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Technology options for feeding 10 billion people

Interactions between climate change & agriculture and between biodiversity & agriculture

Study

Science and Technology
Options Assessment
STOA

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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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ACRONYMS

AES	agri-environment scheme
ANC	Area of Natural Constraint (previously Less Favoured Area or Natural Handicap)
CAP	Common Agricultural Policy
CBD	UN Convention on Biological Diversity
CLC	CORINE Land Cover
CMEF	Common Monitoring and Evaluation Framework
DMP	Drought Management Plan
DNA	deoxyribonucleic acid (genetic material)
EAFRD	European Agricultural Fund for Rural Development
EFA	Ecological Focus Area (part of CAP reform greening proposal)
EFSA	European Food Safety Authority
EIA	Environmental Impact Assessment
EIP	European Innovation Partnership
ETC/BD	European Topic Centre on Biodiversity
ETS	Emissions Trading System
FADN	Farm Accountancy Data Network
FAS	Farm Advisory Service
FP5, FP6, FP7	EU Framework Programme for Research (FP5 1998-2002; FP6 2002-2006; FP7 2007-2013)
GAEC	Good Agricultural and Environmental Condition
GHG	Greenhouse gas (see glossary)
GMO	Genetically Modified Organism (see glossary)
GMHT	Genetically modified herbicide tolerant crop (see glossary)
GM Bt	Genetically modified insect resistant crop containing Bt gene (see glossary)
HNV	High Nature Value (farming areas and systems)

iLUC	indirect land use change
IPCC	International Panel on Climate Change
IPM	integrated Pest Management (see glossary)
IWM	Integrated Weed Management (see glossary)
LULUCF	Land use, land use change, and forestry (in relation to greenhouse gas emissions accounting)
NREAP	National Renewable Energy Action Plan
PES	Payment for Ecosystem Services
PGRFA	plant genetic resources for food and agriculture
RNA	ribonucleic acid (genetic material)
SOC	Soil organic carbon (see glossary)
SOM	Soil organic matter (see glossary)
UAA	Utilized Agricultural Area

GLOSSARY

access and benefit sharing	access to genetic resources controlled by another country and equitable sharing of commercial and non-commercial benefits deriving from this access between the provider and the user
accessions (plant genetic resources)	accessions are distinct, uniquely identified samples of seeds, plants, or other germplasm materials that are maintained as an integral part of a germplasm collection
adaptation (to climate change)	adjustment in natural or human systems [ie agricultural management and related socio-economic and policy framework] in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC, 2007a)
adventitious presence	the presence of a GM gene and/or GM product in a non-GM crop or seeds or crop product at a low level that is not regarded as damaging (eg below minimum thresholds for conventional or organic produce sales)
agroforestry	Agroforestry is an integrated land management system that combines trees and shrubs with crops and/or livestock on the same land
anaerobic digestion	Anaerobic digestion is the process by which microorganisms break down biodegradable material in the absence of oxygen (eg in fermentation and silage production); it is used to produce biogas (ie methane plus other gases) as a fuel, using manure, slurry, food waste, and other green residues.
assessment endpoint	a natural resource or natural resource service that needs protection from risks; the valued attribute of a natural resource that is worth protection (EFSA, 2010) – see also measurement endpoint
Bacillus thuringiensis	a bacterium that occurs naturally in soils and plant tissues and that produces a range of crystalline (Cry) and vegetative (VIP) proteins that are toxic to certain insects
bee colony	group of bees that is organised in such a way as to support the needs of individuals making it up and the collective life. During the high activity season a honey bee colony has 40,000-60,000 bees; in winter the number of bees decreases to 5,000-15,000. The colony is composed of a queen, her female workers, some males, and by the brood, including eggs, larvae and pupae.
bee colony collapse (Colony Collapse Disorder)	a rapid loss of bees that leads to the total destruction of the colony. It affects honey production, unless it appears after the end of the honey production season.
bee colony depopulation	a gradual decrease in the number of bees present in the hive, until the hive disappears; and an associated decline in honey production
bee colony weakening	a decline of colony strength (ie the number of bees in a colony) and development, and behaviour abnormality, leading to a decrease in honey

	production
biochar	Biochar is a stable solid rich in carbon, the product of pyrolysis (ie carbonisation) of biomass; biochar can be used as a soil amendment in order to increase soil fertility in certain conditions, and it might sequester carbon, and improve water retention.
biodiversity	the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (Convention on Biological Diversity 1998, Article 2)
biodiversity (functional)	the quantification of the similarities in phenotypes and ecologies of species (such as their environmental tolerances and how they impact ecosystem function) (Cadotte et al, 2011)
biodiversity proofing (of policy)	a structured process of ensuring the effective application of tools to avoid or at least minimize harmful impacts of EU spending and to maximise the biodiversity benefits (IEEP et al, 2012a)
biological control	EITHER 1) the natural control of pest populations through predators, parasitoids, parasites, and disease through the maintenance of a diverse biological control community in and around crop fields; OR 2) the deliberate introduction of a species that controls a pest population, through the release of eggs, larvae, adults, spores, virus, etc.
bitrophic exposure	exposure of an organism to the stressor (eg GM product or pesticide) by feeding on the plant, pollen or exudates (root exudates, guttation fluid etc), or plant residues, containing the stressor
break crop	a secondary crop grown to interrupt the repeated sowing of cereals as part of crop rotation; oilseed rape is the most important break crop in Northern Europe, maize or field beans in Southern Europe.
breeder lines, breeding lines, elite lines	genetic lines bred in a crossing programme before they are named and officially released for commercial cultivation; elite lines are breeding lines that possess most of the characteristics being sought for a particular environment or plant.
Bt	the GM insect resistance trait conferred by a transgene from the bacterium *Bacillus thuringiensis*
buffer strip	A buffer strip is a strip of land alongside a water course or water body that can be designed to deliver particular environmental benefits, for example to protect water against pollution and run-off. Width and management requirements are defined at Member State level (Nitrates Directive, GAEC standard in Council Regulation (EC) 73/2009)
carbon sequestration	the rate of capture and long-term storage of atmospheric carbon dioxide (CO2), which can refer to the natural geochemical cycling of carbon between the atmosphere and reservoirs, eg in trees or soil organic matter, over

	decades (it can also refer to human-mediated carbon capture and storage or geo-engineering but these processes are not used in this report)
carbon storage	long-term storage of carbon in reservoirs where it cannot affect climate change, ie recalcitrant (long-term) soil organic matter, old forest stands, underground geological reservoirs, or long-lasting materials such as timber or concrete
case-by-case	a risk assessment approach in which the required information may vary depending on the type of GMOs concerned, their intended use and potential receiving environment, taking into account *inter alia* GMOs already in the environment (Directive 2001/18/EC)
catch crop	a catch crop is a fast-growing annual species, typically a cereal, adapted to scavenge nitrogen efficiently from the soil, thereby taking up surplus nitrogen remaining from fertilization of the previous crop, preventing it from being lost through leaching or gaseous denitrification or volatilization. The catch crop is cut before maturity and left to decompose or incorporated into the soil, releasing the captured nitrogen for the next crop.
chronic exposure	repeated and continuous contact with a substance that occurs over the organism's life cycle or over a long time
cisgenesis	gene transfer using recombinant DNA technology between organisms belonging to the same species gene pool - these organisms could usually also be conventionally cross-bred (although this might be very difficult) 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. (New Techniques Working Group 2012 Final Report to the European Commission)
co-existence	the ability of farmers to choose between conventional, organic or GM-based crop production, in compliance with the relevant legislation on labelling and/or purity standards
connectivity	the extent to which ecosystems and natural areas are linked together in fragmented landscapes
conservation of	the maintenance of the diversity of living organisms, their habitats and the

biodiversity	interrelationships between organisms and their environment
conservation tillage / reduced tillage	Conservation tillage is any tillage and planting system that minimises the disruption of soil structure, composition and biodiversity by establishing crops in the previous crop's residues; it may include the use of minimum tillage, shallow ploughing at reduced depth (10cm), and/or non-inversion tillage practices (Holland, 2004).
contamination	the presence of a GM gene and/or GM product in a crop or seeds where it is not wanted and considered damaging, eg in non-GM imports, local varieties, organic crops
conventional tillage	a tillage system in which a deep primary cultivation (30cm depth), such as mouldboard ploughing, is followed by a secondary cultivation to create a seedbed (Holland, 2004)
cover crop / green manure	A cover crop is generally grown between harvesting and sowing the next crop, and is ploughed under before reaching full maturity. Cover crops are planted primarily to protect from soil erosion and retain soil water, with additional benefits for soil fertility and control of weeds, pests, and diseases. Leguminous crops such as lucerne and clover are commonly used because of their nitrogen-fixing ability, and these crops are also known as green manure.
crop diversification	Crop diversification is the introduction of a greater variety of crops at the farm level. It does NOT necessarily imply the adoption of crop rotation. The CAP Greening component involves the adoption of at least 3 crops at farm level on farms with arable area larger than 10 ha, eg a farmer could farm 25 ha of wheat, 20 ha of maize, and 5 ha of barley to comply.
crop rotation	Crop rotation is the practice of growing a series of dissimilar types of crops in the same area in sequential seasons (as opposed to monoculture). Rotations may include from two to six or more crop types, and ideally should include a balance of crops from different crop groups (cereals, legumes, root crops and broad-leaved arable crops). No one crop group (eg cereals) should occupy more than half of the rotation.
crop wild relative	wild species related to crops, including crop progenitors.
Cry toxin	a range of crystalline proteins produced by GM genes from *Bacillus thuringiensis* that are toxic to certain insects, eg Cry1Ab, Cry3Bb, Cry1F (NB the genes themselves are referred to by the name of the toxin in lower case and italics, eg *cry1Ab*)
cryopreservation	storing of plant genetic material in ultra-cold liquid nitrogen.
cultivars	cultivated plant varieties that have been formally approved and registered (see also obsolete cultivars)
ecosystem	an ecosystem is a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional

	unit
ecosystem services	the direct and indirect contributions of ecosystems to human wellbeing; categorised in four main types: provisioning services (eg food, water, fuel); regulating services (eg flood and disease control); supporting/habitat services (eg nutrient cycling, pollination, soil formation); and cultural services (eg recreation, cultural, spiritual and aesthetic values) (Millennium Ecosystem Assessment)
ecotype	a population or group of populations genetically adapted to a particular set of environmental conditions where they naturally occur. See also genotype.
eutrophication	excessive richness of nutrients in a lake or other body of water, frequently due to run-off from the land, which causes a dense growth of plant life
ex situ conservation	the conservation of components of biological diversity outside their natural habitats.
fallow	Land not used for growing crops during one or two growing seasons, for example as part of a crop rotation. See also set-aside.
feral population	a population of crop plants that is self-propagating outside the crop field itself (ie in field margins, roadsides, waste land etc.). Feral populations may be transient, ie their long-term survival depends on continued seed dispersal from other sources (ie crops or seed transport); or they may be persistent, ie able to reproduce successfully to maintain the population or the meta-population (maybe including seed dormancy).
fitness	the successful survival and reproduction of a particular genotype compared to other genotypes in the population (relative fitness), ie the probable contribution of a genotype to the gene pool of the next generation
fragmentation	the division of an ecosystem or habitat into distinct smaller parts, without adequate connectivity between the parts. The parts are insufficiently large to retain the full complement of species without connection to other parts. Fragmentation can result from infrastructure development, such as roads and railways, or natural occurrences like forest fires.
gene flow	the movement of a gene in and between breeding populations of the crop, feral populations, weedy and wild relatives
genetic erosion	The loss over time of genetic diversity caused by either natural or man-made processes.
genetic reserve	A site where the management and monitoring of genetic diversity of natural wild populations within defined areas designated for active, long-term conservation.
genetic resources (plant, animal etc)	Genetic resources are genetic material of actual or potential value; genetic material is any material of plant, animal, microbial or other origin

	containing functional units of heredity (Convention on Biological Diversity Article 2). Plant genetic resources for food and agriculture are a subset of genetic resources, and are defined as any genetic material of plant origin of actual or potential value for food and agriculture (International Treaty on Plant Genetic Resources for Food and Agriculture Article 3). Genetic resources are a subset of biological resources, which are defined as genetic resources, organisms or parts thereof, populations, or any other biotic component of ecosystems with actual or potential use or value for humanity (Conventional on Biological Diversity Article 2).
genetically modified organism (GMO), living modified organism (LMO)	Genetically modified organism (GMO) means an organism, with the exception of human beings, in which the genetic material has been altered in a way that does not occur naturally by mating and/or natural recombination, by recombinant nucleic acid transformation, or by other techniques involving the direct introduction into an organism of heritable material prepared outside the organism including micro-injection, macro-injection and micro-encapsulation; or by cell fusion (including protoplast fusion) or hybridisation techniques where live cells with new combinations of heritable genetic material are formed through the fusion of two or more cells by means of methods that do not occur naturally (EU Directive 2001/18/EC). Living modified organism (LMO) means any living organism that possesses a novel combination of genetic material obtained through the use of modern biotechnology; 'living organism' means any biological entity capable of transferring or replicating genetic material, including sterile organisms, viruses and viroids; 'modern biotechnology' means the application of in vitro nucleic acid techniques, or fusion of cells beyond the taxonomic family, that overcome natural physiological reproductive or recombination barriers and are not techniques used in traditional breeding and selection (Cartagena Protocol on Biosafety to the Convention on Biological Diversity 2000).
genome	an organism's complete set of genes and genetic material (which includes both the DNA in the nucleus and plasmids in the cytoplasm of the cell)
genotype	The genotype is the genetic makeup of a cell, an organism, or an individual (ie the specific allele makeup of the individual) usually with reference to a specific characteristic under consideration. See also ecotype, phenotype and trait.
germplasm	reproductive or vegetative propagating materials of plants
GM event, GM gene construct	the genetic sequence that expresses the GM trait (usually including marker gene, promotor, gene of interest, and terminator), inserted into the GMO using recombinant nucleic acid technology (see definition of GMO/LMO)
GM product	the product (usually a protein, eg an enzyme) that is created (expressed) from the GM gene
green infrastructure	Green infrastructure is the network of natural and semi-natural areas, features and green spaces in rural and urban, terrestrial, freshwater, coastal and marine areas, which together enhance ecosystem health and resilience,

	contribute to biodiversity conservation and benefit human populations through the maintenance and enhancement of ecosystem services (Naumann et al, 2011). Green infrastructure can be strengthened through strategic and co-ordinated initiatives that focus on maintaining, restoring, improving and connecting existing areas and features as well as creating new areas and features.
green manure	See cover crop
greenhouse gas (GHG)	any of the gases whose absorption of solar radiation is responsible for the greenhouse effect, including carbon dioxide (CO2), methane (NH4), nitrous oxide (NO2), ozone (O3), and the fluorocarbons – usually expressed as CO2 equivalents
guttation fluid	Guttation is the exudation of drops of xylem sap on the tips or edges of leaves of some vascular plants, such as grasses. Guttation fluid may contain a variety of organic and inorganic compounds, mainly sugars, and mineral nutrients, and potassium. It can be an important food source for parasitoid wasps.
habitat banking (conservation banking, biodiversity banking)	A market where credits from actions with beneficial biodiversity outcomes can be purchased to offset the debit from environmental damage (EFTEC and IEEP, 2010). Credits can be produced in advance of, and without ex-ante links to, the debits they compensate for, and stored over time. The term 'habitat banking' can be used to refer to both species and habitats, ie analogous to 'conservation banking' and 'biodiversity banking'.
harm, damage (environmental)	a measurable adverse change in a natural resource or measurable impairment of a natural resource service which may occur directly or indirectly (Directive 2004/35/CE). Harm is generally given more weight when it is irreversible.
hazard	hazard is a potential risk, defined as the potential of an organism or any other stressor to cause harm to or adverse effects on human health and/or the environment (EFSA, 2010)
horizontal transfer	the transfer of genetic material from a plant or animal genome directly into the genome of viruses, bacteria or fungi, and its expression
hybridization	the process of combining different plant varieties to create a hybrid, through the exchange of pollen (out-crossing); the hybrid then contains genetic material from both parent varieties
in situ conservation	the conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings and, in the case of domesticates or cultivated species, in the surroundings where they have developed their distinctive properties.
Integrated Pest Management (IPM)	IPM is the integrated management of pest 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.
integrated production / integrated farming	Integrated Production/Farming is a farming system that aims to balance biological, technical and chemical methods of management in order to improve the protection of the environment, farm revenues and animal welfare.
Integrated Soil Fertility Management Plan	plan to optimise a farm's reliance on manufactured fertiliser, making it more resilient under economic or environmental pressures
Integrated Weed Management (IWM)	IWM is a form of IPM for keeping weed populations at an acceptable level for a healthy crop, whilst preventing the evolution of resistant weeds and weed build-up, through the combined use of a diversity of preventative, cultural, mechanical, biological, and chemical control practices. Tactics include crop rotations, early or late planting dates, cover crops, mulching, competitive crop cultivars, the judicious use of tillage, and targeted herbicide applications where necessary.
Intensification of agriculture	agricultural practices that increase productivity and crop yield, that have conventionally included increased fertilizer and/or pesticide use, and/or simplified crop rotations or monoculture, and/or increased tillage, drainage, irrigation (HOWEVER see also definition of sustainable intensification)
intercropping	the practice of growing two or more crops in proximity; the goal is usually to produce a greater overall yield on a given piece of land by making use of synergies and by better use of resources such as soil water, nutrients, light and/or space (whilst avoiding the negative effects of crop competition) – see also agroforestry
intragenesis	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. (New Techniques Working Group 2012 Final Report to the European Commission)
introgression (crop-wild gene flow)	the permanent incorporation of the transgene into a reproductively integrated population of another wild or weedy species
landraces	unique varieties of crops that have adapted to local conditions through a process of farmer selection.
LC50	median lethal concentration at which 50% of the exposed population dies within 24h

LD50	median lethal dose at which 50% of the exposed population dies within 24h
lethal	an effect that causes death
measurement endpoint	a quantifiable indicator of change in the assessment endpoint, that constitutes a measure of hazard and exposure, eg fitness, growth, behaviour, development, fecundity (EFSA, 2010)
mitigation (of climate change)	climate change mitigation encompasses the actions being taken to limit the magnitude and/or rate of long-term human-induced climate change
no-till / zero-till	see zero till
non-target	a non-target species is a species that is not deliberately killed or affected as part of the GM design or pesticide, but which may nevertheless be affected
novel trait	a novel trait is a form of a character that is not typical of that organism or species, eg herbicide-tolerance would only occur very rarely naturally in plants
obsolete cultivars	plant varieties that are considered of no importance at present or no longer popular or used by the farming community (see also cultivars)
on-farm conservation	The sustainable management of the genetic diversity of locally developed traditional animal breeds or crop varieties by farmers (usually within traditional agricultural, horticultural or agri-silvicultural cultivation systems).
organic agriculture	Organic agriculture is a production system that sustains the health of soils, ecosystems and people, by relying on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects; it combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved (IFOAM). Organic systems are defined by a shared set of objectives and principles, defined by the International Federation of Organic Agriculture Movements (IFOAM), EU legislation, and a range of national or private schemes (eg Demeter, Soil Association, KRAV, Nature & Progres).
organic soils	soils that contain at least 12% organic carbon (around 20% organic matter) in at least 40cm depth within the upper 100 cm of soil (ie accumulations of partly or completely decomposed plant residues formed under anaerobic conditions), OR organic rich soils under 10cm thick overlying ice or rock (FAO)
paludiculture	sustainable agricultural production on peatland that has undergone rewetting
parasitoid	an insect which reproduces by laying its eggs inside (endoparasitoid) or on (ectoparasitoid) another insect known as the host, either in the eggs or on or in the larvae. The parasitoid larvae develop feeding in or on the insect, and

	hatch through the skin. Adult parasitoids either do not feed or feed on nectar and/or guttation fluids.
phenotype	the composite of an organism's observable characteristics or traits, such as its morphology, development, biochemical or physiological properties, phenology, behaviour, and products of behaviour (such as a bird's nest); phenotypes result from the expression of an organism's genes as well as the influence of environmental factors and the interactions between the two (see also genotype and ecotype)
plant genetic resources for food and agriculture	see genetic resources
precision agriculture	Precision agriculture refers to a series of technologies that allow the application of water, nutrients, and pesticides only to the places and at the times they are required within fields, thereby optimizing the use of inputs; it includes a wide range of practices within a coherent management structure, which rely on GPS-tracking linked to internet-based information flows to farmers and automation of processes using tractor guidance systems and/or robotics (Pölling et al, 2010).
primitive forms (of crops)	crop varieties that have not been subjected to intensive breeding or growers' selection; they have features or traits that are similar to wild relatives.
problem formulation	the "what could go wrong" step of risk analysis. This involves: identifying the scope of the assessment; identifying the boundaries (temporal, spatial, organisational), identifying the stressor (pesticide, metabolites, GM gene, GM product, GM plant, crop & cultivation practices); identifying potential adverse effects; identifying stakeholders; and identifying the risk analysis strategy, including risk hypotheses. EFSA uses a narrower definition as the process of identification of characteristics of the GM plant capable of causing potential adverse effects (hazards) and of the nature of these effects (hazard characterisation); the identification of pathways of exposure through which the GM plant may adversely affect the environment (exposure identification); and defining assessment endpoints and setting up specific hypotheses (EFSA, 2010).
promoter	the genetic sequence in front of the GM gene that acts as a "switch" telling the plant when and how to read the gene
resilience	Resilience is the capacity of a system to absorb disturbance and reorganise whilst undergoing change so as to still retain essentially the same function, structure, identity and feedbacks (Walker et al, 2004). This recognises that ecosystems can exist in multiple stable states – thus, some species interchange may occur as a result of perturbation without significant impacts on ecosystem resilience, providing that the new species fulfil the same ecological functions as the lost species (Mazza et al, 2012). Resilience usually needs to be specified in terms of the identity (boundaries) of the ecosystem and its valued properties and functions.

resistance (to stressor eg pests, diseases, herbicides, insecticides, GM product)	resistance is the inherited ability of a plant or animal genotype to survive and reproduce following exposure to a dose of a pesticide (or GM product) normally lethal to the wild or normal genotype of the species. Resistance is the result of evolution by mutation and/or cross-breeding with naturally resistant individuals plus intense selection pressure.
restoration	the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed
rhizosphere	The rhizosphere is the narrow region of soil around plant roots that is directly influenced by root secretions and biomass. It is much richer in soil micro-organisms than the bulk soil. Much of the nutrient cycling and disease suppression needed by plants is carried out by these micro-organisms and thus occurs immediately adjacent to roots. Plant secretions determine the composition and function of the rhizosphere community; some plants secrete allelochemicals from their roots which inhibit the growth of other organisms (allelopathy).
risk	the combination of the magnitude of the consequences of a hazard, if it occurs, and the likelihood that the consequences occur (Directive 2001/18/EC). Risk is a probability of a harm occurring, which is quantified as far as is possible, but is always associated with a degree of uncertainty that should be specified with the risk statement.
risk analysis	a process consisting of three interconnected components: risk assessment, risk management, and risk communication (Codex Alimentarius, 2005); a process including a series of analytical and deliberative stages (National Research Council, 1996)
risk assessment	environmental risk assessment (ERA) means the evaluation of risks to human health and the environment, whether direct or indirect, immediate or delayed, which the deliberate release or placing on the market of GMOs may pose (Directive 2001/18/EC)
risk communication	the interactive exchange of information and opinions throughout the risk analysis process concerning risk, risk-related factors and risk perceptions, including the explanation of risk assessment findings and the basis of risk management decisions (Codex Alimentarius, 2005)
risk management	selection of a course of action in response to an identified risk that is based on many factors (eg social, legal, political, and/or economic) as well as the risk assessment results (US EPA 1998)
salinisation (of soil)	the accumulation of soluble salts of sodium, magnesium and calcium in soil to the extent that soil fertility is severely reduced
seed dormancy (primary and secondary)	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 oilseed rape (*Brassica napus*) seeds in the soil are exposed to drought stress in the absence of light.
set-aside	land temporarily taken out of agricultural production; see also fallow Set-aside also refers to a scheme to lay fallow a proportion of the EU arable crop introduced under the Common Agricultural Policy in 1988 to help reduce over-production. Set-aside was abolished in 2008.
shelterbelt / windbreak	one or more rows of trees and/or shrubs planted in such a way as to provide shelter from the wind and/or sun and/or snow for crops, livestock and/or grassland; this report refers only to 'field shelterbelts' ie rows of trees or shrubs on agricultural fields, not shelterbelts around farmyards or livestock facilities, on marginal lands to change land use, or in block plantings to provide woodlots
short-rotation coppice (SRC)	high-yield varieties of tree (generally poplar and willow) grown as an energy crop; planted at a high density, cut at the base (coppiced) after one to two years, and re-harvested on a two to five year cycle for up to thirty years
silage	Silage is fermented, high-moisture stored fodder which can be fed to cattle and sheep or used as a biofuel feedstock for anaerobic digesters. It is fermented and stored in a process called ensilage, ensiling or silaging, and is usually made from grass, maize, sorghum or other cereals, using the entire green plant (not just the grain).
soil organic carbon (SOC)	the total carbon stored in soil organic matter expressed as % C per 100 g of soil – in general soil organic matter contains approximately 58% C, therefore a factor of 1.72 can be used to convert SOC to SOM (NB calcareous soils contain much more inorganic C than SOM)
soil organic matter (SOM)	Soil organic matter is the non-living product of the decomposition of plant and animal substances and residues. It consists of 1) partly decomposed residues (active SOM), 2) microbial biomass and decomposition products, 3) humus (a well-decomposed stable mix of complex carbon molecules), and 4) inert organic matter. SOM does not include living soil organisms (other than microbes), undecayed residues or surface litter, or inorganic (mineral) soil components.
soil sealing	the loss of soil resources due to the permanent covering of land for housing, roads or other infrastructure
sub-lethal	an negative effect on individuals that survive exposure to a toxin, ie a decrease in fitness through changes in physiology and/or behaviour, for example by decreasing fecundity or lifespan or flying behaviour (Desneux et al, 2007)
sustainable	'sustainable intensification' is defined as producing more from the same area of land while reducing negative environmental impacts and increasing

intensification	contributions to natural capital and the flow of environmental services (Baulcombe et al, 2009); this refers to increasing production on existing farmland rather than bringing new areas into cultivation, but at the same time doing this in a way that reduces the negative environmental impacts, and production can refer to food, biomass, fibre, and the range of other ecosystem services provided by agricultural land
synergistic impact	effect of the interaction of several components/factors/organisms that causes higher impacts than the sum of their individual impacts
target	a target species is a species that is deliberately killed as part of the GM or pesticide design, eg insects killed by the toxin in GM insect-resistant crops, weeds killed in GM herbicide-tolerant crops
tolerance (to stressor eg herbicides, insecticides, GM product)	tolerance is the inherent ability of a species to survive and reproduce after exposure to a pesticide or other stressor, for example because it has a naturally low susceptibility
trait (GM trait)	a trait is the particular form of a character of an organism, eg red flower colour or herbicide resistance; most GM traits are expressed by a single gene (whereas most traits eg yield are the result of a complex interaction of many genes); see also genotype
transgene	the genetic sequence that expresses the transgenic trait, taken from an unrelated species and inserted into the GMO (as opposed to cisgene)
transgenesis	the movement of genes between organisms which cannot breed (and which belong to different species); see definition of cisgenesis
tritrophic exposure	exposure of an organism to the stressor (pesticide, metabolite or GM product) via another organism on which it feeds or parasitizes, and which has fed on the plant and/or stressor; exposure of an organism to the stressor (pesticide, metabolite or GM product) via the faeces of another organism that has fed on the plant and/or stressor (see also bitrophic exposure)
volunteer population	a population of crop plants that has propagated in the crop field itself (ie within the subsequent crop or crops) from previous plantings of that crop
weedy races (of crops)	crop varieties that are no longer cultivated and have become naturalized in the wild
zero tillage (no-till)	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.

INTRODUCTION

A. Objectives of the study

The overall purpose of this study is to explore the options for sustainable agricultural production in the EU, in the context of rising demands for biomass for energy and other industrial purposes, climate change and increasing impacts on biodiversity and ecosystem services[1]. It forms the first of a series of five studies which examine various technological options for increasing the productivity, efficiency, sustainability and resilience of agriculture as a means of addressing food security in light of the anticipated growth of the global population to 10 billion people by 2050[2].

Agriculture operates within a global market and the responses appropriate to address food security globally will inevitably vary in different parts of the world depending on factors such as land availability, its fertility, the price and profitability of different crops, levels of technological development and technology transfer, future climatic and other environmental conditions as well as policies influencing land use. However, one of the central challenges is to achieve increases in crop production and agricultural productivity in a way that also restores biodiversity and other required environmental services, and achieves a sustainable use of natural resources at the same time as reducing greenhouse gas emissions and ensuring the sector adapts to climatic changes. The term 'sustainable intensification' has been coined to describe this twin challenge of increasing the productivity of agricultural land to produce more food and more environmental services in the face of a changing climate (Baulcombe et al, 2009; Foresight, 2011)[3]. This is not a new challenge of course. The need to make agriculture more sustainable has been the focus of attention for at least the last four decades (eg Carson, 1962; IUCN et al, 1980; O'Connor and Shrubb, 1986). However, current concerns about food security have reinvigorated this debate and underpinned the importance of sustaining the earth's productive capacity in the long term.

The focus of this study, therefore, is the interrelationship between agricultural land management, climate change and biodiversity and the potential for a range of innovative options for increasing agricultural production in the EU (largely through increasing agricultural productivity) in a way that:

- reduces the climate impacts of agriculture through mitigation actions;
- reduces the detrimental impacts of climate change on agriculture through adaptation actions; and
- reduces the detrimental impacts of agriculture on biodiversity and other environmental ecosystem services.

This **introduction** sets the context for the study by providing a brief overview of the anticipated trends in the demands from agricultural land in the EU over the coming decades and the factors influencing these.

Part 1 focuses on the interactions between agriculture and climate change, outlining the impacts of agriculture on the climate as well as the implications of climate change for agriculture. It then looks at the different types of farm management that could be put in place to:

a) adapt to the impacts of climate change;
b) mitigate the impacts of agriculture on the climate; and

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[1] See glossary for definition of key terms

[2] this is an assumed population scenario for the project rather than a prediction: it corresponds to the current UN high fertility variant population projection for 2050 - the medium fertility variant predicts a population of 9.3 billion in 2050 and 10.1 billion in 2100 (UNDESA, 2011).

[3] See glossary for definition of key terms

c) optimise potential synergies and trade-offs between these actions, other environmental objectives and farm productivity.

Part 2 examines the relationship between agriculture and biodiversity and the provision of environmental ecosystem services, taking account of the impacts of land use changes, different management techniques and technologies. It identifies key practices that can help to maintain and increase biodiversity on farmland (and provide other benefits such as those related to climate change mitigation and adaptation), and what measures are needed to ensure their wider adoption. It also provides a detailed analysis of the current and possible future impacts on biodiversity of:

a. the cultivation of genetically modified crops in the EU;
b. crops for biofuel production;

The study also provides a detailed analysis of the pressures affecting:

c. the conservation of plant genetic material as a means of preventing decline in the genetic diversity of food crops; and
d. pollinator decline, including the collapse of European honeybee colonies;

and identifies options for addressing the factors driving these negative trends.

Sustainability issues relating to the transport, processing and marketing of food are outside the scope of the study but their importance will be referred to in appropriate contexts.

B. Setting the context: future demands on agricultural land – trends and drivers

The rationale for this study is to gain a greater understanding of the potential for agriculture in the EU to increase the production of commodities in view of a growing global population in a way that does not cause damage to the environment and takes into account anticipated changes in climate. In so doing it is important to recognise that any changes in agricultural production or land use in the EU may have global implications, affecting the volume and type of commodities that are imported as well as exported, with related environmental impacts. In considering the EU's role, a broader global perspective is therefore important.

Two of the key drivers affecting overall demand for food are population size (and dynamics) and economic growth. Globally, the population growth of the 1950s-1970s has now slowed but the United Nation's medium projections show global population is likely to grow by 27 per cent by 2030, reaching 9 billion by mid-century and levelling off at around 10 billion towards 2100, with the greatest growth rate in Africa (UN-DESA, 2011). In Europe, population levels are expected to peak by the mid-2030s and then start to decline (FAO, 2006; Rosegrant et al, 2006; UNDESA, 2011). Indeed populations have already started to decline in about a quarter of EU Member States. In addition, the changing age profile of the population, patterns of migration from rural to urban areas (and vice versa) as well as immigration and emigration trends also influence demand for food and other services from land.

As societies have become more affluent, they have tended to consume more processed foods of all types, more livestock products (dairy produce and meat) and to be more wasteful with food. Increased demand for livestock products also increases the demand for land for crops for animal feed, both carbohydrates and protein. Much of Europe has experienced considerable economic growth until recently and this has had a major impact on consumption patterns, with knock on impacts on the environment as well as health. Changes in consumption patterns also are being witnessed increasingly in transition economies such as China, some other parts of Asia and Brazil. For example, world meat consumption has increased by six per cent over the past five years as a result of demand from emerging countries, such as India and China. In the EU by contrast per capita consumption has stayed rather stable (OECD and FAO, 2010).

However, alongside the expanding demand for food, there is evidence to suggest that a larger, higher income, better fed and better informed population may start to care more about the environment and the services that nature provides (for example TEEB, 2011).

There is consensus that demand for agricultural products at a global level will rise significantly by 2050. The FAO has estimated that demand for food will rise by approximately 70 per cent over the next 40 years to feed a rising world population with changing dietary trends (FAO, 2011a). However, it is expected that the majority of this increased demand will arise and be met outside the EU, largely in Africa. This will be achieved by a combination of bringing non-agricultural land into production and by increasing yields (FAO, 2011a; OECD and FAO, 2012). Some increase in production is likely in the EU, particularly in relation to cereals but largely in the EU-12 Member States. Yields in the main productive areas of the EU-15 are already high and the environmental impacts of production are considerable, and in some situations unsustainable (EEA, 2012a; Gay et al, 2009; Sutton et al, 2011). At present there is also increased demand for biomass for energy purposes grown on agricultural land in the EU, although this is primarily driven by policy. This could grow in future in response to renewable energy policy and could include more novel crops such as short rotation coppice.

However, the fact remains that in the EU, there is already a significant environmental "deficit", with serious concerns about the state of biodiversity as well as water and soil resources. Evidence suggests that, although there continues to be some potential to increase crop yields in the EU, the extent of the increases that are likely to be sustainable - ie feasible without further depleting natural resources, particularly water - is far more limited (Hart et al, 2013). The level of yield increases that can be achieved sustainably will to some extent depend on new technological developments and their wider use, which in turn will depend on investments in agricultural research, development and extension (Alene and Coulibaly, 2009; Beintema et al, 2012; IAASTD, 2009)

While changes in consumption patterns (particularly decreases in meat consumption), and a greater effort over time to reduce food wastage are necessary conditions, substantial changes in agricultural systems will be required in Europe in order to reduce the existing environmental deficit as well as deal with new pressures, such as those associated with climate change (EEA, 2010a; Freibauer et al, 2011).

Indeed **climatic changes** present many challenges for increasing production in the future. Increased frequency of extreme weather events, incidences of pests and diseases as well as climate variability and higher overall temperatures all have the potential to outweigh the positive impacts on some yields of increased CO_2 density and warming. For example, there is some evidence to suggest that a 1°C increase in global mean temperature could reduce global grain yields by 10-17 per cent, although such impacts would vary in different parts of the world and for different crops (Lal, 2012; Maracchi et al, 2005). Increasingly, however, experts are warning that the target to limit global warming to 2°C above pre-industrial levels will not be met (Anderson and Bows, 2011; Pricewaterhouse Coopers, 2012) and some are warning that the world is on track to a 3.5°C rise[4]. It is therefore highly likely that under such a scenario, impacts on ecosystems, crop production and other ecosystem services in Europe may be more marked than currently anticipated in the literature (Donatelli et al, 2012; Olesen et al, 2011; Olesen et al, 2012; Semenov and Shewry, 2011).

These serious challenges facing global food systems mean that there is an urgent need to take action on the problems of climate change, environmental degradation and resource depletion at the same time as addressing food security. Changes in technologies and land management practices that lead

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[4] Statement by International Energy Agency Executive Director on COP 18
http://www.iea.org/newsroomandevents/news/2012/december/name,34193,en.html

to the more sustainable production of food will be a central element of strategies for reducing pressure on land resources in Europe and in those countries from which the EU imports products. This report explores some of those opportunities.

PART 1 CLIMATE CHANGE AND AGRICULTURE

Agricultural activities depend directly on climatic conditions and will be influenced by climate change. Agricultural activities also use natural resources and have an impact on climate change. This part of the study looks into the possible effects of climate change on conditions for European agriculture, as well as assessing the opportunities for reducing the emissions of greenhouse gases from agriculture and land management.

Chapter 1 assesses the possible effects of climate change on conditions for agriculture within EU.

Chapter 2 examines opportunities in the sector for mitigating the effects of the warming climate.

Chapter 3 provides an overview of agricultural management actions that may have potential benefits for mitigation and for adaptation.

Chapter 4 provides recommended options for action in the EU.

1 IMPACTS OF CLIMATE CHANGE ON EU AGRICULTURE

1.1 Changes in crop growth and agricultural productivity

Most of the evidence on the likely effects of climate change on agriculture relate to crop production (yields and location), whilst the impacts on livestock has received less attention (Hjerp et al, 2012). It is important to note that there are considerable uncertainties inherent in longer term projections in terms of the likely scale and timescale of the predicted impacts, which are also likely to interact with each other in complex ways.

Climate change already affects crop productivity in Europe with changes in the growing season of crops, the timing of the crop cycle, water availability and irrigation requirements and the increasing frequency and unpredictability of extreme events such as floods, droughts, hail, and storms (EEA, 2012b). The increase in temperature has resulted in an increase in the growing season by more than ten days since 1992[5]. The observed shifts include earlier flowering dates and later harvest dates which alone generally result in higher yields. However, some crops, including cereals, cannot always benefit from this change, due to lower water availability to plants in the growth phase or a shorter grain filling phase[6]. These are some of the factors constraining any growth in wheat yields in parts of Europe, despite advances in crop breeding (EEA, 2012b). Other restraining factors, such as farmers' attitudes and restrictions on fertiliser and pesticide use, may at first appear unrelated to climate change, but may still be linked. Increased uncertainty over crop survival to harvest may be one factor making farmers reluctant to invest very much in increasing yields, especially when prices are low (Hart et al, 2013).

Further lengthening of the growing season is predicted to lead to the northward shift of areas suitable for certain crops, particularly those currently widespread in southern Europe, such as maize, sunflower and soybean (EEA, 2012b), but this may not translate into an overall increase in productivity.

The lengthening of the growing cycle, reduced days of frost and more favourable overall climatic conditions in northern Europe, are expected to lead to some increases in productivity in these latitudes but the adverse effects relating to extreme weather events (eg storms, hail, pests) may be of similar magnitude (EEA, 2010b; EEA, 2012b).

Any increase that does occur in northern Europe may however be offset by reduced yields in southern Europe. By 2030 southern European regions could experience a 5-10 per cent decrease in yields compared to current levels, mainly because of changes in the growing cycle and insufficient water availability for crop growth (Bowyer and Kretschmer, 2011) as discussed below). Quantitative estimates of the distribution and magnitude of such effects vary between different yield models but concur on the overall trends (Donatelli et al, 2012; Hart et al, 2013). Occurrences of drought and high temperatures during the first decade of the 21st century have already greatly reduced crop yields in central and southern Europe (Trnka et al, 2011b). It is foreseen that heat waves and droughts increasingly will affect EU agriculture and aggravate already existing climatic pressures. The impacts of unfavourable weather events at unpredictable and different points in crop growing cycles could lead to increased variability in yields (EEA, 2012b; Maracchi et al, 2005; Trnka et al, 2011a).

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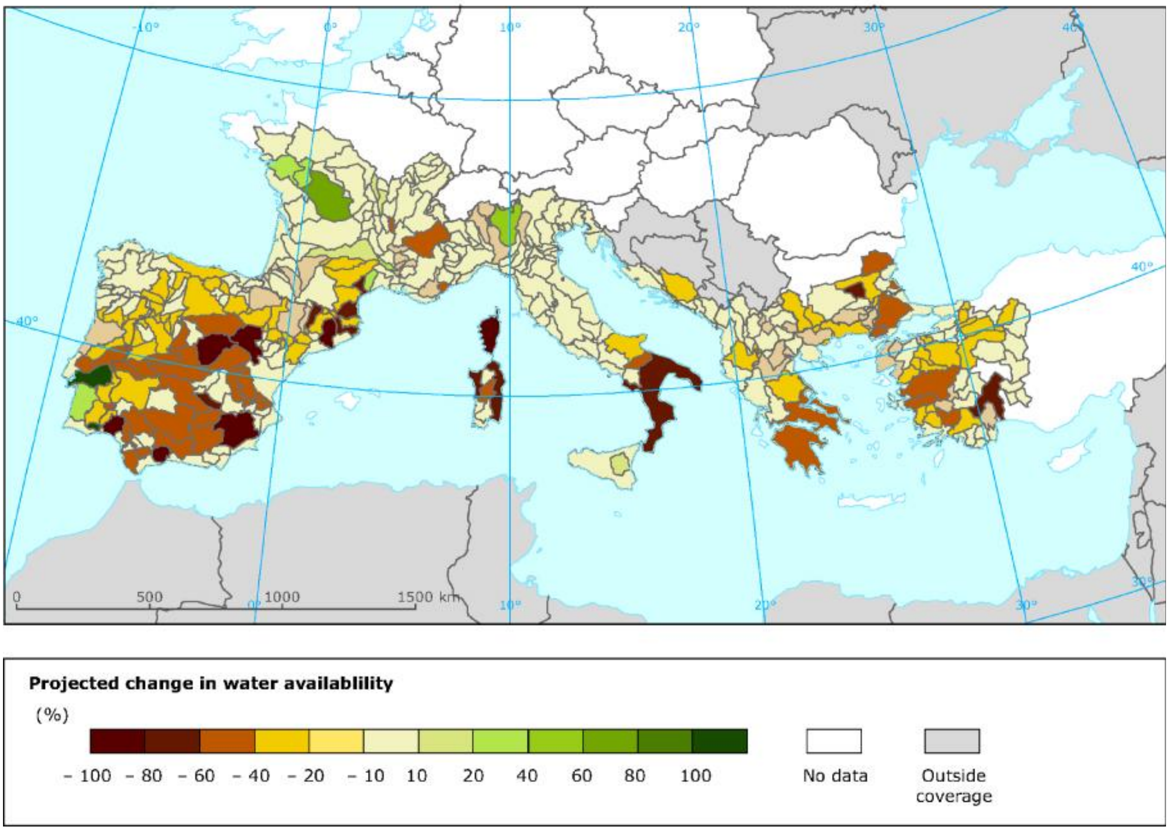
[5] The datasets used by EEA relate to Europe defined with a wider geographic focus than the EU-27.

[6] For example winter wheat has experienced a shorter grain filling phase caused by the fact that its flowering shifted prior to its maturity, with negative effect on yields.

1.2 Changes in water availability

The impacts of climate change on water availability and crop yields are also complex. On the one hand, the efficiency with which crops use water during the growth phase increases with higher concentrations of CO_2 in the atmosphere, thus rising CO_2 levels may positively affect crop productivity. On the other hand, higher temperatures increase evapotranspiration rates, resulting in the likelihood of crops having greater water requirements in the future, as evident in southern Europe (EEA, 2012b; EEA, 2012c). Crop choice and crop management are additional factors which, together with efficiency of water use, determine whether the change in yield is positive or negative. The complex interaction of all these factors also has a major effect on water demand for sustaining the levels of agricultural output. There are indications that current water supply for agriculture may be hard to sustain in some Mediterranean countries, with a predicted increase in water scarcity problems particularly where increasing irrigation is required (EEA, 2012a; EEA, 2012c; Iglesias et al, 2007a); see Box 1-1 and Figure 1-1.

Figure 1-1 Projected change in water availability in the Mediterranean region by 2071-2100



Relative change in water availability for irrigation as projected under the A1B emission scenario by the HIRHAM (DMI) regional climate model for 2071–2100 relative to 1961–1990. Source: Iglesias et al, 2012 cited in (EEA, 2012c)

Box 1-1 Water use for irrigation

In France, Greece, Italy, Portugal and Spain, 80 per cent of total water use is already for agriculture in comparison to 24 per cent across Europe as a whole. By comparison, in central and northern Europe agriculture is typically rain-fed and accounts for less than one per cent of total national water abstractions. Accelerated water use for irrigation has been a catalyst for greater food production in southern Europe since the 1970s. But it has come at a significant environmental cost, for example to biodiversity as discussed in Chapter 5, and to water availability in the medium and long-term. Excessive groundwater exploitation threatens some of the most important wetlands of southern Europe. Conversely, further decreases in the natural capacity of wet areas and wet features to maintain regular flows in river basins may adversely affect water availability. In central and south-eastern Europe, predominantly in Hungary, Romania and Bulgaria, irrigation infrastructure had largely deteriorated by 1990 or was abandoned in the subsequent process of re-structuring. Water abstraction rates have subsequently dropped, for example in Bulgaria and Romania by 80 to 90 per cent compared to 1990 levels. The lack of efficient irrigation and natural water retention methods affects production levels in arid zones, although inappropriate crop choice and soil management may be an additional factor.

Sources: (Wriedt et al, 2008) (EEA, 2012b), (EEA, 2012c); (Russi et al, 2013); (Poláková et al, 2013)

Other pressures in water stressed regions, such as southern and south-eastern Europe, include the increasing frequency of droughts and growing demand for water from industry and urban areas, often competing with agriculture (EEA, 2012c). Figure 1-2 shows the water exploitation index for each EU Member State[7], which compares abstraction levels to the water available and is the main measure for assessing the degree to which continued water abstraction is sustainable. It gives an indication of the water stress already experienced in Member States in recent years.

In addition to water supply issues, climatic conditions, particularly storm events and wet periods, play an important role in the level of diffuse water pollution by nitrates and phosphates from farming. Nitrate is most prone to leaching from soil when rainfall is higher and, similarly, phosphates enter surface water following periods of rain (Hoffmann et al, 2009). Given the observed trend in some parts of Europe towards a sequence of drought years interrupted by wet years, there is a common concern that the effects of leaching on water quality in wet years may affect the availability of clean water for crop irrigation in the dry years.

Climate change already affects the quality of freshwater and aquatic environments in Europe. By shifting the algal blooms in lakes and rivers to earlier dates in the year the impacts of eutrophication are enhanced. Increases in nutrient and dissolved organic carbon concentrations in surface waters due to warming also combine with the nutrient increases caused by fertiliser run-off (EEA, 2012a; OECD, 2012). This trend also has other environmental costs, for example to aquatic habitats and is expected to continue.

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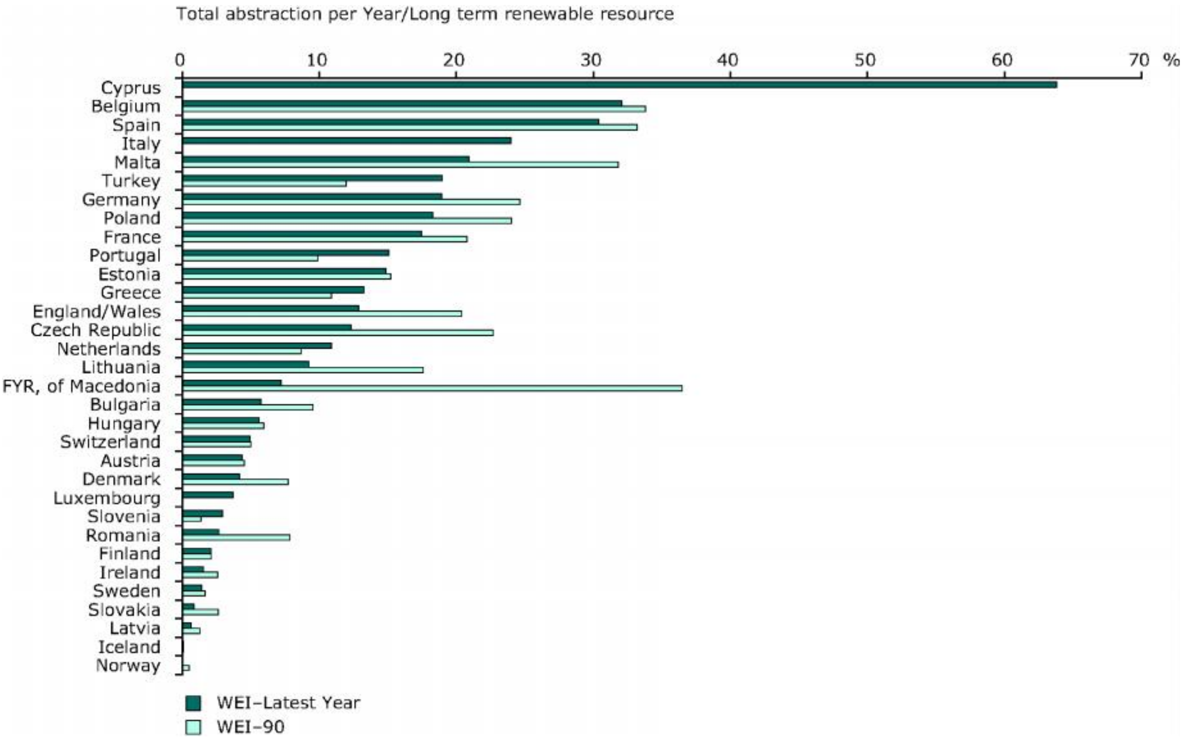
[7] The Water Exploitation Index is the mean annual total demand for freshwater divided by the long-term average freshwater resources, calculated at Member State area level and/or at river basin level

Figure 1-2 Water Exploitation Index in Europe



Source: (EEA, 2012c)

1.3 Changes in flooding

The frequency of flooding events is expected to increase as the climate becomes warmer. The risk of flooding is thought to be greater in the Boreal, Atlantic central, Continental north and Alpine areas compared to other EU agro-climatic zones (EEA, 2012b). Floods are likely to particularly affect lowland agricultural areas in northern Europe where run-off rates in catchments have increased (eg as a result of soil sealing), upstream watercourses have been widened and deepened and active floodplains have been reduced (eg as a result of development) (EEA, 2012a).

Wetland loss, which accelerated in the EU in the last century, adversely affects flows in river basins alongside the loss of floodplains and water meadows, thus weakening resilience to flooding. It is expected that the risk of flooding and its subsequent impact on agricultural production will increase in situations with inappropriate land management (EEA, 2012b).

The impacts of flooding on crops can include lower yields (caused by waterlogging and disruptions during vulnerable stages of development), increased levels of salinity in soils and water in some situations and increased pest and disease problems (Iglesias et al, 2007b). Water retention measures in catchments, such as maintaining grasslands, applying zero-tillage, creating linear features, ensuring soil cover during appropriate seasons and introducing patches of trees (Fiener et al, 2011; Hümann et al, 2011; Reinhardt et al, 2011) increasingly may be required to mitigate the risk of flooding in relevant river basins. Although such actions are likely to be a part of adaptation strategies for agriculture, and may be necessary to maintain medium to long term productivity, they may require changes in land management that could result in localised declines in output.

1.4 Changes in soil characteristics

Soil performs a variety of important functions, such as regulating nutrient and water flow, storage, and filtering. It has a key role in nitrate leaching, and it can store large amounts of organic carbon. Climate change is likely to have complex impacts on soil since changes in both precipitation levels and temperatures can affect the structure of soil and its capacity to leach and exchange nutrients and retain organic matter and water. The changing functionality of soils can be measured by changes in soil organic carbon, soil erosion and soil moisture.

In the long-term, climate change is expected to have an impact on soil organic carbon (SOC) levels[8]. Soils can act as both a sink and a source of carbon and SOC content is directly related to the levels of soil organic matter. Long-term decreases and increases in SOC levels are projected for soils in different climatic zones. There is a considerable likelihood that future SOC levels will be adversely affected by increases in soil erosion and faster decomposition induced by warming and will reflect developments in both land use and management (EEA, 2012b), in turn driven partly by climate change.

In a shorter timeframe, land management practices and land use change are expected to have a greater impact on SOC than climatic changes, which may have little or no effect. However, the interaction between climate and SOC levels is complex and is driven by several climatic and biotic factors on which more research and data is needed.

1.5 Pest/pathogen risk

Pests and pathogens adversely affect agricultural yields and crop quality. Globally, the total potential loss due to pests may vary from about 50 per cent in wheat to more than 80 per cent in cotton production. Weeds have been estimated to be the cause of most losses (over 30 per cent) while animal pests and pathogens are responsible for less than 20 per cent (Oerke, 2006).

Pathogen risks are expected to change in the EU due to climate change, impacting both agriculture and forestry. The main effect on agriculture is expected to be a higher year-to-year variability in yield.

Longer growing seasons, resulting from warmer temperatures, are likely to promote better conditions for the growth and development of organisms such as insect pests and diseases alongside crop growth (EEA, 2012b). However, significant uncertainties remain about the magnitude and direction of change of these risks. Research will be needed to improve the way in which the complex range of effects (listed in Box 1-2) can be accounted for. Together with other challenges, such as insufficient water or nutrient availability, greater pest/pathogen risk or greater competition from weeds may negate the fertilising impact of increased CO_2 concentrations in the atmosphere and of longer growing seasons (Ciscar et al, 2009; Gregory et al, 2009).

Climate change may increase the risk of crop damage, but the actual impact of pests and pathogens on future yields will depend largely on the degree to which they can be controlled. Both the science and new policy measures underline the need to shift toward integrated pest management. This uses crop rotations, more pest- and disease-resistant crop varieties, field edge management to favour beneficial insects, and other alternative practices to complement the use of chemical pest control (Boller et al, 2004).

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[8] With every 10°C increase in soil temperature the rate of mineralisation of soil organic matter which causes a release of nitrous oxide approximately doubles.

Box 1-2 Effects of climate change on pest/pathogen risk

Factors affecting the susceptibility of crops to pests. These include the presence of the pest and the host in a given geographic zone (ie exposure, depending in particular on the dispersal capacity of the pest), the level of virulence of the pest and the level of resistance of the host (sensitivity), the timing of the interaction between the pest and its host (depending in particular on survival and reproduction conditions of the biotic agent), but are also influenced by crop conditions. For example a forest is more susceptible to pests after a storm, and the use of monocultures increases risks within agro-ecosystems.

Shifts in the range of presence. The range of pests is expected to shift, mainly northwards in Europe together with crops and tree species. This may change the interaction potential, eg when new crops are susceptible to pests present in the newly cropped area, or if pests move to new areas. Moreover, pathogens may encounter new hosts and /or new potential vectors. Climate change may profit both native and exotic pest agents. As an example, Pine Processionary moth (*Thaumetopoea pityocampa)*, a native widespread defoliator, is exhibiting altitudinal shifts due to improved winter survival, and latitudinal shifts; it could also recruit new host species.

Increased proliferation of pests. Many insects can complete a greater number of reproductive cycles under favourable climate conditions, thus increasing the risk of proliferation. Higher winter temperatures also may allow certain pests to survive winter conditions better, resulting in earlier and greater infestations.

Changes in conditions alter the resistance of crops. Changes in temperature and humidity are also affecting the resistance of crops and forests. A review shows differential resistance to disease and pests under changed temperature and drought conditions, as well as decreased impact from pests in certain studies.

Adaptation issues. Many crops have been selected to resist pests and pathogens occurring in their natural environments. However, several examples show that climate change may compromise the effectiveness of the selected traits. In addition, most pathogens have short reproductive life cycles, while crops and more particularly trees have longer life cycles, and longer timespans are necessary to select resistant strains. This factor may enable faster adaptation to changing climatic conditions by pests than by crops and forests.

Sources: (BioIntelligence Service, 2011) (Bindi and Olesen, 2011) (Gregory et al, 2009)

1.6 Fire risk

Reduced rainfall in summer and more extreme drought events are expected to increase the frequency and extent of the conditions that allow for damaging wild fires, especially in Mediterranean countries (EEA, 2012b). Within agricultural systems, fires may affect some croplands, semi-natural grasslands, shrublands/heathlands, moorland, woody pastures (eg dehesas and montados) and agro-forestry. Within semi-natural habitats, fire is to some extent an integral part of certain ecosystem dynamics, prompting re-generation and controlling insect and disease damage etc. In some habitats the controlled use of fire is an important management tool for maintaining open habitats, improving forage quality and grazing conditions, and avoiding intense wild fires, particularly parts of northern Europe (Tucker, 2003).

However, uncontrolled wild fires can have devastating impacts on soil and biodiversity as well as on production. The key factors in wildfire risk are weather and vegetation type, whilst fuel load and topography affect the severity of the fire. Over centuries management practices to reduce the fuel load in vegetation have included grazing, thinning and controlled burning. These have become less common with the gradual withdrawal of management, including livestock grazing, and abandonment of extensive agriculture and forestry in many parts of Europe affected by fires. Uncontrolled fires, particularly where they affect organic soils, can release large amounts of soil carbon and disrupt carbon sequestration (eg Bain et al, 2011).

1.7 Energy supply

Climate change is expected to reduce demand for heating in northern and north-western Europe. Since 1980, the number of heating degree days[9] has decreased by an average of 16 per year in these regions (EEA, 2012b), although there may be colder winters and need for more heating in those periods. In southern Europe it is however foreseen that climate change will increase energy demand for cooling strongly, with potentially higher peaks in electricity demand in the summer than at present. These trends are expected to continue and will affect the energy performance of farm buildings (EEA, 2012b). Although artificial cooling of livestock housing was recommended in some literature on climate change adaptation, there is a clear trade-off between the benefit for animal well-being and adverse effect on energy supply (Ecologic, 2010; Hjerp et al, 2012).

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[9] A 'heating degree day' is a proxy for the energy demand needed to heat a building based on outside air temperature.

2 IMPACTS OF EU AGRICULTURE ON CLIMATE

Climate is being influenced by greenhouse gas (GHG) emissions from agriculture worldwide, with as much as 18 to 30 per cent of global GHG emissions attributed to agriculture[10]. The corresponding share for the EU-27 is about 9 per cent but this figure does not account for the footprint associated with the production of agricultural inputs and certain imports (see section 2.4). Agriculture and land use are largely outside the global climate change commitments that are mandatory in other sectors (see Box 2-1). However in 2009 the EU adopted commitments to curb total GHG emissions by at least 20 per cent below 1990 levels by 2020. GHG emissions from European agriculture have fallen substantially since 1990, but the future level of emissions from the agricultural sector remains important for the success of these commitments. The agricultural share of overall EU emissions is expected to rise by 2050, with faster rates of mitigation in other sectors suggesting that action in the sector will attract greater attention.

This chapter first considers key greenhouse gas emissions from agricultural sources in section 2.1, and then the capacity to sequester organic carbon in agricultural soils and vegetation in section 2.2. Finally section 2.3 provides a summary of quantitative estimates of the mitigation potential of the sector based on published sources. IPCC AR4 methodology is followed unless we provide a note on using other methods.

Box 2-1 EU commitments to curb GHG emissions within the agricultural sector

Agriculture is important for the success of EU commitments to curb GHG emissions by 2050 both because of the effect of land management on carbon sequestration and the emissions from soils and land use change on a large part of Europe's territory. For a variety of reasons, agriculture has been integrated only partially in the EU's current quantitative targets for emission reductions. The sector remains outside the reduction commitments set out for the Emissions Trading System (ETS). Non-CO_2 agricultural emissions (relating mostly to the livestock management and use of fertiliser on soils) count toward the targets adopted in non-ETS sectors[11]. Efforts to reduce carbon dioxide emissions from land use, land use change and forestry (LULUCF) have so far only been reported to the UNFCCC and excluded from the quantitative EU reduction targets. However, from 2014 onwards, accounting rules for LULUCF will be implemented as part of EU legislation[12] and there is a wide political agreement that the associated emissions remain critical for meeting the EU climate objective of limiting the global temperature increase to no more than 2°C beyond pre-industrial levels. After 2020, land use and soil related emissions may be considered for inclusion within the LULUCF framework in the next EU reduction commitments as well.

Sources: (European Commission, 2011a; European Commission, 2012a)

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[10] The higher estimate is generated in a modelling scenario including emissions from land-use change with deforestation, the lower estimate does not factor in these emissions. Note that some of the soy feed imported in to the EU comes from land affected by deforestation in the recent past.

[11] The 'Effort Sharing Decision' stipulates the commitment to reduce emissions in the relevant sectors (ie agriculture, waste, buildings, transport) within the EU by 10 per cent by 2020 in comparison to 2005 (Decision No 406/2009/EC of the European Parliament and of the Council of 23 April 2009 on the effort of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020.

[12] Decision No 529/2013/EU of the European Parliament and of the Council of 21 May 2013 on accounting rules and action plans for greenhouse gas emissions and removals resulting from activities related to land use, land use change and forestry

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 (EEA, 2012b)[13]. 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 between individual Member States. See Annex 2 for more details.

The largest share of the EU's agricultural GHG emissions comes from nitrous oxide (N_2O) and methane (CH_4). While the global warming potential (GWP_{100}) of carbon dioxide is 1, the GWP_{100} value for methane is 25 and for nitrous oxide is 298[14].

Agricultural emissions are associated with a range of management activities but also with biological processes that naturally emit GHGs. Uncertainty about the magnitude of emissions is therefore more pronounced in agriculture than in industrial sectors. For the same management activity, net emissions may vary in diverse agronomic, bio-physical, environmental and climatic situations.

Nitrous oxide emissions stem primarily from the use of manure, fertiliser and external inputs to soils, whereas methane emissions result from livestock digestion and manure management[15]. These emissions are reported by the EU Member States on an annual basis as part of a common UNFCCC reporting framework under the category 'agriculture'. It is worth noting that emissions of reactive nitrogen (primarily from ammonia from manure) also are among the top causes of terrestrial ecosystem eutrophication, which leads to significant biodiversity loss (Dise, 2011). Nitrous oxide emissions from agriculture are particularly difficult to calculate accurately.

Further emissions that are closely linked to agricultural activities include carbon dioxide (CO_2) emissions from agricultural soils and vegetation, which, under international rules are reported separately within the 'land use, land use change and forestry' (LULUCF) category[16].

Cropland soils in particular act as a net source of emissions, for example through oxidation of soil carbon following soil erosion or tillage. According to official reports, croplands in the EU-27 emit about 70 million tonnes of CO_2 equivalent per year including N_2O emissions from the cultivation of organic soils and the mineralisation of soil organic matter as a result of land use conversion and drainage (European Commission, 2009a) (see Box 2-3). On the other hand, soils' capacity to remove the carbon dioxide from the atmosphere by sequestration can reduce emissions, with the balance broadly neutral in the EU in recent years.

CO_2 emissions from agriculture can result also from the use of fossil fuels for agricultural machinery, transport, heating and drying. Under IPCC accounting rules these emissions are reported under the energy sector, along with transport emissions.

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[13] Emissions from land use, land use change and forestry are not taken into account in the calculation. Reference year is 2010.

[14] Global warming potential (GWP_{100}) is a measurement unit comparing the amount of heat trapped by a certain mass of the gas in question to the amount of heat trapped by a similar mass of carbon dioxide; calculated over a time interval of 100 years (IPCC AR4, 2007).

[15] Methane emissions also arise from rice management which is a relatively minor sector within the EU.

[16] 'Land use, land use change and forestry' (LULUCF) is a category within the UNFCCC accounting framework for certain GHG emissions. It includes the carbon pools of living biomass (above and below ground), dead organic matter (dead wood and litter) and organic soil carbon for all land categories (forest land, cropland, grassland, wetland, urban land and other land). Emissions from land use change (such as permanent pasture to arable) and deforestation are also reported under this category.

All types of emissions from upstream activities (eg production of fertilisers and pesticides and the production and maintenance of machinery) also could be assigned to the footprint of the agricultural sector if the system boundaries were altered with this intent. In particular, the amount of fossil fuel energy embodied in nitrogen fertiliser, with due effects on climate change, is already high and is expected to double to meet demand by 2050 (Malingreau et al, 2012)[17]. These estimations, whilst outside current accounting conventions, are helpful in illuminating the linkages between the relative greenhouse gas burdens along the food chain and identifying the most sizable opportunities for mitigation. For illustration, a study on the footprint of the whole livestock sector food chain showed that it amounts to between 630 and 863 million tonnes $CO_{2\text{-eq}}$, or 12–17 per cent of total EU27 GHG emissions in 2007 (Bellarby et al, 2013)[18]. Calculating the emissions associated with the production of all key inputs is complex, however, and these are largely outside the focus of this study.

Non-CO_2 agricultural emissions in the EU-27 declined by over 20 per cent in the period from 1990 to 2010 (see Annex 2)[19]. This decreasing trend is the result of several factors, some arising from reduced production and some from improved productivity.

The drop in agricultural production in the new Member States following the change in the political and economic framework after 1990 was a major influence in the downward emission trend. Also important were: changes in agricultural policy away from coupled support; improvements in manure management and farm management practices; and the development and implementation of agricultural and environmental policies (eg the Nitrates Directive and cross compliance).

Reductions in methane emissions resulted primarily from a significant drop in cattle numbers, and also from an increase in animal productivity and improvements in the efficiency of feed use. Nitrous oxide emissions from agricultural soils diminished mainly due to a reduced use of organic and mineral nitrogen fertilisers as well as indirectly due to the existence of obligatory set aside (until its abolition in 2008), and improved protection of permanent pasture (European Commission, 2009b). However, there are other issues that are not taken into account in the official statistics; some are set out in Box 2-2.

Most of the statistics currently available for GHG emissions from agriculture cover periods that ended before the recent increases in production and some emissions might be expected to rise again as production increases, depending on the impact of improvements in productivity and resource use efficiency.

Box 2-2 GHG emissions unaccounted for in the official agricultural statistics from 1990 to 2007

Meat imports. EU beef imports have grown since 1990. Lower livestock numbers in Europe played a role in reducing GHG emissions but emissions in countries exporting to Europe will have grown.

Set-aside. The mandatory set aside introduced in the 1990s meant that a proportion of arable land was not cultivated each year, so reducing input use. This will have contributed to the overall degressive trends of reduced GHG emissions from agricultural soils. Since 2008 the majority of the

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[17] Similarly, the energy for producing phosphate fertilisers is expected to increase as the easily usable high grade reserves are gradually becoming depleted (Schröder et al, 2010).

[18] These calculations are based on a life cycle analysis of beef and dairy products, taking into account GHG balance associated with EU exports, imports and waste. Therefore they differ from a sum of relevant emission data in national inventories for the purpose of UNFCCC reporting.

[19] Includes CH_4 and N_2O emissions from agricultural soils, manure management and enteric fermentation. Emissions from soil management decreased by 23.3 per cent, from manure management by 19.9 per cent and from enteric fermentation by 22.0 per cent

former set-aside has reverted to arable production with associated GHG increases.

Biomass production for energy. Biomass production for EU use, which increased steeply after 2007, takes place to a considerable extent outside Europe, competes with other land uses and has other environmental impacts including emissions associated with deforestation, and the ploughing of grass. These effects are outside the official GHG emission reports up to 2007.

Effects along the food chain. As noted above official GHG emission reports do not take into account the full footprint of inputs into agricultural products, such as fertiliser and feed or other aspects of the food chain, for example food waste. A recent life cycle analysis of the EU livestock sector, taking into account EU exports, imports and waste, demonstrated that overall emissions are much higher than those reported, amounting to between 630 and 863 million tonnes $CO_{2\text{-eq}}$, or 12–17 per cent of total EU-27 GHG emissions in 2007.[20]

Sources: (Bellarby et al, 2013; Diaz-Chavez et al, 2013; European Commission, 2009b)

2.2 Sequestration in soils and vegetation

Land use, land use change and forestry in Europe is a substantial net carbon sink overall (EU 2009a). This is mainly because of the positive contribution made by woodlands, whether managed or not. The land is also responsible for large amounts of stored carbon, much of it in a form that could be released to the atmosphere. EU-27 soil carbon stocks contain an estimated 75,000 Mt of carbon (EEA, 2012b).[21]

Agricultural land use in the EU contributes to both emissions and removals of GHG from the atmosphere. Grasslands have been a net sink in the EU, removing about 13 Mt of carbon per year[22] (European Commission, 2009a). Wetlands on peat soils, such as bogs and fens, are also important as carbon sinks, as long as they remain intact and do not become degraded. When drained or burnt for agriculture, they become a source of CO2 emissions for a long time (Box 2-3).

Box 2-3 Impact of cultivation and drainage on peat soils

Around 16 per cent of Europe's peatland, and up to 70 per cent of peatland in some Member States, is currently used for agricultural purposes and drained, including the vast majority of peat in Northern and Western Europe. Nitrous oxide is released from cultivated peat soils due to the mineralisation of organic matter for decades after drainage. In 2007, EU-27 emissions from cropland on peat soils amounted to 37.5 million tonnes CO2-eq, corresponding to 88 per cent of total emissions from cropland.

Source: (European Commission, 2009b; Gobin et al, 2011; Schils et al, 2008)

Carbon sinks are considered within the official GHG reports for land use and land use change together with the relevant emissions (LULUCF). By 2007 annual removals increased by around 83 per

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[20] These calculations are based on a life cycle analysis of beef and dairy products.

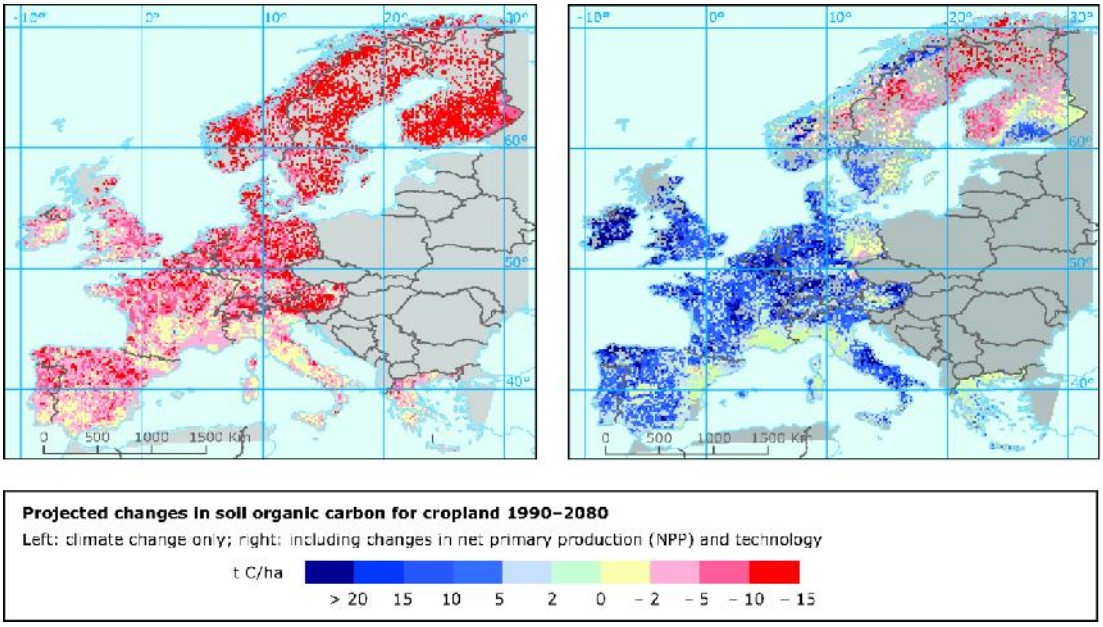
[21] Around 50 per cent of the overall C stock is located in Ireland, Finland, Sweden and the United Kingdom, because of the large area of peatlands in these countries (Bain et al, 2011; Gobin et al, 2011; Joosten, 2009; Schils et al, 2008; Worrall et al, 2011)

[22] Grasslands have relatively high levels of soil carbon content compared to croplands. This is due to the stable soil environment which benefits accumulation of SOM, and the fact that SOM has accumulated during the whole lifetime of the grassland communities (Gobin et al, 2011; Jones, 2010; Soussana et al, 2010). The IPCC emission factor for grasslands represents both the living biomass and below-ground carbon content.

cent for grassland (which turned from source to sink) and emissions from cropland, which remain a net source, decreased by 5.2 per cent in the EU-27 as compared to 1990. The overall trends mask different developments in the various Member States.

Climate change and land management methods are two key (and inter-related) factors potentially affecting soil organic carbon (SOC) loss in agricultural soils (EEA, 2012b; Smith, 2012). SOC may be adversely affected by possible increases in soil erosion, faster decomposition of soil organic matter induced by warming as well as by future land management changes. Further research is needed to clarify the interactions between these diverse factors and the potential enhancement of soil productivity that may result from the 'CO2 fertilisation' effect (Ciais et al, 2010; Lal, 2012). Figure 2-1 shows potential benefits to SOC that could be gained through improved crop management practices, such as new technologies, higher-yield crop types, and increased net primary production (NPP) of soils, over a considerable period.

Figure 2-1 Projected changes in soil organic carbon for cropland 1990-2080



Source: (EEA, 2009)

Appropriate land and farm management can lower the amount of carbon dioxide emitted into the atmosphere from cropland, as well as increase the carbon sequestration potential of arable soils in the EU. Management aimed at maintaining or enhancing SOC stocks in agricultural soils often provides co-benefits to soil fertility, workability through less compaction, water infiltration and holding capacity and reduced erosion risk (Lal, 2004) (see section 3.2).

2.3 Mitigation potential of EU agriculture

Authoritative sources estimate that the *technical* mitigation potential of agriculture[23] globally is high (Box 2-4). For the EU, the technical mitigation potential through all agricultural practices is estimated at approximately 750 Mt $CO_{2\text{-eq}}$ per year (IPCC, 2007b); soil carbon management alone has an estimated mitigation potential ranging from around 67 $MtCO_2$ to 200 $MtCO_2$ per year[24] taking account of a range of options in cropland management, grazing land management and the restoration of cultivated organic soils and degraded land (IPCC, 2007b).

Box 2-4 Technical mitigation potential of agriculture worldwide

The estimated global technical potential is 5.5-6 Gt CO_2–eq per year with some ambiguity over how much of this realistically can be carried out in practice. Appropriate soil management practices alone above could achieve about 89 per cent of this potential, through enhanced sequestration. Globally, net emissions from soils are estimated to represent less than 1 per cent of global anthropogenic CO2 emissions when sequestration is accounted for.

Sources: (Campbell et al, 2011; IPCC, 2007b; UNFCCC, 2008)

The *realistically* achievable potential is calculated by adjusting the technical potential to take account of existing barriers to the adoption of all the relevant mitigation actions, such as insufficient cost-effectiveness, possible decreases in production levels, bio-physical constraints etc. The realistically achievable potential could be about twenty per cent less than the technical potential, with much uncertainty in the modelling estimates (IPCC, 2007b). It is predicted that European agriculture has the potential to reduce non-CO_2 emissions (including from livestock systems and use of fertiliser) by between 42 per cent to 49 per cent by 2050 compared to 1990 (European Commission, 2011a). Chapter 0 provides an overview of the actions that could contribute most, noting that some trade-offs between future levels of GHG emissions and future levels of production are likely.

2.4 Other aspects of the European food chain

Several important areas for reducing the overall footprint of the food chain exist. 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. These include:

- Improvements in efficiency and technical developments.
- Waste reduction throughout the food chain.
- Dietary changes, such as reduced meat consumption.

Methane recovery for energy through anaerobic digestion of agricultural waste is included in the list of mitigation actions in section 3.2. Box 2-5 provides an overview of the potential impact of reducing meat use in the EU. A full examination of these areas is outside the scope of the study.

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[23] According to IPCC, the term 'technical mitigation potential' denotes the amount by which it is possible to reduce GHG emissions (or improve energy efficiency) by implementing an already existing technology or practice.

[24] Lower estimates were identified in studies that factored in possible low cost-effectiveness of some of the measures, certain uncertainties in the estimates of the mitigation potentials, possible negative impacts of some measures on production levels, bio-physical constraints and farmers' reluctance to change management (Vellinga et al, 2011).

Box 2-5 The impact of reducing meat consumption by changes in diet

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 CO2 eq. per annum, of which 209 Mt CO_{2-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_{2-eq}, of which 200 Mt CO_{2-eq} in the EU. A shift to a diet with a day without animal proteins would achieve a reduction of 50 Mt CO_{2-eq}, of which 39 Mt CO_{2-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). Annex 2-3 provides further information.

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, 2013). 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.

3 MANAGEMENT ACTIONS FOR MITIGATION AND ADAPTATION IN EU AGRICULTURE AND THEIR RELATIONSHIP TO INCREASED FOOD PRODUCTION

One of the central challenges facing European agriculture is that of sustainable intensification, maintaining and increasing food production in the face of the challenges posed by climate change whilst at the same time helping to mitigate its climate change and other environmental impacts. A set of actions is required both to mitigate the anthropogenic GHG emissions from agriculture and to adapt the agricultural sector to climate change. These strategies are considered in turn in this chapter.

3.1 Introduction

The list of technically available actions for addressing climate change mitigation and adaptation within the agricultural sector is long and expanding (Bellarby et al, 2013; eg Frelih-Larsen et al, 2008; Hjerp et al, 2012; Smith and Olesen, 2010; UNFCCC, 2008). A large number of these actions can be carried out at farm level, but some require collective action for example by associations, or by a mix of stakeholders.

The sections below provide a summary overview of relevant technologies, including soil management techniques along with a basic analysis of the key groups of stakeholders that would need to take action if they are to be effective. A more detailed database of all these actions is provided in Annex 3, based on a literature review including pan-European studies on the topic and the key IPCC and IPCC-derived literature on actions recommended at the global level. Selected national literature and case studies have been taken into account where readily available.

Mitigation measures

Mitigation related actions have been identified on the basis of their technical mitigation potential[25] documented in the IPCC literature and the modelled estimates of their economic potential, which is typically lower, generally derived from models and taking account of published Marginal Abatement Cost Curves where these appear most pertinent.

For actions identified through literature reviews, the following benefits have been assessed in a qualitative way:

- Benefits for reducing or avoiding GHG emissions and for sequestering carbon;
- Benefits for adapting agriculture to climate change;
- Co-benefits for soils, water and biodiversity;
- Potential trade-offs with other objectives;
- Impacts on productivity and costs

The actions considered focus on the following:

- Reducing or avoiding N_2O emissions from soils and drainage;
- Reducing CH_4 and N_2O emissions from the storage, processing and application of manure;
- Reducing enteric CH_4 emissions from livestock management;
- Avoiding or reducing CO_2 emissions from land use and soils by sequestering carbon and preventing its release;
- Reducing CO_2 emissions from machinery use and energy use on farms;

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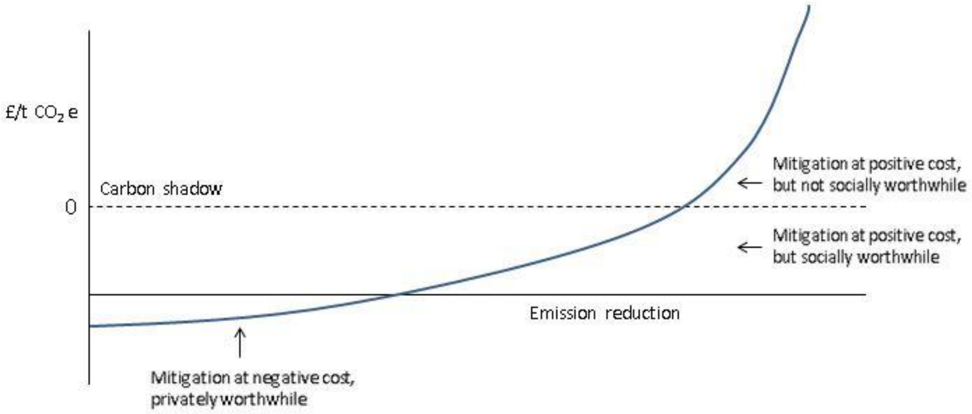
[25] According to IPCC, the term ‘technical mitigation potential’ denotes the amount by which it is possible to reduce GHG emissions (or improve energy efficiency) by implementing an already existing technology or practice.

- Reducing indirect CO_2 emissions from the production of fertilisers.

It is important to note that any changes in practices and emissions do not directly show up in national GHG inventories[26]. This does not diminish their positive impact but may diminish government incentives to use them.

Marginal Abatement Cost Curves are an informative way of assembling data on methods of mitigating GHG emissions by modelling the potential quantities mitigated and their relative costs (see for example FAO, 2012; McKinsey&Company, 2009; Moorby et al, 2007; Moran et al, 2008; Moran and Pratt, 2010; OECD, 2010). Figure 3-1 illustrates the concept, showing that higher emission savings come at increasing additional costs or income forgone compared to the baseline farm or land management practice.

Figure 3-1 Schematic explanation of the Marginal Abatement Cost Curve concept



Source: (OECD, 2010)

Addressing adaptation

As discussed in Chapter 1, there are a number of threats and opportunities that farmers will face in a changing climate, albeit to different degrees in different regions.

Actions can be devised to minimise these impacts, use the opportunities offered, and respond to changes resulting from certain mitigation approaches (for example through biofuel cropping systems).

At the farm level, three main types of adaptation measure can be distinguished (OECD, 2010):

- Those that reduce the vulnerability of affected agro-ecosystems and agricultural soils;

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[26] National GHG inventories are based on empirical emission factors defined in IPCC guidelines. Factors are attributed to types of land use ('cropland remaining cropland' and 'cropland converted into grassland/ forest land', 'grassland remaining grassland' and 'grassland converted into cropland / forest land'). As a result the accounted GHG emissions approximately correlate with areas under these land use types.

- Those that reduce the exposure of a farming system to the effects of climate change such as drought, heavy rainfall, and storms by hazard management; and
- Those that increase resilience, both in ecosystems by conserving resources and the resilience of the farming population to enable them to overcome the losses that do occur.

Appropriate adaptive actions have the potential to strengthen the resilience of farms and agro-ecosystems as well as reducing vulnerability (Bindi & Olesen, 2011; EEA, 2012b; Hjerp et al, 2012; Iglesias et al, 2007b; Smith & Olesen, 2010)[27].

3.2 Key management actions for climate change mitigation and adaptation and their relationships to increased food production

This section presents an overview of management actions that can bring co-benefits for climate change mitigation and adaptation. Different types of action are available for:

- The livestock related sectors, including actions in livestock management and grazing land and pasture management;
- Cropland management;
- Land use change and other land based measures;
- Energy efficiency and renewable energy use on farms and in rural areas

Another group of actions that target adaptation to climate change specifically include:

- Sustainable water use and water efficiency;
- Other key actions for adaptation; and
- Cross-cutting actions

A detailed analysis of these actions, including their benefits for mitigation, adaptation, and other environmental objectives, and a discussion of synergies and trade-offs with agricultural productivity is provided in Annex 3, along with information on costs, which vary considerably between farms in many cases. Priority actions in each group are then identified. The overview below is by contrast schematic and cannot capture multiple linkages between these actions. For example actions concerning manure management, processing and application are linked in multiple ways with decisions on grazing land and cropland management. The particular ways in which farmers develop their production systems and incorporate climate related actions into them in their local settings will affect the resulting GHG profile of the particular farm.

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[27] This is referred to as the ‘win-win’ or ‘no regrets’ option (Smith, 2012). No-regret options are management actions that have an important beneficial impact even in the absence of projected climate change, do not lead to potentially adverse effects under climate change, and contribute to improved resilience.

Livestock management

The key actions on this topic are presented in Table 3-1.

Table 3-1 Key actions for climate change mitigation and adaptation in livestock management

No.	**Key actions**	**Effect of action on**				**Prime actor**			
		Mitigation	**Adaptation**	**Environmental synergies and trade-offs**	**Productivity**	**Farmers**	**R&D**	**Industries**	**Government**
1	Optimising manure application	**		+/-	+	■			
2	Improved manure processing (including introduction of anaerobic digestion for biogas production) **C/F**	**	*	+	0	■			■
3	Optimising manure storage and improving outdoor storage facilities	*		+	0	■			■
4	Feeding techniques to improve digestive nutrient capture, changes to livestock diets	*		+	+		■		
5	Adjust dietary intake by livestock or manipulate the rumen	*		0	+		■		
6	Improved livestock breeding[28]	*	*	+	+		■		
7	Improvement of animal rearing conditions/ animal health		**	+/-	+	■			

Sources: see Annex 3

Notes:

Mitigation / Adaptation potential: Very relevant ** Relevant *

Environmental effects: Strong Positive ++ Positive + Strong Negative -- Negative - Neutral 0

Productivity: Positive + Strong Negative -- Negative - Neutral 0

C/F -- May be implemented at farm level or through collective action at local level

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[28] Livestock breeding and its effect on agricultural productivity is the focus of Study 2.

Grazing land and pasture management

The key actions on this topic are presented in Table 3-2.

Table 3-2 Key actions for climate change mitigation and adaptation in grazing land and pasture management

No.	Key actions	Effect of action on				Prime actor			
		Mitigation	Adaptation	Environmental synergies and trade-offs	Productivity	Farmers	R&D suppliers	Industries	Government
8	Reducing and optimising use of fertiliser	**	*	++/-	0/-	■			
9	Maintenance of permanent grasslands/pasture	**	*	++	+/-	■			■
10	Optimising grazing intensity (length and timing of grazing to avoid overgrazing)[29]	**	*	++/-	+	■			
11	Grassland renewal[30]	*		+/-	+	■			
12	Establishing shelterbelts	*	*	+	+	■			■

Sources: see Annex 3

Notes: Mitigation / Adaptation potential: Very relevant ** Relevant *

Environmental effects: Strong Positive ++ Positive + Strong Negative -- Negative - Neutral 0

Productivity: Positive + Strong Negative -- Negative - Neutral 0

C/F -- May be implemented at farm level or through collective action at local level

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[29] 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

[30] Actively improving the composition of grassland eg by controlled deferred grazing, overseeding and resowing

Cropland management

The key actions on this topic are presented in Table 3-3.

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

No.	Key actions	Effect of action on				Prime actor			
		Mitigation	Adaptation	Environmental synergies and trade-offs	Productivity	Farmers	R&D suppliers	Industries	Government
13	More catch crops / winter cover / green manure / less fallow	**	**	++/-	+	■			
14	Diversified crop rotations	**	**	++/-	+/-	■			■
15	Adding legumes/N-fixing crops to rotation or undersowing	**	*	+	+/-	■			
16	More intercropping	*	**	++	+/-	■			
17	Zero tillage	**	*	++/ -	+/-	■	■		
18	Conservation / reduced tillage	**	*	+/-	+/-	■	■		
19	Restrictions on agricultural activities on slopes[31]	*	**	+	-	■			■
20	Crop residue management in-field	**	*	++/ -	+	■	■	■	
21	Reducing or optimising use of fertiliser and pesticides[32]	**	*	++/-	+	■	■	■	
22	Precision agriculture	**	*	+	+	■	■		
23	Planting of hedgerows	*	*	++	-	■			■
24	Establish buffer strips	*	*	+	0/-	■			■
25	Reintroducing/ maintaining terraces	*	*	++	+	■			■
26	Grass in orchards & vineyards	*	**	+/-	0/-	■			
27	Replacing annual with perennial/ permanent crops	*	*	++	+/-	■			
28	Replacement of synthetic pesticide with natural treatments	*	*	++/-	0/-	■	■	■	

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[31] 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.

[32] 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.

No.	**Key actions**	**Effect of action on**				**Prime actor**			
		Mitigation	**Adaptation**	**Environmental synergies and trade-offs**	**Productivity**	**Farmers**	**R&D suppliers**	**Industries**	**Government**
29	Integrated farming	*	*	+/-	0/-	■			
30	Organic farming	*	*	++	0/-	■			
31	Use of adapted plants and plant varieties[33]	*	*	+	+	■	■	■	
32	Improved pest strategies/integrated pest management		*	+/-	+	■	■		
33	Modifying sowing dates		*	+/-	+/-	■			
34	Extended use of biochar	*		+/ -		■	■	■	
35	Establishing more firebreaks		*	0	+/-	■			
36	Plant breeding and genetic modifications[34]		*	+	+	■	■	■	

Sources: see Annex 3

Notes: Mitigation / Adaptation potential: Very relevant ** Relevant *

Environmental effects: Strong Positive ++ Positive + Strong Negative -- Negative - Neutral 0

Productivity: Positive + Strong Negative -- Negative - Neutral 0

C/F -- May be implemented at farm level or through collective action at local level

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[33] Planting adapted crops/varieties, and planting mixtures of different species (eg for pastures) and species genotypes

[34] 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). The benefits of plant breeding for agricultural productivity are the focus of Study 2

Land use change and other land based management actions

The key actions on this topic are presented in

Table 3-4.

Table 3-4 Key land use change and other land based management actions with co-benefits for climate change mitigation and adaptation

No.	Key actions	Effect of action on				Prime actor			
		Mitigation	Adaptation	Environmental synergies and	Productivity	Farmers	R&D suppliers	Industries	Government
37	Peatland and wetland restoration (rewetting of organic soils) C/F	**	*	++/-	-	■			■
38	Afforestation of cropland/ Woodland creation C/F	**	*	++/-	-	■			■
39	Conversion of arable land to grassland in high risk areas	**	*	++/-	-	■			■
40	Shift crop and grazing zones[35]		*	+/-	0	■			
41	Agroforestry (farmland trees)	*	*	++	+/-	■			■
42	Extensification / deintensification of agricultural management	*	*	++	-	■			
43	Set aside	*	*	++/-	-	■			■
44	Restoring river patterns; restoring natural aquatic ecosystems and riparian forests C		*	++	0	■			■

Sources: see Annex 3

Notes: Mitigation / Adaptation potential: Very relevant ** Relevant *

Environmental effects: Strong Positive ++ Positive + Strong Negative -- Negative - Neutral 0

Productivity: Positive + Strong Negative -- Negative - Neutral 0

C/F -- may be implemented at farm level or through collective action at local level

C – can only be implemented through collective action at local level

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[35] Shifting areas geographically, following the creation of new conditions determined by a changing climate.

Energy efficiency and renewable energy use on farms and in rural areas

The key actions on this topic are presented in Table 3-5.

Table 3-5 Key actions for energy efficiency and renewable energy for climate change mitigation on farms and in rural areas

No.	**Key actions**	**Effect of action on**				**Prime actor**			
		Mitigation	**Adaptation**	**Environmental synergies and**	**Productivity**	**Farmers**	**R&D suppliers**	**Industries**	**Government**
45	More energy efficient equipment	**	*	0	0	■	■	■	
46	Greater efficiency of farm buildings/greenhouse buildings	**	*	0	0-	■	■		
47	Reducing machinery fuel use	*	*	+	0	■	■	■	■
48	Processing of agricultural and forest residues for energy[36] **C/F**	*	*	+/-	0	■			▯
49	Installation of infrastructure for renewable energy (solar, wind, geothermal) **C/F**	**	*	+/-	0	■		■	■

Sources: see Annex 3

Notes: Mitigation / Adaptation potential: Very relevant ** Relevant *

Environmental effects: Strong Positive ++ Positive + Strong Negative -- Negative - Neutral 0

Productivity: Positive + Strong Negative -- Negative - Neutral 0

C/F -- May be implemented at farm level or through collective action at local level

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[36] Study 5 of the present project provides an assessment of the potential for producing bioenergy from agricultural sources with low environmental impacts such as waste and residues. Therefore the topic is not discussed in detail in this study.

Sustainable water management and water efficiency on farm and in rural areas

The key actions on this topic are presented in Table 3-6.

Table 3-6 Sustainable water use and water efficiency on farm and in rural areas

No.	Key actions	Effect of action on				Prime actor			
		Mitigation	Adaptation	Environmental synergies and trade-offs	Productivity	Farmers	R&D suppliers	Industries	Government
50	Precision irrigation		**	+	+	■			
51	Reconstruction and upgrading of drainage infrastructure[37]	*	*	+/-	+	■			■
52	Mulching or protective film covering		*	+/-	+				
53	Improvements in irrigation equipment		**	+	+	■	■	■	
54	Re-use of greywater on farms; rainwater harvesting		**	+	+	■			
55	Improved irrigation scheduling **C**		**	+	0		■		
56	Reconstruction of outdated rural water supply networks[38] **C**		*	+/-				■	■
57	More effective water regulation and allocation **C**		**	+	0/-			■	■
58	Water footprinting, auditing and labelling **C**		*	0	0/-			■	■
59	Extended water pricing and water metering **C**		**	+	0/-			■	■

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[38] 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.

Sources: see Annex 3

Notes: Mitigation / Adaptation potential: Very relevant ** Relevant *

Environmental effects: Strong Positive ++ Positive + Strong Negative -- Negative - Neutral 0

Productivity: Positive + Strong Negative -- Negative - Neutral 0

C – can only be implemented through collective action at local level

Other key actions for adaptation to climate change and cross-cutting actions

Key actions in this final category are presented in Table 3-7.

Table 3-7 Other key actions for adaptation to climate change and cross-cutting actions

No.	Key actions	Effect of action on				Prime actor			
		Mitigation	Adaptation	Environmental synergies and	Productivity	Farmers	R&D suppliers	Industries	Government
Risk management									
60	Defences against floods and extreme events (hails etc)		**	-	+			■	■
61	Establishing disaster information systems and monitoring C		**	0	+/-			■	■
62	Establishing crop insurance schemes[39] C		*	0	0			■	■
Cross cutting actions									
63	Information, training & advisory services	**	**	+	0			■	■
64	Co-operation for collective action	*	*	+	0			■	■

Sources: see Annex 3

Notes: Mitigation / Adaptation potential: Very relevant ** Relevant *

Environmental effects: Strong Positive ++ Positive + Strong Negative -- Negative - Neutral 0

Productivity: Positive + Strong Negative -- Negative - Neutral 0

C – can only be implemented through collective action at local level

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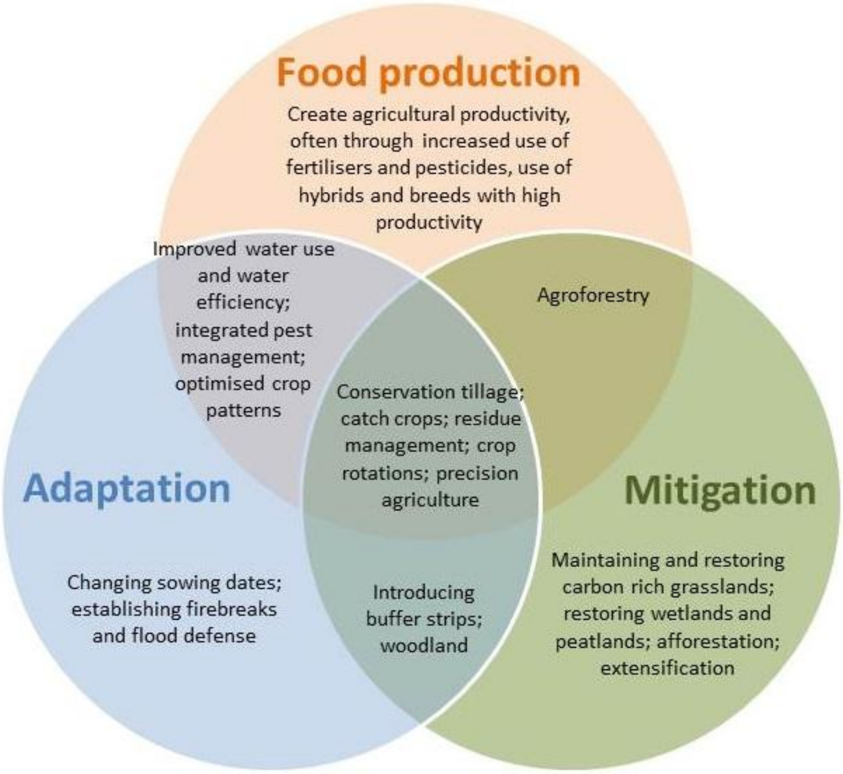
[39] Note the element of moral hazard associated with this action: support for risk management might discourage farmers and foresters from strengthening their adaptive capacity by offering them support regardless of the actions taken.

Summary

An important challenge for European agriculture to 2050 will be to adapt farm management to climatic change, whilst simultaneously reducing its GHG emissions and other environmental impacts and increasing its productivity. This represents a major technical and policy challenge. This study has identified 64 individual actions that could all help meet this challenge, but with varying implications for other goals in agriculture and rural areas. Some actions are essential for climate change mitigation but will reduce productivity; some may be extremely beneficial for adaptation but may increase GHG emissions or have other adverse environmental consequences. Detailed analysis of such synergies and trade-offs in each group of actions is in Annex 3. An attempt has been made to summarise this in Figure 3-2.

An obvious strategy for meeting the central challenge of sustainable intensification is therefore to focus first on those actions that lie within the intersection of all three circles in this diagram. These are likely to be beneficial wherever they are deployed and, where they have income benefits, farmers may undertake them for purely economic reasons.

Figure 3-2 Potential synergies and trade-offs between climate change adaptation, mitigation and food production goals



Source: own analysis using a presentation adapted from (Campbell et al, 2011)

3.3 Productivity issues

Chapter 1 described the challenges that climate change will pose for agriculture across Europe. Adapting agriculture to cope with these challenges so that it can produce more food whilst also helping to mitigate climate change is going to be a complex task. Tables 3-1 to 3-7 listed 64 individual actions that could potentially assist with the task. Table 3-8 classifies these according to their impact on production in broad terms.

Table 3-8 Analysis of the 64 potential climate change measures according to their impact on agricultural productivity

Contribution to climate change response	Impact on agricultural productivity			
	Positive	**Uncertain or variable**	**Negative**	**Total actions**
Mitigation only	4	2	0	6
Adaptation only	8	11	0	19
Co-benefits for mitigation and adaptation	11	21	7	39
Total actions	23	34	7	64

Twenty three of the 64 potential climate change response actions (36%) are likely also to increase productivity and 34 of the 64 (53%) are likely to have a variable, uncertain or neutral impact. Only 7 of the 64 (11 %) are likely to have a negative impact according to the literature and taking account of the rather general nature of this analysis.

At a more detailed level, the analysis suggested that those actions that are expected to have an uncertain or variable effect on productivity are spread across all the categories used in this report. Land use change actions however dominate those expected to have an unequivocally negative impact on production, contributing 5 of the total of 7 actions categorised in this way. This is hardly surprising as they will often involve taking some land out of agricultural production in order to facilitate either mitigation or adaptation.

If all of the 64 measures, or most of them, were to be applied on a significant scale across the EU the net effect would be to reduce total agricultural output. It remains unclear how far it is possible both to adapt EU agriculture to climate change, reduce its contribution to GHG emissions, and limit its other adverse environmental impacts without adopting actions that require local reductions in productivity. Creative and innovative ways will need to be found to limit these reductions. Less widespread technologies such as paludiculture and agroforestry may have a role to play in this.

If a net reduction in EU production were nevertheless unavoidable then - unless this were matched by reductions in EU consumption - this would imply greater imports, with consequences for emissions in the exporting countries.

3.4 Costs

Table 3-9 provides an overview of the 64 actions by their category and by their estimated cost. The cost estimates of each action are included in Annex 3, where evidence could be found on which to base these estimates.

Table 3-9 Analysis of the 64 actions by category and by the range of anticipated costs

Category of action	**Cost estimate L = low, M = medium, H = high**						**Total actions**
	L	**L/M**	**M**	**M/H**	**H**	**No Estimate**	
Livestock management	0	0	5	0	2		7
Grazing land and pasture management	2	2	0	0	0	1	5
Croplands	12	2	2	2	2	4	24
Land Use Change	0	0	4	2	1	1	8
Energy efficiency & renewable energy for climate change mitigation	1	0	1	0	1	2	5
Water management & other measures for climate change adaptation	1	0	3	2	2	7	15
Total actions	16	4	15	6	8	15	64

Overall, estimates were available for 49 actions and of these 16 (33%) were estimated to be low cost and some would actually increase farm incomes. At the other extreme, some involve significant upfront costs. There are some interesting differences. Of the 20 cropland actions for which cost estimates were available, 12 were considered as being low cost. By contrast, of the 12 actions for livestock management and grazing land and pasture for which cost estimates were available, only 2 were estimated as being low cost. This suggests that some types of farm enterprises may find it easier to respond to climate change than others; targeting of policy support on specific measures and types of farm may be appropriate.

Land use change actions also tended to have higher costs with none of the 8 actions for which cost estimates were available having either a low or a low/medium estimate. Given the negative effect many of these are thought to have on production at a local scale, relatively few of these actions seem likely to be widely taken up without third party intervention such as policy support.

Overall it appears that some of the political actions summarised here represent rather basic farm management or land management that could be achieved with little or no cost ot the farmer and even financial benefits, others come at moderate cost to farmers, while other actions involve significant upfront investment, some of which farmers are unlikely to make on their own.

These rather qualitative assessments demand more detailed empirical analysis and the more widespread and systematic construction of marginal abatement cost curves (MACCs) across the EU would be helpful.

3.5 Enabling mechanisms and policy measures

This section provides an overview of the enabling mechanisms and policy measures which could help European agriculture adapt to and help to mitigate climate change, focussing on the parties that will have to take the action. This then leads to a brief consideration of what policy changes may be needed to stimulate the various actors to take these actions.

Barriers to uptake

The analyses of the 64 different actions for adaptation and mitigation in the tables above sought to identify the key actors who will seem most likely to need to take them forward. Not surprisingly farmers will have a prominent role in nearly all cases; responsible for implementing 50 of the 64 actions discussed. For most of them, cost and localised negative impacts on productivity are two obvious barriers to uptake. Nevertheless, the analysis also has shown that there are actions available with potentially positive impacts on productivity that could be implemented at modest or even negative cost, improve profitability, and at the same time reduce GHG emissions.

Experience to date suggests however that even for these actions, widespread uptake cannot always be guaranteed without additional incentives. There are several possible reasons for this. There may be an unwillingness by farmers to try new techniques, which in some cases might be overcome through advice. It may be that the data on which the assessments are based does not accurately reflect the detailed and precise nature of the decision processes on the ground. Risks and transaction costs may be higher, or perceived to be higher, than portrayed in the literature for example. Alternatively there may be other factors preventing apparently optimal decisions by farmers. These could include risk and uncertainty, poor access to technology and the limited availability and cost of credit. In other situations farmers may not be able to implement the actions on their own and need advice, training or the co-operation of others, for example in sharing costs.

A large number of the actions also involve other actors. Further research and development is indicated for 18 of them. There is a close connection between much of this R&D investment and the efforts which are required from the agricultural supply industries and food processors. These actors will have to be involved in 19 of the 64 actions identified. Action at EU level and by national and sub-national governments would appear to have a major role to play in 28 of the 66 actions. The proportion of actions requiring government is particularly high for measures concerned with land use change (75 per cent) and water and other measures (67 per cent). This may reflect the fact that these categories more often require regulation, financial incentives, action at a larger scale and infrastructural change. In addition to these specific actions, government at various levels usually will have an important initial role in raising the awareness of all the parties involved in the food chain to be more aware of the threats and opportunities brought by climate change.

Mechanisms enabling a sufficient response to climate change

As noted above, it is unlikely that any individual action alone will be sufficient to meet the full scale of the challenge regarding adaptation, mitigation and food production needs. Using mixes of actions will bring with it the imperative to manage the complex trade-offs that will result. The evidence gathered for this report suggests that this will require:

- **A holistic approach:** An approach that does not pursue one objective disproportionally at the expense of others, which actively manages the trade-offs and which remains alert to the possibility of unforeseen perverse effects.
- **Focussed advice and support to farmers**

- **Coordinated and targeted action at a landscape scale:** Many of the actions described in this chapter require measures to be carefully targeted across whole landscapes to be effective[40].
- **Cooperation and collaboration:** The need for coordinated action at a landscape scale means that farmers will need to collaborate with each other and that other parties will need to be involved to inform, facilitate and steer action and to monitor the outcomes.
- **Research and development:** Including development to refine and turn into commercial propositions some of the actions that do appear to have the greatest potential to produce co-benefits, such as paludiculture, agro-forestry and precision farming.
- **The active involvement of government at all levels:** The CAP, other EU funding instruments and EU environmental legislation need to provide well focussed regulatory and funding mechanisms that discourage inappropriate actions and promote and enable beneficial actions, especially those that will have a wider public good but may not be in the immediate interest of individual farmers. The EU also has a role in funding relevant Research & Development work, especially in areas where commercial funding is not available.

Measures under the Common Agricultural Policy promoting response to climate change

The Common Agricultural Policy (CAP) can play a prominent role in two ways. The first is by developing the instruments of the CAP, across both pillars, to facilitate and encourage the beneficial adoption of the practices and actions which have been identified above. The second is by requiring that Member States recognise and act on the need for climate adaptation and mitigation in their decisions about how to implement these CAP instruments in pursuit of broader EU policy. One area where the CAP is likely to have an important role is in facilitating the actions that are necessary to reduce GHG emissions or to help the industry adapt to climate change but which have negative effects on productivity or which impose other costs on farmers. This may require a combination of a stronger regulatory regime, perhaps making better use of cross-compliance and greening as instruments of the Common Agricultural Policy as well as financial incentives. The main relevant measures are listed in Table 3-10[41] and a detailed analysis is presented in Annex 3.

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[40] A good example of the need for careful targeting is the establishment of new riparian woodlands for flood management, where the location within the catchment is critical to achieve the intended effect and minimise the potentially adverse effects of afforestation on agricultural production and on other habitats.

[41] Several forestry-related RDP measures could significantly benefit climate change objectives. However assessment of these measures is outside the scope of the study.

Table 3-10 Overview of proposed CAP measures that could be used for support to climate change mitigation and adaptation on farms

Proposed measure	Measure Description
Pillar 1	
Cross compliance[42]	Cross compliance – Statutory management requirements (SMRs) and Good agricultural environmental condition (GAEC) (Article 91 and Annex II of the proposal). Specifies conditions placed on the receipt of Pillar 1 direct payments and the baseline requirements for agricultural area based payments under Pillar 2.
Green payments[43]	Payment for agricultural practices beneficial for the climate and environment - to be finalised - Article 29.
Farm Advisory System[44]	Obligations for Member States to provide advice on the SMRs and GAEC under cross-compliance. Farmer participation is voluntary (Article 12),
National Frameworks for Fruit and Vegetables[45]	Actions aimed at protection of water: • The use of environmentally sound cultivation practices, production techniques and waste management (Article 3 (b)); • Restricted use of plant protection products and other inputs to protect water quality and availability (Article 20 (c)(vi)).
Pillar 2[46] - key measures	
Article 18	Investments in physical assets
Article 19	Restoring agricultural production potential damaged by natural disasters and catastrophic events and introduction of appropriate prevention actions
Article 21	Basic services and village renewal in rural areas
Article 23	Afforestation and creation of woodland and
Article 24	Establishment of agro-forestry systems
Article 29	Agri-environment-climate
Pillar 2 - supporting measures	
Article 15	Knowledge transfer and information action
Article 16	Advisory services, farm management and farm relief services
Article 17	Quality schemes for agricultural products
Article 20	Farm and business development
Article 30	Organic farming
Article 31	Natura 2000 and Water framework directive payments
Article 32	Payments to areas facing natural or other specific constraints
Article 36	Co-operation, including cooperation in the context of European Innovation Partnership (EIP)
Articles 42-45	LEADER approach

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[42] European Commission (2011) *Proposal for a regulation of the European Parliament and of the Council on the financing, management and monitoring of the common agricultural policy*, COM(2011)628, Brussels, 19 October 2011, http://ec.europa.eu/agriculture/cap-post-2013/legal-proposals/com628/628_en.pdf

[43] European Commission (2011) *Proposal for a regulation of the European Parliament and of the Council establishing rules for direct payments to farmers under support schemes within the framework of the common agricultural policy*, COM(2011)625, Brussels, 19 October 2011, http://ec.europa.eu/agriculture/cap-post-2013/legal-proposals/com625/625_en.pdf

[44] European Commission (2011) *Proposal for a regulation of the European Parliament and of the Council on the financing, management and monitoring of the common agricultural policy*, COM(2011)628, Brussels, 19 October 2011, http://ec.europa.eu/agriculture/cap-post-2013/legal-proposals/com628/628_en.pdf

[45] Council Regulation (EC) No 1182/2007 of 26 September 2007 laying down specific rules as regards the fruit and vegetable sector.

[46] European Commission (2011) *Proposal for a regulation of the European Parliament and of the Council on support for rural development by the European Agricultural Fund for Rural Development (EAFRD)*, COM(2011)627, Brussels, 19 October 2011, http://ec.europa.eu/agriculture/cap-post-2013/legal-proposals/com627/627_en.pdf

National and regional governments need to develop strong and effective programmes to make use of the measures provided by the CAP and other EU level instruments. These measures need to be used, together with their own knowledge of the agricultural and environmental geography of their territories, to ensure coordinated action and to support and pay for the facilitation, collaboration, cooperation and targeting that is needed to produce coordinated landscape-scale action. At a local level government bodies need to be actively involved in the planning implementation and monitoring of holistic, landscape scale action, bringing together the key stakeholders, providing data to inform the process and ensuring that regulatory and incentive mechanisms are effectively delivered.

Key RDP measures for support to capital investments to infrastructure. The key RDP measures are identified in Table 3-10, including support for investments in physical assets (Article 18), for basic services and village renewal in rural areas (Article 21), and for restoring agricultural production potential to areas damaged by natural disasters (Article 19). Support for investments in physical assets (Article 18) covers a broad range of capital investments: from improving agricultural performance to processing, marketing and development of products, and on farm infrastructure improvements. Support to village renewal in rural areas (Article 21) can help facilitate the improved efficiency of collective infrastructure, eg for sustainable water use. To ensure environmental additionality, investments should only be granted where sound evidence is provided taking into account multiple environmental objectives. Care should also be taken to avoid funding investments that are stipulated as requirements in national and / or EU legislation. Where new infrastructures are constructed, attention should be paid to ensure that it does not increase greenhouse gas emissions or decrease water availability. Support for the restoration of agricultural production potential that has been damaged by natural disasters (Article 19) can be used to strengthen adaptive capacity. There is a risk that support for disaster recovery might discourage farmers and foresters from strengthening their adaptive capacity by offering them support regardless of the actions taken. Care should be taken to use this article to encourage the uptake of investments for defence against floods and other extreme events, and to establish disaster information systems and monitoring, rather than to provide subsidised insurance.

Key RDP measures for soil and land management actions. Three key RDP measures have been identified here, the agri-environment-climate measure (Article 29), support for afforestation and creation of woodland (Article 23) and support to establish agro-forestry systems (Article 24). It is important to ensure that the support provided under these measures is used to deliver public goods and results in environmental additionality, particularly where there is a risk of a negative environmental outcome. For example, in order to mitigate climate change, there is a risk that semi-natural grasslands might be used to cultivate energy crops or short rotation coppice, resulting in the loss of a carbon sink and important biodiversity habitat (see Chapter 5). Where the afforestation and agro-forestry measures are being used to deliver mitigation, care should be taken to ensure that the use of these measures is coherent with other environmental objectives, especially biodiversity. Afforestation should avoid peat soils and existing high quality semi-natural habitats. In terms of adaptation, particular vigilance is needed when considering afforestation and the establishment of agro-forestry systems in water scarce areas. The species composition and location of new planting should be chosen to avoid negative impacts on water availability through increased absorption and transpiration. Agri-environment-climate schemes focussed on soil protection require the effective use of targeting and differentiation of management requirements in specific areas, in order to ensure that the most cost effective actions for mitigation and adaptation are targeted at specific soil types and risk areas.

4 CLIMATE CHANGE AND AGRICULTURE: RECOMMENDED OPTIONS

The response of agriculture to climate change is both a classic example of market failure and a trans-boundary issue. It is an area where there is a clear case for action at a European level. It is also an area of European competence. The EU Common Agricultural Policy has a huge influence on the shape and direction of agriculture in Europe. Through this and other instruments of European policy, the European Union can play a very important part in helping European agriculture meet the central challenge of simultaneously adapting agriculture to climatic change, reducing its greenhouse gas emissions and other environmental impacts and increasing its productivity, which is what is needed to achieve sustainable intensification.

Options relating to the Common Agricultural Policy

The European Union and its Member States are currently working on the future of the Common Agricultural Policy up to 2020. This provides an opportunity to ensure that this Policy helps agriculture meet this central challenge during the rest of the decade. The ways in which it could do this are as follows:

1. **Use the Common Agricultural Policy to help raise farmer awareness of climate change and the need for adaptation**

   There are four specific EU-level actions that could help impress on farmers the need to focus on climate issues:

   - Integrate a climate dimension into all relevant requirements for individual farming operations to receive CAP payments and into all programmes of funded measures. Ensure that principles of sustainable agriculture, of which climate mitigation/adaptation is a part, are consistently applied throughout the EU.
   - Establish databases of environmental performance of individual representative farms of all sizes, types and in all EU regions. This could be done through the Farm Accountancy Data Network, which could then be used to benchmark the greenhouse gas accounts for individual farms, and link these to certifications or payment for ecosystem services (PES) schemes in the same way that the FADN has stimulated numerous private or private-public benchmarking activities for the financial accounts of individual farms.
   - Use a cautious approach in using the Rural Development measure for disaster recovery. Ensure that this measure is not used in a way that discourages but rather encourages adaptation. This would require support for recovery from a disaster to be made conditional on the production and implementation of an adaptation strategy.
   - Farm advisory and extension services are key to informing farmers about potential improvements in practice, their associated economic benefits, as well as funding opportunities. Provide advisors with the means to adequately inform and train farmers about mitigation and adaptation actions.

2. **Promote actions that have economic benefits for the farmer as well as benefits for climate change adaptation and mitigation**

   The initial focus should be on helping farmers take autonomous action to use water, soil and energy resources more efficiently. Such actions have three key advantages:

   - They can be undertaken at farm level
   - They should not require subsidy, as they make production more efficient and should be self-financing
   - They do not require radical change to farming systems or a change in mind-set

This report has identified a group of such actions that can help farmers achieve this goal (see Figure 3-2). In arable farms, for example, these include reducing and optimising the use of fertilisers and pesticides but also better management of crop residues[47] and appropriate use of catch crops to provide winter cover to prevent soil erosion. The CAP Pillar 2 should help overcome the barriers to action in these areas by modest support to upfront investment costs and start-up costs where it is needed to overcome initial barriers to uptake, the knowledge transfer and advisory service and collaboration to enable exchange of good practice. This approach can be also used for encouraging improvements in water use and water efficiency and autonomous risk management across all types of farms.

There seems to be less scope for applying this approach to actions with co-benefits for mitigation and adaptation in the livestock sector. This is partly because there are fewer actions with direct productivity benefits. It is also partly because many of the actions farmers need to undertake to improve the efficiency with which they use natural resources, for example in manure application and processing, require a relatively high initial investment. There is nevertheless scope for the CAP to support extension and advice to promote the better and more economical use of fertilisers and animal feed.

Autonomous actions could go a considerable way towards reducing agriculture's GHG emissions. These actions also often offer benefits for adaptation to climate change and water protection and reduce impacts on soils, and thus support more efficient and sustainable agricultural production and financial rewards to farmers. Such measures are however unlikely to offer a complete solution to the central challenge.

3. **Use the Common Agricultural Policy to help pay for actions that have clear long term climate and/or production benefits, but which do not provide an immediate benefit to the individual farmer**

This report has identified many such actions which are necessary if the central challenge is to be met. Some may require a significant investment in farm infrastructure, such as improvements to manure storage and processing and its use to produce biogas. Other types of collective water and energy infrastructure at a local scale offer sustainability benefits and a long-term economic return but require a significant initial investment. Loans and Pillar 2 support to infrastructure are ways in which the CAP may assist, provided that the polluter pays principle is respected.

Others actions may require adapted soil and crop management, for example use of crop rotations, intercropping, conservation tillage, reduced livestock densities to maintain grassland carbon stocks and prevent erosion through overgrazing, the installation of unfarmed buffer strips, and some changes involving areas taken out of highly productive use, eg rewetting of peatlands and the selective use of afforestation in order to provide wider benefits. These improvements depend to a large extent on incentives through a mix of Pillar 2 payments.

Rural Development Plans may be used to implement these long-term actions. The Common Monitoring and Evaluation Framework under the CAP should then be rigorously applied at EU and national levels to monitor the impact of climate change actions supported under the Rural Development Plans.

In the longer term, more thought needs to be given to better ways in which the Common Agricultural Policy could be used to help bring about permanent changes in land use, where this is needed.

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[47] For example leaving the over-winter stubble and the incorporation of straw in soils.

4. **Provide and fund CAP Measures that can help bring about action at a landscape scale**

   This report has shown that many of the actions needed to meet the central challenge need to be planned and targeted at a scale larger than the individual farm. The draft Rural Development Regulation contains a number of important supporting measures that can help encourage and pay for the necessary planning and targeting by funding the creation of local partnerships, facilitators and advisors. The supporting measures can also help meet the extra costs of collective actions by farmers. It is important that Member States are encouraged to make full use of these measures in their Rural Development Plans and earmark an adequate share of funding to it, and that their plans to do so are checked against the needs assessment in the process of plan approval.

Other Options

5. **Encourage Research and Development**

   This report has made it clear that we do not yet have all the knowledge that will enable us to meet the challenge of achieving sustainable intensification in the face of climate change. Research and development is needed to fill the gaps. The EU policies have a particular role in encouraging strategic research and development whose results are likely to be widely applicable across Europe and which private sector funding sources are unlikely to support.

   Much commercial R&D is currently focused on incremental improvements to existing agricultural systems to improve yields and increase resource efficiency at the farm level. Two areas that may particularly benefit from EU R&D funding are development work to refine and turn into commercial propositions novel production systems such as paludiculture[48] on rewetted peatlands, agroforestry and research to develop better systems for managing the complex spatial analyses needed to optimise the targeting of multiple actions. Another important area is research of methods to improve yields in organic farming systems which have a particular role to play in developing added value products in less productive agriculture areas of Europe.

   As well as directly funding such research, the EU policies should also encourage private sector research by establishing a regulatory framework that encourages its application to all aspects of food production.

6. **Encourage greater innovation**

   Agricultural businesses already innovate to increase the productivity and profitability of food production. This needs to continue as Europe's and the global population continues to rise for the next few decades. As well, it should be ensured that:

   - Considerable investment targets knowledge transfer to the areas of Europe where the potential for increased productivity is highest and locally adapted research is lacking or difficult to access though.
   - Existing streams of yield innovation are comprehensively integrated with innovation to reduce the damaging environmental effects of agriculture in highly productive areas.
   - Innovation should focus on avoiding past mistakes, such as damage to water and soils, when promoting intensification in large areas of Europe where present yields are low or sub-optimal.

   In this way the production of 'public goods', such as the storage of greenhouse gases or water storage and retention, can be turned into a business opportunity. The recently launched

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[48] See glossary

Innovation Partnerships may be one mechanism, and research to improve the legal basis of private or private-public payments for ecosystem services may enable another mechanism.

PART 2: BIODIVERSITY AND AGRICULTURE

Part 2 examines the relationship between agriculture and biodiversity and the provision of environmental ecosystem services, taking account of the impacts of land use changes, different management techniques and technologies.

Chapter 5 reviews the biodiversity impacts of agriculture in Europe and the status of the ecosystem services and biodiversity underpinning agricultural production. It identifies key farming practices that can help to maintain and increase biodiversity on farmland (and provide other benefits), and the measures that are needed to ensure their wider adoption.

Chapters 6 and 7 provide detailed analyses of the impacts of the cultivation of genetically modified crops and of crops for biofuel production on biodiversity, both in the EU and globally. Both chapters review the evidence base for estimating the current and possible future impacts of these cropping systems and options for mitigating negative impacts.

Two vital components of the biodiversity that underpins sustainable agriculture are pollinators – both honeybees and wild pollinators – and plant genetic resources for food and agriculture. Both of these are under threat in Europe for many reasons.

Chapter 8 gives an overview of the decline in the genetic diversity of plant genetic resources for food and agriculture in Europe. Chapter 9 reviews the impact of pollinator decline in Europe, particularly the loss of honeybee colonies. Both chapters detail the actions that are being taken to address the factors driving these trends, and specify some options for the EU.

5 THE IMPACT OF AGRICULTURAL PRACTICES ON BIODIVERSITY AND OF BIODIVERSITY ON AGRICULTURE IN THE EU

This chapter examines the biodiversity implications, both within and outside farmland ecosystems, of expected agricultural activities in the EU over the next few decades, including the on-going impacts of intensification and specialisation, and abandonment in some areas. It firstly identifies the main farming ecosystems in the EU and assesses their biodiversity importance and status. It then identifies the main causes of biodiversity losses within agriculture, and their implications in relation to the achievement of nature conservation objectives and the maintenance of agricultural productivity. Finally it identifies key farming practices that can help to maintain and increase biodiversity on farmland (and provide other benefits such as those related to climate mitigation and adaption), and the measures that are needed to ensure their wider adoption.

5.1 Biodiversity in EU agricultural ecosystems

Biodiversity and agricultural systems in Europe are closely interrelated. Firstly, agriculture depends on the ecosystem processes that support plant production, such as the maintenance of soils, pollination, and the regulation of pests and diseases. Secondly, most of the habitats that exist in Europe are the result of human activities over thousands of years, of which agriculture has had the most profound impact. In fact the legacy of low-intensity and diverse traditional agricultural practices and their interactions with the varying climates, topography and soils of Europe has created a rich diversity of landscapes and habitats. Consequently, although natural habitats declined as agriculture spread, diverse semi-natural habitats were created with novel species communities, which initially probably increased species richness across much of Europe (Baumann, 2006; Ellenberg, 1988; Kornas, 1983; Stoate, 2011). Some of these semi-natural habitats that depend on livestock grazing for their maintenance are likely to be analogous to former natural habitats that were dependent on grazing by wild herbivores (Goriup, 1988; Vera, 2000).

However, agricultural change since the 1950s has caused the loss of many of the semi-natural habitats and elements that were created by extensive agricultural practices, resulting in a predominance of highly modified and simplified agricultural habitats and landscapes over much of the lowlands of the EU (Poláková et al, 2011). Now 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 European agriculture is very diverse[49]) (Oppermann et al, 2012; Poláková et al, 2011) (see Annex 5.1 for details).

Other important factors that influence biodiversity in agricultural landscapes include: 1) the spatial scale of 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); and 3) landscape diversity, such as in terms of the variety of field sizes, boundary types and interactions with other habitat types (eg forests, wetlands, or urban areas).

As a result of the historic changes in farmland type and agricultural practices the current farming systems of highest biodiversity importance are the remaining traditional low-intensity farming systems that maintain semi-natural habitats, especially those with diverse habitats and landscapes. Such farming systems are often referred to as High Nature Value Farming systems (HNV) (Baldock et al, 1993; Baldock, 1999; EEA, 2004; Veen et al, 2009), and they still make up around a third of the EU

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[49] Agricultural land use intensity varies significantly between Member States: in the Netherlands and Belgium over 70% of farms are classed as high input; in Bulgaria, Estonia, Latvia and Slovakia less than 10% of farms use high levels of inputs (Eurostat, 2012a).

agricultural area[50] (Paracchini et al, 2008). Many of these semi-natural habitats and their associated species are of European conservation importance (Table 5-1) and therefore the subject of conservation measures under the EU Habitats and Birds Directives. But despite the protection of 10 per cent of farmed land within the **Natura 2000 network**, a particularly high proportion of these habitats have an unfavourable conservation status compared to non-agricultural habitats (see Figure 5-1) (EEA, 2010c; European Commission, 2009c).

Biodiversity monitoring over recent decades has demonstrated that the impacts of past and continuing agricultural improvements, intensification and specialisation has led to further significant falls in diversity and loss of specialist agricultural species over much of Europe. The best evidence of widespread declines comes from farmland bird populations, as they have been relatively well monitored. Their trends have been used to develop a **Common Farmland Bird Indicator**, one of the indicators used by the EEA to monitor the status of biodiversity in the EU.[51] The index of common farmland bird population changes in Europe in relation to 1980 levels (see Figure 5-2) shows a substantial 51% decline in their populations. The observed decline was particularly rapid up to about 1985 and especially in the EU-15 (Báldi and Batáry, 2011; Donald et al, 2001; Donald et al, 2006; Fox, 2004). Although there is a suggestion from the combined data that the rate of decline may have decreased in recent years, examination of regional trends indicate that the declines are continuing unchecked in all regions other than in southern Europe. Furthermore, it is important to note that these trends relate to common farmland birds, and population declines in rarer threatened farmland species appear to be unabated and are therefore of particular concern (Birdlife International, 2004).

Grassland butterfly populations have declined by almost 50 per cent since 1990 across Europe due to the intensification or abandonment of grasslands (EEA, 2013; van Swaay et al, 2010a; van Swaay et al, 2006), and wild bees and their forage plants are disappearing (Bommarco et al, 2011; Carvell et al, 2006; Goulson et al, 2008; Kosior et al, 2007). Farmland mammals such as Brown Hare (*Lepus europaeus*), European Hamster (*Cricetus cricetus*), and bats have declined significantly (La Haye et al, 2012; Robinson and Sutherland, 2002; Temple and Terry, 2007; Ziomek and Banaszek, 2007).

It is important to remember that even intensively farmed ecosystems support significant biodiversity, and although many of the remaining species are widespread generalists they are frequently encountered by people and therefore often of high cultural value.

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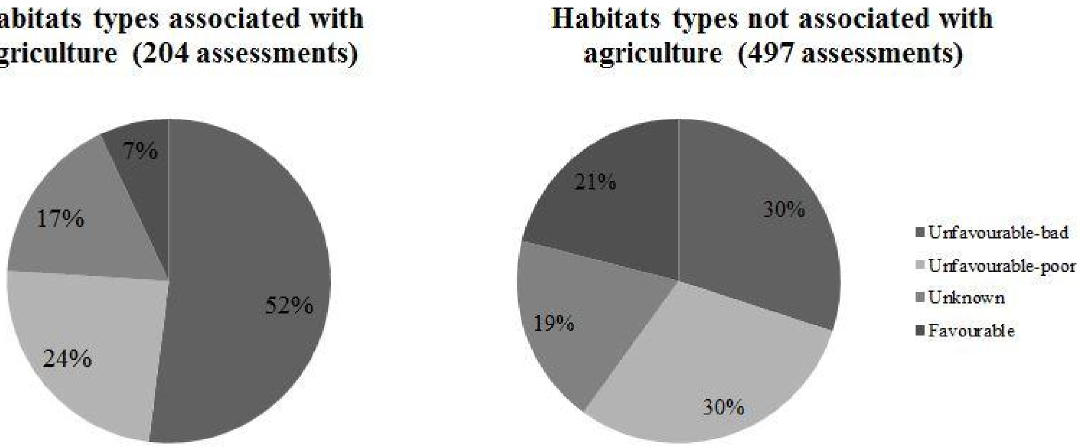
[50] 75 million hectares (Paracchini et al, 2008)

[51] http://biodiversity-chm.eea.europa.eu/information/indicator/F1090245995

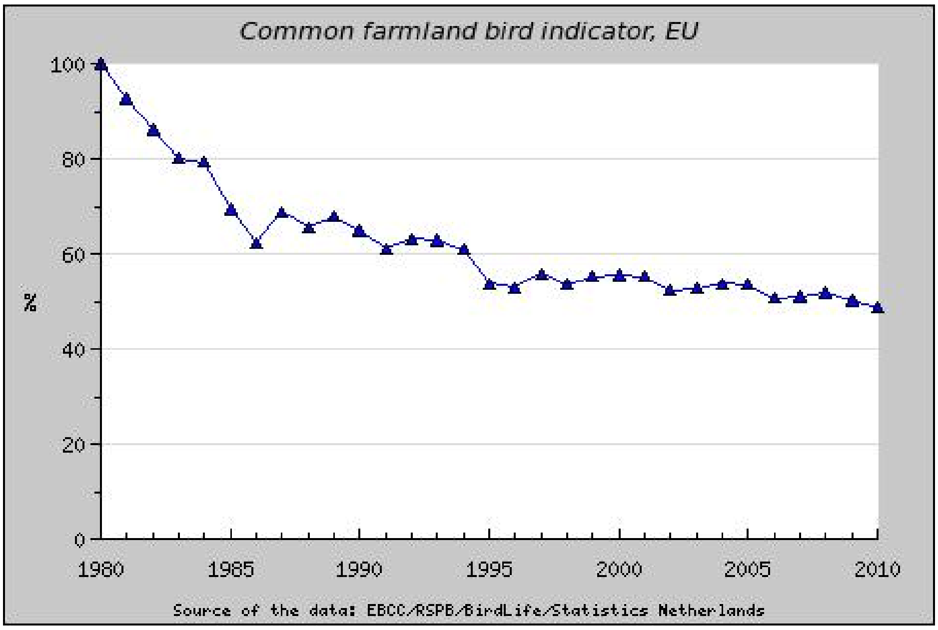
Figure 5-1 Conservation status of 63 habitat types considered as being associated with agriculture compared to the 155 habitat types not associated with agriculture



NB does not include assessments from Romania and Bulgaria or habitat types unique to those countries

Source: Composite Report on the Conservation Status of Habitat Types and Species as required under Article 17 of the Habitats Directive. European Commission, 2009. COM(2009) 358 final; (Halada et al, 2011)

Figure 5-2 Changes in the Common Farmland Bird Indicator in Europe



Note: The index is compiled by the Pan-European Common Bird Monitoring Scheme (PECBMS) based on national species indices which are produced by annually operated national breeding bird surveys. The common farmland bird indicator presents the combined population trends of 37 common farmland bird species based on data collected from 23 EU countries: AT, BE, BG, CY, CZ, DK, EE, FI, FR, DE, EL, HU, IE, IT, LV, NL, PL, PT, SK, SI, ES, SE & UK.

Source: http://www.ebcc.info/index.php?ID=493&result_set=Publish2012&indik%5BEU1_Fa%5D=1

Table 5-1 Agricultural habitats in the EU, their importance for selected threatened habitats and species, and their overall biodiversity importance

Key: HD = Habitats Directive, BD = Birds Directive. Sources: Adapted from Poláková et al (2011), 1 Halada *et al* (2011); 2 adapted from Tucker and Evans (1997); 3 adapted from van Swaay *et al* (2006) using updated an annexes available from Butterfly Conservation Europe (http://www.bc-europe.org/upload/Butterfly%20habitats%20-%20Appendix%201.pdf): 4 (Temple and Cox, 2009a); 5 (Temple and Cox, 2009b). Note: Habitat divisions for each taxa group reflect the habitat types distinguished in the available data.

	Permanent grassland and other habitats grazed by livestock					**Crops**					
Habitat types	Natural habitats	Semi-natural habitats		Improved grassland		Cultivated			Permanent		
		Pastures	Meadows	Organic	Conventional	Extensive	Organic	Intensive	Extensive	Organic	Intensive
HD Annex 1 habitats[*1]	63			0		0	0		0	0	
BD Annex 1 birds[*2]	54			32					5		
HD Annex II butterflies[*3]	9	25		0	0	0	0	0	0	0	0
European threatened amphibians[*4]	3	5		0		1	0		0	0	
European threatened reptiles[*5]	1	4		0		0	0		4	0	
Overall biodiversity importance	Very high, many species are restricted to such habitats	Very high, these habitats tend to be species-rich and declining; some species are restricted to such habitats and dependant on specific agricultural practices		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		High, such habitats are now rare and support some threatened species (esp birds)	Low, especially in intensive farmland dominated landscapes, but biodiversity levels can be enhanced by appropriate measures		Moderate - High, such habitats are declining and support some threatened species	Low, especially in intensive farmland dominated landscapes, but biodiversity levels can be enhanced by appropriate measures	

5.2 Abandonment of agricultural management on semi-natural habitats in the EU

The loss and degradation of semi-natural habitats dependent on farming is the most serious threat to agricultural biodiversity in most of the EU (Billeter et al, 2008). Such impacts are now mostly attributable to partial or complete abandonment of agricultural management (sometimes through afforestation) as a result of their low economic viability and social and agronomic change (IEEP and Veenecology, 2005; Keenleyside and Tucker, 2010). Extensively managed livestock systems are most at risk, especially in mountainous and remote regions and areas with poor soils and harsh climates (Dover et al, 2011; Laiolo et al, 2004). Determining the area and distribution of abandoned land across the EU is problematic (Keenleyside & Tucker, 2010), but as examples, annual losses of 0.17 per cent of Utilised Agricultural Land (UAA) in France and 0.8 per cent in Spain were recorded from the late 1980s to the end of the 1990s (Pointereau et al, 2008). Overall, the EU lost 2.4 per cent of semi-natural farmland since 1990, 40 per cent of which has become scrub or forest, and a fifth converted to more intensive farming (EEA, 2010c). Abandonment of semi-natural farmland is likely to continue over the next decades, as despite increasing agricultural demand (European Commission, 2012b), it seems reasonably certain that the profitability of extensive livestock farming will continue to decline (Nowicki et al, 2009; Rienks, 2008).

In some circumstances such abandonment may enable habitat restoration with beneficial biodiversity impacts (Navarro and Pereira, 2012). But given the high biodiversity importance of the semi-natural grasslands that are at most risk (see Table 5-1), in most situations large-scale abandonment of semi-natural habitats is likely to be significantly detrimental for biodiversity in the longer term (IEEP & Alterra, 2010; Macdonald et al, 2000; Stoate et al, 2009)

5.3 The impacts of farming practices on biodiversity in Europe

It is important to understand the effects of specific practices in order to be able to formulate effective conservation measures. The farming practices summarised below have been shown to have negative effects on biodiversity, based on Poláková et al (2011) and evidence from a range of studies (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). The impacts of two practices – the use of fertilisers and the use of pesticides - are reviewed in detail. In Annex 5.2 a detailed review of the impact of each practice is provided.

It should be borne in mind that 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 their intensity, the habitat affected, and the context. For example, optimal levels of grazing can help maintain habitats, but over and under-grazing can be damaging. But some practices, such as conventional tillage, pesticide use, drainage and irrigation, and the use of artificial fertilisers, nearly always result in less biodiversity.

It is also important to note that fragmentation from urbanisation and other infrastructure developments, as well as climate change (see Chapter 1), will exacerbate all expected pressures on agricultural habitats and species (EEA and FOEN, 2011; IEEP & Alterra, 2010).

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. Consequently Central and Eastern European grasslands, which are less often fertilised, retain more biodiversity (Báldi & Batáry, 2011).

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 results in grass dominance and much reduced plant species diversity, leading to the conversion of semi-natural habitats into agriculturally improved grassland. For example, in the UK an average of only three broad-leaved species are found where nitrogen inputs exceed 75 kg/ha/yr (a currently average fertilisation rate on grassland in the UK[52]) (McCracken and Tallowin, 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.

Declines in plant species diversity from eutrophication result in knock-on declines in invertebrates (Nagy, 2009; Oeckinger et al, 2006). 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.

Use of 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 more abundant and 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 intensively cultivated crops (ie herbicides, insecticides, and fungicides) and most improved grasslands (mainly herbicides) (see Box 5-1 for details). For example, most cereal and maize in the EU relies heavily on the use of herbicides for weed control; around a third of the maize area[53] 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.

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). Amphibians, the most threatened and rapidly declining vertebrate group in

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[52] 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

[53] eg 50-60% of maize in Hungary and 32-42% of maize in France receives insecticides

Europe, are particularly vulnerable to pesticide toxicity due to their permeable skin and a life-style that encompasses terrestrial and aquatic phases (Brühl et al, 2013).

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 contact insecticide sprays only reach some of the organisms in a field, as some can usually hide[54], and populations recover between sprays; however, insecticide and herbicide drift onto field margins affects more species (Drapela et al, 2008; Haughton et al, 2001; Pekár, 2012). Insecticides used in a systemic way, for example 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 5-2 for details). Four systemic insecticides have now been restricted for two years to only non-flowering crops, winter cereals and greenhouse crops[55] because of concern for their impact on honey bees and bumblebees that forage in these treated crops (EFSA, 2013a; EFSA, 2013b; European Commission, 2013a), (Gill et al, 2012; Kindemba, 2009; Whitehorn et al, 2012), as recommended by a recent report for the European Parliament (Grimm et al, 2012). As further discussed in Chapter 8, pesticides may be contributing to declines in bee populations in the EU.

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[54] except species that are particularly active at the time when the insecticide is applied, for example bumblebees in the early morning

[55] 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 imidacloprid, 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

Box 5-1 Pesticide use in Europe

Overall pesticide use in Europe is steadily increasing by weight, 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.[56]

Pesticide active ingredients are therefore classified according to their environmental impact, combining data on eco-toxicity, persistence and environmental characteristics (Eurostat, 2012b) (see Box 5-2). 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[57]).

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[58] and FOOTPRINT[59] 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 insecticide disulfoton (a systemic seed and soil treatment used on potatoes, fruit trees, beets, hops and other crops in the EU) to only 8.67 for flonicamid, a relatively new insecticide now widely used to control aphid on potatoes, wheat and fruit trees.[60] This means disulfoton is assigned over 10 times greater impacts on birds and beneficial insects per unit of pesticide 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[61] 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. 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

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[56] For this reason, atrazine has been withdrawn from the market in the EU since 2005

[57] http://www.milieumeetlat.nl/en/home.html

[58] HAIR: http://www.hair.pesticidemodels.eu/home.shtml

[59] FOOTPRINT: http://www.eu-footprint.org/ppdb.html

[60] http://ec.europa.eu/food/plant/protection/evaluation/newactive/technical_review_flonicamid.pdf

[61] 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

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.

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). **Fungicides** can persist in soil for many months and so can have chronic effects on soil organisms (see Box 5-2 for details). 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.

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, 2010a). Herbicide drift is also significantly reducing field margin plants (Robinson & 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, 2007).

Box 5-2 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[62], and is determined by its rate of **degradation** and its degree of **mobility** in soil, water and air. Pesticides are **degraded** by light (photodegradation), by pH or other soil or water factors (chemical degradation), and by micro-organisms (microbial degradation). Some pesticides remain toxic or increase toxicity when degraded into smaller molecules (metabolites). Fat-soluble pesticides can accumulate within the bodies of animals (known as **bio-accumulation**), and poison their predators (eg Kean et al, 2013).

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 pesticide dispersing into the air, soil, weeds, field margins or water. Granular or liquid soil treatments (generally before sowing or together with the seed) generally 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 (Krupke et al, 2012), though dust can be substantially reduced with new technology.[63] A certain proportion of foliar sprays drifts away and lands on the soil or field margins. Pesticide that lands on foliage is also washed off into soil or dissipates into air (volatilization).

Water-soluble pesticides in soil either **run off into surface waters** (through soil pipes or on the soil surface) or **leach 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

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[62] http://www.eionet.europa.eu/gemet/concept?ns=1&cp=6131

[63] http://seedgrowth.bayer.com/index.php?id=29

fungicide mancozeb is rapidly broken down in soil, its metabolite ETU is more persistent and highly toxic to aquatic life such as amphibians[64] (DG SANCO, 2013; Shenoy et al, 2009). Some pesticides are strongly **adsorbed onto soil** organic matter, and remain in the soil until they are broken down by microbes or run-off with soil erosion. Glyphosate is readily adsorbed onto soil particles, preventing much 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). It is also frequently detected in surface waters, reflecting its widespread use (Horth and Blackmore, 2009). Vineyard soils often contain quite high levels of persistent pesticides (Komárek et al, 2010).

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 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 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). Organisms can 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. They are exposed to systemic insecticides over long periods, resulting in highly effective pest control, but also in cumulative toxicity to non-target organisms, including insects and mites that suck phloem, seed or seedling eaters such as ladybird larvae (Moser and Obrycki, 2009) and birds (Prosser and Hart, 2005). Systemic pesticides are taken up by weeds and are present in sap, pollen, and nectar (Krupke et al, 2012), affecting insects (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).

Other agricultural changes that result in loss of biodiversity on farmland

- **Declines in mixed farming systems** lead to reduced landscape-scale diversity, which leads to biodiversity losses because many species 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 and reduced ecological connectivity amongst habitat patches for animals (Doxa et al, 2012), and few 'refuge' habitats for plant species (Roschewitz et al, 2005).
- **The removal of farmland habitat features** such as hedgerows, trees, ponds, ditches, stone terraces and uncropped areas with patches of rough grass or scrub lead to the loss of important habitat elements in many farmland landscapes. These support food resources, provide shelter and breeding sites and facilitate species movement (Batáry et al, 2010a; Davies and Pullin, 2007; Frey-Ehrenbold et al, 2013; Newton, 2004). 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).

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[64] http://www.epa.gov/espp/litstatus/effects/redleg-frog/2011/mancozeb/assessment.pdf

- **Drainage of grasslands** leads to the loss of shallow pools and ditches, less winter flooding and lower groundwater levels, and changes the vegetation composition. It is a key factor in the decline of many butterfly species (van Swaay et al, 2006; WallisDeVries and van Swaay, 2009), and breeding birds (Newton, 2004), as well as many plant species.
- **Ploughing and reseeding** of grassland with a few selected grass cultivars adapted to high nutrient conditions clearly has a profound impact on the vegetation and knock-on impacts on the whole ecosystem.
- **Intensive grazing** reduces the heterogeneity of plant vegetation and decreases invertebrate species richness (Kruess and Tscharntke, 2002; WallisDeVries et al, 2002). High stocking rates can also lead to soil compaction, which destroys the structural diversity that maintains soil life and hinders access of birds and other animals to soil invertebrate food.
- **Early mowing of grass for silage** on former hay meadows and pasture results in a significant loss of biodiversity of plants, invertebrates, amphibians, reptiles, and birds and mammals dependent on seed food resources and on a sufficient period of undisturbed habitat in which to breed successfully (Buckingham et al, 2006; Buckingham et al, 2010; Vickery et al, 2001) (Oppermann and Spaar, 2003).
- **The use of avermectins and other drugs against parasites of livestock** reduces invertebrate densities in dung, which reduces food resources for the birds and bats that feed on them (Beynon, 2012; Floate et al, 2005; Hutton and Giller, 2003; Vickery et al, 2001).
- **Switches from spring-sown crops to winter-sown crops** in many areas results in the early ploughing of cereal stubble fields in autumn and winter, which deprives many farmland birds and mammals of the key food resource seeds (Geiger et al, 2010a). The loss of winter stubbles has contributed to farmland bird declines (Chamberlain et al, 2000; Newton, 2004; Whittingham et al, 2005). The switch to winter cereals in Denmark also led to a dramatic decline in the weed flora (Hald, 1999).
- **Ploughing and other tillage operations** result in the direct mortality of soil invertebrates and disruption of the soil ecosystem (Nieminen et al, 2011; Postma-Blaauw et al, 2012; Roger-Estrade et al, 2010), which reduces food availability for soil-invertebrate feeding birds (Tucker, 1992).
- **Irrigation** leads to intensification of many agricultural practices, as described above, with substantial impacts on biodiversity. For example, this has resulted in severe declines in farmland bird species, on former extensive cereals in Spain (Brotons et al, 2004; Ursúa et al, 2005). Trickle irrigation of permanent crops such as olives or citrus is associated with soil erosion and salinization, which has an indirect impact on soil biodiversity and weed diversity (European Commission, 2010a).

5.4 Impacts of agricultural practices on biodiversity outside agriculture in the EU

Intensive farming practices have significant impacts on other habitats that can lead to substantial habitat changes and biodiversity losses. Agriculture in the EU consumes a third of all water use, and in Mediterranean regions this diverts up to 80% of water from freshwater habitats (EEA, 2009). The increase in fertiliser use, ploughing of grasslands, and stocking densities, has led to increases in pollution, including water pollution, especially from nutrient-rich silty run-off from cultivated fields. Pesticides have significant impacts on species in freshwater habitats (Beketov et al, 2013). The most important pollution impacts result from emissions of reactive nitrogen (primarily ammonia from manure), which is now considered to be one of the most important causes of biodiversity loss, both terrestrial and aquatic (Dise, 2011).

5.5 The impacts of agricultural production on biodiversity outside the EU

EU agriculture has a substantial biodiversity footprint resulting from its feed imports from non-EU countries (AEA, 2008; Lugschitz et al, 2011). Although the EU is relatively self-sufficient in cereals, it imports around 70% of its animal feed needs, mainly in the form of soybeans or maize. It is estimated that EU soy imports account for 12 million hectares of soybean cultivation outside Europe (Westhoek et al, 2011), nearly all in Brazil and Argentina, where semi-natural habitats high in biodiversity (eg Cerrado in Brazil, Chaco in Argentina) have been converted to soy plantations (Kessler et al, 2007; Mann et al, 2010; Smaling et al, 2008; Zak et al, 2008). Soybean cultivation also causes indirect deforestation through the displacement of livestock farming into forest (FAO, 2010a; Nepstad et al, 2006). The net embodied deforestation associated with EU-27 imports of crop and livestock products between 1990 and 2008 was calculated at 7.4 million ha (European Commission, 2013b), equivalent to 4 per cent of the EU's forest area. Half of this was from soybean imports from Brazil and Argentina. The impacts of palm oil, sugarcane, and maize for bioenergy feedstocks are described in Chapter 7.

5.6 Why biodiversity losses in agricultural systems matter

5.6.1 The impacts of biodiversity loss on agricultural production and ecosystem services

Biodiversity losses should be a concern for farmers, as well as nature conservationists, because they affect the long-term sustainability of agricultural production (EASAC, 2009; EEA, 2010a; PBL, 2009). Many species within agricultural systems have an important role to play in the provision of ecosystem services that underpin sustainable agricultural production. Consequently, there are concerns over the impacts of losses of biodiversity on important farmland ecosystem components and functions, some of which are discussed below.

Plant and animal genetic resources

Plant and animal genetic resources for food and agriculture are the biological basis of food security, as well as being an important part of our cultural heritage and regional identity in Europe. Genetic resources for food and agriculture comprise the diversity of genetic material contained in local or regional livestock breeds and varieties, traditional plant varieties and modern crop cultivars, as well as wild relatives and other wild species that can be used now or in the future for food and agriculture (FAO, 2007; FAO, 2010b). Adapting agriculture to the changing climate (eg drought resistant crops and breeds), or new demands, such as for bioenergy or biomaterials, may depend on species and varieties that are of little economic value today.

Europe harbours a large part of the world's recorded domestic **livestock diversity** (Nitsch, 2006), but almost half of European livestock breeds have endangered or critical status or are extinct[65] (DEFRA, 2013a; FAO, 2007). The genetic diversity in Europe's cultivated crops was eroded by the replacement of **landraces** by high-yielding varieties (eg Piergiovanni and Lioi, 2010) (together with other developments on agriculture that have changed the diversity of crops grown). It is now increasing again due in part to a greater use of crop wild relatives in breeding (Hajjar and Hodgkin, 2007; van de Wouw et al, 2010), but the European continent's significant endemic genetic diversity of **crop wild relatives** is vulnerable or threatened with extinction (Bilz et al, 2011).

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[65] http://www.eea.europa.eu/data-and-maps/indicators/livestock-genetic-diversity/livestock-genetic-diversity-assessment-published

Chapter 8 describes the status of European plant genetic resources and options for its protection.

Soil functions

Sustainable agricultural production fundamentally depends on soil functions (see Box 5-3). Soils are highly complex systems with a very high level of biodiversity (Turbé et al, 2010), the majority of which is still unknown. Soil life supports agricultural production by decomposing plant residues and driving nutrient cycling, and by helping to stabilise soil structure, degrading pollutants, and regulating soil pests and diseases (Turbé et al, 2010). Soils also provide important ecosystem services for the wider landscape, including water retention and purification (through nutrient trapping), and carbon sequestration and storage which has an important impact on climate regulation (see Chapter 3). Because of the huge biodiversity present in soil, the essential ecosystem services it provides are remarkably robust: there is a high level of functional redundancy, so the loss of some species diversity does not affect service provision directly.

Box 5-3 The role of soil biodiversity in supporting soil processes and agricultural production

A range of soil organisms help break down plant residues to start decomposition and humus formation. Springtails (Collembola) are extremely abundant "**litter transformers**" that fragment plant residues and make them more accessible for microbial decomposition. Enchytraeid worms are very abundant in arable soils and digest large quantities of plant residues.

Bacteria, algae and fungi are the "**chemical engineers**" that decompose the molecules in plant residues, and transform them into nutrients (eg nitrogen, phosphorus, sulphur) that can be used again by crops. Mycorrhizal fungi have a crucial role because they scavenge for phosphorus and other nutrients and make them available to the plant roots on and in which they live (Hijri et al, 2006). Nitrogen-fixing bacteria and algae are very important for bringing nitrogen into soils and making it available for plants. Some are free-living in the soil, but most are found in the root nodules of leguminous plants.

Many soil organisms, such as earthworms, are "**ecosystem engineers**" because of the way they create and maintain soil structure and mix organic matter into soil. A key ecosystem engineering and chemical engineering process is the creation of long-lasting **soil organic matter** (humus), which is crucial for both soil structure and resilience, ability to retain water, and the long-term storage of nutrients – a "life-force" of the soil. Fungal hyphae and bacterial slimes are key binding factors that create humus and hold together soil.

Some soil organisms are "**biological regulators"** because their grazing, predation or parasitism controls the populations of potentially damaging groups, including soil borne pests and diseases. Nematodes, one of the most diverse soil invertebrate groups, are the main consumers of fungi and bacteria, as well as other nematodes including root-feeding pests and virus transmitters. Carabid beetles are active predators of slugs, root weevils, and soil-living larvae such as cutworms or wheat bulb fly larvae.

However, soils are vulnerable and many soils are degraded across Europe (Jones et al, 2012). A recent expert review indicates that soil biodiversity is potentially under high pressure in nearly a quarter of the EU[66], and is under very high pressure on 8 per cent of this area (Gardi et al, 2013; Jeffery et al,

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[66] the EU-25 (excluding Sweden and Finland)

2010). Much of this is due to the serious decline of soil organic matter on most of Europe's arable land (Jones et al, 2012). In turn, the reduction of soil organic matter is a large contributor to other soil degradation processes, such as soil erosion and soil compaction (Jeffery et al, 2010).

Soil organic matter is the result of soil organism activity decomposing plant residues, and is the main 'fuel' driving the 'engine' of the soil food web (Jeffery et al, 2010). Soil biodiversity is intimately bound to soil organic matter: a large, varied source of organic matter supports a wide variety of organisms on its diverse substrates and nutrients. Generally, a reduction in soil organic matter is associated with a lower soil organism abundance and diversity. Almost half of Europe's land area has very low levels of soil organic matter[67] (Jones et al, 2012), and erosion rates on tilled arable land are 3 to 40 times greater than the upper limit of tolerable soil erosion[68] (Verheijen et al, 2009). However, soils are very diverse: sandy soils, which are naturally low in organic matter, host specialised species; whilst peat soils support a unique and mostly unknown soil biodiversity as well as storing large volumes of organic matter (Littlewood et al, 2011).

Pollination

Many food and biofuel crops (such as oilseed rape, vegetables and fruit) rely on insects and other invertebrates for pollination. Pollination enables the development of seeds and fruit and is therefore essential for the production of these crops. Pollinators pick up pollen grains on their bodies as they visit flowers, which rub off as they visit another flower. Honeybees (*Apis mellifera*) are major pollinators of crops worldwide, but bumblebees (*Bombus* spp.) are also very important pollinators of long-corolla flowers such as field beans, clover, and many wild species (Albrecht et al, 2012). Their buzz pollination (shaking the flower to dislodge more pollen) is particularly efficient at pollinating tomatoes, potatoes and other *Solanum* species. Mason bees (*Osmia* spp) are key pollinators of apple trees (Brittain et al, 2013). Flies, including hoverflies, bee flies, drone flies, carrion flies and fruit flies, are important for some plant species and are general pollinators when bees are absent. Butterflies and moths pick up pollen on their proboscis and pollinate some adapted species.

Semi-natural habitat patches are particularly important for supporting pollinator populations in agricultural landscapes (Oeckinger & Smith, 2007; Ricketts et al, 2008). The way pollinators are being lost in our agricultural landscapes, and the value of pollinators to European agriculture, is described in Chapter 9.

Natural biological control

Natural biological control is the natural control of pest populations through predators, parasitoids, parasites, and disease, through the actions of a diverse biological control community in and around crop fields.[69] Most native pests are eaten, parasitized, and infected by a wide range of insects, other invertebrates, bacteria and viruses, as well as amphibians, reptiles, birds and mammals (known as 'natural enemies'), which in ecologically intact communities can keep pest populations at a low level.

In crop monocultures, pest populations can increase faster than their natural enemies. If these natural enemies are not able to survive on alternative food or hosts or cannot move into the crop from other habitats fast enough, pest populations will escape their control and cause damage, triggering more insecticide use (see Box 5-4). However, if natural enemies can build up their populations on non-

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[67] Low levels are defined as below 3.4 per cent soil organic matter or two per cent soil organic carbon

[68] Tolerable soil erosion is defined as any actual soil erosion rate at which a deterioration or loss of one or more soil functions does not occur

[69] Biological control also refers to the use of introduced biological control agents in agricultural fields, greenhouses, etc ("classical" biological control or importation or augmentation biological control). This includes the use of *Trichogramma* wasp egg cards, the release of captive-bred ladybirds, lacewings, parasitoid wasps, etc, or the spraying of preparations of bacteria, viruses or insect attractants or hormones.

damaging levels of pests in the crop, on weeds, or in the field margins, they are ready to increase their activity and keep pests in check. This is why insecticide use early in the crop season can be very damaging: it kills both pests and natural enemies, but the pests recover more quickly and cause a second wave of much greater damage to the crop (Dutcher, 2007).

There is evidence that biological control services across Europe's arable farmland are compromised because of insecticide use (Geiger et al, 2010b) and the lack of refuge habitat and floral resources to sustain populations eg in untreated flower-rich margins and on weeds (Holland et al, 2012; Landis et al, 2005; Rusch et al, 2013; Winqvist et al, 2011).

Box 5-4 The downside of biodiversity: pests, diseases and weeds

A diversity of pests, diseases and weeds present challenges to agricultural production in Europe, and can destroy yields if not controlled. It is predicted that climate change and climate variability will increase pest and disease losses in agriculture, especially in Southern Europe (see Chapter 1 for details).

Sucking pests take away energy from growing plants and transmit viral diseases, they include Aphids (Aphididae), Thrips (Thysanoptera), Sucking Bugs (Homoptera) incl. Frog Hoppers, Leaf Hoppers (Cicadellidae), and Plant Bugs (Miridae), Spidermites (Acaridae). **Chewing pests**, including various caterpillars (Lepidoptera), and Leaf Beetles (Chrysomelidae), are most damaging to young plants or when they have lifestyles hidden away from predators, such as stemborers of **maize**, which also encourage fungal infections that reduce grain quality (Meissle et al, 2010). Western Corn Rootworm (*Diabrotica virgifera virgifera*) is a new and damaging pest of maize that is spreading across Europe (Gray et al, 2009). **Soil pests** include pest nematodes eg Potato Cyst Nematode, Cutworms (Lepidoptera) that cut off seedlings, Beetle grubs (Coleoptera) such as Wireworms (Elateridae larvae), Leatherjackets (Tipulidae larvae), Millipedes (Diplopoda), Symphylids, Slugs, and Springtails (eg *Onychiurus* spp).

Diseases can be caused by fungi, viruses, bacteria, and/or other pathogens, and can be transmitted by water, wind, soil, plant material, insects, or other animals. Cereals are attacked by common soil- and residue-transmitted fungi including *Alternaria alternaria* (sooty mold), *Cochliobolus sativus* and *Fusarium* spp. (common root rot, head & seedling blight). *Rhizoctonia solani* (root rot). The average yield increases from fungal disease control in Danish winter **wheat** are estimated to be about 10%, but vary considerably across years, depending on the earliness of disease onset and actual disease severity levels in individual seasons (Petersen et al, 2010). **Apples** receive up to 20 fungicide sprays per year to control fungal disease. **Potatoes** are attacked by long-standing fungal diseases such as Fusarium Potato Blight and Ring rot (*Clavibacter michiganensis*), and new diseases (eg *Dickeya solani*).

Weeds present management challenges in almost all crops, and can result in significant crop losses. In each crop a few persistent weed species cause most of the problems, and integrated weed management systems actually aim to increase weed diversity so that dominant weeds are suppressed. Ragwort (*Jacobaea vulgaris*) and White Hellebore (*Veratrum album*) are common pasture weeds that are poisonous to livestock. **Sugar beet** is susceptible to weeds because of its slow biannual growth.

5.6.2 The implications for the EU's nature conservation objectives

It is clear from this brief review of existing evidence that arresting and reversing losses of biodiversity and ecosystem services in EU agricultural habitats, and in habitats affected by agricultural activities, is essential if the EU is to meet its headline biodiversity target, which is '*to halt the loss of biodiversity and the degradation of ecosystem services in the EU by 2020, restore them in so far as feasible, while stepping up the EU contribution to averting global biodiversity loss*'.[70] The Biodiversity Strategy 2020 recognises that in order to achieve this goal, significant action is needed to protect and conserve biodiversity in relation to agriculture, and four of the targets refer specifically to this.

- Target 1 requires improvements in the status of habitats and species protected by the Natura Directives; 28% of the non-marine habitat types and around 15% of the non-marine species are associated with farming, and 10% of the area of the Natura 2000 network is farmland, which is mostly in unfavourable conservation status and depends on the reinstatement or continuation of low-intensity management (Olmeda et al, 2013).
- Target 2 requires the maintenance of ecosystem services from land and the restoration of at least 15% of degraded ecosystems; the negative impacts of high input agricultural practices are currently a major factor degrading ecosystem services from land in the EU, whilst a significant proportion of High Nature Value farmland is degraded (Tucker et al, 2013).
- Target 3 requires a significant increase in the contribution of agriculture to maintaining and enhancing biodiversity, through better coverage and effectiveness of CAP measures for biodiversity and ecosystem services, and through the conservation and use of agricultural genetic diversity.
- Target 6 requires a step up in the EU's contribution to averting global biodiversity loss; this includes a reduction in the biodiversity impacts of EU consumption patterns, within which agricultural imports are a significant factor.

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[70] And '*By 2050, EU biodiversity and the ecosystem services it provides – its natural capital – are protected, valued and appropriately restored for biodiversity's intrinsic value and for their essential contribution to human wellbeing and economic prosperity, and so that catastrophic changes caused by the loss of biodiversity are avoided.*'

5.7 Maintaining and increasing biodiversity in agricultural systems to 2050

5.7.1 Biodiversity-friendly agricultural practices

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). Their main benefits for biodiversity are summarised in Table 5-2 together with impacts relating to climate change mitigation and adaptation (see Chapter 3), and ecosystem service provision. Biodiversity benefits are described in more detail in Annex 5.2.

Table 5-2 Farming practices that are beneficial for biodiversity and their impacts related to climate change mitigation and adaptation, and ecosystem services

Protection and management of farmland habitat features	Biodiversity benefits	Climate change mitigation impacts	Climate change adaptation impacts	Other ecosystem service impacts
Protection, restoration and management of natural and semi-natural agricultural habitats	Natural / semi-natural habitats are of highest conservation importance and maintain many threatened species	Many such habitats are on carbon-rich soils, especially peatlands and grasslands on other types of soils with high carbon content	Such vegetation stabilises soils, improves water infiltration, thereby reducing run-off and improving water availability	flood alleviation; water provisioning; maintains pollinator populations; cultural & recreational benefits
Extensive grassland management, decreased grazing density, mixed stocking, mosaic / rotational grazing	Livestock increase botanical and structural diversity of grass swards, increasing niches and thereby overall biodiversity. Livestock and their dung support invertebrates and their predators	As semi-natural	As semi-natural	high cultural value; maintains pollinator populations; reduces soil erosion and leaching from manure
Hay meadow management (late cutting, restricted or no fertilisation etc)	Stimulates high botanical diversity and associated fauna	Avoiding GHG emissions from the production and use of fertilisers and mechanical operations		high cultural value; maintains pollinator populations
Establishment / restoration of farmland features (hedges, shelterbelts, woodland patches, terraces, farm ponds, stone walls etc)	Farmland features are key breeding and feeding habitats for many species on farmland	Trees and shrubs sequester carbon	Can reduce risks of soil and wind erosion (esp. terraces); protect livestock from heat and wind	Cultural benefits (eg recreational value of countryside)
Protection and use of crop and livestock genetic diversity and crop wild	Traditional hardy livestock breeds are often most suitable	Livestock with lower supplementary	more diverse and climate resilient	Cultural benefits

Protection and management of farmland habitat features	Biodiversity benefits	Climate change mitigation impacts	Climate change adaptation impacts	Other ecosystem service impacts
relatives	for management of semi-natural habitats. Interbreeding with CWR can reduce crop dependency on eg pesticides & fertilisers. Protection of crop wild relatives in genetic reserves also protects other threatened species.	feed requirements reduce GHG emissions; increased crop genetic diversity can reduce crop dependency on pesticides & fertilisers	livestock and crops can maintain productivity in the face of climate shocks	
Integrated Farm management / Integrated Production / Precision agriculture / Organic management	Reduced or no use of artificial fertilisers and pesticides increases soil biodiversity and invertebrate populations, providing more food for associated species	May reduce GHG emissions from the production and use of artificial fertilisers; reducing N2O and CO2 emissions (due to increased efficiency and optimised use of manure)	Reduced input costs and increased input use efficiency improve farm resilience to price increases; improved water use efficiency & better soil water retention reduce impacts of drought	Reduced pollution of freshwater habitats from fertiliser and pesticide run-off; premium food products
Conversion of arable land to species-rich grassland	Increases soil biodiversity and plant diversity, and associated fauna (eg soil invertebrate feeding birds)	Higher carbon sequestration & reduced GHG emissions from mechanical operations	Restoration of soil organic matter, protection against soil erosion, improved water balance	As semi-natural habitats
Integrated Pest Management (IPM), Integrated Weed Management (IWM)	Increases soil biodiversity and plant diversity, and associated fauna	Reduced use of pesticides (and benefits of diversified crop rotations as below)	Benefits of diversified crop rotations as below	Natural biological control of pests and diseases; reduced pollution from pesticide run-off
Diversified crop rotations, including more leguminous crops, fodder crops and green manures / catch crops	Increases soil biodiversity and associated fauna, and landscape diversity creating more niches and therefore biodiversity, notably flower resources for	May reduce GHG emissions from the production and use of fertilisers and pesticides due to nitrogen fixation and improved pest and weed	Improved soil structure and water retention capacity due to increased soil organic matter; increased resilience of soil and crop production to	Natural biological control of pests and diseases; possibly reduced pollution from nutrient run-off

Protection and management of farmland habitat features	Biodiversity benefits	Climate change mitigation impacts	Climate change adaptation impacts	Other ecosystem service impacts
	pollinators	control; may improve soil carbon sequestration	climate shocks	
Under-sowing spring cereals and grass-clover leys in cereal rotations	As rotations (but flower visitors only benefit if clover allowed to flower); more grassland habitat in arable areas benefits some species	May reduce GHG emissions from the production and use of fertilisers and mechanical operations	Improved soil organic matter and water balance	
Conservation tillage, zero-till and direct drilling (including cover crops, mulching)	Increases soil biodiversity and associated fauna; increased herbicide use may have negative effects	Reduced carbon losses from soil maintains carbon sequestration; reduces GHG emissions from mechanical operations	Reduced soil erosion, improves water infiltration, thereby reducing run-off and improving water availability (but fungal diseases may reduce yield)	Flood alleviation and water resource enhancement; less nutrient run-off and eutrophication; possibly increased herbicide pollution
Field margins: grass & shrub buffer strips, flower rich field margins, bird food strips	Buffer strips protect water courses from run-off and spray drift; margins managed for biodiversity can increase plant diversity and food resources for pollinators, other insects and birds	May reduce GHG emissions from the production and use of fertilisers; reduced use of pesticides if natural biological control is enhanced; trees & shrubs store carbon	Can reduce soil erosion and improve water retention; can reduce susceptibility to pests & diseases through natural biological control	Helps protect water resources, cultural values, maintains pollinator populations, improved recreational access on farmland (grass strips only)
Uncropped arable field margins, arable in-field bird patches	As above; bird patches provide nesting and feeding sites; key habitat for rare arable weeds	May reduce GHG emissions from the production and use of fertilisers	Can lead to small increases in soil erosion and reduced yields	
Overwinter stubbles and winter bird crops	Prolongs the availability of food resources for birds	Can increase soil organic matter	Reduced soil erosion and run-off	Helps protect water resources
Set-aside, fallow	Provides breeding and feeding habitats for invertebrates, birds and mammals; key habitat for rare arable weeds	May reduce GHG emissions from the production and use of fertilisers and reduced mechanical	as stubbles	Improved recreational access on farmland, maintains pollinator populations

Protection and management of farmland habitat features	Biodiversity benefits	Climate change mitigation impacts	Climate change adaptation impacts	Other ecosystem service impacts
		operations, and reduces carbon losses		
Maintenance of permanent species-rich ground cover in perennial crops	Species-rich grassland is key habitat for plants, invertebrates and food resource for birds and other species	Maintains or enhances carbon sequestration in soil	Significantly reduces soil erosion and improves water retention	Maintains pollinator populations; reduces run-off into water sources

5.7.2 The current status of biodiversity-friendly practices in EU agriculture

Most of the beneficial practices listed in Table 5-2 are supported under agri-environment schemes in Member States' Rural Development Programmes, though the range and scope of actions varies greatly amongst programmes (Keenleyside et al, 2012). A meta-analysis of published research shows clear evidence that agri-environment schemes benefit species richness and abundance on both arable and grassland across Europe (Batáry et al, 2010b), but reviews also show that current agri-environment schemes are not sufficient to reverse the declines in Europe's farmland biodiversity (Berendse et al, 2004; Kleijn et al, 2006; Kleijn et al, 2011). Many agri-environment schemes are insufficiently targeted at biodiversity conservation or do not cover enough area (Concepción et al, 2012; Le Roux et al, 2009; Merckx et al, 2009).

Farmers are more likely to take up changed field margin management practices rather than in-field practices such as bird patches or fallow fields, over-wintered stubbles, crop diversification, or integrated pest or weed management (Poláková et al, 2011; Vickery et al, 2008). However, modelling based on bird conservation requirements shows that the main priority for most of the declining bird species on farmland are practices that provide in-field resources and breeding habitat, although some species also benefit from field edge management practices (Butler et al, 2007a; Butler et al, 2007b; Butler et al, 2009; Butler et al, 2010).

A number of reviews conclude that agri-environment programmes need to be better targeted to the nature of the landscapes of the regions where they are implemented and the type of species groups that should be benefiting (Batáry et al, 2010b; European Court of Auditors, 2011; Whittingham et al, 2007).

5.8 What is needed to maintain and increase biodiversity in agricultural systems?

Agriculture has created many habitats of high biodiversity value, but more recently has contributed substantially to the overall loss of biodiversity in Europe and the failure to meet the 2010 targets. Whilst progress has been made in regulating the use of more persistent pesticides, and introducing a new generation of agri-environment incentives for farmers, the scale of the challenge is such that a **step change in biodiversity conservation on farmland** in Europe is needed if the ecosystem services underpinning sustainable agricultural production are to be restored and enhanced, and the 2020 biodiversity targets met.

The spatial scale over which agricultural biodiversity is delivered needs to be increased significantly and the efficiency and effectiveness of measures improved to ensure that biodiversity thrives in the wider countryside as well as in protected areas (Poláková et al, 2011). For example, a study estimated that Germany would need active management actions over at least 15 per cent of its UAA in order to reverse the declines of farmland species and secure habitats, including restoring and maintaining semi-natural landscapes, extensifying 10 per cent of intensive grassland, and allocating 7 per cent of arable and grassland to farmland features (Hampicke, 2010). A Netherlands study estimated that a country-wide approach to conservation of farmland biodiversity would require active biodiversity management practices on at least 20 per cent of UAA (Overmars and Zeijts, 2010).

Active interventions to support and protect semi-natural farmland and the farming systems that maintain it are needed

Part of the response should be focussed on arresting the continued decline of the HNV farming systems still characteristic of considerable areas of Europe, particularly extensive livestock grazing. These play an important part in maintaining semi-natural habitats, many of which require protection and management under the Habitats Directive. The challenge is to maintain economic viability of these systems through a combination of support and enhanced investment in traditional management alongside the development of new approaches and adaptation to changing socio-economic conditions. Extensive livestock farming under appropriate management conditions can make a key contribution to European biodiversity.

Farmers who deliver the essential management of biodiverse habitats and species of conservation value on farmland often farm under difficult circumstances using labour-intensive systems on marginal land. This requires an integrated package of support measures that ensures the **long-term viability of High Nature Value farming systems** and their value for biodiversity, including combined support from both pillars of the CAP[71], as well as better management within the Natura 2000 network:[72]

- Member States can use the new CAP framework to develop an HNV policy package that 1) ensures that farming of semi-natural habitats continues; 2) supports the long-term viability of the farming systems that protect and maintain biodiversity; 3) builds farm capacity and add value to farm produce to improve economic and social sustainability; and 4) supports specific conservation actions for habitats and species on farmland (Olmeda et al, 2013; Oppermann et al, 2012)
- Specific support and advice should be targeted at farming systems that maintain and restore Natura 2000 habitats and species, both within Natura 2000 sites and outside, especially where they buffer or connect Natura 2000 sites.
- Recognise the substantial ecosystem services supplied by semi-natural farmland and farming systems by more explicitly linking public support to their continuation (including carbon storage, water flow regulation and purification, cultural and recreational value), through better monitoring, assessment and recognition of multifunctional land management and outcomes.

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[71] It is estimated that maintaining HNV farming practices over 80 million ha of EU-27 farmland would need €16 to €23 billion per year (including the farmland within Natura 2000) (Beaufoy and Marsden, 2010; Hart et al, 2011), compared to current annual spending on CAP Pillar 2 environmental measures (axis 2) of €41.2 million (including Member State co-financing.

[72] It is estimated that currently only a fifth or less of the funding that would be necessary to maintain and restore the Natura 2000 network to favourable conservation status, including the 22.2 million ha of farmland, is actually being made available (European Commission, 2011b; Gantioler et al, 2010; Kettunen et al, 2011).

Actions to avoid and reduce the detrimental impacts of agriculture to below threshold levels

At the same time there are opportunities to manage the pressures arising on biodiversity in the more specialised, high yielding and intensively managed parts of European agriculture. Firstly this involves the effective implementation of existing EU legislation, such as the Nitrates Directive and legislation on pesticides. In addition, greater priority on the development and application of integrated pest management (IPM) is required, where progress appears to be lagging and where substantial biodiversity, climate and agronomic benefits could be gained.

It is clear that ambitious actions are needed to constrain and reduce the negative impacts of intensive agricultural production on biodiversity in order to meet the goal of sustainable intensification. The EU can:

- Push for ambitious pesticide reduction targets and full implementation of integrated pest management under the Sustainable Use of Pesticides Directive. 20 Member States have now produced plans[73], indicating that training and awareness is improving; however, they lack ambition. Only Denmark[74] and France[75] set quantitative pesticide reduction targets.[76] Farm Advisory Services are now obliged to provide farmers with IPM advice.
- EU policies to reduce nitrogen (N) emissions and leaching[77] all demand substantial action from the agricultural sector. The strict and uniform implementation all over the EU of 1) balanced fertilisation (fertiliser use that does not lower crop yields[78] but that decreases N leaching losses to less than 50 mg $NO_3^- \, l^{-1}$ [79]), 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, would increase Nitrogen Use Efficiency by 25 per cent, while ammonia emissions would decrease by 31 per cent and N leaching by 41 per cent (Oenema et al, 2009). This would bring substantial benefits for biodiversity both on farmland and in freshwater and marine habitats in Europe.
- CAP cross-compliance regulations have established a baseline of minimum environmental standards for farmland management across the EU, for example some protection for farmland features (Poláková et al, 2011). In the new CAP regulations Member States have been given greater flexibility to set GAEC[80] requirements. It is therefore important that Member States ensure high and enforced national standards that include the protection and management of permanent grassland, riparian buffer strips, and farmland features.

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[73] http://ec.europa.eu/food/plant/pesticides/sustainable_use_pesticides/national_action_plans_en.htm

[74] The Danish plan aims to reduce pesticide use by 40%

[75] The French Ecophyto plan aims to reduce pesticide sales in France by 50% by 2018, http://agriculture.gouv.fr/Ecophyto-in-English-1571

[76] http://www.pan-europe.info/News/PR/130620_letter_Borg.pdf

[77] The Nitrates Directive, the Thematic Strategy on Air Pollution, and the National Emission Ceiling Directive

[78] 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)

[79] The Nitrates Directive specifies that nitrate concentrations entering groundwater and surface waters must be reduced to less than 50 mg $NO_3^- \, l^{-1}$ in all designated nitrate vulnerable zones (NVZ). 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.

[80] Rules for Good Agricultural and Environmental Condition, including establishment of buffer strips, protection of groundwater and soil organic matter, minimum soil cover and management to limit erosion, and retention of landscape features

Actions to encourage and support the adoption of biodiversity beneficial practices and habitat restoration

Conflicts between increasing scale, specialisation and input use on arable land and in horticulture on the one hand, and the revival of biodiversity on the other, can only be addressed by action at different levels. This includes stronger education and advice for farmers, measures to maximise the biodiversity benefits of ecological focus areas being introduced into the CAP, more focussed and effective agri-environment schemes and further deployment of good practises.

All the actions listed in Table 5-2 bring biodiversity benefits and co-benefits for climate change adaptation and/or mitigation, and should be implemented as widely as possible. Two specific actions that bring multiple benefits for biodiversity, climate change mitigation and adaptation, and resource use efficiency are:

- Precision farming within which inputs are matched as precisely as possible to crop conditions can substantially decrease off-farm impacts of fertilisers, pesticides and irrigation.
- Flower rich field margins boost pollinator abundance and natural biological control, thus increasing yields of crops such as oilseed rape, provide resources for birds and mammals, and act as buffer strips that catch run-off and decrease soil erosion.

Actions to increase research, monitoring and innovation to maximise biodiversity benefits of agricultural change

Some of the beneficial practices on intensive arable and grassland may reduce overall output or constrain productivity increases per unit area over the short term, principally fallowing and grazing extensification; however this does not take account of their contribution to the long term sustainability of farming practices, for example through co-benefits for soil organic matter and climate change adaptation. This has led to a debate on the degree to which actions that focus on enhancing biodiversity within existing farmland (“land sharing”) drive agricultural expansion and thus the loss of non-farmed or extensively farmed habitats elsewhere, and whether it would be better for overall biodiversity if yields are maximised on existing farmland despite the biodiversity loss, in order to retain and recreate biodiversity-rich habitats outside agriculture (“land sparing”) (Balmford et al, 2005; Green et al, 2005; Phalan et al, 2011). Current evidence suggests that in mega-biodiverse countries with large areas of natural habitat, land sparing would be a more effective conservation strategy than land-sharing. However, the situation in Europe may be very different, due to the high biodiversity importance of semi-natural habitats. More research is therefore needed to establish the applicability of the land sparing concept in the EU, the influence of scale on the issues, and policy options that support land-sparing if needed (Ewers et al, 2009; Oeckinger & Smith, 2007; Phalan et al, 2011; Tscharntke et al, 2012).

In-field monitoring and constant review of the impacts of changing farming practise on the species and habitats dependent on agricultural ecosystems, and that underpin agriculture (such as soil biodiversity), needs to be maintained and further strengthened if our understanding of the dynamics between farming and biodiversity is to be improved and applied more systematically by the actors involved.

Actions to reduce the external impact of Europe’s food and feed imports

Whether EU food production increases, and contributes to feeding the world, depends on global price trends, trade policies, biofuel policies, and consumer preferences for domestic versus imported food products (Hart et al, 2013). The EU’s substantial imports of soy, palm oil and maize are facing increasing competition from countries with rapidly increasing demand, such as China. There is also a fear that a substantial scaling up of biodiversity-friendly farming practices in the EU could reduce agricultural production and increase demand for agricultural imports, increasing the EU’s impacts on global biodiversity loss. However, as described above, many biodiversity actions will also increase agricultural sustainability, or, if well designed and implemented, have little productivity impact.

Furthermore, the EU can make a more substantial contribution to reducing global biodiversity loss through actions to **improve the environmental footprint of the EU's food, feed and feedstock imports**, and to encourage consumer demand for environmentally sustainable food, including:

- active EU engagement in international initiatives to develop global environmental principles for food, fibre and energy production and clarification of assessment standards in the forthcoming policy paper on sustainable food;
- encouragement and support for voluntary and private certification schemes and products, such as the Roundtable on Sustainable Soy, Roundtable on Sustainable Palm Oil, organic, fair trade, GlobalGAP;[81]
- education and awareness campaigns to reduce unhealthy meat consumption levels, whilst promoting the livestock products from European High Nature Value farms;
- and actions to increase domestic production of animal feed that also brings benefits for biodiversity and adaptation to climate change, such as legume crop systems that do not require high levels of pesticide use.

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[81] http://www.globalgap.org/uk_en/for-producers/

6 CULTIVATION OF GM CROPS IN THE EU: WHAT IMPACTS ON BIODIVERSITY?

This chapter provides an overview of the kinds of impacts genetically modified (GM) crop varieties can have on biodiversity, and explores the possible impacts of new GM crop varieties that might be considered relevant for sustainable agriculture in Europe in the future.

6.1 Genetically Modified Organisms

Genetically modified organisms (GMOs)[82] are animal or plant varieties that contain one or more genes inserted into their genome using the breeding technology known as recombinant nucleic acid transformation[83]. Since the 1980s (Tiedje et al, 1989), GMOs have been developed from arable and perennial crops, trees, flowers, grasses, bacteria, algae, fish, insects, mammals and birds. However, the only GMOs that currently play a role in food and biomaterial production are GM bacteria and GM crops[84]. GM crop breeding enables the insertion of genes with desirable traits into crops without the yield drag associated with the transfer of unwanted genetic sequences (Jacobsen and Schouten, 2007), and enables the insertion of genes with desirable traits from completely unrelated species.

GM crops differ from most conventionally bred crops in three main ways[85]: 1) the GMO's genetic material (genome) contains a deliberately modified gene construct and may also contain other altered genetic sequences; 2) the GMO expresses a specific novel trait, which may mean the organism produces a novel desired GM product (usually a protein) in all or most of its tissues throughout all or most of its lifecycle, which changes its metabolism, and may result in other changes in the organism, such as different stress tolerance; and 3) the GMO may be managed in novel ways as a consequence of the GM specific trait, such as crops with changed herbicide applications, and/or crops that are grown in new areas or environments.

GM crops may be designed to offer agronomic, economic, nutritional, or environmental benefits, if they are managed appropriately, for example by reducing the negative environmental impacts associated with agricultural production; however, there are also potential environmental risks[86]. This section focuses on the possible impacts of GM crops on biodiversity, in particular those crops that have been considered for use in Europe, and GM traits and crops that are being developed and could potentially be used in Europe in the next decades.

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[82] see definition in the glossary

[83] The Directive also mentions other techniques involving the direct introduction into an organism of heritable material prepared outside the organism including micro-injection, macro-injection and micro-encapsulation; and cell fusion (including protoplast fusion) or hybridisation techniques where live cells with new combinations of heritable genetic material are formed through the fusion of two or more cells by means of methods that do not occur naturally. The techniques of *in vitro* fertilisation; natural processes such as: conjugation, transduction, transformation; and polyploidy induction are not considered to result in genetic modification (provided they do not involve recombinant nucleic acid transformation).

[84] In this report it is assumed that GM micro-organisms and GM crops producing pharmaceuticals will only be cultivated in strictly regulated closed environments, therefore their impact on biodiversity is not assessed here. Nevertheless it is recognised that if they were released into the environment they could pose significant environmental risks (Andow et al, 2004; EFSA, 2009; Snow and Smith, 2012; Stevens et al, 2004).

[85] Like all crop varieties, GM varieties have underlying varietal characteristics differing in some ways from all other varieties, both GM and non-GM, except the untransformed parental variety. The scale of differences depends partly on whether the GM gene was inserted into a widely used or specially bred variety.

[86] National and EU laws and the international Cartagena Protocol on Biosafety therefore require environmental risk assessments of GMOs before they are released into the environment

6.2 GM crops grown in the EU or that could be grown in the EU in the coming decades

In Europe only two GM crops are currently authorised for cultivation – insect-resistant Bt maize (MON810) and BASF's starch-modified Amflora potato. Globally, around 130 different GM transformations or 'events' are used in commercial GM crop varieties[87], and these have been bred and combined (stacked) into a wide range of different crop varieties or cultivars[88]. However these all express only four different transgenic trait types in four main crops, dominated by herbicide-resistance, followed by insect-resistance using Bt proteins, with a minor use of virus-resistance and starch-modification (James, 2012). This situation contrasts sharply with the far broader range of GM traits, genes and crops that have been developed in small-scale tests, but that have not been cleared for commercial use. Even so, these few crops and traits have resulted in the most rapid adoption rates of any new agricultural technology, significantly changing soybean, maize, and cotton production in North and South America, China, India and Australia (James, 2012).

A review was carried out for this study 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 (see Annex 6.1 for details). Around 25 GM crop applications are currently (early 2013) in the EU authorisation procedure for cultivation (deliberate release)[89], but due to the lack of consensus between EU Member States none of these applications have been given final authorisation for cultivation. The majority incorporate a single herbicide tolerance or insect resistance trait, or have stacked traits (Lusser et al, 2012), for example GM maize (MON88017) with resistance to corn rootworm and stem borers combined with herbicide tolerance (Devos et al, 2012a). Notably, no wheat varieties are on the list, though new GM varieties are being developed in the US[90].

Research on GM crops continues in Europe but applications for experimental releases of GM plants are decreasing[91]. About one-third of applications come from universities and public research bodies[92], but current private sector GM research is aimed at markets where acceptance and market potential are higher than in Europe. It therefore seems 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).

New GM traits include improved nutrient profiles; altered crop metabolism for industrial products; abiotic stress tolerance including drought-tolerance, freezing-tolerance and salinity-tolerance; disease resistance traits; nitrogen use efficiency; and bioremediation capacity. 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 transfer 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).

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[87] including more than 90 GM varieties approved in the US, around 30 in Brazil.

[88] Crop cultivars and varieties are genetically different strains of the crop that can all contain the GM gene, so that for example in China the Bt insect-resistance transgene can be found in over 500 different varieties.

[89] GMO Compass database http://www.gmo-compass.org/eng/gmo/db/

[90] http://www.guardian.co.uk/environment/2013/jun/22/agriculture-oregon-monsanto-gm-wheat

[91] 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.

[92] http://gmoinfo.jrc.ec.europa.eu/gmp_browse.aspx

6.3 How GM breeding differs from conventionally bred plants and animals

Unexpected changes resulting from the GM breeding process

The GM (recombinant nucleic acid transformation) process can produce unintended genetic changes (Latham et al, 2006), such as the insertion of multiple copies or fragments (Rang et al, 2005)[93], gene alterations (La Paz et al, 2010; Rosati et al, 2008)[94], or unexpected tissue expression (Zakharov et al, 2004), though plant breeders underline the precision of modern GM breeding in comparison to conventional plant breeding (Baudo et al, 2013; EASAC, 2013; Ricroch, 2013). GM breeding can also create new traits by silencing specific genes using non-coding RNA sequences, which might pose the risk of silencing other genes (Ramesh, 2013). Most unintended changes are noticed during the plant breeding process and removed (Jacobsen & Schouten, 2007), but sometimes an effect may not be noticed until the plant is subjected to stress such as drought or low temperature (eg Van Gelder et al, 1988), or during the food safety risk assessment process (eg Prescott et al, 2005).

Because the potential risks are specific to each different GM event, the risk assessment must be based on data specific to each event (EFSA, 2010). Current GM crops with single gene locus traits that produce one protein are relatively simple to verify (Cellini et al, 2004), but future GM traits such as abiotic stress tolerances will involve changes to regulatory and metabolic genes which affect several aspects of plant development and fitness, and often influence responses to multiple abiotic stresses (Mittler and Blumwald, 2010).

Biological novelty 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 and regulatory terms, and in public perception) 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 the status as GM or non-GM is currently not legally defined. An expert group convened by the European Commission has evaluated whether eight new techniques[95], including cisgenesis and intragenesis, constitute genetic modification within the scope of EU GMO legislation[96] (see Box 6-1 and Annex 6.1 for discussion).

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[93] The widely grown Round Up Ready (event GTS 40-3-2) soybean transcribes variant bits of RNA from GM gene fragments in its genome, possibly producing protein fragments the effects of which are unknown

[94] The YieldGard MON810 Bt maize event lacks the terminator sequence, so the gene is read on further resulting in an extra bit added onto the GM protein, which does not however seem to affect the protein's activity

[95] 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.

[96] New Techniques Working Group (2012) Final Report, European Commission http://ec.europa.eu/food/plant/gmo/new_breeding_techniques/index_en.htm

Box 6-1 Status of cisgenic and intragenic crops

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[97] – 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 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).

6.4 Possible impacts of GM crops on biodiversity and current evidence for effects

This section summarises the possible risks and benefits of GM crops for biodiversity, according to the categories of environmental risk used by the European Food Safety Authority (EFSA, 2010), and the current scientific evidence. The possible risks and the corresponding evidence are described in more detail in Annex 6.2.

The scientific evidence is ranked according to whether it demonstrates a) risks or benefits with a measureable 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. The published scientific evidence of the impacts of GM crops on biodiversity mainly relates to the current herbicide-tolerance and Bt insect-resistance traits (Andow and Zwahlen, 2005; Snow et al, 2005). 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 the **impacts of the specific cultivation, management and harvesting techniques associated with GMOs**

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 comparable 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 on 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

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[97] See definitions in the glossary

negative effects on biodiversity, and the overall impact can vary according to the precise management practices, environment, and landscape context.

***Impacts of changed management of GM herbicide-tolerant (GMHT) crops** (evidence=a) risks or benefits with a measureable impact on a biodiversity assessment endpoint)*

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, 2003; Heard et al, 2003) (see Annex 6.2 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, 2012c; Squire et al, 2003), the negative effect on weeds was considered important enough to conclude that on balance the **GMHT crops would reduce biodiversity**[98] (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.

GM herbicide-resistant crops in North America have not decreased the quantity of herbicide used on crops[99] 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 & 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).

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). However, 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), and/or the re-introduction of tillage into zero-till systems (Binimelis et al, 2009;

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[98] Whilst recognising that the GM HT maize had a positive effect compared to atrazine-treated maize

[99] 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 and Barfoot, 2012; Kleter et al, 2007).

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.

Impacts of changed management of GM insect-resistant Bt crops *(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)*

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[100], mainly on sweetcorn rather than field maize (feed maize) as insecticide use on the latter is low[101] (Brookes & Barfoot, 2013). In Spain, a study has estimated that GM Bt maize has reduced the environmental impact of insecticide use by around 40 per cent compared to pre-GM (Brookes, 2009). However, insecticide use against 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).

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 would have to be compared to current best practices in order to demonstrate which has greater environmental impacts (see Chapter 5 for discussion of pesticide use in Europe).

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 risk of resistance evolution[102] in the target pest. The possible biodiversity impacts of resistance evolution are associated with **increased pesticide use and toxicity** to control the resistant pests. Resistance to the current herbicide-tolerant and insect-resistant GM crops has already appeared.

Risk management specifications are mandatory for GM insect-resistant crops but not for herbicide-tolerant crops *(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)*

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

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[100] 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.

[101] 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.

[102] 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 in most regions (Huang et al, 2011)[103].

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 (see above). 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

Virus-resistant and fungal and bacterial disease-resistant GM crops pose resistance risks 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 (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 introgression of the GM gene and loss of wild genes.
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**.

Gene flow occurs but it is often difficult to clarify or achieve consensus on the actual harm to 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)*

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). There is a risk that 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 6-2) 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 hybrid generation, and the GM trait may tip the balance towards increased fitness of second and later generations. Research has shown that a GMHT gene persisted in oilseed rape crop-wild hybrids despite the absence of herbicide selection pressure and in spite of fitness costs associated with hybridization (Warwick et al, 2008).

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[103] but not in South Africa (Kruger et al, 2011).

Box 6-2 Persistence and ferality 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[104]. 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 ferality 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[105]. 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 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

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[104] see definitions in glossary

[105] 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.

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. For example, 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, 2003; 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).

So far, gene flow and its consequences have not been actively managed in GM growing countries (other than by the exclusion of certain areas[106]), and GM volunteers, ferals and crop-wild hybrids have not been classed officially as serious environmental problems. 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)[107], 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 have been found in wild/feral cotton populations in Mexico (Wegier et al, 2011).

It is widely accepted that if current 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, 2012b; EFSA, 2013c; 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 6-3), 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[108] 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 such as insect resistance or nitrogen use efficiency in oilseed rape might have greater consequences if they were used on a wide scale in Europe (see Annex 6.2 for scientific evidence).

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[106] 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.

[107] (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.*'

[108] Gene flow of herbicide resistance is equally likely from conventionally bred oilseed rape (Krato & Petersen, 2012)

Box 6-3 What are the consequences for biodiversity of gene flow from GM herbicide resistant oilseed rape in Europe?

In Europe, GMHT **oilseed rape** (*Brassica napus*) 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). Oilseed rape also readily hybridises with a number of wild relatives that occur as weeds in agricultural areas (see Annex 6.2). 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, 2012b; EFSA, 2013c; 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 crop-wild hybrids are also likely to be relatively common (Crawley and 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)[109]. 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, 2013c), 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 rigorous measures to prevent seed spills from transport etc (EFSA, 2013c).

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 8.1), 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[110], there are currently no GM crops subject to significant crop-wild gene flow[111] grown at the commercial scale, so there is a corresponding lack of scientific evidence of large-scale impacts on biodiversity. The detection of GM genes within genetically diverse wild plants and crop landraces

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[109] 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*."

[110] GM Bt maize cultivation is now authorised in Mexico, the home of the maize wild ancestor teosinte, 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); maize-teosinte gene flow has been shown to occur spontaneously in the field (Guadagnuolo et al, 2006)

[111] The two other principal GM crops – soybean and cotton – are not (officially) grown near their wild relatives

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.

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 (Ahuja, 2009; 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 *Polypogon monspeliensis* in the US (after just a few years of field trials) illustrates this (Reichman et al, 2006; Zapiola et al, 2007; Zapiola and Mallory-Smith, 2012). There is concern that it is also hybridising with the invasive grass *Agrostis gigantean*, and that the hybrids will cause problems for biodiversity 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 gene flow of abiotic stress tolerance and industrial chemical production traits. Stress-tolerance traits are likely to influence fitness of crop-wild hybrids. 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 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 & Blumwald, 2010). Because the environmental tolerance of the GM crop differs from its non-GM comparators, no direct risk assessment comparisons are possible.

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 Annex 6.2 for details).

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

GM Bt maize has certain impacts on soil organisms, but no impacts on soil functions could be definitely attributed to the GM Bt trait (although many differences between crop varieties have been found) (see Annex 6.2 for details). 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, 2008).

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

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).

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 GM product is usually expressed in nearly all plant tissues throughout the life cycle of the plant, and that the GM 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.

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

GM Bt crops produce Bt toxins that target either caterpillar (Lepidoptera) pests[112] or beetle (Coleoptera: Chrysomelidae) pests.[113] 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 Annex 6.2 for details). However, GM Bt maize pollen has been shown to have an adverse effect on the caterpillars of some butterfly and moth species (see Box 6-4).

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[112] Cry1Ab, Cry1Ac, Cry1F, VIP3a proteins

[113] Cry3Bb1 protein

Box 6-4 Could the pollen of GM Bt maize affect non-target butterfly and moth populations?

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[114], and this could affect valued species. Seven European **butterfly** species[115], 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 (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 prove or disprove 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, 2010b). See Annex 6.2 for more details on this issue.

Small-scale tests with GM Bt crops have not found effects on honey **bees** (Duan et al, 2008a; 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).

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).

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 GM genes from GM crop cultivation.

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

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[114] Examples are: *Issoria lathonia* and *Argynnis adippe* on *Viola arvensis*; *Lythria purpuraria* on *Polygonum aviculare*; *Tyta luctuosa* on *Convolvulus arvensis* (Hilbeck et al, 2008).

[115] 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*).

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; Mohr and Tebbe, 2007).

6.5 What is the evidence for effects of GM crops on biodiversity in Europe?

GMOs cover a very broad spectrum, and their characteristics and possible impacts vary greatly, so it is not possible to make any generalised statements about the consequences for biodiversity. Current GM crops have shown statistically significant effects on ecological processes and organisms in the field, but most of these effects are smaller than or comparable to those due to general agricultural practices. However, as shown in Chapter 5, some of these **current agricultural practices** are having significantly adverse effects on biodiversity, including gene flow of crop genes into wild relatives, weed problems from crop volunteers and ferals, resistance development in pests, and loss of agro-biodiversity from more intensive cultivation practices. The current controversy is partly about whether new GM crop varieties should simply be no worse than current practice, or whether they should be measured against standards and criteria for more environmentally resilient and sustainable cropping systems.

The **evidence for benefits to biodiversity** from the current EU-relevant GM crops comes mainly from North and South America and relates to changes in farm management, such as reduced use of certain broad spectrum insecticides and greater up-take of zero-tillage arable systems, with benefits for soil biodiversity. Some of these benefits may not be applicable in Europe, where for example the potential for zero-till agriculture is constrained by the limitations of soil types and the smaller scale of farming systems. The US National Research Council has concluded that GM crops in the US have brought environmental benefits but “excessive reliance on a single technology combined with a lack of diverse farming practices could undermine the economic and environmental gains” (National Research Council, 2010).

In most of the EU, commercial planting of GMOs has been on a very small scale to date, and it is **difficult to forecast the balance of hazards and benefits to biodiversity** from a larger scale use of GMOs in Europe. If GM cultivation were to expand in scale in Europe it would be likely to involve a broader range of new generation GM traits than are currently grown in comparable regions, for which the evidence base is therefore still very limited. Evidence from the US and other part of the world can inform risk appraisal and analysis in Europe, but each GM variety must be evaluated in the specific local conditions of European cropping systems.

A number of EU governments have chosen to adopt the **precautionary principle**, mitigating against the use of GMOs, whilst others regard the risks as acceptable (European Commission, 2011c). Eight Member States have implemented national bans on GM crop cultivation citing concerns about impacts on biodiversity[116] - Austria, Bulgaria, Germany, Greece, Hungary, Poland, Luxembourg and France (see Annex 6.1 for details of Member State concerns).

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[116] 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

Impacts of agricultural systems on biodiversity are often only apparent at the scale of commercial fields and over multiple seasons, and it is likely that some of the positive and negative effects of GM traits on biodiversity are only detectable after large-scale cultivation has already begun (eg Jorgensen et al, 2009), or are only detectable with increased monitoring effort (Aviron et al, 2009). **Better monitoring and increased research** could provide better understanding of risks in order to help inform decisions on GM crop cultivation and its risks and benefits to the environment. Improved monitoring and research on conventional crops and gene flow would provide the necessary comparative analysis on which to make sound assessments.

Where GM crops are authorised in the EU in the near future, it will be important to ensure **good management practices** that mitigate known risks to biodiversity. Mandatory resistance management rules on GM Bt crops have been successful in prolonging the benefits of that GM cropping system, but where these rules have not been followed, and on GMHT crops where no mandatory rules have been implemented, the GM system is showing signs of breaking down. Increasing GM cultivation in Europe would require active resistance management rules and management of crop-to-crop gene flow through a co-existence regulatory framework (legal, agronomic, and institutional). Ideally, these should be Europe-wide (Messean et al, 2009) in order to prevent legal disputes and excessive risk for farmers. Measures specific to certain crops would also be needed, such as rigorous removal of sugar beet bolters and strict isolation of GM sugar beet seed production (Darmency et al, 2009; Fénart et al, 2007).

In the longer term, if it were to be established that GMO based cropping systems were both stable in the longer term and able to sustain a higher level of yield than conventional crops without adverse environmental impacts, then there would be the prospect that the pressure to expand the agricultural land area can be constrained and more land could be available for biodiversity conservation (see Chapter 5 for discussion). Key biodiversity considerations would include the likelihood and consequences of gene flow, particularly to wheat and sugar beet wild relatives, and the risk of invasive feral populations with stress tolerance traits. At present, however, it is unclear whether GMO based arable systems in Europe could perform such a role and it would be premature to conclude that a gain for biodiversity could be made this way.

7 IMPACTS OF BIOFUEL FEEDSTOCKS ON BIODIVERSITY

7.1 Biofuel technologies

Biofuels are liquid fuels made from the processing of plant material or waste food products[117]. There are two main types of liquid biofuel: bioethanol, an alcohol fuel which is blended with petrol; and biodiesel, which can be used on its own or in combination with conventional diesel.

The first biofuels to reach large scale commercial viability and widespread use, commonly referred to as '**conventional**' biofuels for this reason, were those for which the process of conversion to fuel is most straightforward (see Table 7-1). These are sometimes also called 'first generation' biofuels. The process for making conventional bioethanol involves the fermentation of the sugar content of starchy or sugary crops (similar to the process of producing alcoholic beverages). Biodiesel is produced from the crushing of oilseeds, yielding vegetable oils that are transformed into biodiesel through a chemical reaction. Biodiesel can also be produced from used cooking oil and tallow[118].

A more advanced suite of processes has emerged in recent times which allow biofuels to be developed from more difficult to access sources, creating what is often referred to as '**advanced**' or 'second generation' biofuels. The most prominent of these is the conversion of ligno-cellulosic material (such as crop residues, grasses or wood) to bio-ethanol, through a multiple stage process of hydrolysis, fermentation and distillation. The feedstocks within this category include perennial energy crops such as tall rapidly-growing grass with high lignin content, short rotation coppice (SRC) of fast growing trees and crop residues. Although they have not yet been used commercially for this purpose, they are generally expected to be economically feasible by 2020, although this remains controversial (Elbersen et al, 2012a; OECD and FAO, 2011).

A third process involves the use of land-based or marine microalgae to either extract oils or derive ethanol and biogas. These 'third generation' technologies remain hampered by high production costs and will likely only reach an early commercial demonstration stage after 2020 (Elbersen et al, 2012b).

Table 7-1 Feedstocks of conventional and advanced biofuels

Biofuel type	Feedstocks of conventional biofuels	Feedstocks of advanced biofuels
Bioethanol	EU: wheat, sugar beet or maize Outside EU: sugar cane, maize	Tall-growing grasses (eg *Miscanthus*, Canary Grass, Switch grass); short rotation coppice (eg willow, poplar); and crop residues (eg straw)
Biodiesel	EU: oilseed rape, sunflower, waste products (eg used cooking oil and tallow) Outside EU: soya, jatropha and palm oil	n/a

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[117] Biogas, which is produced by anaerobic digestion, is typically derived from waste materials, including from livestock farms or captured from landfills. It is predominately used for heating, but can be used for transport.

[118] Tallow is rendered animal fat, also used in candles and soaps.

7.2 Current production and projections of future biofuel consumption

This section provides a review of some estimates of future European biofuel consumption and associated land use impacts. The majority of the modelling work undertaken to establish such estimates is focused at the 2020 horizon, when the Renewable Energy Directive's (RED) targets are to be met. The key driver behind EU biofuel use is the RED's current target to increase the share of renewable energy in the transport sector to 10 per cent in each Member State as well as the target to reduce the greenhouse intensity of transport fuels supplied to the European market by 6 per cent by 2020. This target is anticipated to lead to a tripling of biofuel use in the EU in 2020 compared to 2008 levels, predominantly met by first-generation biofuels produced from traditional food and feed crops (Kretschmer et al, 2012).

However, it is important to note that these scenarios are likely to change as a result of the Commission's recent proposal to amend the RED by measures to address indirect land use change (ILUC) (see Box 7-6), and they are also subject to changes in agricultural markets.

Current biofuel production locations and footprints

The current EU biofuels market is dominated by conventional biofuels produced from food and feed crops. In particular, rapeseed oil dominates the biodiesel market, amounting to almost half of all consumption, while sugar beet, wheat, maize and sugar cane dominate the ethanol market.[119] Total biofuel consumption in 2010 amounted to close to 13 million tonnes of oil equivalent (Mtoe); ie 4.27 per cent of total transport energy (Ecofys et al, 2013). The total land used for biofuel feedstock production for the EU in 2010 was about **5.7 million ha**; 3.2 million ha (57 per cent) within the EU and 2.4 million ha (43 per cent) outside (Ecofys et al, 2013). This is around **1.8 per cent** of the total Utilised Agricultural Area (UAA) in the EU-27[120], and the most important domestic biofuel feedstocks are wheat, sugar beet and rapeseed oil (Elbersen et al, 2012a). Some Member States, such as Germany, already have significant areas of biofuel feedstock production. At the same time, feedstocks and processed biofuels are imported from outside the EU, particularly from North and South America, and to a lesser extent Southeast Asia. These are frequently imported from areas with high biodiversity and weak protection regimes (Schmidt et al, 2012), resulting in high external biodiversity impacts (see section 7.3).

The 2020 biofuel market – consumption projections

An analysis of Member States' National Renewable Energy Action Plans (NREAPs) by Bowyer and Kretschmer (2011) gave the following outlook for meeting the 10 per cent target for 2020 (summarised in Table 7-2):

- The EU-27 Member States anticipate consuming 29.6 Mtoe of biofuels in 2020. This translates into an increase in biofuel use between 2008 and 2020 of 19.5 Mtoe. The majority will be conventional biofuels, making up about 92 per cent of total predicted biofuel use or 27.3 Mtoe in 2020, equating to 8.8 per cent of the total energy in transport. Advanced biofuels will not gain an important market share and are anticipated to account for only 7.1 per cent (2.1 Mtoe) of total biofuels by 2020.
- Conventional biofuels are anticipated to be 72 per cent biodiesel and 28 per cent bioethanol; anticipated imports amount to 44 per cent of bioethanol and 36 per cent of biodiesel used in 2020.

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[119] Based on recent figures provided in the Commission's Staff Working Document accompanying the 2013 renewable energy progress report, COM(2013)175, 2013.

[120] Around 172.4 million ha in 2007: Eurostat (ef_kvaareg)

Table 7-2 The projected composition of EU biofuel consumption in 2020

	Total Mtoe	**Biodiesel**		**Bioethanol**	
		Mtoe	*share*	Mtoe	*share*
Consumption	**29.6**	21.3	*72% of total biofuels*	8.3	*28% of total biofuels*
Imports	**11.3**	7.7	*36% of biodiesel consumption*	3.6	*44% of ethanol consumption*
Production	**18.3**	13.7	*74.4% of total biofuels*	4.7	*25.6% of total biofuels*

Source: Own compilation based on Bowyer (2011), and NREAPs. **Note**: With regard to the trade shares, actual imported levels of feedstock could be higher, as it is unclear whether the figures reported in the NREAPs also include imported feedstock for 'domestic' processing into biofuels or only refer to imports of processed biofuels.

The 2020 biofuel market – land use projections

Land requirements for biofuel feedstocks are expected to more than double from present levels when the anticipated consumption levels as set out in the NREAPs are taken into account. If we assume that the average cropland requirement per unit of biofuels remains the same as currently[121], the predicted EU biofuel consumption in 2020 (29.6 Mtoe) will require 12.96 million ha of land globally - an increase of **7.3 million ha** over 2010 levels. Based on the current mix of EU and external land use for biofuel feedstock production (57 per cent and 43 per cent respectively) this amounts to an *additional* 4.1 million ha of land required within the EU and 3.1 million ha outside. This is equivalent to an additional **2 per cent** of the UAA in the EU-27. Other studies predict that even larger areas of land in the EU would be required to grow first-generation biofuel feedstock crops in order to fulfill current EU targets; although it is thought that half of production will occur outside the EU (Box 7-1).

Box 7-1 Estimates of land use requirements for biofuels in the EU

The European Commission in 2008 calculated that 17.5 million hectares of land within the EU is likely to be required to meet the 10 per cent biofuels target by 2020 (about 10 per cent of EU-27 UAA). This assumes that 50 per cent of biofuel comes from domestic production of conventional biofuels and the remainder comes from either domestic ligno-cellulosic products or biofuel imports (European Commission, 2008).

The OECD, presenting a less optimistic scenario of ligno-cellulosic technology development, estimated that about 45 million hectares of land in the EU would have been required to reach the RED's EU energy targets by 2020. This is based on the use of conventional biofuel technologies only, and assumes that yields remain at the same levels as they were in 2006 (OECD, 2006). This would be more than a quarter of the UAA of the EU-27.

However, these figures represent only a crude assessment that does not take into account market responses and mitigating factors such as the use of co-products, demand response due to increased food prices (see section 7.4 for discussion), and yield improvements. The importance of such factors is illustrated in Figure 7-1. The most prominent mitigation measure that can reduce the net land use impacts of biofuels is the use of co-products to displace livestock feed. The biofuel process produces a

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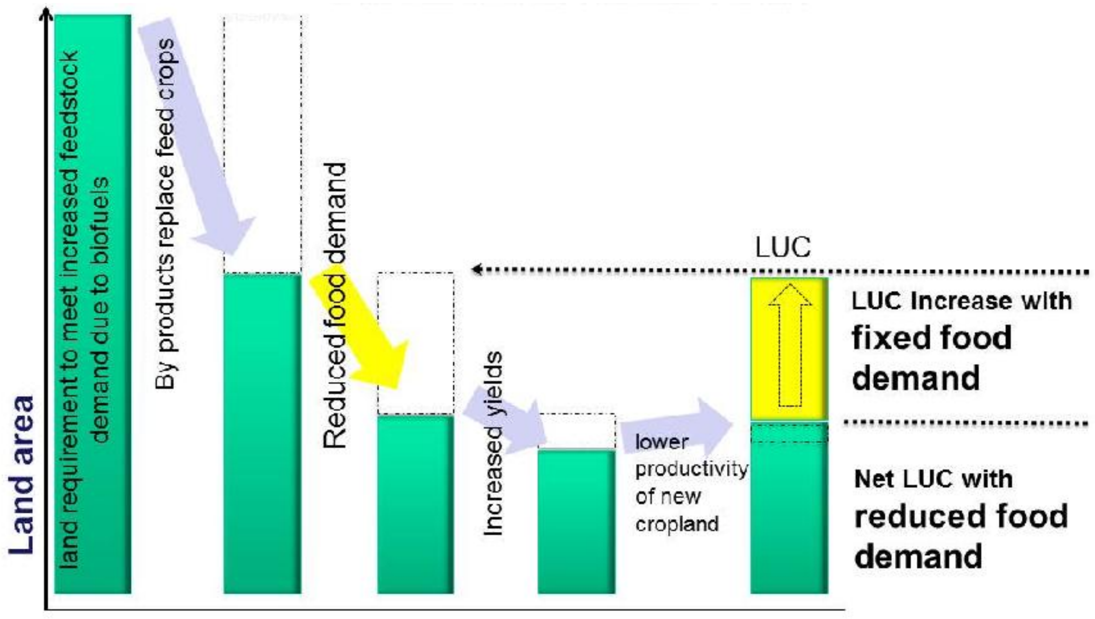
[121] 0.438 ha/toe of biofuel calculated as the ratio of the amount of biofuels consumed in the EU in 2010 (13 Mtoe) and the estimated total land required for their production (5.7 Mha) (Ecofys et al, 2013)

number of co-products, two of which - dried distillers grain with solubles from bioethanol production and oilseed cake from biodiesel - are used as high protein animal feed in the EU livestock sector. The expectation is therefore that the use of such co-products will displace some of the imported soy requirements for animal feed, thus reducing associated land needs.

Figure 7-1 Schematic impact of external factors on land requirements for biofuel feedstock production



Source: From Fritsche *et al* (2012) based on a presentation by DG JRC-IET

A number of modelling studies have accounted for these influencing factors and estimated the amount of potentially *additional* cropland conversion expected as a result of EU biofuel policy. These range from **1.73 to 1.87 million ha** globally in 2020, depending on the scenario (Laborde, 2011). Most of this additional cropland is expected to come from outside the EU, with only 6 per cent of the expansion or 105,000 - 118,000 ha expected within the EU (ie an additional **0.07 per cent** of EU-27 UAA).

Clearly there is a huge difference between the estimated additional land requirement in absolute terms and the estimated additional land requirement taking into account the large-scale use of co-products and other factors (see Table 7-3). Furthermore, different models and studies give different estimates of additional land requirement (Edwardson and Santacoloma, 2013; Fritsche et al, 2012; Fritsche and Wiegmann, 2011). These differences relate to the relative assumptions underpinning the different modelling approaches, for example on co-products and future yield developments.

It is important to understand the impact of such assumptions and whether or not they will materialise in reality or if they are masking a much greater land use impact, for instance whether co-products will actually be taken up as a feed crop replacing traditional feeds (Allen et al, 2013). To make co-products an economically viable option that is taken up by the livestock sector, the price of co-products often must be lower or the quality must be higher than for traditional feeds in order to promote a change from the status quo. In practice, their potential to displace soy is limited by their lower nutrient content and higher levels of fibre. There is also some doubt regarding their additionality, as the same co-products are produced through other processes such as the production of vegetable oil, alcohol and other food products (Allen et al, 2013). However, regardless of their additionality, even when co-products are taken into account a degree of land use change (LUC) is shown in most modelling studies (Edwards et al, 2010; Laborde, 2011).

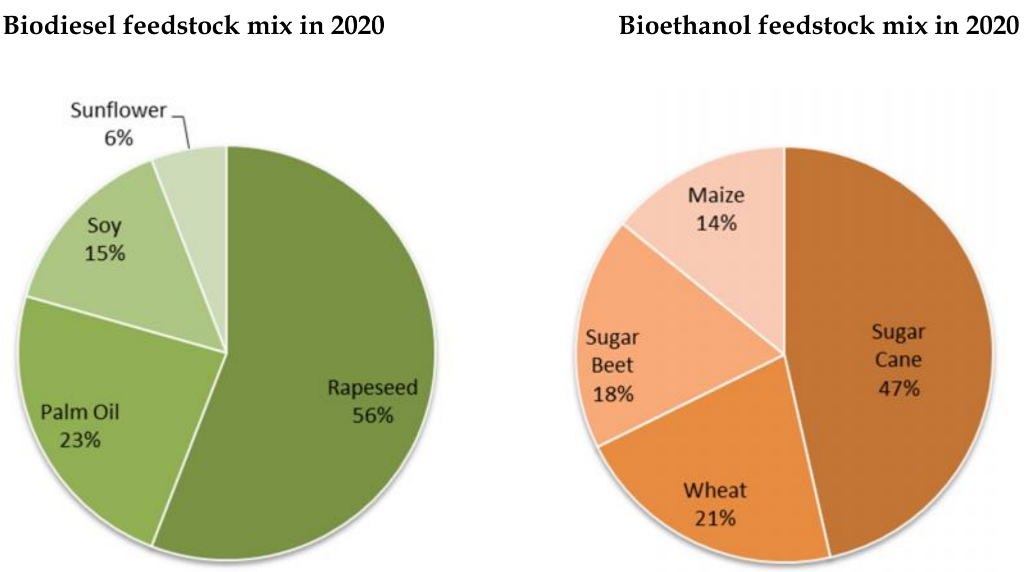
The projected feedstock mix and location of the EU's biofuel footprint in 2020

The NREAPs do not report on the feed stocks that Member States expect to utilise in future, so economic modelling studies are used to estimate this. One of the most prominent is the 'IFPRI study' commissioned by the European Commission's TRADE Directorate-General (Laborde, 2011). This investigated the (agricultural) market and land use implications of EU biofuel use as predicted by the NREAPs (ie 8.8 per cent use in 2020), and estimated the projected 2020 biofuel feedstock mix (see Error! Reference source not found.**) and imports (see**

) under two scenarios of trade policy. This study shows a continued dominance of rapeseed in the biodiesel market given current policy. The market for ethanol in the EU is projected to become increasingly reliant on sugar cane in the run-up to 2020, accounting for almost half of all feedstock.

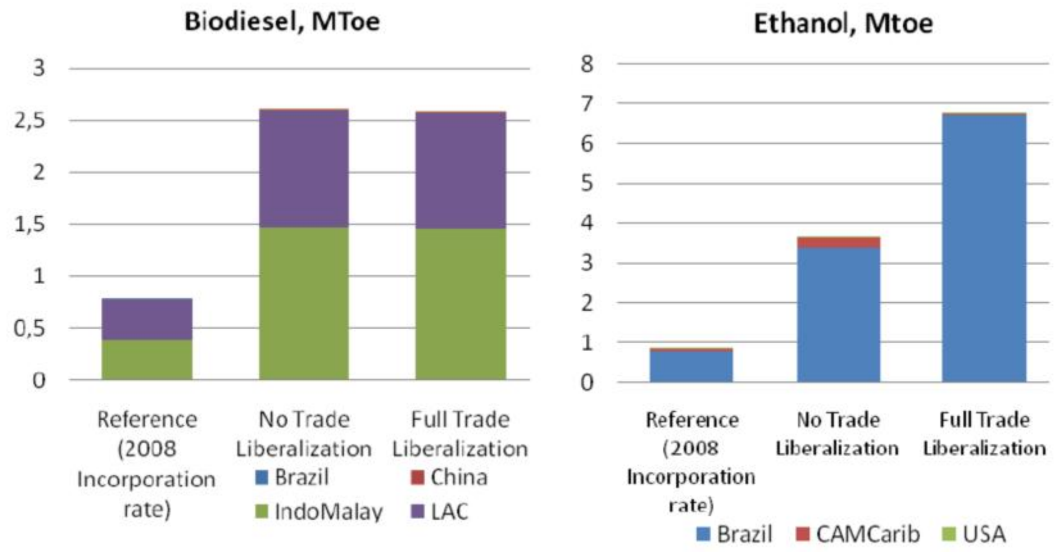
Biodiesel is projected to be imported mainly from Indonesia and Malaysia (palm oil), followed by Latin America without Brazil (this relates primarily to soy-based biodiesel from Argentina). The dominant source of ethanol is Brazil (sugarcane). The most pronounced changes in feedstock imports are projected for rapeseed and oil palm, likely to be used to produce biodiesel domestically in the EU, but imports of feed and food crops such as maize and soy and, to a lesser extent, wheat, increase depending on the scenario. These projected trade patterns translate into an expansion of cropland as a result of EU biofuel policy where roughly half of all the expansion takes place in Brazil, Russia and Central Asia (Commonwealth of Independent States CIS), and Sub-Saharan Africa.

Figure 7-2 Projected shares of feedstock for biofuels consumed in the EU in 2020



Source: Own calculation based on Laborde (2011), Table 3.

Figure 7-3 Projected EU imports of biofuels in 2020 (Mtoe)



IndoMalay = Indonesia & Malaysia; LAC = Latin America & Caribbean; CAMCarib = Central America & Caribbean

Source: Mirage-Biof Simulations; taken from Laborde (2011, p46)

7.3 Biodiversity impacts of current and projected biofuel consumption

Current and possible future biodiversity impacts within the EU

The biodiversity impacts of conventional biofuel feedstocks are comparable to arable cropping impacts generally (see Chapter 5). The biodiversity impacts of advanced biofuel feedstock crops vary according to each feedstock's management practices and to the land requirements, as determined by the rate of return per hectare and the efficiency of the energy transformation rate (biomass to energy yield) of the feedstock.

A major concern is the conversion of natural or semi-natural ecosystems, either for production of biofuel feedstock themselves (ie direct land use change) or for production of other crops that have been displaced by biofuels (ie indirect land use change or ILUC). Land could also come from the utilisation of marginal or degraded land. Some of the energy crops used as feedstocks for advanced biofuels can be grown on land where there are constraints on food crop production (such as on low nutrient soils or land prone to flooding) and therefore do not necessarily compete with food for agricultural land. However, such land may support natural and semi-natural habitats and therefore be of high biodiversity value. The most significant losses of biodiversity in the EU may be expected if biofuel pressures result in land use change from pasture (especially extensive systems), forests, wetlands or peatlands to arable land (Bertzky et al, 2011). While a spatially explicit analysis of the impacts of the target on biodiversity (Hellmann and Verburg, 2010) finds that the **direct** effects of the original targets on European biodiversity are likely to be relatively small due to a preference for the cultivation of biofuels on land with good overall agricultural quality (and therefore already under agricultural cultivation), **indirect** land use change within the EU is likely to be much higher. It estimates a reduction of 3 to 8 per cent of semi-natural vegetation by 2020 compared to 2000, as a consequence of the displacement of grasslands and arable farming into these areas. As discussed earlier however, the total area required for feedstocks and consequently the biodiversity impacts may be lower once mitigating factors such as use of co-products are taken into account.

On the other hand, a significant advantage of the perennial species (such as *Miscanthus* and short rotation coppice) is the reduced disturbance to soils and longer periods needed for species to establish, typically remaining *in situ* for 7 to 25 years (Haughton et al, 2009). This can provide environmental benefits in terms of water retention and reduced soil erosion (International Energy Agency, 2010) which can be beneficial for biodiversity. In addition, energy crops typically use few agrochemical inputs compared to most crop-derived biofuels (Biemans et al, 2008; Haughton et al, 2009). For example, eutrophication is reported to be two to three times lower from biofuels based on sugar beet or willow compared to biofuels based on wheat (Börjesson and Tufvesson, 2011).[122]

Studies comparing the impacts of dedicated energy crops for advanced biofuels to the impact of conventional biofuel feedstocks on butterfly and bird species support the idea that advanced biofuels feedstock may have less impact on biodiversity (see Box 7-2). However, increased experience and efficiency of feedstock on farms in the future may reduce or eliminate the presence of weeds and other features that act to increase biodiversity in these early studies. Furthermore, it should be noted that the studies to date on biodiversity have not looked at the cumulative impacts of large developments and regional concentrations of energy crop mono-cultures - likely to be necessary to supply large power plants. This could result in the displacement of farmland species and open-field specialists. Therefore, it is too early to judge the overall biodiversity impacts of commercial scale production of advanced biofuel feedstocks, and much will depend on which habitats are being replaced and the scale and location of planting.

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[122] Unfertilized grassland is used as a reference in this calculation.

Box 7-2 Biodiversity impacts of selected advanced biofuel crops compared to arable crops

Initial field studies suggest a possible biodiversity benefit from the use of advanced feedstock crops compared to arable crops. A comparison of the abundance of families of butterfly in field margins of *Miscanthus* and SRC willow compared to arable crop breaks found that abundance was significantly higher in field margins surrounding *Miscanthus* and SRC willow (60% and 132% more butterflies respectively) than in arable crops. SRC appears to support a greater density and number of bird species than arable land (particularly scrub and woodland species) including certain species of high conservation concern. However, skylark nesting success was found to be lower in Reed Canary Grass (*Phalaris arundinacea*) than in cereals.

Sources: (Haughton et al, 2009) (Sage et al, 2010) (Vepsäläinen, 2010).

Current and future biodiversity impacts outside the EU

Globally, the conversion of natural or semi-natural land to agriculture remains one of the most significant pressures on biodiversity worldwide and is increasing (FAO, 2008a).

Palm oil plantations in South-East Asia are often cited as a critical driver of forest and biodiversity loss (Friends of the Earth, 2005; Wilcove and Koh, 2010). Palm oil has many uses, one of them being for biofuels. An estimated 27 per cent of oil palm concessions displace peatland rainforest and an estimated 55 to 59 per cent of oil palm expansion in Malaysia, and 56 per cent in Indonesia has occurred at the expense of forests (Campbell and Doswald, 2009). Palm oil plantations are also implicated in the deforestation of areas in Colombia, Ecuador, Brazil, Central America, Uganda and Cameroon (AEA, 2008; Campbell & Doswald, 2009; FAO, 2008a), including the highly biodiverse lowland evergreen tropical forest in South East Asia (Hoojier et al, 2006; Koh and Wilcove, 2008; Mace et al, 2005). Fires and soil erosion associated with land clearance pollute air and water (Donald, 2004). Only 15 to 22 per cent of species recorded in primary forests are found in palm oil plantations (eg a 72 per cent reduction in arthropods), and these plantations support lower levels of biodiversity than other tree crops, agricultural crops and abandoned pastures (Campbell & Doswald, 2009; Danielsen et al, 2009; Donald, 2004; Fitzherbert et al, 2008). In addition, those species lost are generally specialist species of high conservation concern, some of which are threatened with global extinction. Oil palm plantations could be managed to enhance wildlife habitat (Turner et al, 2008), nevertheless the sheer scale of the plantations significantly threatens biodiversity (Sheil et al, 2009).

Soybean is also currently a major source of biodiesel for EU consumption; the impacts of soybean production on biodiversity in Latin America are described in Chapter 5 section 5.5.

Bioethanol production is one of the main economic drivers for the expansion of **sugar cane** in Brazil. Sawyer (2008) reported encroachment by sugarcane into the Brazilian Cerrado, the world's most biodiverse savannah. According to Sparovek et al (2007), 45 per cent of the land converted to sugarcane between 2007 and 2008 in São Paulo state in Brazil was previously rangeland (Zuurbier and van de Vooren, 2008).

Agricultural practices used for growing biofuel crops also result in biodiversity impacts. **Maize**-based ethanol in the USA is reported to have the highest impacts, compared to other agricultural crops, due to its high fertiliser and pesticide requirements (Campbell & Doswald, 2009). Maize is often irrigated, which also has an impact on riparian and aquatic wetlands if it results in lower water availability. One recent study estimates the EU water footprint as a result of biofuel production at around 82 km^3, of which 39 km^3 is used from European water resources[123] (see Charles et al, 2013, p66). Pesticides and

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[123] For comparison, Germany's total annual freshwater resource is around 188 km^3

fertilisers used on oil palm and palm oil processing effluents have negative effects on aquatic biodiversity (Donald, 2004; Fitzherbert et al, 2008).

Laborde (2011) estimates that the EU 2020 biofuels mandate could lead to a global increase in cropland of 1.73 to 1.87 million ha, mainly in Latin America (primarily Brazil), Russia and Central Asia, and Sub-Saharan Africa. The principal sources of cropland expansion would be pasture and managed forest, followed by savannah and grasslands and then primary forest. The biodiversity impacts arising from these land use changes will vary, with the highest losses resulting from primary forest and lowest from pasture and managed forests.

7.4 Competition for agricultural land and influence on food prices

All of the conventional feedstocks, with the exception of jatropha and those derived from waste streams, are also used as food for animal or human consumption. This has raised concerns over competition for land between food and energy crops for biofuels and the potential impacts of EU biofuel policy. The additional demand for agricultural commodities will translate into an increase in their prices but by how much is the subject of continued debate. In 2011, the High Level Panel of Experts on Food Security and Nutrition identified two major reasons for biofuels playing an important role in the global increase of food prices and volatility since 2004 (HLPE, 2011). First, with the simultaneous increase in oil prices in that time, ethanol manufacturers could bid up the price of maize (and through it also the price of other crops) while remaining competitive. Second, the production and supply of grain, vegetable oil and sugar since 2004 has not been growing as fast as their demand, which is mainly due to the rise in demand for biofuels.

Modelling studies focusing on the impacts of EU (as opposed to global) biofuel policies show the most significant price increases are projected for oilseeds and vegetable oils (Ecofys et al, 2011), with increases in world prices by 2020 typically ranging between 8 to 20 per cent and 5 to 36 per cent respectively (for example, see Taheripour et al, 2010). Laborde (2011) projects increases in world rapeseed prices (anticipated to be the most significant feedstock for EU biofuel use in 2020) of around 11 per cent. However, the most recent paper by the HLPE highlighted the difficulties of estimating increases in food prices as a result of biofuel consumption and estimating the actual impacts the price increases have on food security (HLPE, 2013). The use of models and other analytical tools in this context is far from being straightforward and has to be built on several assumptions on short- and long-term elasticities for different commodities, which make the results uncertain.

Price increases can have multiple effects. If people consume less food in response to higher prices, this could lead to malnutrition among poorer people, while at the same time a general reduction in consumption can alleviate the price increases. A study from the JRC found that from 34 to 52 per cent of maize or wheat diverted to ethanol would not be replaced in the food chain due to reduced food consumption (Edwards et al, 2010). The consequences of reducing food consumption are obviously most severe for the 850 million food insecure people worldwide, who already spend 60 per cent or more of their incomes on food. It is estimated that around 44 million people in low- and middle-income countries have fallen into poverty because of higher food prices since June 2010 (World Bank, 2011).

Converting land to biofuel plantations can also have indirect effects on poverty and malnutrition. Most importantly, if the land was previously used by local communities for pasturing, collecting firewood or for gathering and selling products, converting the land into biomass plantations could lead to a loss of those income opportunities, which are in turn needed to buy food (Wunder et al, 2012). There is substantial evidence that access to land for the rural poor is essential for food security and economic development in developing countries (Cotula et al, 2008; Gerstter et al, 2011).

In recent years, the general competition for land opened up an international debate around the phenomenon of “land grabbing”. Land grabbing can be defined as large-scale land acquisitions from foreign and domestic investors, which are often associated with severe social and environmental impacts. Due to unclear or non-existent land rights in the targeted countries, investors can buy or lease land from governments, often affecting land used previously by local communities. As a result, many people are evicted from their land or lose access to valuable resources for their livelihood such as water, timber or pastoral land (see for example the Kenyan example in Kay (2012) as well as FIAN (2010)). However, there is a lack of detailed evidence on this topic and the exact motivations underlying land deals are not always transparent.

Models of commodity prices and trends do not capture all the institutional questions of relevance or necessarily the role of key actors. As the land grabbing phenomenon shows, mainly in developing countries there is usually an imbalance in power relations between investing companies who buy or lease land from national governments on a large scale and displaced small holders for whom access to a small piece of land could determine their survival. Both the national governments in developing countries, who try to attract investors for their agricultural sectors assuming that this will lead to economic development, and governments in industrialised countries, who are dependent on imports to fulfil their biofuels targets, can contribute significantly to alleviating the increasing pressure on land and avoiding the most severe social impacts. First, national governments can establish or reinforce a land tenure policy building on the internationally acknowledged 'Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests' adopted by the FAO Committee on World Food Security as a response to land grabbing. Although voluntary, those Guidelines set out clear provisions on responsible land tenure practices, which can serve as an internationally agreed benchmark for any legally binding measures on land tenure at national and international level. Second, governments in industrialised countries could rethink their biofuel policies, in particular the binding targets for first generation fuels.

7.5 Effectiveness of biodiversity and social sustainability criteria in the EU RED

RED sustainability criteria for biofuels

EU sustainability criteria for biofuels were introduced as part of the RED with the objective of preventing the conversion of biodiversity-rich habitats and high-carbon storage areas to cropland to grow biofuel feedstocks. While these regulations are important to allow for more careful siting of biofuel crops (ie regulating direct land use change), they do not mitigate against ILUC risks, because other crops are not banned from these areas of high biodiversity value. Indeed, it is likely that the sustainability criteria of the RED will have little or no effect on global agricultural systems due to leakage effects in the food and animal feed sectors and the biofuel sector outside Europe. This is because biofuels are likely to be grown on current agricultural areas, resulting in the crops formerly grown on these areas being displaced, potentially, to areas important for biodiversity and/or carbon storage (Frank et al, 2012).

Social aspects of biofuel production such as impacts on land tenure, food security and labour conditions are not directly addressed by sustainability criteria under the Renewable Energy Directive. Instead, the Commission is obliged to report on progress in addressing such aspects in exporting countries. The first report was due by the end of 2012. No separate report has been published by the Commission, but its stance on biofuel sustainability in relation to social issues was explained in the 2013 renewable energy progress report.[124] As part of this the Commission concluded that no further sustainability criteria are needed but that continued monitoring is warranted. In a recent study Kaphengst et al (2012) pointed to the risk of a "race to the bottom" in terms of social criteria in the certification schemes that biofuel producers have to participate in to show the sustainability of their

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[124] The Commission's renewable energy progress report COM(2013) 175 final of 27 March 2013 http://ec.europa.eu/energy/renewables/reports/doc/com_2013_0175_res_en.pdf

biofuels in order to be counted towards the 10 per cent target under the RED. To date, 14 certification schemes have been approved by the Commission. Some of these schemes have more ambitious (social) criteria than others and biofuel producers' enthusiasm for them varies. Since the fulfilment of social criteria is not obligatory under the RED, producers can opt for certification schemes which address them either superficially or not at all (see Kaphengst et al, 2012).

To be effective, the policy would need to target a wider range of agricultural commodities and a more comprehensive group of countries. Nonetheless, it is worth noting that the criteria are very important as a first step in mitigating the impact of the biofuel industry and may in turn lead to tighter standards in other industries that currently have a negative impact.

Proposal to revise the EU RED to address ILUC

Partly in recognition of the impact on food security and prices and concern over the extent of any actual GHG savings from conventional biofuels, the Commission has made a proposal[125] to limit the contribution that biofuels derived from food crops can make towards the attainment of the RED target to a maximum of 5 per cent of energy in transport in 2020 (see Box 7-3).

Box 7-3 Amending the RED to address ILUC – the current state of play of the legislative process

As part of its proposal COM(2012)595[126] issued in October 2012, the Commission put forward a set of measures, the most important ones being a suggested five per cent cap on the contribution of biofuels from food crops (cereals, oil and sugar crops) towards the RED's ten per cent target; increased incentives for advanced biofuels from certain feedstocks, mainly wastes and residues, by counting their energy content double or even four times; and the introduction of 'ILUC emission factors' that attribute to different crop categories their estimated ILUC impact (determined through modelling) for GHG reporting under the RED.

The proposal is currently undergoing discussions in both the Council and different Parliamentary committees (the EP's environment committee being in the lead). Both Member States and committees in the European Parliament have voiced opposition to the various elements of the proposal. A particularly contentious issue is the proposed five per cent cap, which various actors are trying to weaken or abolish altogether. One alternative that has been suggested is the introduction of a 'sub-target' for advanced biofuels, in order to increase their market share going towards 2020. The ILUC dossier is unlikely to be resolved before the end of 2013.

The aim of the proposal is to attempt to encourage advanced biofuel technologies, which reduce interference with global food production because the feedstocks they use are usually not food crops. However, it has to be noted that some of the feedstocks for advanced biofuels referred to in the Commission's proposal also require land for their production. For example, wood and switch grass, which is used for the production of ligno-cellulosic ethanol, has to be grown in plantations or on farmland, which might lead to the conversion of land that might also be suitable for the production of food. The only 'land-neutral' feedstocks are those solely based on residues and organic wastes (see Study 5 for further discussion). However, residues are a limited resource and some fulfil important

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[125] Commission proposal of 17 October 2012 to amend the RED and FQD: http://ec.europa.eu/clima/policies/transport/fuel/documentation_en.htm

[126] COM(2012)595 (2012) Proposal for a directive of the European Parliament and of the Council amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources. http://ec.europa.eu/clima/policies/transport/fuel/documentation_en.htm

functions in agricultural practices, eg straw being returned to the soil. Moreover, they are more dispersed than traditional crops and therefore pose important logistical challenges (HLPE, 2013; Kretschmer et al, 2013b).

7.6 What are the consequences of biofuel feedstocks for biodiversity?

The demand for food and feed crops for the production of conventional biofuels for EU consumption will lead to significant additional land requirements. Estimates vary and are sensitive to the relative assumptions underpinning the different modelling approaches, in particular with regards to the use of co-products and yield developments (Allen et al, 2013). What is certain, however, is that ILUC impacts from EU biofuel demand are a real and tangible problem and affect the potential contribution biofuels can make towards decarbonising the EU transport sector (IEEP, 2013).

ILUC is not only a problem with regard to associated land use change emissions. It may also entail significant biodiversity impacts. It has been argued that direct impacts on biodiversity arising from the conversion of (semi-)natural land for biofuel cropping may remain limited. The sustainability criteria as part of the RED will play a part in this. Indirect impacts, on the other hand, ie those resulting from ILUC with land use change taking place at the end of a chain of displacement effects, are believed to be a considerable risk and one that is not at all monitored let alone regulated at present as part of the RED's sustainability scheme (Frank et al, 2012; Hellmann & Verburg, 2010).

With regards to social sustainability, impacts on agricultural markets and ultimately food prices are often cited as a major concern along with 'land grabs' in developing countries associated with biofuel development. Impacts on agricultural commodity prices and even more so on consumer food prices are difficult to estimate (HLPE, 2013). Analysis seeking to quantify this is also driven by the set of assumptions underlying modelling, with particular parameters of uncertainty being, for example, yield developments and consumer response to rises in food prices. What is clear is that biofuel demand constitutes a 'new' demand and will hence add to existing pressure on agricultural markets stemming *inter alia* from a growing world population, income rises and associated changes in dietary patterns and climate change related impacts on agricultural productivity.

A conceptually, if not politically straightforward solution to most of the problems rehearsed here would be the phasing out of volume targets for (conventional) biofuels in the EU (and elsewhere). The current legislative process, following the Commission's ILUC proposal, demonstrates how difficult it is to change the political status quo, however. While volume targets have been successful in bringing about a significant scale up of first generation biofuel production, they turn out to be inflexible in light of the need to respond to evidence based challenges such as ILUC and all its associated effects. Therefore, such targets should be replaced by emission reduction targets for fuel suppliers (as enshrined in the Fuel Quality Directive) and increasingly stringent vehicle CO2 standards in the longer term (IEEP, 2013).

Promoting advanced biofuels from wastes and residues would help overcome the EU's overreliance on conventional biofuels. Several options are currently being discussed, one being a binding sub-target for advanced biofuels. Such options merit consideration. However, advanced biofuels from wastes and residues are not inherently sustainable and any incentives to use them need to be accompanied by environmental safeguards to prevent harmful indirect effects, such as those related to the displacement of residues used to build up soil carbon on fields and in forests (Kretschmer et al, 2013a); see STOA Area 5 study on bioenergy and biomaterials for a discussion of the safeguards needed.

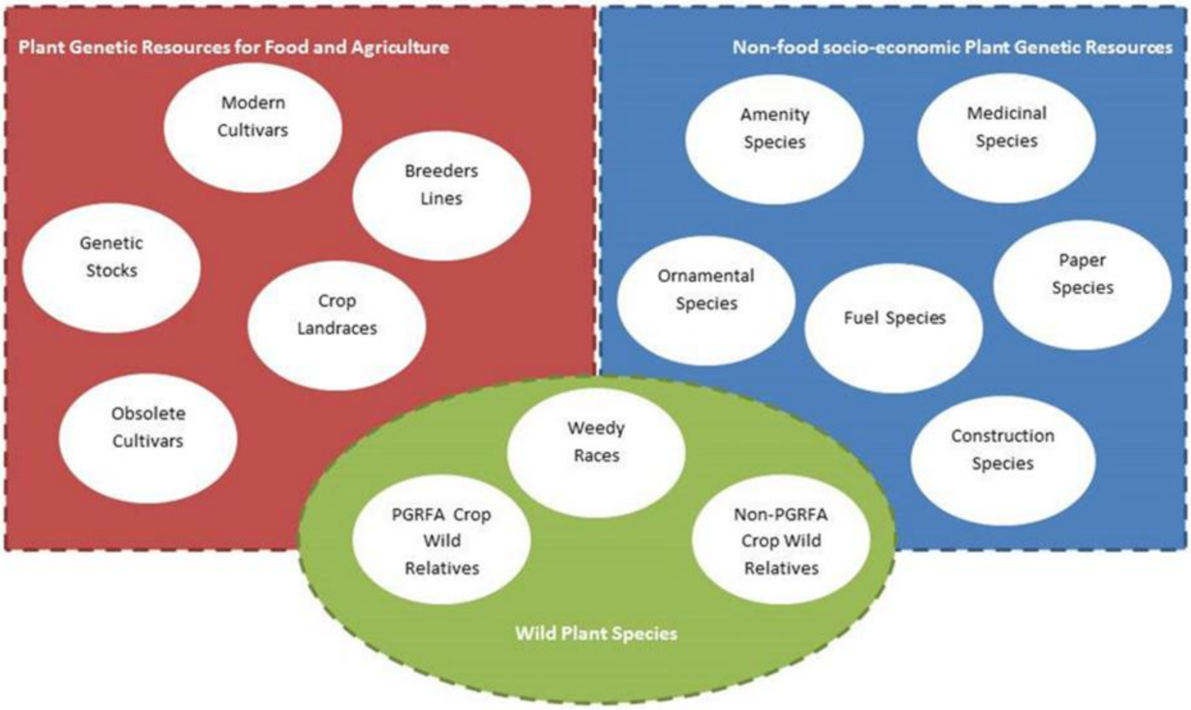
8 CONSERVATION OF PLANT GENETIC RESOURCES FOR FOOD AND AGRICULTURE IN THE EU

8.1 Plant genetic resources for food and agriculture

Biodiversity in agriculture encompasses the genetic diversity within crops and related species (Figure 8-1), which plays an important role in adaptation to different environmental conditions across the EU, eg crop cultivars that are planted at different periods, such as winter or spring wheat, or for different purposes, such as soft wheat for bread or hard durum wheat for pasta. The genetic diversity of agricultural crops is a crucial factor in agriculture's ability to adapt to a changing climate, resist new pests and pathogens, and provide high yielding varieties under different conditions, or to meet changing consumer preferences. However, the continuing genetic erosion or extinction of plant genetic diversity reduces the plant breeding options, and the options of future generations, for adapting to such challenges and for ensuring food security.

FAO (FAO, 2010b) warns that the world's food security is threatened by our failure to conserve crop genetic diversity and crop wild relatives, and emphasises that this loss of biodiversity will have a major impact on the ability of humankind to feed itself in the future, with the poorest regions of the world experiencing most severe shortages. FAO estimates that three-quarters of crop diversity has been lost globally since 1900, in particular due to the widespread abandonment of genetically diverse traditional crop landraces in favour of genetically uniform modern crop varieties, and predicts a further loss in the future. This is even more problematic in the context of climate change and human population growth impacts, which are expected to increase the need for diversity of plant genetic resources (FAO, 2008b).

Figure 8-1 The diversity of plant genetic resources (Maxted et al, 2008)



Plant genetic resources for food and agriculture (PGRFA) encompass a wide range of categories that differ in how much genetic diversity they contain, including modern cultivars, breeding lines and genetic stocks, obsolete cultivars, ecotypes, landraces and crop wild relatives (CWR) (Maxted et al, 2008), as well as weedy races and primitive forms of crops (Maxted et al, 2011) (see glossary for an explanation of key terms). Strategies to preserve PGRFA will need to target a diversity of resources and stakeholders, and use the full range of available techniques for *ex situ* and *in situ* conservation and use.

8.2 International and European policy targets for plant genetic resources

The international institutional framework governing plant genetic resources consists of the Convention on Biological Diversity (CBD) and the more genetic resource-specific International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), under the FAO Commission on Genetic Resources for Food and Agriculture, which was adopted in 2001 and entered into force in 2004 (Box 8-1).[127] The ITPGRFA establishes a multilateral system of access and benefit sharing for crop genetic resources[128], promotes the *in situ* conservation of crop wild relatives, and commits the parties to the implementation of the Global Plan of Action for Plant Genetic Resources for Food and Agriculture.

Box 8-1 The scope of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) and the Nagoya Protocol on Access and Benefit Sharing under the Convention on Biological Diversity (CBD)

The ITPGRFA establishes a multilateral system of access and benefit sharing for 35 food and 29 forage crop genepools. Parties to the Treaty have guaranteed access to these genetic resources, without the need for bilateral negotiations, and share the commercial and other benefits arising from their use, facilitated by the Standard Material Transfer Agreement (SMTA) agreed in 2007.[129] As of 1st January 2013, the Treaty has been ratified by 127 countries including the European Union.[130] However, the non-ratifying countries, including China, Japan, Mexico and the United States, host a significant proportion of the genetic diversity of some of the crops listed in the Treaty. Moreover, the list of crops in the Treaty Annex was compiled as the result of a political process rather than science-based considerations, and some important crops are excluded, including soya, quinoa, sugar cane, oil palm, tomato, and a number of other vegetables (Visser, 2013).

For crops not included under the ITPGRFA, the access and benefit sharing provisions of the CBD are applicable, and, after its entry into force, the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization.[131] The relationship between the ITPGRFA, the CBD and the Nagoya Protocol still needs further clarification with respect to the crops covered under the treaty (Cabrera Medaglia et al, 2013), though in practice many gene banks responsible for germplasm distribution use SMTAs for all material, whether covered by the ITPGRFA or not.[132]

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[127] ftp://ftp.fao.org/docrep/fao/011/i0510e/i0510e.pdf

[128] It was designed to strike a compromise between the situation that prevailed before the rise of intellectual property and access and benefit-sharing laws, when all PGRFA were *de facto* considered public domain (common heritage of mankind) and free to use by all (Stec, 2010), and the race-to-the-bottom scenario that has ensued since the 1980s in terms of establishing forms of private control over PGRFA which favours large multinational companies (Aoki and Luvai, 2007; Halewood et al, 2013).

[129] ftp://ftp.fao.org/ag/agp/planttreaty/agreements/smta/SMTAe.pdf

[130] Council Decision 2004/869 concerning the conclusion, on behalf of the European Community, of the International Treaty on Plant Genetic Resources for Food and Agriculture, OJ L378, 23.12.2004

[131] http://www.cbd.int/abs/doc/protocol/nagoya-protocol-en.pdf. The Nagoya Protocol will enter into force after it has been ratified by 50 countries (18 countries on 1 June 2013).

[132] FAO (2010) First Meeting of the Ad Hoc Advisory Technical Committee on the Standard Material Transfer Agreement and the Multilateral System of the Treaty. IT/AC-SMTA-MLS 1/10/Report. International Treaty on

Considerable progress has been made globally in implementing the Global Plan of Action for PGRFA (FAO, 2011b), but more needs to be done in particular with a view to the expected impacts of climate change. The second GPA lays out agreed priority plans and actions to protect the diversity of genetic resources and to ensure a sustainable flow of improved varieties from plant breeding. Implementation will require a substantial increase in current activities in countries, and the active involvement of international and regional organizations, donors, scientists, farmers, indigenous and local communities, the public and private sectors, civil society, and research and educational institutes (FAO, 2011b). Further policy targets that support the preservation of plant genetic resources for food and agriculture at EU level are listed in Table 8-1.

Table 8-1 European targets and actions for PGRFA and CWR to 2014/2020

Strategy	**Target to 2014**
European Strategy for Plant Conservation 2008-2014 (implementing the Global Strategy for Plant Conservation)	7.1 60% of species of European conservation priority[133] plant and fungal species, including crop wild relatives, conserved *in situ* by 2014 through the implementation of national strategies for conserving priority species 7.2 Develop database of plant micro-reserves, genetic reserves for crop wild relatives, and where relevant other small *in situ* protected areas 9.1 Establishment of 25 European crop wild relative genetic reserves covering the major hotspots of species and genetic diversity[134] 13.1 Projects in place in four European subregions demonstrating sustainable methods of conserving plant resources (crop wild relatives, land races, medicinal plants) whilst supporting European livelihoods
Strategy	**Target to 2020**
EU 2020 Biodiversity Strategy (implementing the Strategic Plan for Biodiversity)	Target 3A) Agriculture: (see Chapter 5 for details of target) Action 9b) The Commission and Member States will establish mechanisms to facilitate collaboration among farmers and foresters to achieve…. protection of genetic resources.. Action 10: Conserve Europe's agricultural genetic diversity: The Commission and Member States will encourage the uptake of agri-environmental measures to support genetic diversity in agriculture and explore the scope for developing a strategy for the conservation of genetic diversity.

Source: (Council of Europe, 2008; European Commission, 2011d)

Plant Genetic Resources for Food and Agriculture, FAO, Rome. Available online (accessed 30 September 2011): ftp://ftp.fao.org/ag/agp/planttreaty/gb4/AC_SMTA_MLS1/ac_smta_mls1_repe.pdf

[133] *Prioritised according to their inclusion in regional and national legislation, including the EC Habitats and Species Directive, the Bern Convention and IPA programmes, and with reference to European Red Lists for all taxonomic groups as they are developed

[134] Including: Action 1 Establish baseline of genetic diversity for priority crop complexes of European socio-economically important wild species to assist conservation prioritisation and as a means for assessing genetic erosion; Action 2 Assess genetic diversity against time for all European socio-economically important wild species; Action 3 Develop a preliminary list of crop wild relative hotspots of species and genetic diversity at national and European levels; Action 4 Prepare a gap analysis review of *ex situ* holdings of European crop wild relative species; Action 5 Prepare a European inventory of traditional, local crop landrace varieties; Action 6 Prepare a priority list of European crop wild relatives; Action 7 Promote the Crop Wild Relative Information System.

8.3 European initiatives for the conservation and use of plant genetic resources

Many initiatives have been undertaken in Europe both to reduce the threats to PGRFA and to conserve crop genetic diversity and crop wild relatives (Damania, 2008; Hajjar & Hodgkin, 2007; Johnson, 2008; Maxted and Kell, 2009; Treuren et al, 2012). These initiatives can be categorised according to their purpose into threat assessment, collection and conservation, coordination and access to information, public research, plant breeding, and education and public awareness. It is important to recognise that for PGRFA the end product is not conservation *per se* but the sustainable utilisation of conserved germplasm (EASAC, 2011).

Threats and threat assessment of PGRFA

At least 11.5% of the high priority European crop wild relative (CWR) species are threatened, primarily from unsustainable farming practices, urbanisation, and other infrastructure developments (Bilz et al, 2011; Kell et al, 2012), and many are affected by gene flow and hybridization with crops (see Annex 8.1 for details of the status of European CWR). It is more difficult to assess the threats facing European landrace diversity as the threat assessment techniques are not so well developed, but Negri *et al.* (Negri et al, 2009) conclude that landrace diversity is likely to be the most threatened element of all biodiversity in Europe because: (a) we have no idea how many landraces exist as there are no inventories available, (b) landrace maintainers are almost always older (average over 65) and their number is dwindling each year, (c) seed companies, breeders and government agencies are actively promoting modern cultivars to replace landraces, and (d) in most countries there is no single agency with direct responsibility for their conservation. Their conclusion is that without urgent action further loss or complete extinction is the only possible outcome.

Collection and conservation ex situ and in situ of PGRFA

Europe has approximately 500 gene banks and other institutes such as botanical gardens for *ex situ* conservation, with storage facilities as well as field gene banks (EASAC, 2011). Together they maintain 2 million *ex situ* accessions, representing a wide range of origins (see Annex 8.2 for details). Most EU countries have their collections duplicated in centralised collections on a crop-by-crop basis, whilst partner institutions maintain regional crop collections, and the state of phenotypic characterisation and evaluation of PGRFA across Europe is generally good by global standards (EASAC, 2011).

In terms of *in situ* PGRFA conservation, there is currently no coordinated or systematic attempt to conserve landraces or crop wild relatives nationally or regionally within Europe (Maxted et al, 2012b; Veteläinen et al, 2009). However, many (mainly small-scale, farmer or agro-NGO-led) ad hoc initiatives focus on *in situ* conservation of specific plant varieties and increasingly on participatory plant breeding (Bocci and Chable, 2009) (see Annex 8.2 for details). For example, the Scottish Landraces Protection Scheme[135] stores landrace seed each season, providing a safety net for growers and making the seed available for research, breeding and education. For crop wild relative diversity the main focus of *in situ* conservation should be the implementation of genetic reserves, but there are no European genetic reserves that meet the minimum quality standards (Iriondo et al, 2012) and the Natura 2000 network does not recognise the conservation of crop wild relative diversity as a goal.

Coordination and access to information on PGRFA

In Europe 43 national networks of gene banks and other conservation initiatives collaborate in the European Cooperative Programme for Genetic Resources (ECPGR)[136], aimed at contributing to

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[135] http://www.scottishlandraces.org.uk/scotlandrace_index.htm

[136] http://www.ecpgr.cgiar.org (formerly European Cooperative Programme/ Genetic Resources (ECP/GR)

national, sub-regional and regional programmes to rationally and effectively conserve PGRFA *ex situ* and *in situ* and increase their utilization. Crop specific and *in situ* technique-based working groups provide a platform for current initiatives in a number of European countries (see Annex 8.2 for examples).

The web-based catalogue EURISCO[137] contains data on more than half of the *ex situ* accessions maintained in Europe and roughly 16% of total worldwide holdings[138]. The Crop Wild Relative Information System[139] contains a checklist for all 25,000 crop wild relatives present in Europe (Kell et al, 2007).

Public research on PGRFA conservation and use

Research actions funded by DG AGRI under the Second Community Programme on the conservation, characterisation, collection and use of genetic resources in agriculture (2006-2011) included 17 GENRES projects completed in 2011 (European Commission, 2013c). One was the Leafy Veg project (2007-2010), which resulted in International Leafy Vegetable Databases for lettuce, chicory, spinach and minor leafy vegetables and identified collection gaps (Treuren et al, 2012).

Research initiatives funded under DG Research framework programmes (FP) have made key advances in knowledge, practice and coordination. EPGRIS[140] produced the EURISCO Catalogue providing information about *ex situ* accessions maintained in Europe; CRYMCEPT[141] determined cryopreservation methods for conserving European plant germplasm focusing on coffee, banana, olives and garlic; Farm Seed Opportunities[142] was developed in order to enhance the diversity of seeds available in Europe and support Member States' implementation of two Directives on seed regulation and marketing[143]; and ENSCONET[144] brought together the key European botanic garden facilities involved in the conservation of European native seeds. Major projects under the current Framework Programme (2007-2013) focusing on plant breeding using the diversity of PGRFA include RECBREED[145], SOLIBAM[146], and DROPS[147].

ECPGR has a *in situ* and on-farm conservation network and this has been successful in using EU funding to implement action: the FP5-funded PGR Forum project provided a European forum for the discussion of crop wild relative conservation methodologies (2002-2005)[148], the DG AGRI project AEGRO provided a means of case study testing of crop wild relative and landrace conservation

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[137] http://eurisco.ecpgr.org/

[138] Updated to May 2012.

[139] http://www.pgrforum.org/cwris/cwris.asp

[140] http://ipgri.singer.cgiar.org/ECPGR/epgris/Index.htm

[141] http://www.agr.kuleuven.ac.be/dtp/tro/CRYMCEPT/CRYMCEPT.htm

[142] http://www.sad.inra.fr/en/All-the-news/Farm-Seed-Opportunities-European-project

[143] 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.

[144] http://ensconet.maich.gr

[145] Recombination: An old and new tool for plant breeding, www.recbreed.eu

[146] Strategies for Organic and Low-input Integrated Breeding and Management, www.solibam.eu

[147] Drought tolerant yielding plants, www.dropsproject.eu

[148] FP5 project (2002-2005) http://www.pgrforum.org

methodologies (2006-2010)[149], and the FP7-funded PGR Secure project is developing national and regional conservation strategies for European crop wild relative and landrace diversity linked to enhanced utilisation of the conserved material (2011-2014)[150].

Use of PGRFA in plant breeding

Plant breeding depends on the ability of breeders to access genetic diversity and use it in new varieties with desired properties, such as better disease resistance, increased shelf-life, enhanced taste, and nutritional value (EASAC, 2011; van den Hurk, 2011). Plant breeders' use of genetic diversity is demonstrably increasing in the face of changing consumer demands, the demands of climate change mitigation, and increased production to feed the rising human population (Maxted et al, 2012a), and the diversity they use is increasingly taken from landraces and crop wild relatives (Feuillet et al, 2008)[151]. Plant breeding companies often work in close cooperation with gene banks, facilitating characterisation and regeneration, and in some cases co-financing collecting trips in order to increase access to genetic diversity. Europe has relatively well advanced public breeding institutions and programmes and an important plant breeding sector (Mwila, 2013; Visser and Borring, 2011) - for example, the Netherlands is a world player in vegetable seeds, and Germany and France are major producers of seeds for arable crops - but all are finding that access to genetic diversity is a limiting factor on cultivar development.

Increasing education, awareness and consumer demand for PGRFA products

Public awareness of plant genetic resources and agricultural biodiversity and the momentum for action has increased through the plethora of largely NGO based activities such as community gardens, farmer markets, seed exchanges, listings of forgotten and endangered crop varieties, books and documentary films, and the availability of internet-based information. Worries over contaminated food stuffs have also stimulated consumers to become more demanding, seeking fresher, less intensively produced and more localised food production (Lang and Heasman, 2004; Pretty, 1999), and the food and retailing sector is trying to strengthen its competitive position by offering specialty products for niche markets based on new varieties or local traditional landraces. The sector has created new governance structures focused on quality, safety and sustainability attributes of products (Fulponi, 2006; Gereffi et al, 2005), and new organic and fair trade business models that encourage greater crop and product diversity, such as Agrofair[152] and Eosta[153].

The NGO Slow Food Foundation for Biodiversity[154] establishes stronger links between producers, consumers and local communities through the listing of endangered PGRFA products in its Ark of Taste[155], its producer communities called Presidia[156], 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). However, a more coordinated and systematic approach to the recording and conservation of landraces and crop wild relatives nationally or regionally within Europe is required (Maxted et al, 2012b; Veteläinen et al, 2009).

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[149] http://aegro.jki.bund.de/aegro/

[150] FP7 project (2011-2014) http://www.pgrsecure.org/

[151] FAO Integrated Food Security Support Service reports

[152] http://www.agrofair.nl

[153] http://www.eosta.com

[154] http://www.slowfoodfoundation.com

[155] 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

[156] http://www.slowfoodfoundation.com/presidia

Various European universities provide courses in agricultural sciences, plant breeding, and plant science, which include aspects of plant genetic resources; however, the one specific MSc course in the subject has recently closed.

8.4 Challenges and opportunities from the European perspective

This section describes the challenges and opportunities for PGRFA conservation and use in Europe based on discussion with authoritative experts, representing the main categories of international public governance, gene banks, public research, plant breeding companies, and agro-NGOs. The interview questionnaire and the list of interviewees are provided in Annex 8.2.

Gaps in the conservation and characterisation of PGRFA

The interviews have confirmed that there is an urgent need for increased *in situ* and *ex situ* conservation and characterisation of PGRFA, not only of major and minor crops but particularly of land races and crop wild relatives. This was also emphasised by the European Academies Science Advisory Council in their 2011 report (EASAC, 2011).

Knowledge about the conservation status of European landraces is still limited and will require a comprehensive and systematic inventory in all EU Member States (Veteläinen et al, 2009), though such work has begun for crop wild relative diversity (see above). The network of *ex situ* seed gene banks and field gene banks is well established but *in situ* conservation of PGRFA in Europe is very limited. Currently there are a few on-farm based projects conserving landraces (Veteläinen et al, 2009) but there is no *in situ* conservation of crop wild relatives using the international recognised standard (Iriondo et al, 2012) and only 6 per cent of European crop wild relative species have any collections in seed gene banks (Maxted et al, 2012b).

One interviewee stressed that *ex situ* conservation efforts should not only focus on seed producing plants but also on species with other reproduction mechanisms, such as vegetative species (eg yam, cassava, and banana). Cryopreservation has recently become available as an effective conservation technique for these species, enabling similar *ex situ* conservation initiatives as already exist for seed producing plants. It could be an option to create an initiative for vegetative crops which is comparable to the Svalbard Seed Vault.

Support for use of PGRFA in farming still too limited

Several interviewees emphasised that the use of PGRFA is still far too limited in farming. Farmers using landraces and the products derived from them are not yet using the opportunities offered by diversification of agricultural and horticultural production and the development of local niche products. Product designation schemes[157] such as Protected Designation of Origin (PDO), Protected Geographical Indication (PGI) and Traditional Specialty Guaranteed (TSG) may support the marketing of these products. However, it was noted that often farmer's use of landraces is limited by their availability: if land races are unrecognised or not conserved then it is not possible for farmers who wish to cultivate them to obtain the necessary seed (Veteläinen et al, 2009).

Inadequacies related to the institutional framework

The institutional framework provided by the GPA and ITPGRFA is seen by several interviewees as a step in the right direction, but its implementation is lagging. This is confirmed by a survey among gene banks showing that thus far the Treaty has not created a significant change in actors' willingness to make new materials internationally available through the Consultative Group on International

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[157] Council Regulation No 509/2006 on agricultural products and foodstuffs as traditional specialities guaranteed [2006] OJ L93/1 and Council Regulation510/2006 on the protection of geographical indications and designations of origin for agricultural products and foodstuffs [2006] OJ L93/12.

Agricultural Research (CGIAR) centres' gene banks (Halewood et al, 2013). On the contrary, it has been claimed that accessions have diminished as well as their use.

Interviewees have pointed at difficulties in drawing up bilateral agreements for collection purposes which is complicating the work of gene banks and breeding companies. Some participating countries have taken a principled stance against such agreements, although cooperation is generally better in the case of collection for scientific rather than commercial purposes. Other countries seem to lack the knowledge and competence to make proper agreements, and the support provided by national focal points and the ITPGRFA Secretariat is seen as insufficient. Similar remarks have been made about quarantine authorities that lack the capacity for adequate control of plant genetic material. An additional problem is that countries do not always report which accessions have been used successfully and consequently do not make any payments to the benefit sharing fund.

The interviewees considered the scope of the ITPGRFA to be limited as not all relevant food crops are covered, particularly minor crops and vegetables, the former being of interest to local communities and the latter to the plant breeding sector (Visser, 2013) (see Box 8-1). Thus far, the Contracting Parties have been hesitant to propose the inclusion of additional crops. Furthermore, a number of countries with high stakes in PGRFA have not ratified the Treaty.

Insufficient cooperation and coordination between stakeholders

Several interviewees are of the opinion that the mutual cooperation between gene banks could be improved. To this end, ECPGR (2012) have suggested creating 'A European Genebank Integrated System' (AEGIS) for PGFRA aimed at conserving the genetically unique and important accessions in Europe and making them available for breeding and research. Although a complementary approach for on-farm and *in situ* conservation has been discussed at the global level, led by FAO[158], there has been limited discussion of such a parallel initiative in Europe thus far. There is also a lack of integration between the communities working on PGRFA and other biodiversity conservation, such that the *in situ* conservation activities of protected areas and genetic reserves for crop wild relative conservation and the *ex situ* conservation activities of gene banks and botanic gardens are not coordinated. For example, the conservation of crop wild relatives has historically fallen between those involved in the conservation of socio-economically important species and the nature conservation community with neither taking responsibility for their conservation (Maxted et al, 2012b).

Legal uncertainty hampering access and technological innovation

Several interviewees using PGRFA mentioned that access to plant genetic resources is hampered by the institutional framework provided by the CBD, and fear that under the Nagoya Protocol the situation will further deteriorate because many countries are not willing or able to implement it properly, thereby increasing legal uncertainty. The EU has proposed due diligence obligations for users of genetic resources[159] that go further than the Protocol requires, demanding from users to seek, keep, and transfer to subsequent users detailed information relevant for access and benefit sharing for at least 20 years. This will put an additional administrative burden on the breeding sector. A counter view held by several European farmer or grower based NGOs is that those farmers and growers who have maintained crop diversity for millennia should be fairly and equitably treated by the community when exploiting their resources.[160] It is also argued that the establishment of a clear legal framework of responsibilities, the system of Union trusted collections, and the proposed EU platform will lower

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[158] www.fao.org/agriculture/seed

[159] Draft Regulation on access to genetic resources and the fair and equitable sharing of benefits arising from their utilisation in the Union COM(2012) 576 final

[160] Eg http://www.scidev.net/global/indigenous/opinion/making-the-nagoya-protocol-work-at-the-community-level.html

the risks and costs for researchers and plant breeding development in Europe of using illegally acquired genetic resources, and improve resolution of issues and provision of advice. There is still legal uncertainty and only limited information to assess options, and the EU needs to play a careful policy role (IEEP et al, 2012b).

The plant breeding sector is also stressing that it needs legal certainty about the EU's course of action with regard to new biological techniques that enable the use of more genetically distant crop varieties and crop wild relatives[161]. These novel plant breeding techniques are currently being evaluated to decide whether they fall within the legal EU definition of genetically modified organisms (GMOs), whether the current regulatory exemptions in these Directives apply, and/or whether additional EU regulation should be considered for these techniques[162] (see Chapter 6 for discussion). However the decision is delayed and no legislative initiative is currently foreseen.

The proposed EU seed regulation[163] strengthens protection of intellectual property rights on breeder produced varieties. However, some companies in the plant breeding sector would prefer to maintain the old system based on UPOV[164] as they fear that the open access to plant genetic resources will be further limited to the advantage of the larger multinational companies, leading to increased uniformity instead of diversity (van den Hurk, 2011).

Diversity-eroding side-effects of EU regulations

The number of EU rules has significantly increased in practically all stages of the plant breeding cycle and is perceived by several interviewees as 'over-regulation', promoting uniformity of crops and produce rather than diversity. For example, the DUS (distinct, uniform and stable) requirements for inclusion of a variety in the common catalogue of agricultural plant varieties have a limiting effect on diversity. The EU marketing standards for fresh produce[165], designed to protect consumers and facilitate trade, limit market access for varieties that deviate from these standards specifying inter alia commercial type, quality, and sizing.

Human diets based on a limited amount of plant species

Several interviewees mentioned that food consumption needs to diversify, referring to FAO figures that people's diets rely on four crops -- rice, maize, wheat and potatoes -- for over 50 per cent of the food supply and only 30 crops provide 90 per cent of the world's calorie intake. Although public awareness has grown in Europe, several interviewees were convinced that much more work needs to be done to stimulate people to better understand the benefits of diversified diets (Fanzo et al, 2013).

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[161] These techniques include: Oligonucleotide Directed Mutagenesis (ODM); Zinc Finger Nuclease Technology (ZFN) including ZFN-1, ZFN-2 and ZFN-3; Cisgenesis and Intragenesis; Agro-infiltration; RNA-dependent DNA methylation (RdDM); Reverse breeding; Synthetic genomics.

[162] http://ec.europa.eu/food/plant/gmo/new_breeding_techniques/index_en.htm

[163] COM(2013) 262 final

[164] http://www.upov.int/portal/index.html.en

[165] Council Regulation (EC) No 1234/2007 establishing a common organisation of agricultural markets and on specific provisions for certain agricultural products (Single CMO Regulation) [2007] OJ L299/1

8.5 Options for the EU for the conservation and use of plant genetic resources

It is vital that policy-makers in the EU and at the Member State level recognise the current threats facing European PGRFA, as well as the need to ensure policies are in place to support their enhanced conservation and use (eg EASAC, 2011). This means that the EU should give a higher profile and priority to issues related to PGRFA. Diversity of plant genetic resources should be recognised as a necessity, not a luxury. The current challenges to the conservation and use of PGRFA and the needs of future generations demand an integrated, multifaceted approach that builds on the initiatives of all stakeholders concerned and is based on increased cooperation and mutual learning.

In concrete terms, recommended options for the EU include the following:

Greater collaboration and coordination among national, European and international policy and scientific stakeholders to promote PGRFA conservation and use

PGRFA conservation is directly linked to maintenance of food security. This requires a coordinated effort at the national and European levels to effectively conserve PGRFA, with appropriate links to the global context.

- Place the existing ECPGR Network on a more sure footing and provide better resources;
- Encourage all EU Member States to ratify the ITPGRFA and work to amend Annex 1 to include all major crops.

Systematic and effective PGRFA in situ *and* ex situ *conservation*

The PGRFA user community has a growing need for more PGRFA diversity to sustain food security, yet European PGRFA diversity is threatened by ecosystem mismanagement and is poorly conserved. Moreover, lack of PGRFA availability limits economic growth. Systematic and effective PGRFA *in situ* and *ex situ* conservation is required.

- Establish a European network of *in situ* genetic reserves for crop wild relatives and on-farm conservation sites for landraces (funded by targeted CAP agri-environment schemes);
- Set up a more coordinated European Genebank Integrated System, including an evidence based research internet platform.

Concerted attention to conserve crop wild relative diversity

Climate change is forcing plant breeders to search for mitigating diversity through utilisation of the broader range of PGRFA diversity found in crop wild relatives. Yet there is no active *in situ* protected areas conservation of European crop wild relatives and 94% of them have no accessions in *ex situ* gene banks; their conservation tending to fall between the priorities of both environmental and agricultural agencies.

- Develop and implement a European action plan for crop wild relative conservation.

Greater integration of PGRFA conservation with other biodiversity conservation activities

There are two distinct communities working within European biodiversity conservation, those involved in the conservation of socio-economically important species and those involved in nature conservation. Despite obvious overlap between the targeted sites and techniques applied, the two communities work independently and duplicate effort. There is a need to mainstream PGRFA with European nature conservation.

- Integrate PGRFA conservation with existing European biodiversity conservation actions using the Natura 2000 network.

Improve policy incentives for European PGRFA utilisation

The regulatory environment can be improved by systematically analysing the positive and negative implications of the EU regulatory regime upon the diversity of crops and plant genetic resources. The priority in legislation should be to create an environment that fosters a constant flow of conserved PGRFA into utilisation programmes.

- Modify variety and seed production legislation that conflicts with on-farm diversification;
- Reduce unnecessary administrative burdens for the plant breeding sector.

Secure the evidence research base that underpins PGRFA conservation and utilisation

The end product of PGRFA conservation is not conservation of the resource itself, but sustainable utilisation of the conserved resource. Most European conserved PGRFA is not well used by breeders because it lacks characterisation and evaluation information that identifies which traits each accession contains. Therefore there is need for greater actual or predictive characterisation and evaluation of conserved PGRFA and the web-enablement of this information to help promote utilisation of conserved PGRFA.

- Give greater prominence in the Horizon 2020 programme, and specifically the European Innovation Partnership on agricultural productivity and sustainability, to research on PGRFA involving all scientific disciplines and stimulate an improved use of scientific evidence;
- Carry out a systematic assessment of climate change impacts on PGRFA conservation and utilisation to ensure continued food security.

9 THE IMPACTS OF BEE DECLINE ON BIODIVERSITY AND POLLINATION IN THE EU

9.1 The importance of pollinators

Pollinators ensure the reproduction and fruit set of many crops and wild plants by transporting pollen from one flower to another (pollination by wind and water is also possible). Cross-pollination is the process by which pollen is transferred from the male part of the flower of one plant to the female part of a flower on another plant, enabling the cross-fertilisation and sexual reproduction of plants, maintaining genetic diversity. Pollinators ensure crop yields and the transfer of genes within and among populations of plant species (Kjøhl et al, 2011) (see Box 9-1).

Whilst a range of species (including birds, thrips, flies, wasps and ants) are pollinators, bees are the primary pollinators for most crops requiring animal pollination (Klein et al, 2007; Potts et al, 2010b), including domestic honey bees and wild species such as stingless bees, bumblebees and solitary bees. Studies have shown the importance of pollinator diversity: wild species are more efficient pollinators of many plant species than honey bees, because of their physical compatibility with the flower (Albrecht et al, 2012; Klein et al, 2003; Le Féon et al, 2010; Winfree et al, 2007). The interaction between wild pollinators (especially bumblebees) and honeybees increases honeybee pollination efficiency (Brittain et al, 2013; Greenleaf and Kremen, 2006).

Box 9-1 Role of pollination in Europe

In Europe, 84% of crop species, ie more than 150 plant species (Williams, 1994)[166], and 80% of European wild plant species (Blacquière et al, 2012; Potts et al, 2010b) are directly influenced by insect pollination for fruit and seed set (especially by bees). The European crops in which fruit and seed production and quality is dependent upon, or enhanced by, insect pollination (Corbet et al, 1991; STEP, 2013), include:

- Fruits: apple, orange, tomato, pear, peach, melons, lemon, strawberry, raspberry, plum, apricot, cherry, kiwifruit, mango, and currants
- Vegetables: eggplant/aubergine, carrot, onion, pepper, field bean, French bean, soy bean, courgette/zucchini, squash/pumpkin, and cucumber
- Industrial crops: cotton, oilseed rape, white mustard, and buckwheat
- Seeds and nuts: sunflower, almond and chestnut
- Herbs: basil, sage, rosemary, thyme, coriander, cumin and dill
- Forage crops for animals: alfalfa, clover and sweet clover
- Essential oils: chamomile, lavender, and evening primrose

9.2 Pollinator decline in Europe

An abnormal decline of bees (both honeybees and wild bees) has been observed worldwide for several decades.[167] 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 in Annex 9.1) and van der Zee et al (2012) indicated mortality rates in European

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[166] Considering that 57 food crops represent 94,5% of the European food production

[167] NB Colony Collapse Disorder is a specific syndrome of rapid worker bee loss in the presence of brood, queen and food stores in the hive reported in the US; only one incident has been reported in Europe, and this study reports on bee decline more generally (Dainat et al, 2012; OPERA, 2013)

countries of 7 to 22% in the 2008-2009 winter and 7 to 30% in the 2009-10 winter. Such studies are however relatively recent and generally investigate only honey bee losses, with less information available on wild bee losses. However, monitoring has been increased recently (eg COLOSS survey[168]).

9.3 European beekeeping

The European Union had around 700,000 beekeepers in 2010 with an estimated 15 million hives. The hive density varies greatly between Member States, as does the number of hives per beekeeper. For example hive density is more than five times higher in Hungary than in Germany, but the number of beekeepers is five times higher in Germany (De la Rúa et al, 2009). The sector is fragmented, as only 3 per cent of beekeepers are professionals, with around a third of EU hives (European Commission, 2010b). Many beekeepers do not belong to an organisation, so are not counted in national and European statistics (Hendrikx et al, 2009). Moreover, the methods for data collection vary between countries (Potts et al, 2010b), making comparisons and evaluation of issues complex. Understanding whether and why wild bees decline is an even more challenging issue.

9.4 The factors affecting bee/pollinator populations in the EU

The causes of bee colony loss are disputed and vary across regions of the world. Current knowledge suggests the cause of decline is due to **multiple factors** (AFSSA, 2008; Breeze et al, 2012; European Parliament, 2011; Schweiger et al, 2010; Tylianakis et al, 2008). The frequency, severity and rapidity of bee colony mortality varies depending on the type of factor affecting bees (exposure and virulence), the bees' health, and the environment (AFSSA, 2008). The following key pressures and drivers on bee colonies and pollinators are identified as possible factors (Table 9-1):

Table 9-1 Pressures and drivers of bee colony and pollinator declines

Main factors	**Effects on bee colonies and/or pollinators**	**Studies on the topic**
Factors with substantial scientific evidence and widespread impact		
Pests and pathogens		
Invasive species - *Varroa destructor* mites	*Varroa destructor* is a disease vector and an external parasite of the honeybee. It breeds within the colony by laying its eggs within capped brood and feeding on larvae. It also transmits bee viruses including Deformed Wing Virus and Acute bee paralysis virus (in the absence of *Varroa* these viruses cause only covert /benign infections). *Varroa in combination with diseases is the major driver of winter colony mortality across Europe. Almost all colonies need annual treatment; most untreated colonies die within one to three years. Some bee varieties are relatively resistant but current bee breeding is not selecting for resistance and may actually be selecting against it.*	(Le Conte et al, 2010) (Carreck et al, 2010) (Dietemann et al, 2012) (Dainat et al, 2013) (Genersch, 2010) (Meixner et al, 2010) (Costa et al, 2012) (Büchler et al, 2010)
Nosema parasites	*Nosema ceranae* is a microsporidian parasite of the Asian honeybee that has probably been infesting European honeybees for at least the last two decades. It causes a progressive depopulation of	(Higes et al, 2010) (Paxton, 2010) (Higes et al, 2008) (Fries, 2010)

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[168] part of the COLOSS project (Prevention of honey bee COlony LOSSes, www.coloss.org)

Main factors	**Effects on bee colonies and/or pollinators**	**Studies on the topic**
	hives reducing colony strength. *N ceranae* virulence and distribution is still relatively unknown, but its impact is limited in Northern Europe, perhaps due to lower genetic susceptibility (whilst *N apis*, more prevalent in cooler climates, has lower virulence). *In 2004, it was present in 90-97% of hives in Spain, and it is now recorded from all EU countries that have the technical capacity to distinguish N ceranae from N apis.*	(Dainat et al, 2012) (Dussaubat et al, 2013)
Bacterial brood diseases	Bee mortality from European Foulbrood, previously a minor disease, has recently become a major problem for apiculture in Switzerland and the UK. American Foulbrood is an easily diagnosed disease not associated with inexplicable colony losses, but is nevertheless a major threat to honey bee health and causes considerable economic losses to beekeepers.	(Forsgren, 2010) (Genersch, 2010)
Lack of appropriate, adapted and accessible treatment	*Varroa* and other pest mites[169] have developed resistance to acaricides, partly due to over-reliance on a few agro-chemicals to treat beehives.	(AFSSA, 2008) (Thompson et al, 2002)
Interaction of treatments with other factors	Treatment against *Varroa* can cause significant bee population mortality if not applied appropriately. Antibiotics used to treat bee diseases may increase the susceptibility of bees to some insecticides.	(Haubruge et al, 2006) (Hawthorne and Dively, 2011)
Agricultural practices		
Pesticides	Pesticides can have lethal or sub-lethal effects on bees. The bees can be poisoned by the insecticides present in the air due to spray drift or volatilisation and can come into contact or ingest residual products in the soil or on crops. Exposure depends on bees' interest for the treated area, climatic conditions, pesticide quantity and method of application, eg film-coat quality. Neonicotinoid insecticides (imidacloprid, thiamethoxam and clothianidin) are quoted as being among the most dangerous pesticides with direct lethal effects from contact exposure. Imidacloprid seems to have adverse sub-lethal effects on larval development. Neonicotinoid insecticides act as neurotoxic agents and can affect bee mobility at high doses (Blacquière et al, 2012). The phenylpyrazole pesticide fipronil has similar impacts. Further studies are needed on chronic effects of pesticides because the link between exposure through bee food and individual mortality is	(Johnson et al, 2010) (AFSSA, 2008) (Alaux et al, 2010) (Blacquière et al, 2012) (Whitehorn et al, 2012) (Grimm et al, 2012) (Thompson, 2012) (Gill et al, 2012) (DEFRA, 2013b)

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[169] Eg *Acarapis woodi* (honey bee tracheal mite)

Main factors	**Effects on bee colonies and/or pollinators**	**Studies on the topic**
	currently not clearly proved. Wild pollinators are potentially also affected by pesticides, although fewer studies are available on their impacts (Whitehorn et al, 2012). Declared cases of bee poisoning are decreasing, reflecting both better farming practices and a tendency of beekeepers to declare fewer incidents (AFSSA, 2008).	
Destruction of habitat	Urbanisation, land use change and agricultural intensification cause bee habitat loss and fragmentation. Habitat fragmentation isolates bee populations from each other and means bees have to travel further to find sufficient and varied food. Fragmentation reduces reproduction of plants dependent on pollinators. *Wild pollinators depend on semi-natural habitat patches as breeding habitat, and their pollination services decline by half or more at 100m to 500m from breeding habitat.*	(Tscharntke et al, 2005) (Aguilar et al, 2006) (Albrecht et al, 2007) (Klein et al, 2007) (Ricketts et al, 2008) (Kohler et al, 2008) (Garibaldi et al, 2011)
Lack of nutrient sources, diversity and quality due to intensification of arable land	Monoculture and simplified crop rotations impoverish crop diversity, in particular species rich in pollen and nectar, ie leguminous and entomophilous species (rapeseed, field bean, clover, etc), and shorten the crop flowering period. Crop food resources are thus both decreasing and lacking during a longer period.	(Kremen et al, 2002) (Tscharntke et al, 2005) (Carvell et al, 2006) (Klein et al, 2007) (AFSSA, 2008) (Potts et al, 2009)
Lack of nutrient sources, diversity and quality due to intensification of grassland	Semi-natural grassland is increasingly being replaced by improved grassland with few nectar and pollen-producing flowers, reducing feeding resources for bees. Dairy farmers often mow before meadows flower, reducing available food sources such as clover (*Trifolium* spp).	(Kohler et al, 2006) (Pywell et al, 2006) (Holzschuh et al, 2007) (AFSSA, 2008)
Decline in pollen quality	Pollen quality is important to ensure an optimal larvae development and survival and activity during the winter season, and diet diversity increases immune-competence levels. Pollen quality could also have an effect on temperature regulation (tested on bumble bees) and the sensitivity of bees to pesticides.	(AFSSA, 2008) (Mapalad et al, 2008)
Beekeeper practices		
Beekeeper practices	Bad beekeeper practices can cause bee loss, including: • Loss of the queen during manipulation • Bad maintenance of the hive (too much humidity, lack of food or drinking water, etc) • Bad management of swarming • Lack of disease and pathogen monitoring and inadequate treatment.	(AFSSA, 2008) (OPERA, 2013)

Main factors	**Effects on bee colonies and/or pollinators**	**Studies on the topic**
	Moreover, there is currently no selection of bees when composing the hive.	
Lack of genetic diversity and vitality, restriction of queen bee breeding	Local bee strains tend to show more resistance to pathogens and environmental stresses, and suffer fewer losses. Native bee genetic diversity is being lost by introgression from commercial subspecies, which is further exacerbated due to the specialisation of a small number of beekeepers to queen breeding, distributing large numbers of progeny around Europe from few queen mothers.	(Soland-Reckeweg et al, 2009) (Meixner et al, 2010) (Costa et al, 2012)
Emerging threats with substantial scientific evidence but currently limited impact		
Pests and pathogens		
Invasive species - *Vespa velutina*	*Vespa velutina*, the Asian Hornet, attacks bees and feeds its larvae with bee brood. Attacks kill an estimated 20 to 30% of bees and only 8 hornets in a hive can kill the colony. *The species is currently only present in southwestern France and Spain*[170] *but is also reported from Belgium and Portugal.*	(Villemant et al, 2006) (AFSSA, 2008) (OPERA, 2013)
Invasive species – *Tropilaelaps clareae* and *Tropilaelaps mercedesae* mites	*Tropilaelaps* mites develop on the brood - larvae and nymphs – and adults. Brood mortality rate can be 50%. The main factor currently limiting survival and spread of exotic mites in northern Europe is their dependency on a continuous, year-round food supply of immature bees within infected colonies. *Tropilaelaps mites have not currently been detected in Europe but the risk of accidental import is considered to be high*[171]	(AFSSA, 2008)
Invasive species - *Aethina tumida*	*Aethina tumida*, the Small Hive Beetle, lays its eggs on the hive. Once the eggs become larvae, they feed with bee eggs and larvae and dig galleries that destroy brood cells and honey. A high level of infestation can cause the death of the colony. *Aethina tumida is currently not detected in Europe but the risk of accidental import is considered to be high*[172]	(Hauser, 2004) (AFSSA, 2008)
Possible factors with less documenting evidence available		
Climate change		
Synchronization of flowering and bee seasonal activity	Climate change can induce earlier flowering of plants and crops, which can cause maturity gaps between colony development and the availability of pollen. It may also affect morphological and physiological matching of flowers and pollinator	(Memmott et al, 2007) (Schweiger et al, 2010)

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[170] http://www.europe-aliens.org/speciesFactsheet.do?speciesId=50954#

[171] https://secure.fera.defra.gov.uk/beebase/index.cfm?pageid=92

[172] https://secure.fera.defra.gov.uk/beebase/index.cfm?pageid=125

Main factors	**Effects on bee colonies and/or pollinators**	**Studies on the topic**
	species by modifying the appropriateness of plants or pollinator characteristics[173]. If pollinators and plants are no longer compatible, pollination fails.	
Increased pest pressure	Climate change could trigger the appearance of new bee pests.	(Schweiger et al, 2010)
Electromagnetic waves		
Effect of Electromagnetic radiation	Bees perceive electric and magnetic fields, in particular from Digital Enhanced Cordless Telecommunication (eg cordless phones) and antennas, through small abdominal crystals containing iron. Electromagnetic radiation seems to affect returning bees and bee behaviour.	(Kimmel et al, 2007) (Favre, 2011) (Sainudeen, 2011)
Potential future threats		
GMOs		
GMOs	GM insect-resistant crops modified with proteinase inhibitors have been shown to be toxic to bees, but these crops are currently not approved for cultivation. No negative effects of GM insect-resistant Bt crops on bees have been found.	(Brødsgaard et al, 2003) (Duan et al, 2008b) (Ramirez-Romero et al, 2008) (Johnson et al, 2010)

Many of these factors are linked or interact, adding to the complexity of understanding the exact causes of bee decline. For example, climate change facilitates the presence of new pest species, and increasing weather variability presents challenges to winter colony survival. Similarly, evidence on neonicotinoids pesticides seem to show that such products do not necessarily have significant impacts alone, but reduce the resistance to pests, making both factors in combination a significant threat to bees (eg Potts et al, 2010b). Similarly, the *Varroa destructor* mite is a vector for viruses, including the Deformed Wing Virus and the Acute Bee Paralysis Virus, that lower bee immunity and enhance their sensitivity to other infections (Dainat et al, 2013). According to Didham et al (2007), **the effects of interactions could be almost as important as those of each driver in isolation.**

Similar interactions are observed for wild bees (Goulson et al, 2008; Whitehorn et al, 2012), but more research on the threats to wild bees is needed in order to implement effective actions to sustain pollination by wild pollinators.

Pollinator decline is seen as an early-warning sign or bio-indicator of broader environmental issues, as it may be linked to the decline of the plants that they visit (Biesmeijer et al, 2006), and bees are seen by many as bio-indicators due to their sensitivity to environmental stress factors (Balayiannis and Balayiannis, 2008; Devillers and Pham-Délègue, 2002; Porrini et al, 2003).

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[173] (flower tongue length, quantity of secreted nectar, sugar concentration, etc.)

9.5 The impact of bee/pollinator declines on crop production in the EU

Impact of pollinator decline on crop production in the EU

Klein et al (2007) calculated that pollinators have an impact on the yield of 76% of crop types in Europe[174], which together represent 35% of food production (by weight). Considering that the area dedicated to pollinator-dependent crops is increasing worldwide, in particular in the developed world (Aizen et al, 2008), the decline of managed and wild pollinators could have an important impact on food production, and possibly in the future on biomass production too.

However, estimates of yield losses due to pollinator declines depend greatly on the crops considered. Aizen et al (2008) question the impact of pollinators on yield. They show that the yield of pollinator-dependent and the yield of non-pollinator-dependent crops have increased similarly over forty years (from 1961 to 2006) whilst pollinators have been declining. In another study, Aizen et al (2009) estimated that the expected direct yield reduction in the absence of animal pollination ranged from only 3 to 8% because of the low dependence of rice and wheat (the highest volume crops) on animal pollination (Ghazoul, 2005). For fruits and vegetables, a hypothetical complete pollinator loss translated into a production deficit over current consumption levels of -12% for fruits and -6% for vegetables globally (Gallai et al, 2009).

Economic impact of pollinator decline

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) (see details in Annex 9.2). In the EU, the economic value of food production from animal-pollinated crops is estimated at €15 billion per year, and resorting to human-assisted pollination is estimated to cost at least twice as much (European Parliament, 2011). In the USA, honey bee colonies are rented and transported to pollinate specific crops such as almonds, and the average cost has increased steeply from €35 in the 1990s to €150 in 2006, partly due to bee decline (National Research Council, 2007).

Nutritional impacts of pollinator decline

Pollinator-dependant crops supply us with important nutrients; for example, 74% of all lipids produced globally come from oils from animal-pollinated plants; 98% of available vitamin C comes from animal-pollinated plants, primarily citrus; and many other vitamins are supplied by animal-pollinated fruits and vegetables (Eilers et al, 2013). The pollinator decline may thus lead to nutritional imbalances and deficiencies, jeopardizing human health.

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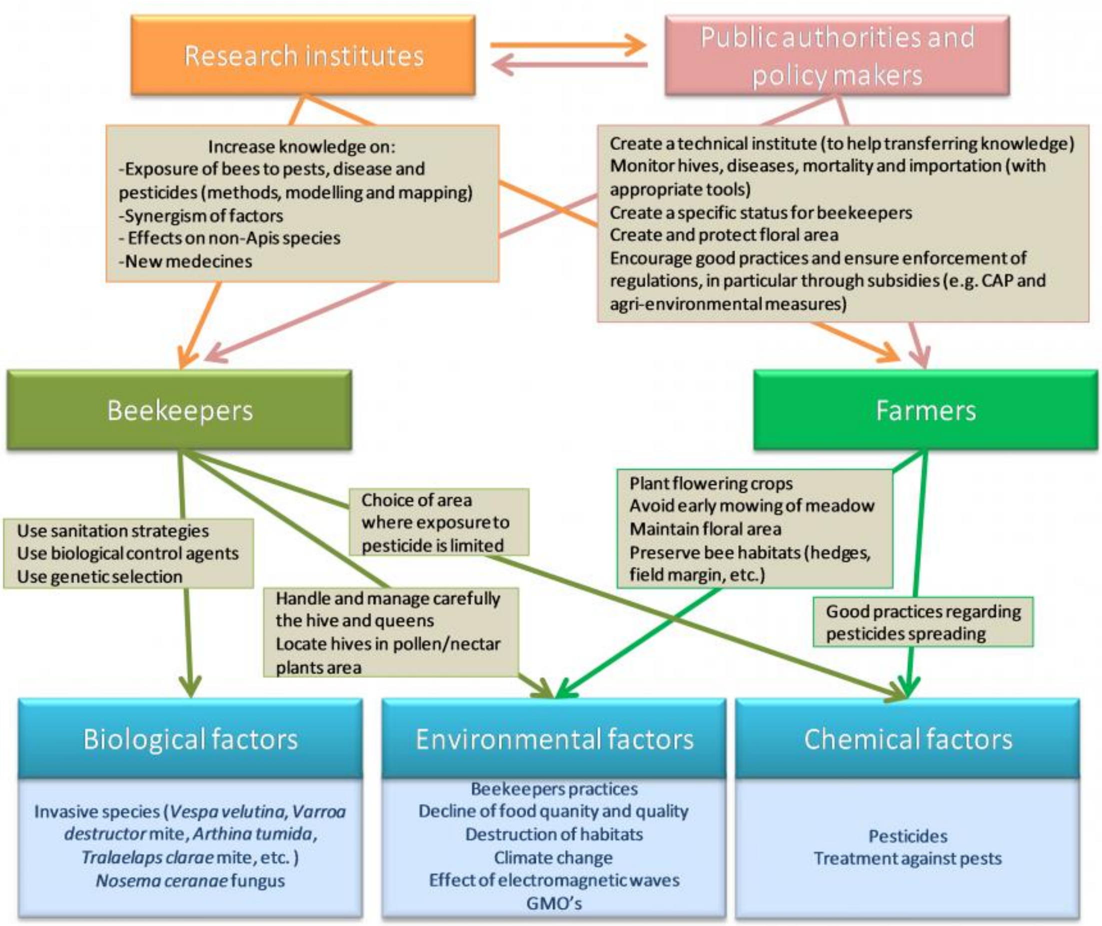
[174] 92 out of 108 studied crops present an increased yield with animal pollination, among which data are available for 82 from experiments comparing pollination with and without animal-pollination. The 10 others are deduced from the fact that self-pollination and wind-pollination are not possible.

9.6 Actions to address each of these factors and maintain pollination services

A number of actions to address the causes of bee mortality and control pollinator decline are available and being investigated. Stakeholders have different roles to play in each case (Figure 9-1).

Figure 9-1 Actions to be implemented by stakeholders and their impact on the factors causing bee declines (Source: own figure)



Biological factors affecting bees

Beekeepers often rely on antibiotics and pesticides (fungicides) to control pathogens and parasites, but inappropriate use of these chemicals can affect honeybees. Moreover, pathogens and parasites often develop resistance quickly due to the low number of available substances and their lack of target specificity (AFSSA, 2008; Arbia and Babbay, 2011). Due to the limited size of the sector[175], pharmaceutical firms have little interest in developing more diverse and appropriate chemical treatments (European Parliament, 2011).

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[175] (so called minor uses, minor species or MUMS markets)

More sustainable practices for controlling diseases include:

- *Using sanitation strategies*: good practices include keeping clean, well ventilated hives (AFSSA, 2008), avoiding transfer of combs between colonies, and replacing storage and brood combs annually (Flores et al, 2005). Alternative compounds for fumigation of equipment against *Varroa* mites include lactic acid (Ritter and Akratanakul, 2006), formic acid (Amrine and Noel, 2006) or oxalic acid (Emsen and Dodologlu, 2009).
- *Using biological control agents*: bacteria inhibit fungal growth (Evans and Armstrong, 2006), essential oils inhibit bacterial and fungal growth (Bailac et al 2006 cited by Arbia & Babbay, 2011; Emsen & Dodologlu, 2009) and propolis has antibacterial properties (Bastos et al, 2008; Ivancajic et al, 2010).
- *Using genetic selection*: selecting bees for their natural resistance to pests or disease, particularly *Varroa* mite (Büchler et al, 2010), including hygienic behaviour (ability to detect and discard diseased larvae early to prevent spread of disease) (Spivak and Gilliam, 1998).
- *Monitoring hives and diseases*: monitoring is essential for the assessment and control of colony mortality. There is a wide variety of monitoring and surveillance systems for bee mortality and bee health in Europe (European Parliament, 2011; Hendrikx et al, 2009), and a corresponding need for improvement, harmonization and standardisation (OPERA, 2013).
- *Controlling the entry and spread of alien invasive species*: bee predators, pests and diseases have entered Europe via imports, and prevention will require continuation (and possibly strengthening) of border controls. Bee imports are now strictly regulated[176] and several bee pests have been made notifiable in the EU.[177] The European Parliament has called for a temporary ban on bee imports[178].
- *Encouraging research*: there is a need for research on bee pests, diseases and the effects of pesticides; mapping of factors to create a more precise model of bee exposure (Thompson, 2012); understanding the contribution of each factor and of multi-factorial interaction to bee decline; studying wild bees; and developing appropriate veterinary medicines.
- *Proposing training*: to increase awareness of bee diseases by beekeepers and veterinarians, and help them identify and cure pathogens more effectively (European Parliament, 2011). Some Member States such as the UK already offer specific beekeeper training for recognition of diseases (OPERA, 2013).

Agro-chemical factors affecting bees

Pesticide risks depend on the toxicity of agro-chemical active ingredients and bee exposure, so measures should target these factors. Some measures identified for biological factors are useful to mitigate agro-chemical factors, such as using sanitation strategies, monitoring and training. Additional specific good practices include:

- *Choosing areas where exposure to pesticides is limited*: beekeepers can install their hives in "pesticide-safe" areas. This requires mapping of these areas and beekeeper access to the maps.

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[176] All consignments of bees must conform to the general animal health conditions laid down in Council Directive 92/65/EC and the specific animal health conditions and accompanying health certificates in Commission Decision 2003/881/EC

[177] This means that all beekeepers who suspect their colonies are infested by the Small Hive Beetle or *Tropilaelaps* mites have to inform the appropriate authorities in their Member States under Commission Regulation (EC) No 1398/2003

[178] European Parliament Committee on Agriculture and Rural Development 25.10.2011. Report on honeybee health and the challenges of the beekeeping sector (2011/2108(INI)) RR\881743EN.doc

- *Encouraging farmers' good practices*: studies argue that honey bees are not harmed when best practices for pesticide application are implemented[179], and point to bad practices by farmers. Good pesticide use practices can be encouraged through information and training and bad practices discouraged through cross-compliance in the CAP.
- *Ensure the enforcement of pesticide regulations*: the Sustainable Use of Pesticides Directive requires the implementation of integrated pest management strategies (see Chapter 5).
- *Improving pesticide risk assessment*: the European Food Safety Authority has produced new guidelines for bee risk testing including semi-field and field test methods using four exposure routes, repeated exposure and larval exposure, including wild bee tests (EFSA, 2012b; EFSA, 2013d).

Environmental factors affecting bees

Hive handling and management

Hive management has a major impact on bee health, and good practices can significantly reduce bee mortality. Good practices include careful handling of hives and queens (AFSSA, 2008). Beekeepers must provide access to water and food of sufficient quality, with supplementary feeding if needed, in order to ensure good colony health (Arbia & Babbay, 2011). Migratory beekeeping requires particular attention as transport results in stress for colonies (OPERA, 2013). Good beekeeper management practice depends on their level of information, awareness and training. The creation of a guide to good beekeeping practice could be helpful. Since the beekeeping sector is very fragmented, the transfer of knowledge and information between stakeholders (beekeepers, farmers, public authorities, pharmaceutical industries) could be improved by measures such as (AFSSA, 2008):

- The creation of a technical institute that brings together inter-professional honey sector stakeholders and improves knowledge of bee mortality factors, prevention and mitigation measures (for example in France a scientific and technical institute for beekeeping[180] was created in 2009);
- The development of tools for collecting bee data with the help of beekeepers;
- The creation of a specific status for professional beekeepers and non-professional beekeepers.

Food resources of sufficient quantity and quality in the landscape

Farmers play an important role in providing food for bees through the cultivation of nectar and pollen-rich crops and grassland, though beekeepers also have a limited influence on access to food through moving colonies (OPERA, 2013). Public institutions and policy makers can encourage the provision of bee food resources through information, agri-environmental measures, etc (see Chapter 5 for key actions). Good practices include (AFSSA, 2008; Allen-Wardell et al, 1998; OPERA, 2013):

- Encourage diversification of crop rotation and mass-flowering crops, particularly legumes such as alfalfa and clover;
- Prevent early mowing of meadows before flowering;
- Limit mowing of roadsides, parks and public gardens;
- Encourage the maintenance of flowering meadows, fallow land, and flower-rich field edges through incentives;
- Prevent the loss of (semi-)natural areas to arable land, managed forest or urbanisation;
- Recommend winter soil cover plants that provide late-season food for pollinators[181].

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[179] For example applying appropriate pesticides at the adequate quantity at the right timing, avoiding application in windy conditions or at a certain distance from water bodies

[180] ITSAP-Institut de l'abeille, see www.itsap.asso.fr/asso/qui-sommes-nous.php

[181] Under the Nitrates Directive and/or cross-compliance rules, countries may require the partial or total covering of arable land during the period of leaching risks (in winter). Each Member State defines the period of

Preservation and maintenance of bee habitats

Farmers participate in the preservation of bee habitats, especially of wild species, through their role in the maintenance of landscape features. In particular, they can prevent the destruction of farmland features such as hedges, field margins, and river banks, and maintain and plant hedges with indigenous species beneficial to pollinators (AFSSA, 2008; OPERA, 2013). Public institutions and policy makers can encourage such practices (see above).

Other factors affecting bees

Efforts to mitigate climate change must be continued, in order to avoid the most critical possible impacts on pollinators. Measures to reduce other factors may also increase the resilience of bees, although the current level of knowledge is often insufficient to recommend good practices other than avoidance or preventative measures where possible.

9.7 What is needed to reverse pollinator decline in Europe?

The loss of pollinators in Europe is having a proven economic impact on food production and an ecological impact on wild plant species. Our **dependency on both honeybees and wild pollinators** for a nutritionally diverse and balanced food supply is high.

The causes of honeybee decline are multi-factorial, including the influence of pests, agricultural practices and beekeeper practices, and interact with each other; the causes of wild bee declines are less investigated, but expected to be similar. This means a **range of measures** are needed, **requiring concerted actions** by public authorities, beekeepers, farmers, the pharmaceutical industry, and researchers. **The fact that no one factor seems to be the cause of bee decline should not be used as a reason for inaction.** Monitoring and reporting, and finding causes and solutions, is made more difficult because of the fragmentation of the beekeeper sector, and the fact that most beekeepers are non-professional. However, monitoring systems are now being implemented in most Member States, and significant new research programmes are underway.[182]

Whilst recognising that multiple factors require action, three specific actions are:

Increasing knowledge of the risks posed by neonicotinoids and other systemic pesticides

The recent European Food Safety Authority reports (EFSA, 2013a; EFSA, 2013b; EFSA, 2013e; EFSA, 2013f) show risks from these pesticides for bees, but also that information is still lacking for performing a full assessment.[183]

Breeding for Varroa resistance and improved availability of better treatment methods

Current control methods for Varroasis are failing due to resistance and their significant costs and side-effects on honey production and bee vitality. The genetic diversity of European honeybees is compromised due to narrow selection criteria and restricted queen bee breeding, but the remaining subspecies and ecotypes of honey bee in Europe still provide a genetically diverse landscape for selection of *Varroa* resistance.[184] It is important that disease resistance is bred multiply into locally adapted varieties, so as not to lose even more genetic diversity. However, disease mechanisms are

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risks and the list of permitted crops (example in France: http://www.herault.equipement.gouv.fr/4eme-programme-d-actions-directive-a1020.html).

[182] See for example BEEDOC http://www.bee-doc.eu/ STEP http://www.step-project.net/ and the COST action of the COLOSS network http://www.coloss.org/

[183] NB the EFSA reports provide detailed information that has not been reproduced in this report

[184] high survival rates in some local populations and significant variability in mite infestation levels between breeding lines demonstrate this (Büchler et al, 2010; Costa et al, 2012)

complex, as host-parasite interaction are dependent on environmental conditions and hive management techniques, and substantial research is still needed, including better mite treatment methods.

Increasing flower resources for pollinators in agricultural landscapes

Pollen and nectar resources in agricultural landscapes have declined significantly, as shown for example in the UK, and this is the primary factor limiting wild pollinator populations[185] (Carvell et al, 2006; Rouston & Goodell, 2010). A number of Member States are committing to national and regional action plans and programmes to increase 'bee-friendly' agricultural practices including the promotion of Integrated Pest Management (IPM) for reducing the impacts of pesticides on pollinators, and agri-environment measures for protection of semi-natural habitat patches in farmland and creation of field margins.[186] The scale of action needed across Europe's landscapes will become clearer as research results come out.

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[185] Nesting sites in undisturbed semi-natural vegetation patches are also important eg bare ground in field margins & hedge banks, mouse holes, drystone walls & terraces, tree cavities (Rouston and Goodell, 2010)

[186] Eg Welsh Assembly Draft Action Plan for Pollinators; French Plan de développement durable de l'apiculture; Denmark's National Stategy on Honey Bees 2009-2013

10 THE INTERACTIONS BETWEEN AGRICULTURE AND CLIMATE CHANGE, AND AGRICULTURE AND BIODIVERSITY: RECOMMENDED OPTIONS

As a result of inevitable population growth (possibly to 10 billion by 2050) and expected economic development it is clear that there will be rising demands for food and energy over the coming decades. Moreover this requirement for increased production will coincide with increasing climate change related threats to agriculture (which will probably outweigh opportunities in Europe) and therefore put pressure on agriculture to adapt to cope with these threats. At the same time, there is also the potential for agriculture to play its part in mitigating climate change by reducing its net greenhouse gas emissions, although some mitigation options may conflict with the goal of increasing agricultural production.

Furthermore, projected drivers of agricultural change suggest that biodiversity losses will continue due to the ongoing impacts of intensive agricultural practices, and especially in Eastern Europe due to intensification and specialisation in some areas (and abandonment of low-intensity biodiversity-rich farming systems in others). This will undermine the EU's ability to meet its nature conservation targets (and those of the Convention on Biological Diversity), and threaten the long-term sustainability of farming in some areas as a result of, for example, soil degradation, declines in pollinators and increased outbreaks of pests and diseases. Agriculture relies on good soil quality, pollination, and low pest and disease pressure. Also, the loss of components of biodiversity such as flowering weed populations and livestock genetic diversity has significant detrimental impacts on many related ecosystem services, including the loss of pollination services and honey production through the collapse of European honeybee populations, and the loss of adaptation potential through disappearing European plant and animal genetic resources for food and agriculture.

These interrelated challenges clearly lead to the conclusion that if agricultural production is to be increased through intensification then it has to be achieved sustainably, taking into account climate and biodiversity needs in the EU and elsewhere. Step changes in actions are therefore required to ensure rapid reductions in agricultural emissions of greenhouse gases, and effective agricultural adaption and biodiversity conservation in Europe. In this respect EU policies, including the CAP and other initiatives such the European Innovation Partnership (EIP) on agricultural productivity and sustainability, have key roles to play in increasing the scope, pace and effectiveness of actions. Such actions should include the application of legislation to avoid unsustainable practices and protect important ecosystems and their biodiversity, the provision of incentives to support beneficial practices and funding to stimulate research and the transfer of technological and non-technological innovation options, such as better soil and water management practices on farms. Private funded and market based measures may also contribute, but these may require an improved legal framework for private or public-private payments for ecosystem services in order to increase the use of the land for the delivery of 'public goods', such as biodiversity, the storage of greenhouse gases, or water storage and retention.

The following are some recommended priority options for sustainably increasing agricultural productivity whilst supporting key actions to facilitate agriculture related climate change adaptation and mitigation, and biodiversity conservation. These are based on a review of the implications of the interrelationships between climate change and agriculture, and between agriculture and biodiversity, and take into account the potential for using a range of innovative options to increase agricultural productivity on a sustainable basis.

1. Provide incentives for climate resilient and biodiversity-friendly farmland management

Promote actions that have benefits for climate change adaptation and mitigation and avoid significant biodiversity damage, and that may be taken up by farmers as a result of the economic benefits

- Help farmers identify and take appropriate actions to use water, soil and energy resources more efficiently.
- Public funding should help overcome barriers to action by farmers, through modest support to upfront investment costs and start-up costs where needed, particularly in the livestock sector where there are fewer direct productivity benefits.
- A climate dimension needs to be integrated into a range of CAP measures, including rural development programmes.

Strengthen the protection and management of semi-natural agricultural habitats and the economic viability of the farming systems that maintain them

- This requires a combination of support and enhanced investment in traditional management alongside the development of new approaches and adaptation to changing socio-economic conditions.
- Member States can use the new CAP framework to develop measures that assist High Nature Value farming in different ways, such as supporting the appropriate management of valuable semi-natural habitats on farmland; and less direct measures such as adding value to HNV farm produce to improve economic and social sustainability.
- Increase targeted support and advice to farming systems that maintain and restore Natura 2000 habitats and species, both within Natura 2000 sites and outside, especially where they buffer or connect Natura 2000 sites.

Develop policy measures that recognise the substantial ecosystem services supplied by semi-natural farmland and farming systems

- More explicitly link public support to the provision of ecosystem services that are not supported by economic markets (including carbon storage, water flow regulation and purification, cultural and recreational value), through ecosystem assessments, strategic multifunctional land use planning and management, payment for ecosystem services schemes and improved monitoring.

Provide well-designed, targeted and monitored agri-environment schemes on farmland that provide co-benefits for biodiversity and climate change adaptation

- Some actions require adapted soil and crop management, for example use of crop rotations, integrated weed and pest management, intercropping, conservation tillage, unfarmed flower-rich buffer strips, reduced livestock densities.
- Some limited areas may be taken out of highly productive use, such as the creation of areas of flower and seed resources on intensive arable land, the rewetting of peatlands, and the extensification of grassland.
- Many of the actions needed are more beneficial if they are planned and targeted at a scale larger than the individual farm, as is occurring in some Member States. The Rural Development Regulation contains a number of important supporting measures that can help encourage and pay for the necessary planning and targeting of long-term actions at a landscape scale by funding the creation of local partnerships, facilitators and advisors.

2. Constrain unsustainable practices through policy mechanisms

Ensure compliance with the Nitrates Directive and other EU legislation that reduces nitrogen emissions

- Better management of the nitrogen cycle on farmland is beneficial for both biodiversity, reducing GHG emissions, and water quality.
- The more consistent and rigorous implementation all over the EU would be helpful and would lead to more balanced fertilisation , combined with improved crop and manure management; low-protein animal feeding, combined with improved herd management; and ammonia emissions abatement measures, including improved manure application and storage.

Push for ambitious pesticide reduction targets and full implementation of integrated pest management

- Member States are currently failing to set ambitious pesticide reduction targets under the Sustainable Use of Pesticides Directive. Under the new CAP framework, Farm Advisory Services are now obliged to provide farmers with IPM advice.

Use CAP cross-compliance requirements to ensure protection and management of farmland elements that benefit biodiversity and climate change adaptation

- Ensure that Member States use the greater flexibility to set GAEC requirements in the new CAP cross-compliance regime so as to enhance protection and management of permanent grassland, riparian buffer strips, and farmland features, as well as water and nitrogen use efficiency.

3. Implement options to maximise climate resilient agriculture that benefits biodiversity through the CAP and through the new EU-level mechanisms to support innovation

Ensure that innovation investment targets areas of greatest potential and knowledge gaps, combining yield improvement with sustainability objectives

- Existing streams of yield innovation need to be better integrated with innovative practices that reduce the damaging environmental effects of high yielding agriculture. Innovation should focus on the sustainability and efficiency of contemporary systems across the spectrum in both high yielding and extensive systems.
- Other research priorities include methods to improve yields in organic farming systems; and options to refine and turn into commercial propositions novel production systems that provide the greatest co-benefits for climate change mitigation and adaptation, resource efficiency, and biodiversity conservation such as precision farming and paludiculture on rewetted peatlands, and other beneficial approaches such as some forms of agroforestry. This includes the targeted creation of green infrastructure to restore connectivity and ecosystem services in agricultural landscapes.

Environmental safeguards, research and evaluation of the possible negative impacts of new technologies

- Innovations are not inherently more sustainable or biodiversity-friendly, and their potential impacts need careful research and evaluation, with environmental safeguards associated with any incentives for use.
- For example: the promotion of advanced biofuels from wastes and residues requires appropriate environmental safeguards to prevent harmful indirect effects, such as those related to the displacement of straw and other crop residues that are needed to retain soil carbon in fields.

- GM crops can be beneficial or detrimental to biodiversity depending on their traits and management. A relatively narrow stock of GM crops and traits is currently used globally, while a wide range of new generation traits and crops for potential future use is being developed. However, it is too early to conclude whether these crops would have beneficial or detrimental biodiversity impacts in Europe if they were to be authorised for deliberate release. It is also important to bear in mind that a suite of new plant breeding techniques is now available, most of which have the potential to produce biologically novel crops and cropping systems[187]; consequently their potential environmental impacts should also be carefully assessed.

Ensure Europe's genetic resources for food and agriculture are better used and conserved

- Give greater prominence in the Horizon 2020 programme to research on plant genetic resources for a more biodiverse crop base better adapted to climate change.
- Establish a more coordinated European Genebank Integrated System that provides crop breeders with greater actual or predictive characterisation and evaluation of conserved plant genetic resources, and more available online information linked with better mutual cooperation between gene banks.
- Establish a European network of *in situ* genetic reserves for crop wild relatives and on-farm conservation sites for landraces, and support measures for farmers to use and conserve genetic diversity on-farm.
- Stimulate the use of plant genetic resources and the marketing of a greater variety of crops by enacting legislation that systematically fosters PGRFA diversity in each link of the plant breeding cycle.

Provide increased direct funding for research on tackling the multiple factors causing honeybee losses and wild pollinator decline

- Public funding is urgently required to address the multiple factors causing European honeybee losses. The fact that no one factor seems to be the cause of bee decline should not be used as a reason for inaction. Because the interactive effects can cause greater impacts than each factor in isolation, an integrated response with concerted actions by public authorities, beekeepers, farmers, the pharmaceutical industry, and researchers is needed.

4. Reduce the external impacts of European agriculture and biofuel imports

Increase the EU's efforts to reducing global biodiversity loss through actions to reduce the environmental footprint of the EU's food, feed and biofuel imports, and to encourage consumer demand for environmentally sustainable food

- Increase the EU's active engagement in international initiatives to develop global environmental principles for food, fibre and energy production.
- Encourage and support effective voluntary and private environmental certification schemes and products.
- Encourage certification schemes with effective environmental sustainability standards for biofuel imports, and increase efforts to reduce the indirect impacts of biofuel related land use change, because these are believed to be considerably more important than direct

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[187] Biological novelty that deviates substantially (genetically, biochemically, and physiologically as well as in ethical and regulatory terms, and in public perception) from what classical, selection-based breeding has achieved, and which therefore poses a new scale of potential risk.

impacts and are not monitored let alone regulated by the EU directive's sustainability scheme.

- Increase education and awareness campaigns to reduce unhealthy and unsustainable meat consumption levels, whilst promoting the livestock products from European High Nature Value farms.
- Take steps to increase domestic production of animal feed that also brings benefits for biodiversity and adaptation to climate change, such as legume crop systems that do not require high levels of pesticide use.
- Fund research on the potential biodiversity trade-offs of increasing or constraining (through environmental measures) agricultural production in the EU with respect to EU and global biodiversity impacts, considering also the possible impacts of land sparing versus land sharing strategies in the EU and elsewhere.

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This document is the final report of the STOA study ‘Technology options for feeding 10 billion people - Interactions between climate change & agriculture and between biodiversity & agriculture’.

Annexes, a ‘study summary’ and an ‘options brief’ related to this study are also available.

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