <i>H.bulbosum</i> , <i>H.marinum</i> , <i>H.murinum</i> (5 ssp), <i>H.secalinum</i>	Population declines due to coastal habitat destruction & disturbance; lack of grazing	<b>Gene flow:</b> Barley crosses easily with wild <i>H.vulgare</i> to form fertile hybrids. It also hybridises with other <i>Hordeum</i> species, but typically produces highly sterile hybrids.	(Ellstrand, 2003) (and references therein); (Veteläinen et al, 2009)
<i>Secale cereale</i> x <i>Triticosecale</i> Wittmack	<b>Rye</b> Triticale Forage rye	<b>No:</b> 2 CWR species <b>Status:</b> No CWR are threatened. <i>Secale strictum</i> ssp. <i>balcanum</i> , <i>S.strictum</i> ssp. <i>strictum</i> <i>Secale sylvestre</i> NB wild rye is not considered native to Europe ( <i>Secale cereale</i> ssp. <i>ancestrale</i> , <i>S.cereale</i> ssp. <i>cereale</i> )	Overgrazing of grassland (potential threat)	<b>Gene flow:</b> Cultivated rye and the wild rye subspecies can freely hybridise. Rye is interfertile with <i>Secale strictum</i> ssp. and hybrid swarms are reported (based on morphological characteristics). (NB An aggressive weedy rye has evolved in the US, however there is no evidence of introgression of wild rye traits).	(Ellstrand, 2003) (and references therein); (Burger et al, 2007); (Burger et al, 2006)
<i>Avena sativa</i>  (also <i>Avena strigosa</i> Small Oat	<b>Oats</b> Husked oats Naked oats Forage oats	<b>No:</b> 13 CWR species <b>Status:</b> 15.4% of CWR are threatened Examples: <i>Avena insularis</i> (EN) <i>Avena sterilis</i> (5 ssp.) <i>Avena fatua</i> <i>Avena murphyi</i>	Fragmented and small populations; afforestation and air pollution; eutrophication	<b>Gene flow:</b> <i>Avena sterilis</i> and <i>Avena fatua</i> are widespread common noxious weeds of cereals including oats (esp. because of herbicide resistance) and hybridise easily with the crop (though gene flow through pollen in <i>Avena</i> is very limited).	(Cavan et al, 1998); (Ellstrand, 2003) (and references therein) (Julius Kühn-Institut, 2011)

or Lopsided Oat)			and loss of grassland		
<i>Vicia faba</i> ssp. <i>faba</i> var. <i>major</i> ; <i>V.f.ssp.faba</i> var <i>minor</i>	<b>Broad bean,</b> Fava bean Field bean (forage)	<b>No:</b> 21 CWR species <b>Status:</b> 14.3% of CWR are threatened Examples: <i>Vicia narbonensis</i> , <i>Vicia sativa</i> <i>Vicia barbatizae</i> (NT), <i>Vicia capreolata</i> (EN), <i>Vicia costae</i> (CR)	Fragmented populations; Climate change & fires; habitat loss to urbanisation; alien species	<b>Gene flow:</b> <i>Vicia narbonensis</i> has never successfully been crossed with broad beans, and crosses with other <i>Vicia</i> are very rare.	(Maxted and Kell, 2009)(and references therein); (Veteläinen et al, 2009)
<i>Pisum sativum</i> ssp. <i>sativum</i> (var <i>sativum</i> and var <i>arvense</i> )	<b>Peas</b> Garden peas, split (field) peas, snow peas, sugar/snap peas, mangetout	<b>No:</b> 2 CWR species <b>Status:</b> 1 CWR threatened <i>Pisum sativum</i> ssp. <i>sativum</i> , <i>P. s. ssp. elatius</i> <i>P.fulvum</i> ssp <i>amphicarpum</i> (NT)	Overgrazing, fires & climate change	<b>Gene flow:</b> Cultivated and wild <i>P.sativum</i> varieties are fully cross-fertile. Crosses between <i>P.sativum</i> and <i>P.fulvum</i> are possible, particularly if <i>P sativum</i> is the female parent.	(Jing et al, 2012); (Maxted & Kell, 2009)(and references therein)
<i>Beta vulgaris</i> ssp. <i>vulgaris</i>	<b>Beets:</b> Sugarbeet Beetroot, Chard Fodder beet	<b>No:</b> 10 CWR species <b>Status:</b> 50% of CWR are threatened Examples: <i>Beta vulgaris</i> ssp. <i>maritima</i> <i>Beta patula</i> (CR) <i>Beta nana</i> (VU) <i>Patellifolia webbiana</i> (CR)	Fragmented populations; coastal tourism & decline of traditional salt pan management; lack of grazing & climate change	<b>Gene flow:</b> <i>Beta vulgaris</i> x <i>B.maritima</i> hybrids are troublesome weeds of sugarbeet and also occur as ruderals. Gene flow is primarily due to seed escape but long-distance pollen flow is possible, and weedy beets act as bridges.	(Arnaud et al, 2003; Arnaud et al, 2009; Bartsch et al, 1999; Fénart et al, 2008; Viard et al, 2004)
<i>Brassica napus</i>	<b>Oilseed rape</b> Forage rape or kale Swede	<b>No:</b> 137 CWR species (same as below) <b>Status:</b> 18.2% of CWR are threatened (also applies to cabbage and radish) Examples (see also below):	Many of the species in the <i>Brassica</i> complex are common	<b>Gene flow:</b> <i>B. napus</i> readily hybridises with <i>B.rapa</i> and oilseed rape growing regions in Europe contain hybrid populations as arable weeds. <i>B.napus</i>	(Allainguillaume et al, 2006; Darmency et al, 1998; Darmency

		<p><i>Brassica rapa</i> (syn.<i>campestris</i>), <i>B. juncea</i>, <i>B. incana</i>, <i>B.nigra</i>  <i>Brassica glabrescens</i> (VU), <i>Brassica hilarionis</i> (EN)  <i>Armoracia</i> ssp., <i>Barbarea</i> ssp, <i>Camelina</i> ssp, <i>Crambe</i> ssp., <i>Diplotaxis</i> ssp., <i>Eruca</i> ssp., <i>Isatis</i> ssp., <i>Lepidium</i> ssp., <i>Raphanus</i> ssp., <i>Rorippa</i> ssp., <i>Sinapidendron</i> ssp., <i>Sinapis</i> ssp.</p>	<p>weeds of crops, especially <i>B.rapa</i>.  Rare CWR are threatened by river regulation; overgrazing or abandonment; tourism developments in coastal habitats</p>	<p>also hybridises with <i>B.juncea</i>, <i>Hirschfeldia incana</i>, <i>Raphanistrum raphanistrum</i>, and <i>Brassica oleracea</i>.  Hybrids are also possible with <i>Sinapis arvensis</i> but likely to be very rare, as are hybrids with <i>Erucastrum gallicum</i> and <i>Diplotaxis tenuifolia</i>; hybridisation with <i>Brassica nigra</i>, <i>Brassica carinata</i>, <i>Raphanus sativus</i> and <i>Sinapis alba</i> is poorly researched. Gene flow pathways in the <i>Brassica</i> group are complex and not fully understood.</p>	<p>and Fleury, 2000; Davenport et al, 2000; Devos et al, 2009; Elling et al, 2010; FitzJohn et al, 2007; Ford et al, 2006; Guéritaine et al, 2003; Hansen et al, 2001; Luijten and de Jong, 2011; Moyes et al, 2002; Pallett et al, 2006; Rieger et al, 2001; Warwick et al, 2003)</p>
<i>Brassica rapa</i> ssp <i>rapa</i>	<b>Turnip</b> Oilseed rape	<p>Examples (see also above):  <i>Brassica rapa</i> ssp.<i>campestris</i>, <i>Brassica juncea</i>, <i>B.incana</i>, <i>B.nigra</i></p>	See above	<p><b>Gene flow:</b> Wild <i>B.rapa</i> is a noxious weed. <i>B. napus</i> readily hybridises with <i>B.rapa</i> and oilseed rape growing regions in Europe contain hybrid populations as arable weeds.</p>	<p>(Andersen et al, 2009);  See above for <i>B.napus</i> x <i>B.rapa</i> refs  <a href="http://www.hear.org/gcw/species/brassica_rapa/">http://www.hear.org/gcw/species/brassica_rapa/</a></p>
<i>Brassica oleracea</i>	<b>Cabbages,</b> Brussels sprouts, Kohlrabi, Cauliflower, Broccoli, Tree Cabbage Kale/Polish oilseed rape/	<p>Examples (see also above):  <i>Brassica oleracea</i> ssp <i>oleracea</i>, <i>B. oleracea</i> ssp. <i>bourgeaui</i>  <i>B. macrocarpa</i> (CR), <i>B. hilarionis</i> (EN), <i>B. glabrescens</i> (VU)  <i>Crambe maritima</i></p>	See above	<p><b>Gene flow:</b> Many wild <i>Brassica</i> species readily interbreed with cultivated cabbages if these are allowed to flower, as well as cultivated <i>Brassica napus</i>. <i>Brassica hilarionis</i> is potentially threatened by hybridisation with cultivated cabbage. Gene flow pathways in the <i>Brassica</i> group are complex and not fully</p>	<p><a href="http://www.herbmedit.org/bocconea/7-095.pdf">http://www.herbmedit.org/bocconea/7-095.pdf</a>  (IUCN, 2012);  (Ford et al, 2006);  (FitzJohn et al, 2007); (Veteläinen et al, 2009)</p>

	Summer turnip rape Chinese Cabbage/Pak - Choi/Tender green Turnip, Italian Turnip /Rapini, Turnip Broccoli			understood.	
<i>Raphanus sativus</i>	<b>Radish</b> (spring or summer radishes; winter radishes eg black radish, white radish)	Examples (see also above): <i>Raphanus raphanistrum</i> <i>Eruca vesicaria</i> (Garden Rocket and wild rocket ssp.)	See above	<b>Gene flow:</b> Where <i>R.sativus</i> and <i>R.raphanistrum</i> co-occur, spontaneous hybridization results in local hybrid swarms. (NB In California, <i>R.raphanistrum</i> has been swamped by gene flow from cultivated radish, so that only hybrids now exist). Gene flow pathways in the <i>Brassica</i> group are complex and not fully understood.	(Campbell and Snow, 2007; FitzJohn et al, 2007; Hegde et al, 2006; Snow et al, 2010)
<i>Lactuca sativa</i>	<b>Lettuce</b> Cos lettuce, stem lettuce, oilseed lettuce	<b>No:</b> 27 CWR species <b>Status:</b> 11.1% of CWR are threatened. Examples: <i>Lactuca watsoniana</i> (EN), <i>L.singularis</i> (VU), <i>L.tetrantha</i> (VU), <i>L.alpestris</i> (NT), <i>L.serriola</i> , <i>L.saligna</i> , <i>L.virosa</i> , <i>L.tatarica</i>	Overgrazing / abandonment; climate change; wildfires; road maintenance, trampling & collection;	<b>Gene flow:</b> <i>Lactuca</i> species readily hybridise. Hybrids between <i>L.sativa</i> and <i>L.serriola</i> are common in Northern Europe.	(D'Andrea et al, 2008; Uwimana et al, 2012) (Treuren et al, 2012) <a href="http://documents.plant.wur.nl/cgn/pgr/ildb/con_spec.asp">http://documents.plant.wur.nl/cgn/pgr/ildb/con_spec.asp</a>
<i>Daucus</i>	<b>Carrot</b>	<b>No:</b> 12 CWR species	Some species are	<b>Gene flow:</b> Evidence that crop carrot	(Magnussen and

<i>carota</i>		<b>Status:</b> No CWR is threatened. Examples: <i>Daucus carota</i> (wild) (13 ssp)	data deficient as threats are unknown	genes have introgressed into the wild species around crop fields. (NB wild carrot shows high outcrossing rates and long-distance pollen dispersal).	Hauser, 2007; Rong et al, 2010)
<i>Allium cepa</i> <i>A.ampeloprasum</i> <i>A.sativum</i> <i>A.schoenoprasum</i> <i>A. oschaninii</i>	<b>Onions,</b> shallot Leeks, elephant garlic, Egyptian leek Garlic Chives French shallots	<b>No:</b> 115 CWR species <b>Status:</b> 5.2% of CWR threatened. Examples: <i>Allium corsicum</i> (CR) <i>Allium schoenoprasum</i> subsp <i>sibericum</i> <i>Allium oleraceum</i>	Many species are data deficient as threats are unknown; recreational activities in natural habitats	<b>Gene flow:</b> Cultivated <i>Allium</i> species and wild species have hybridised in greenhouse experiments, but there is no evidence of crop-wild gene flow in the wild, although many wild <i>Allium</i> species hybridise freely. Usually vegetatively propagated and harvested before flowering, reducing likelihood of gene transfer through pollen.	(Veteläinen et al, 2009) (Kik, 2002)
<i>Asparagus officinalis</i>	<b>Asparagus</b>	<b>No:</b> 19 CWR species <b>Status:</b> 26.3% of CWR are threatened Examples: <i>Asparagus officinalis</i> ssp. <i>officinalis</i> , <i>A.o. ssp.prostratus</i>	Fragmentation due to road building & urbanisation; overgrazing; invasive alien species; forest fires	<b>Gene flow:</b> Phylogenetic study suggests the tetraploid asparagus landrace “Morado de Huetor”, cultivated in Spain and Italy, is a hybrid of cultivated and wild species, <i>A. officinalis</i> and <i>A. maritimus</i> .	(Moreno et al, 2008) (Riccardi et al, 2011) (Treuren et al, 2012) <a href="http://documents.plant.wur.nl/cgn/pgr/minorlv/con_spec.asp">http://documents.plant.wur.nl/cgn/pgr/minorlv/con_spec.asp</a>
<i>Cichorium intybus</i> <i>Cichorium endivia</i>	<b>Chicory</b>  Endive	<b>No:</b> 3 CWR species <b>Status:</b> No CWR threatened <i>Cichorium intybus</i> (wild), ssp. <i>spicatum</i> <i>C.pumilum</i> , <i>C.spinsum</i> (DD)	Some species are data deficient as threats are unknown	<b>Gene flow:</b> Crop forms hybrid swarms with wild chicory (along roadsides in Denmark).	(Kiaer et al, 2007) (Treuren et al, 2012) <a href="http://documents.plant.wur.nl/cgn/pgr/chicory/con_spec.asp">http://documents.plant.wur.nl/cgn/pgr/chicory/con_spec.asp</a>
<i>Lens</i>	<b>Lentils</b>	<b>No:</b> 5 CWR species	No threats noted	<b>Gene flow:</b> Viable hybridization can	(Veteläinen et al,

<i>culinaris</i> ssp. <i>culinaris</i>		<b>Status:</b> No CWR is threatened <i>Lens nigricans, Lens ervoides, Lens lamottei, Lens odemensis, Lens orientalis</i>		occur between cultivated and wild <i>Lens</i> , however interbreeding potential divides the genus into two groups ( <i>L. culinaris</i> – <i>L. odemensis</i> and <i>L. ervoides</i> – <i>L. nigricans</i> ), with failure of crosses between members of different groups because of hybrid embryo abortion.	2009) (Ladizinsky and Muehlbauer, 2011) (Ahmad et al, 1995)
<i>Cicer arietinum</i>	<b>Chickpea</b> Garbanzo	<b>No:</b> 4 CWR species <b>Status:</b> 50% of CWR are threatened. <i>Cicer canariense</i> (EN), <i>Cicer graecum</i> (EN), <i>Cicer incisum, Cicer montbretii</i>	Fragmented populations; overgrazing; wildfires	<b>Gene flow:</b> All species of <i>Cicer</i> are highly self-pollinated, and there is no field evidence of hybridization (crosses with the two closest wild relatives in Turkey & the Middle East are possible).	(Ellstrand, 2003) (and references therein)
<i>Olea europaea</i>	<b>Olive</b>	<b>No:</b> 2 CWR species <b>Status:</b> No CWR are threatened (but see gene flow note) <i>O.eu. ssp. cerasiformis, O.eu. ssp. europaea, O.eu. ssp. guanchica, O.eu. ssp. oleaster, O.eu. var. sylvestris</i> <i>Olea maderensis</i> (DD)	<i>Olea maderensis</i> is data deficient as threats are unknown (see also gene flow)	<b>Gene flow:</b> It is not known to what extent the genetic identity of the wild subpopulations has been affected by hybridization with cultivated olive. It may be the case that all wild olives are feral populations of the crop.	(Ellstrand, 2003) (and references therein); (Veteläinen et al, 2009); (IUCN, 2012)
<i>Vitis vinifera</i> ssp. <i>vinifera</i>	<b>Grapes,</b> raisin, sultana, currant	<b>No:</b> 1 CWR species <b>Status:</b> No CWR are threatened. <i>Vitis vinifera</i> ssp. <i>sylvestris</i>	No threats noted (but see gene flow)	<b>Gene flow:</b> Grapes and wild grapes are fully cross-fertile, and where wild grapes occur near vineyards they are likely to be hybrids.	(Di Vecchi-Staraz et al, 2009); (Ellstrand, 2003) (and references therein); (Veteläinen et al, 2009)
<i>Prunus dulcis</i> <i>Prunus avium</i> <i>Prunus</i>	<b>Almond</b> <b>Cherry</b> <b>Peach,</b> nectarine <b>Plums,</b>	<b>No:</b> 16 CWR species including many minor plum species <b>Status:</b> 12.5% of CWR are threatened. Examples: <i>P.avium</i> ssp. <i>avium, P.cocomilia, P.cerasifera</i>	Many species data deficient as threats are unknown; fragmentation,	<b>Gene flow:</b> There is substantial and symmetric gene flow between the domesticated almond <i>P.dulcis</i> and wild <i>P. orientalis</i> in the eastern Mediterranean.	(Delplancke et al, 2012); (Veteläinen et al, 2009)



<i>persica</i> <i>Prunus</i> <i>domestica</i>	prunes, damsons (apricot is not considered native to Europe)	<i>P.orientalis</i> , <i>P.spinosa</i>	hydrological changes (incl dams), climate change; lack of pollinators		
<i>Pyrus</i> <i>communis</i> ssp. <i>communis</i>	<b>Pear</b>	<b>No:</b> 11 CWR species <b>Status:</b> 1 CWR species is critically threatened. Examples: <i>P.communis</i> ssp. <i>pyraster</i> , <i>P.c.</i> ssp. <i>caucasica</i> (wild pear) <i>Pyrus magyarica</i> (CR) <i>Pyrus cordata</i>	Many species data deficient as threats are unknown; <i>P</i> <i>magyarica</i> threatened by urbanization and agricultural development	<b>Gene flow:</b> Hybridization with cultivated <i>P. communis</i> is reported as a threat to wild pear species.	(IUCN, 2012); (Veteläinen et al, 2009)
<i>Malus x</i> <i>domestica</i>	<b>Apple</b>	<b>No:</b> 5 CWR species <b>Status:</b> Data Deficient (see gene flow) Example: <i>Malus sylvestris</i> (crab apple) (DD)	<i>Malus sylvestris</i> is data deficient as status and threats are insufficiently known	<b>Gene flow:</b> Although <i>Malus sylvestris</i> is relatively widely distributed in Europe, hybridization with cultivated <i>M. domestica</i> is thought to be having a significant impact on the population. It is not known to what extent the genetic diversity of the species has been affected; therefore, it is regionally assessed as Data Deficient.	(IUCN, 2012); (Veteläinen et al, 2009); (Cornille et al, 2013)
<i>Fragaria x</i> <i>ananassa</i>	<b>Garden strawberry</b>	<b>No:</b> 3 CWR species <b>Status:</b> No CWR are threatened in Europe. <i>Fragaria vesca</i> , <i>F.viridis</i> , <i>F.moschata</i>	No threats noted	<b>Gene flow:</b> Gene flow between cultivated hybrid octaploid strawberries and the diploid or hexaploid CWRs is very rare in Europe (however, crop-wild gene flow is likely in the US).	(Schulze et al, 2011)

## ANNEX TO CHAPTER 8(a) REFERENCES

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## ANNEX TO CHAPTER 8(b) CONSERVATION OF PLANT GENETIC RESOURCES FOR FOOD AND AGRICULTURE (PGRFA) IN THE EU

van der Grijp, Nicolien

### Key stakeholders in plant genetic resources conservation and use in Europe

This annex describes the main stakeholders in the conservation and use of plant genetic resources for food and agriculture (PGRFA) in Europe representing the main categories of international public governance, gene banks, public research, plant breeding companies, and agro-NGOs. It also mentions their major initiatives. The analysis of the challenges facing plant genetic resources conservation in Europe in Section 8.4 of the main report is based on interviews with key authoritative experts, representing these stakeholder groups.

#### *Collection, conservation and characterisation*

*Coordination and access to information on PGRFA:* The European Cooperative Programme for Genetic Resources (ECPGR)<sup>119</sup> is a collaborative programme of 43 national networks of gene banks and other conservation initiatives, aimed at contributing to national, sub-regional and regional programmes to rationally and effectively conserve PGRFA *ex situ* and *in situ* and increase their utilization. It is also the platform for the implementation of the Global Plan of Action in the European region. ECPGR will be brought under the umbrella of the Global Crop Diversity Trust in 2014.

The European web-based catalogue EURISCO<sup>120</sup>, created by ECPGR, contains data on more than half of the *ex situ* accessions maintained in Europe and roughly 16% of total worldwide holdings<sup>121</sup>. It currently contains passport data of almost 1.1 million samples of crop diversity representing 5,586 genera and 36,356 species from 43 countries, and is now being hosted and maintained by the Leibniz Institute of Plant Genetics and Crop Plant Research, Germany<sup>122</sup>.

The Crop Wild Relative Information System<sup>123</sup>, created by the FP5 PGR Forum project, contains a checklist for all 25,000 crop wild relatives present in Europe (Kell et al, 2007).

*Ex situ conservation:* Major gene banks include Leibniz Institute of Plant Genetics and Crop Plant Research<sup>124</sup> in Germany, the Netherlands Centre for Genetic Resources<sup>125</sup> and the Scandinavian NordGen<sup>126</sup>. Botanic gardens have an important role in the conservation of crop wild relatives. The Royal Botanic Gardens Kew in the UK initiated the Millennium Seed Bank Partnership<sup>127</sup> and is involved in a global *ex situ* conservation initiative for crop wild relatives as a step to food security and climate change mitigation<sup>128</sup>. Botanic gardens in Austria<sup>129</sup> and Italy<sup>130</sup> have important collections of

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<sup>119</sup> <http://www.ecpgr.cgiar.org> (formerly European Cooperative Programme/ Genetic Resources (ECP/GR))

<sup>120</sup> <http://eurisco.ecpgr.org/>

<sup>121</sup> Updated to May 2012.

<sup>122</sup> <http://www.ipk-gatersleben.de/>

<sup>123</sup> <http://www.pgrforum.org/cwr/cwrinfo.asp>

<sup>124</sup> <http://www.ipk-gatersleben.de>

<sup>125</sup> <http://www.wageningenur.nl/en/Expertise-Services/Legal-research-tasks/Centre-for-Genetic-Resources-the-Netherlands-1.htm>

<sup>126</sup> <http://www.nordgen.org/index.php/en/content/view/full/2>

<sup>127</sup> <http://www.kew.org/science-conservation/save-seed-prosper/millennium-seed-bank/index.htm>

<sup>128</sup> <http://www.cwrdiversity.org/>

landraces. The Government of Norway has established the Svalbard Global Seed Vault<sup>131</sup> in the permafrost for safe storage of *ex situ* seed collections of world crops; it currently houses more than 500,000 accessions and provides an additional level of security to existing *ex situ* collections worldwide. The Global Crop Diversity Trust<sup>132</sup>, set up as an endowment fund, builds partnerships with selected international gene banks to provide financial stability, allowing for long-term planning and conservation.

*In situ conservation*: Numerous small-scale, farmer or agro-NGO-led initiatives focus on on-farm conservation of plant genetic resources, and increasingly participatory plant breeding (Bocci and Chable, 2009). National networks, united in the European Agrobiodiversity Network and ASEED Europe<sup>133</sup>, provide a platform for initiatives for *in situ* PGRFA conservation and use in a number of European countries (see Table A8-2Table ).

**Table A8-2 National networks for *in situ* conservation in Europe**

Network	Country	Website
Arche Noah	Austria	<a href="http://www.arche-noah.at">www.arche-noah.at</a>
Semences Paysannes	France	<a href="http://www.semencespaysannes.org">www.semencespaysannes.org</a>
Rete Semi Rurali	Italy	<a href="http://www.semirurali.net">www.semirurali.net</a>
De Oerakker	Netherlands	<a href="http://www.deoerakker.nl">www.deoerakker.nl</a>
Red de Semillas	Spain	<a href="http://www.redsemillas.info">www.redsemillas.info</a>
Pro Specie Rara	Switzerland	<a href="http://www.prospecierara.ch">www.prospecierara.ch</a>
Garden Organic Heritage Seed Library	UK	<a href="http://www.gardenorganic.org.uk/hsl">www.gardenorganic.org.uk/hsl</a>

#### Research and education

The European Plant Science Organisation (EPSO)<sup>134</sup> represents more than 226 research institutes, departments and universities from 30 countries in Europe and beyond. EPSO's mission is to improve the impact and visibility of plant science in Europe. Besides facilitating scientific exchange, it organises the annual Fascination of Plants Day<sup>135</sup>.

Research initiatives funded under DG Research framework programmes have made key advances in knowledge, practice and coordination. EPGRIS<sup>136</sup> produced the EURISCO Catalogue providing information about *ex situ* accessions maintained in Europe; CRYMCEPT<sup>137</sup> determined cryopreservation methods for conserving European plant germplasm focusing on coffee, banana, olives and garlic; Farm Seed Opportunities<sup>138</sup> was developed in order to enhance the diversity of seeds available in Europe and support Member States' implementation of two Directives on seed

<sup>129</sup> Vienna Botanic Gardens, <http://www.botanik.univie.ac.at/hbv/index.php?nav=1&lang=en>

<sup>130</sup> Botanical Garden of Padova, <http://www.ortobotanico.unipd.it/en/>

<sup>131</sup> <http://www.croptrust.org/content/svalbard-global-seed-vault>

<sup>132</sup> <http://www.croptrust.org>

<sup>133</sup> <http://aseed.net/en>

<sup>134</sup> <http://www.epsoweb.org>

<sup>135</sup> <http://www.plantday12.eu>

<sup>136</sup> <http://ipgri.singer.cgiar.org/ECPGR/epgris/Index.htm>

<sup>137</sup> <http://www.agr.kuleuven.ac.be/dtp/tro/CRYMCEPT/CRYMCEPT.htm>

<sup>138</sup> <http://www.sad.inra.fr/en/All-the-news/Farm-Seed-Opportunities-European-project>



regulation and marketing<sup>139</sup>; and ENSCONET<sup>140</sup> brought together the key European botanic garden facilities involved in the conservation of European native seeds.

Table A8-3 lists some of the major projects under the current Framework Programme (2007-2013) relevant to PGRFA.

**Table A8-3 Current FP7 projects relevant for diversity and conservation of PGRFA**

Acronym	Full title	Coordinating partner	Period	Website
RECBREED	Recombination: An old and new tool for plant breeding	Karlsruhe Institute of Technology (KIT), Germany	2009- 2013	www.recbreed.eu
SOLIBAM	Strategies for Organic and Low-input Integrated Breeding and Management	<a href="#">Institut National de la Recherche Agronomique</a> (INRA)	2010- 2014	www.solibam.eu
DROPS	Drought tolerant yielding plants	Institut National de la Recherche <a href="#">Agronomique</a> (INRA)	2010- 2015	www.dropsproject.eu
PGR Secure	Novel characterization of crop wild relative and landrace resources as a basis for improved crop breeding	University of Birmingham	2011- 2014	www.pgrsecure.org

#### *Plant breeding*

At the level of the Member States, plant breeding companies are organised in national associations; at the European level, the sector is represented by the European Seed Association<sup>141</sup>, and globally by the International Seed Federation<sup>142</sup>.

The European Technology Platform 'Plants for the Future' (Plant ETP)<sup>143</sup> is a stakeholder forum for the plant sector with members from industry, academia and the farming community, representing the whole plant breeding innovation chain from fundamental research to crop production and food processing. It serves as a platform for all stakeholders concerned to provide their views and represent their interests in an open discussion process, and has produced 20-year vision<sup>144</sup> and a Strategic Research Agenda<sup>145</sup> for Europe's plant sector. It recently organized a conference about the role of the newly created European Innovation Partnership (EIP) for Agricultural Productivity and

<sup>139</sup> Directive 2008/62/EC providing for certain derogations for acceptance of agricultural landraces and varieties which are naturally adapted to the local and regional conditions and threatened by genetic erosion and for marketing of seed and seed potatoes of those landraces and varieties [2008] OJ L162/13; and Directive 2009/145/EC providing for certain derogations, for acceptance of vegetable landraces and varieties which have been traditionally grown in particular localities and regions and are threatened by genetic erosion and of vegetable varieties with no intrinsic value for commercial crop production but developed for growing under particular conditions and for marketing of seed of those landraces and varieties [2009] OJ L312/44.

<sup>140</sup> <http://ensconet.maich.gr>

<sup>141</sup> <http://www.euroseeds.org>

<sup>142</sup> <http://www.worldseed.org/isf/home.html>

<sup>143</sup> <http://www.plantetp.org>

<sup>144</sup> [http://www.plantetp.org/images/stories/stories/documents\\_pdf/Vision%20paper.pdf](http://www.plantetp.org/images/stories/stories/documents_pdf/Vision%20paper.pdf)

<sup>145</sup> [http://www.plantetp.org/images/stories/stories/documents\\_pdf/Strategic%20Research%20Agenda.pdf](http://www.plantetp.org/images/stories/stories/documents_pdf/Strategic%20Research%20Agenda.pdf)

Sustainability<sup>146</sup> in stimulating innovation in plant genetic resources<sup>147</sup>. By organising the support of other economic actors in production chains, such as the food and retailing industry, the plant breeding industry seeks to ensure that the new varieties are produced and marketed under optimal circumstances, eventually as branded products.

The Consultative Group on International Agricultural Research (CGIAR)<sup>148</sup> is a partnership of 15 centres dedicated to agricultural research for development. CGIAR has recently moved to a new design of its research programmes, with a stronger focus on cross-cutting issues and multidisciplinary. The CGIAR Research Programme for Managing and Sustaining Crop Collections<sup>149</sup>, executed in partnership with the Global Crop Diversity Trust<sup>150</sup>, aims to conserve the diversity of plant genetic resources in CGIAR-held collections and to make this diversity available to breeders and researchers. In addition, CGIAR has specific research programmes for: dryland cereals; grain legumes; maize; rice; roots, tubers and bananas; and wheat. CGIAR's partner Bioversity International<sup>151</sup> is located in Europe. Much of its research focuses on the conservation and use of plant resources 'in situ' or 'on farm' (eg Seeds for Needs<sup>152</sup>), but it is also involved in *ex situ* initiatives. In July 2013, it launched, together with other major global players, the Bridging Agriculture and Conservation initiative<sup>153</sup> in order to provide evidence-based solutions to feed a growing population, while ensuring long-term conservation of vital biodiversity, including agricultural biodiversity.

#### *Farming, food marketing, and consumption*

Farming practices differ widely between member states and regions in terms of scale, production methods and inputs. Producers in greenhouses tend to rely on modern cultivars of crops, whereas open field producers are using modern cultivars as well as landraces. European farmers are organised in national farmers' organisations as well as COPA-COGECA<sup>154</sup> at the European level. In addition, there are several smaller-scale farmers' organisations focusing for example on specific production techniques, such as organic agriculture and integrated production, and specific crops.

The NGO Slow Food Foundation for Biodiversity<sup>155</sup> promotes the conservation and use of PGRFA as part of its aim to preserve the global agricultural and food heritage<sup>156</sup>. It seeks to establish stronger links between producers, consumers and local communities through the listing of endangered products in its Ark of Taste<sup>157</sup>, its producer communities called Presidia<sup>158</sup>, and the Terra Madre network of sustainable food communities (Petrini, 2009). Europe now counts around 90 Presidia focusing on the conservation of traditional plant varieties and seeds (Peano and Sottile, 2012).

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<sup>146</sup> <http://ec.europa.eu/agriculture/eip/>

<sup>147</sup> [http://www.plantetp.org/index.php?option=com\\_content&view=article&id=176&Itemid=53](http://www.plantetp.org/index.php?option=com_content&view=article&id=176&Itemid=53)

<sup>148</sup> <http://www.cgiar.org/>

<sup>149</sup> <http://www.cgiar.org/our-research/cgiar-research-programs/cgiar-research-program-for-managing-and-sustaining-crop-collections/>

<sup>150</sup> <http://www.croptrust.org/>

<sup>151</sup> <http://www.bioversityinternational.org/>

<sup>152</sup> [http://www.bioversityinternational.org/research/sustainable\\_agriculture/seeds\\_for\\_needs.html](http://www.bioversityinternational.org/research/sustainable_agriculture/seeds_for_needs.html)

<sup>153</sup> Declaration: Bridging Agriculture and Conservation, 12 July 2013, Rio de Janeiro, Brazil.

<sup>154</sup> <http://www.copa-cogeca.be/>

<sup>155</sup> <http://www.slowfoodfoundation.com>

<sup>156</sup> [http://www.slowfoodfoundation.com/pagine/eng/pagina.lasso?-id\\_pg=6](http://www.slowfoodfoundation.com/pagine/eng/pagina.lasso?-id_pg=6)

<sup>157</sup> Manifesto Ark of Taste by the Slow Food Foundation for Biodiversity. See at [http://www.slowfoodfoundation.com/pagine/eng/arca/pagina.lasso?-id\\_pg=37](http://www.slowfoodfoundation.com/pagine/eng/arca/pagina.lasso?-id_pg=37)

<sup>158</sup> <http://www.slowfoodfoundation.com/presidia>

Companies have emerged that are based on new business models such as Agrofair<sup>159</sup>, a trader in tropical fruit which is co-owned by farmers in developing countries and Eosta<sup>160</sup>, a leading international distributor of organic greenhouse crops and overseas fruits, with its Nature & More "trace & tell" transparency system.

### **Stakeholder interviews about conservation of PGRFA in Europe**

Six semi-structured interviews have been done with authoritative experts from international public governance, gene banks, public research, plant breeding companies, and agro-NGOs (see Table A8-4). The following questions were used as a guideline for the interviews by telephone or face-to-face:

- 1) What is your opinion about the current state of affairs concerning the access to and the use of the diversity of plant genetic resources (PGR) in Europe and globally? What do you consider the most important problems, now and in the future?
- 2) Do you think that the approach agreed in the Global Plan of Action for Plant Genetic Resources for Food and Agriculture (GPA) and the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) provides sufficient means to stimulate the diversity of PGR?
- 3) What do you think are currently the most important initiatives to stimulate the access and the use of the diversity of PGR, promoted by public as well as private actors in Europe and globally
- 4) In which initiative(s) are you involved yourself?
  - Initiative A
  - Initiative B
  - Initiative C

For each initiative:

- What has been the rationale for building the initiative?
  - Which partners are involved and in what roles?
  - What are the main results of the initiative?
  - What are the main barriers encountered in practice?
  - What are the main lessons learned?
  - What could the EU contribute to stimulate the initiative?
- 5) Do you think that there are possibilities for the EU to enhance its profile in the issue area of access to and the use of the diversity of PGR?
  - 6) Based on what has been discussed: do you have any suggestions for policy recommendations for the EU?
  - 7) Do you have suggestions for other interviewees?

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<sup>159</sup> <http://www.agrofair.nl>

<sup>160</sup> <http://www.eosta.com>

**Table A8-4 List of interviews carried out in May and June 2013**

Interviewee	Function and organisation	Type of actor	Initiatives
Ehsan Dullo	Programme leader for the Conservation and Availability Programme at Bioversity International, lead author of SOW-1 and SOW-2 reports, previously at FAO	CGIAR research institute	Seeds for Needs programme PGR Secure project
Chris Kik	Head curator at Center for Genetic Resources at Wageningen UR	University research organisation	Genebank International Leafy Vegetables Database PGR Secure project
	Board member of Foundation "De Oerakker"	Diverse group of small scale actors, mostly farmers, agro NGOs and consumer groups	Network "Eeuwig Moes": 40 initiatives for conservation of crop genetic resources
Kees Reinink	Managing director of Rijk Zwaan	Plant breeding company	Major innovator in breeding of vegetables Tomato Trial Center PGR Secure project
Suzanne Sharrock	Director of Global Programmes at Botanic Gardens Conservation International	Umbrella organization for botanic gardens worldwide	International Plant Exchange Network (IPEN) PlantSearch database Plant Conservation Day
Rony Swennen	Professor at Faculty of Bioscience Engineering at KU Leuven	University research organisation	International Transit Centre for Bananas (genebank)
	Banana breeder at International Institute of Tropical Agriculture (ITTA) in Tanzania	CGIAR research institute	Banana breeding programme
Anke van den Hurk	Senior policy advisor biodiversity at Plantum NL, European Seed Association and International Seed Federation	Business association for the plant reproduction material sector	Working groups Biodiversity PGR Secure Project

## ANNEX TO CHAPTER 8(b) REFERENCES

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## ANNEX TO CHAPTER 9 THE IMPACTS OF BEE DECLINE ON BIODIVERSITY AND POLLINATION IN EUROPE

Berman, Sandra & Sarteel, Marion

### Number of hives, beekeepers and mortality rate of bee colonies

An abnormal decline of bees (both honeybees and wild bees) has been observed worldwide for several decades. A number of studies have documented this decline; for example, AFFSA (AFSSA, 2008) highlighted abnormal losses in 8 out of 12 and 11 out of 12 countries studied in 2006 and 2007. Detailed figures are available in the table below.

**Table A9-1 European statistics on the number of hives, beekeepers and mortality rate of bee colonies for 2006 and 2007**

Figures in brackets are for professional beekeepers. \* Mortality data expressed as number of statements

Source: (AFSSA, 2008)

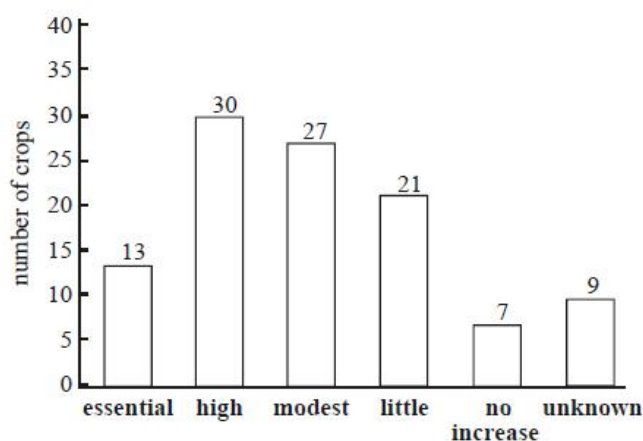
Country	2006			2007		
	Beehives	Beekeepers	Mortality rate (%)	Beehives	Beekeepers	Mortality rate (%)
Austria	-	-	-	-	-	-
Belgium	110000	8600	-	-	-	-
Cyprus	41478 (21633)	707 (120)	-	40533 (22500)	712 (129)	-
Czech Republic	525560 (19155)	46647 (83)	10	520084 (20521)	48919 (90)	20
Denmark	80000 (15000)	4100 (150)	15	- (15000)	4100 (150)	7
Estonia	48000 (12000)	7000 (60)	08-10	48000 (12000)	7000 (60)	08-10
Finland	53000 (28900)	3300 (77)	9,3	54000 (29306)	3200 (78)	10,2
France	1324565	66924	808*	1243046	65050	142*
Germany	700000	82000	13	710000	82000	9
Greece	1380000	23000 (5000)	-	1380000	23000 (5000)	-
Hungary	923103	15764	-	897670	15320	-
Ireland	20000 (7000)	2200 (70)	-	20000 (7000)	2200 (70)	-
Italy	1083266 (350000)	75000 (1,5%)	30-40	1100000 (400000)	55000 (1,5%)	40-50
Latvia	62000 (11687)	3300 (53)	-	70000 (11700)	3400 (53)	-
Lithuania	100000 - 120000	11000 (20-40)	-	100000 - 120000	11000 (20-40)	-
Luxembourg	5637	369 (3)	16	5300	358 (3)	20
Netherlands	80000 (5000)	-	26	80000 (5000)	7500 (20)	15
Norway	70000 (10000)	3500 (35)	10,6	70000 (10000)	3500 (35)	-

<b>Portugal</b>	-	-	-	555049	15267 (4,1%)	-
<b>Romania</b>	1100000 (165000)	3200 (480)	10	996000 (199200)	2942 (588)	>20
<b>Slovakia</b>	217338 (7852)	12797 (49)	-	247678 (57)	14854 (57)	
<b>Sweden</b>	105000	13000	18	110000	12000	12
<b>United Kingdom</b>	274000 (40000)	43900 (300)	11,1	274000 (40000)	43900 (300)	11,7

### Dependence of food crops on animal-mediated pollination

The graph shows the level of dependence of crops for direct human consumption on animal-mediated pollination (Klein et al, 2007). This degree of dependence is calculated based on the global production reduction with and without animal pollination using FAOSTAT data. Pollinator dependence is “essential”, “high” and “modest” if the presence of pollinators increases yield by at least 10%. The yield decrease due to pollinator loss is directly related to the degree of dependence of the crop (Garibaldi et al, 2011).

**Figure A9-1 Number of crops that have different degrees of dependence on animal-mediated pollination for yield production (own calculations using FAOSTAT data)**



Studies demonstrating the relationship between yield and pollinators are also available for single crops. In Indonesia, rain forest conversion affects pollinators, which causes a reduction of coffee yields by up to 18%, depending on the location and the magnitude of the conversion (Priess et al, 2007). For three squash species, honeybee pollination increases individual fruit weight by 28-78%, and for two squash species, the number of fruit is affected (Walters and Taylor, 2006). For canola, the number of fruit per plant, the seed weight and the yield are higher with honey bee pollination than without (pollination controlled with exclusion cages) (Bommarco et al, 2012; Morandin and Winston, 2005). In a context of increased biofuel production, pollinator decline may therefore have an impact not only on food production but also on the biofuel market.

## Economic impact of insect pollination of the world agriculture production used directly in human food

The ALARM project has estimated the global economic value of the ecosystem service provided by pollinators at €153 billion per year, roughly 9.5% of the total global value of human food production, based on the value of production resulting from pollinators (Gallai et al, 2009). The table below shows the economic value of pollination per crop category.

**Table A9-2 Economic impact of insect pollination of global agricultural production used directly in human food**

Stimulant crops are cocoa, coffee, etc.

Source: (Gallai et al, 2009).

CROP CATEGORY	AVERAGE VALUE OF A PRODUCTION UNIT	TOTAL PRODUCTION ECONOMIC VALUE (EV)	INSECT POLLINATION ECONOMIC VALUE (IPEV)	RATE OF VULNERABILITY (IPEV/EV)
	€ PER METRIC TONNE	10 <sup>9</sup> €	10 <sup>9</sup> €	%
Stimulant crops	1 225	19	7.0	39.0
Nuts	1 269	13	4.2	31.0
Fruits	452	219	50.6	23.1
Edible oil crops	385	240	39.0	16.3
Vegetables	468	418	50.9	12.2
Pulse	515	24	1.0	4.3
Spices	1 003	7	0.2	2.7
Cereals	139	312	0.0	0.0
Sugar crops	177	268	0.0	0.0
Roots and tubers	137	98	0.0	0.0
All categories		1 618	152.9	9.5



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This document contains the annexes to the final report of the STOA study  
'Technology options for feeding 10 billion people - Interactions between climate  
change & agriculture and between biodiversity & agriculture'.

A summary related to the study is also available.

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