4.1 Current systems and future scenarios for food production activities

4.1.1 Introduction

Food systems consist of the following subsequent activities: production, processing, packaging and distributing, retailing and consumption. This paper describes the key current food production activities in the European Union, the main drivers with respect to evolution of those systems in the coming decades and finishes off with an initial outlook on how those systems might evolve under different scenarios. The latter is crucial to identify a research agenda taking into account uncertainties with respect to drivers and factors which are largely exogenous to the food production part of the system.

Three questions have been identified in the course of the process of the ESF/COST Forward Look that frame the analysis and outlook of food production systems:

- Will there be substantial changes in agricultural resource use in Europe as a consequence of intensified production systems and policies on energy security/diversity?
- Will changes in global food markets (resulting e.g. from industrialisation in China, India and South America, energy security policies in the USA, and climate change in sub-Saharan Africa) result in changed production systems in Europe?
- Will new technologies be adopted in Europe or elsewhere that result in "best" methods of food production, enhance environmental management and healthy foods?

In the following sections these questions are not addressed one by one. Instead, we provide information about present systems that forms a basis for answers to the three questions. The information is structured according to the three questions, but the information provided allows analysis of a broader set of questions. We preferred this set-up as there is overlap in information needed to answer the three questions, and we also think the selection of the three questions is somewhat subjective and arbitrary. We hope the information provided in this paper is somewhat robust and useful also for addressing slightly different questions. In Section 4.1.5 we make a start in trying to address the questions, though answering them is beyond the scope of this paper and would be speculative by definition, given the uncertainties surrounding the exogenous drivers.

The paper starts with a short account of the methodology followed to describe current production systems in Europe. Section 4.1.3 presents empirical and experimental information about key attributes and indicators of agricultural production systems which are necessary to address the three questions listed above. Section 4.1.4 provides an overview of important drivers which are largely exogenous to agricultural production systems, but affect their evolution in the decades to come. Section 4.1.5 makes an initial attempt to relate the information on agricultural production provided in Section 4.1.3 to the drivers presented in Section 4.1.4, using the three questions. Section 4.1.6 presents possible implications, from a production perspective, of four scenarios which have been developed in the ESF/COST Forward Look and which underpin the process, to come to a robust research agenda, of which a first version is presented in the final Section 4.1.7.

4.1.2 Methodology for describing and analysing food production systems in the European Union

4.1.2.1 Indicators

The analysis of the three questions listed in the Introduction, or related questions, requires information on a range of characteristics of agricultural systems. For this purpose we will use so-called "indicators" of agricultural systems, of their sustainability and their contribution to sustainable development at large. Indicators are defined as "parameters, or values derived from parameters, which provide information about the state of a phenomenon/environment/area with significance extending beyond that directly associated with a parameter value" (OECD, 1993). Indicators can be used to help monitor and assess policies and programmes (including R&D) and to provide contextual information, to identify new agri-environmental issues, to assist in targeting programmes addressing such issues and to understand linkages between agricultural systems and other economic sectors and ecosystems (after EC, 2000).

For the analysis of the three questions above, in the light of the purpose of this Outlook exercise, we need indicators reflecting the economic, environmental and social aspects of sustainability of agricultural production systems and of the contributions of such systems to sustainable development of society at large. We propose that only this broad perspective allows a sufficient holistic analysis of the three questions and, importantly, provides flexibility as to the questions to be addressed. The analysis keeps relevance (i.e., the indicators can still be used) when the precise questions at stake change.

Indicators reflecting the status and performance of agricultural systems and their relationship with the environment are increasingly used in the policy domain and agro-industries. Analyses using established indicators will benefit from "recognition" and "a common ground". For us this was a reason to make use of existing indicators, if possible and relevant, in particular those of the European Commission and the recently-established list of agri-environmental indicators by the European Environmental Agency (EEA, 2005). Obviously, these lists of indicators were developed for a particular purpose, with limitations for our aim. In particular, we argue that the degree of agronomic detail in the indicators, allowing analysis of agricultural management and resource-use efficiency, is inadequate. We have therefore extended our analysis to include indicators reflecting resource-use efficiency and identification of limitations and shortcomings of current production systems and technologies. These indicators also provide a handle to identify new systems and technologies in the ESF/COST Forward Look phase.

The EEA listed criteria used to evaluate the usefulness of individual indicators. These criteria include: political relevance, responsiveness to actions, analytical soundness, data availability and measurability, ease of interpretation and cost effectiveness in relation to information derived from the indicator (EEA, 2005).

In our assessment of the performance of agricultural systems and how this evolves, we need to consider some (indicators for) external factors that are subject to change and may affect agricultural systems, especially those reflecting economic growth, technological development, climate change, energy prices, international agreements and policy development.

4.1.2.2 Spatial and temporal detail

Indicators used for policy evaluation (ex-post) or assessment (ex-ante) in the European Union generally use a spatial detail at NUTS2 (administrative) level or at member state level. Indicators derived from the so-called Farm Accountancy Data Network (FADN) of DG Agriculture can be presented only at a slightly coarser scale, i.e. HARM level, which is a level between NUTS2 and NUTS1. Pan-EU information on agricultural management is scarce and will not allow greater spatial detail than HARM regions for two reasons: (1) data may not be available; and (2) if available, disclosure rules do not allow their presentation. For the purpose of this paper, we however need some more location- and case-specific information on agricultural production options. We therefore provide indicators at three different spatial levels: (1) member state level; (2) NUTS2 level within EU-27; (3) examples of specific location production systems reflecting the different biophysical and socioeconomic conditions in the EU. If possible, we use so-called existing typologies, such that specific examples have some statistical representation. Typologies for farms are based on those developed within the EU project SEAMLESS (Van Ittersum et al., 2008).

Data availability allows a fairly complete picture for the former EU-15, but less for the 10 countries which joined the EC in 2005 and even less so for Bulgaria and Romania which entered the EU in 2007. In this paper, EU-15 refers to member states of the EU until 2005; EU-10 to the ten new member states as per 2005. In a few cases data of Norway and Switzerland are part of the analysis. In some instances we cluster European countries following the zonation used by Olesen and Bindi (2002) (Figure 4.1).

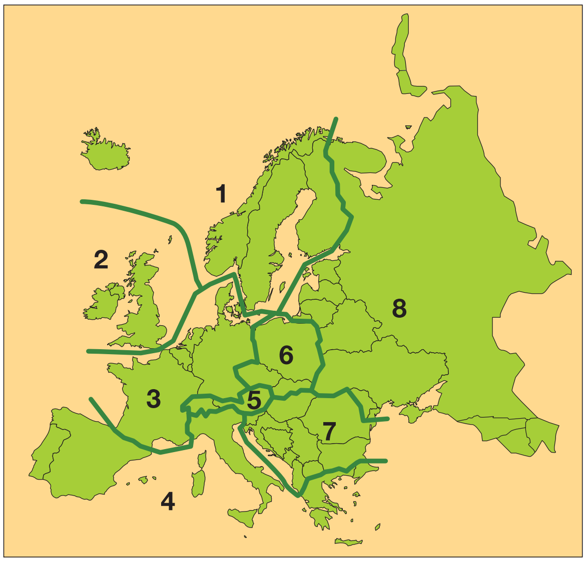


Figure 4.1. Agricultural regions in Europe. For names, see Table 4.2; for countries see Appendix 1. (Source: Olesen and Bindi, 2002)

In Section 4.1.3.2 indicators are presented, mainly to reflect the current situation, implying indicators with the most recently available information (generally dated 2003-2005 or older). Wherever useful and available, we also provide some information on trends, and an indication of what may be achieved with already available ("on-the-shelf") knowledge, systems, technologies and information which is currently not in widespread use. The indicators relate to the three questions, as presented in Table 4.1 (next page). In Section 4.1.5 we try to tentatively answer the three questions.

4.1.2.3 Comprehensiveness

It is by no means possible to provide a full picture of the EU's agricultural systems for two reasons: (1) information is largely lacking; (2) the paper would become a bulky report with lots of information and cumbersome analysis. The choice of indicators and information presented reflects the information available and includes subjectivity of the authors to get to an analysis, and a basis for an outlook of EU's agricultural systems.

4.1 Current systems and future scenarios for food production activities

Table 4.1. Relation between indicators presented in Section 4.1.3.2 and the three questions related to future food production

	Question 1	Question 2	Question 3
Resource use (per ha) • land • energy • nutrients • water	×	×	
Resource-use efficiency (per kg or € product)	×	×	
Intensity of production • output intensity • input intensity	×	×	
Yield gap	×	×	
Competitiveness • farm structure • labour productivity • cost price		×	×
Climate change • climate change • adaptability		×	
Use of GM crops			×

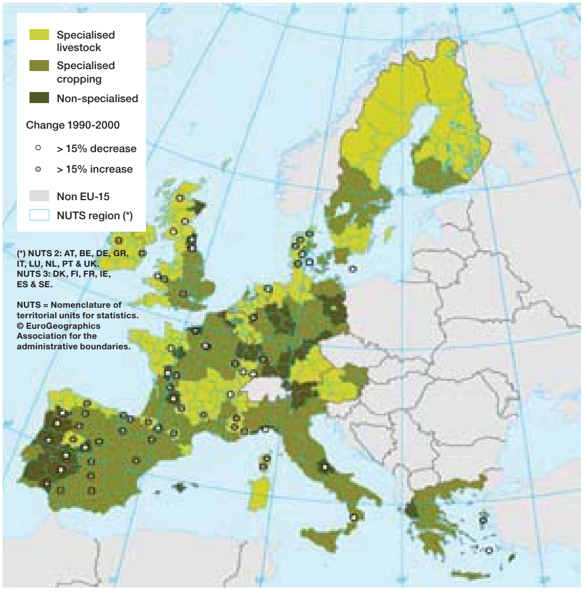


Figure 4.2. Regional distribution of dominant farm types by specialisation and the trend 1990-2000. "Non-specialised" includes non-specialised livestock, non-specialised cropping and non-specialised cropping/livestock. Information on trends in the regions of Finland, Sweden, Austria and Germany is not available. (Source: EEA, 2005; Eurostat)

Table 4.2. Land use and output per region in Europe based on EU statistics till 2005. For country-level data, see Appendix 1. UAA = Utilised Agricultural Area. (Source: Eurostat, 2007)

Region		Agricultural area (2004)		% of agricultural area (different years/period)						Output (2004)		
Number	Name	Agricultural area (1000 Ha)	Agricultural area of total (%)	Arable land[1] (2005)	Permanent crops[1] (2005)	Permanent pasture[1] (2005)	Horti-culture[2] (2001-2004)	Irrigable area[3] (2005)	Organic farming (2003)	Agricultural industry Mio euro	% of the EU-27 (%)	Euro per ha UAA
1	Nordic	5407	7	93	0	7	0.5	4.4	10.5	4233	2.6	1710
2	British Isles	21377	68	38	0	62	0.7	1.0	3.4	6169	8.9	1621
3	Western	52765	52	66	3	31	1.6	10.0	2.9	6858	41.7	2748
4	Mediterranean	46355	45	51	21	27	10.9	21.6	4.6	595	31.5	2280
5	Alpine	3254	39	42	2	56	0.7	3.7	10.1	5804	1.7	1779
6	North Eastern	21867	50	75	2	22	2.9	1.6	1.6	3623	5.7	927
7	South Eastern	26008	56	72	3	24	3.6	4.1	0.7	3464	7.1	953
8	Baltic	5017	29	66	1	32	2.0	0.1	1.8	473	0.7	474
	EU-27	182048	42	61	7	32	4.3		3.4	347573	100.0	1916

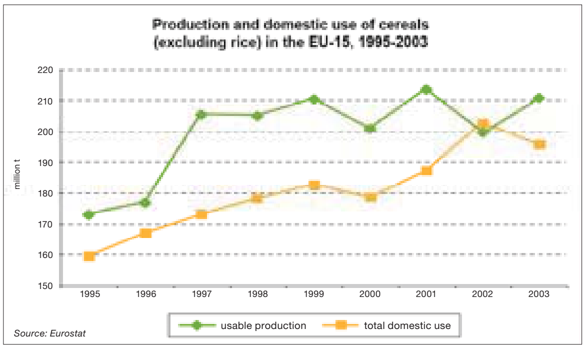
[1] Cyprus, Bulgaria, Romania: 2003 data — [2] 3 to 4 year average — [3] some countries: no data

4.1.3 Current agricultural production systems in the EU

4.1.3.1 Initial characterisation of agricultural production in the EU

The EU-27 uses 182 of its 433 million ha for agriculture, which amounts to 42% (Table 4.2). On this area 348 billion € gross value is produced. The EU-25 counts close to 10 million farms (ca. 5% of the total employment, varying from 1.2% in the UK to 18.7% in Lithuania); Bulgaria and Romania add another ca. 5 million farms. For the EU-25 the gross production per farm is ca. 31 k€. The EU-15 was already the largest exporting trade block globally with respect to agricultural products (2004), taking ca. 24% of the global agricultural exports; the EU-10 added another ca. 4% to this share. The EU is also the largest importer of agricultural goods (the EU-15 takes 23% of the global imports). The share of agricultural production in GDP is 1.6%.

Table 4.2 provides some values of the regional distribution of agriculture, in terms of area and output. Of the agricultural area 61% is in use for arable farming, 32% for permanent grassland and 7% for perennials. Some spatial differentiation between arable and livestock farming can be observed in the EU-15 (Figure 4.2). Dominant crops are wheat, barley, maize, potato and sugar beet (Table 4.3). Horticulture under glass amounts to 113.6 kha (EU-25), of which Spain, Italy and the Netherlands take 84.8 kha (LEI, 2005). Evidently, agriculture is a very important sector in the EU, policy-wise. An annual 43 billion €, ca. 34% of the budget of the EU, are spent on agricultural policies; in addition, part of the 12.4 billion € for rural development is used directly or indirectly for the agricultural sector. Partly due to decreases in price subsidies, production of cereals now almost matches total use in the EU; for meat, production is still much higher than internal consumption (Figure 4.3).



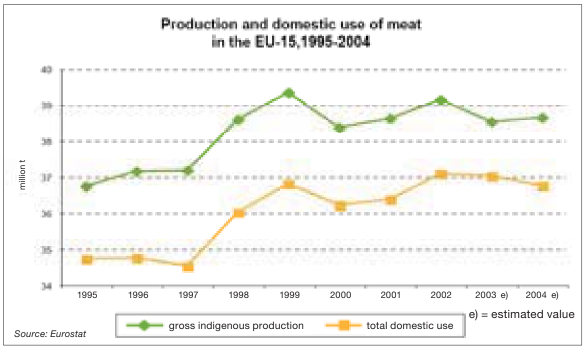


Figure 4.3. Production and domestic use of cereals (excluding rice) in the EU-15, 1995-2003 (top) and of meat in the EU-15, 1995-2004 (bottom) (Source: Eurostat 2007)

Agriculture is associated with a range of environmental externalities, including water use and water pollution with nutrients and pesticides, soil degradation, greenhouse gas emissions, air quality and effects on landscape quality and biodiversity.

Table 4.3. Area under arable crops (1 000 ha), by crop, 2004.
For country-level data, see Appendix 2. (Source: Eurostat, 2007; Eurostat, 2006a; Eurostat, 2006c)

	Region	Wheat	Rye	Barley	Oats	Corn	Potatoes	Sugar beet	Silage maize
1	Nordic	629	51	925	552	0	58	78	5
2	British Isles	2097	4	1189	142	0	160	184	117
3	Western	9371	691	4403	416	2324	724	1059	3274
4	Mediterranean	5523	133	3580	724	2060	263	361	471
5	Alpine, Austria	290	46	191	30	179	22	45	76
6	North Eastern	3543	1642	1707	604	647	773	398	598
7	South Eastern	4541	77	1100	322	4902	335	89	194
8	Baltic	597	107	559	141	1	138	37	17
	EU-27	26591	2750	13652	2930	10116	2472	2252	4751

Data for oats: Estonia, UK and Cyprus — potatoes: France and Cyprus — sugar beet: Latvia are from previous year

4.1 Current systems and future scenarios for food production activities

4.1.3.2 Analysis of agricultural production systems in the EU

(a) Resource use and resource-use efficiency of agricultural production

Land

Agriculture uses more than 40% of the land area and is the prime user of land (Table 4.2). In terms of land use, arable crops and permanent grassland are the dominant types of agriculture. Analysing land use efficiency is equivalent to assessing productivity (yields per hectare). Figure 4.4 and Table 4.4 show the dramatic increase in agricultural productivity for several crops; note that yields in Figure 4.4a are expressed on a fresh weight basis, which gives the impression that yields of cereals, having a high dry matter content, have increased relatively little. However, expressed on a dry matter basis this would not be the case. Figure 4.4b shows that increases vary substantially across countries. In Figure 4.5 wheat yields are used as an indicator for productivity of arable farming. Evidently there is an enormous variation across the EU in terms of land productivity. The highest productivity is found in NW Europe and the lowest in Mediterranean regions. Variation is also high within relatively homogeneous biophysical conditions. For example, yield variation across different farms in NE Italy was 13-122 GJ per ha of rape and 14-124 GJ per ha for sunflower (Venturi and Venturi, 2003). Table 4.5 provides an overview of productivity of wheat and milk across the EU-27. Milk productivity seems to vary less than wheat productivity, but it is likely that when milk productivity is expressed on a hectare basis, the variation would be quite similar.

Intensity of agriculture

Intensity of farming can be expressed in the amount of inputs per hectare or the amount of output per hectare. The two indicators do not lead to the same conclusions with respect to intensity of a region, though relationships are evident (compare Figures 4.6 and 4.7). High output intensities are associated with high fertiliser and crop protection use, low share of fallow, high stocking density and high milk yields per livestock unit (Tables 4.6 and 4.7).

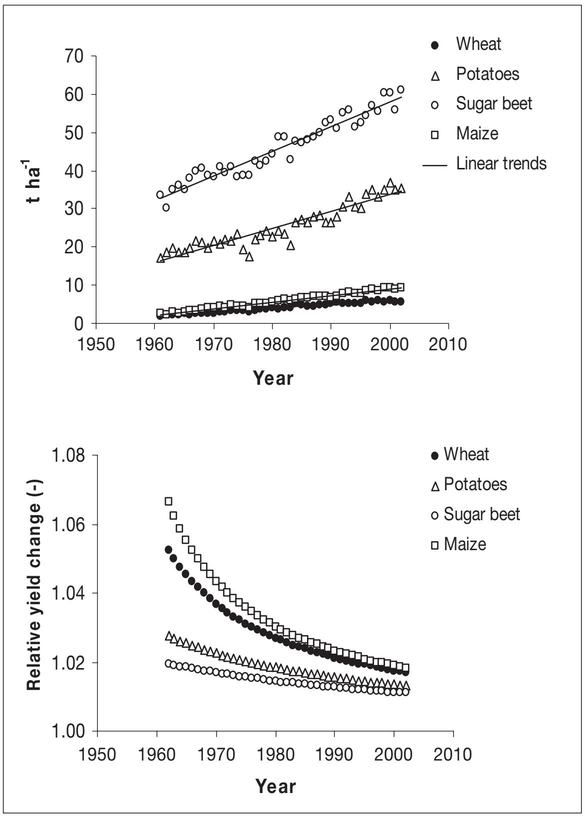


Figure 4.4a. Observed (FAO, 2003) (a) yields and (b) relative yield changes for selected crops in EU-15 + Norway and Switzerland (Source: Ewert et al., 2005)

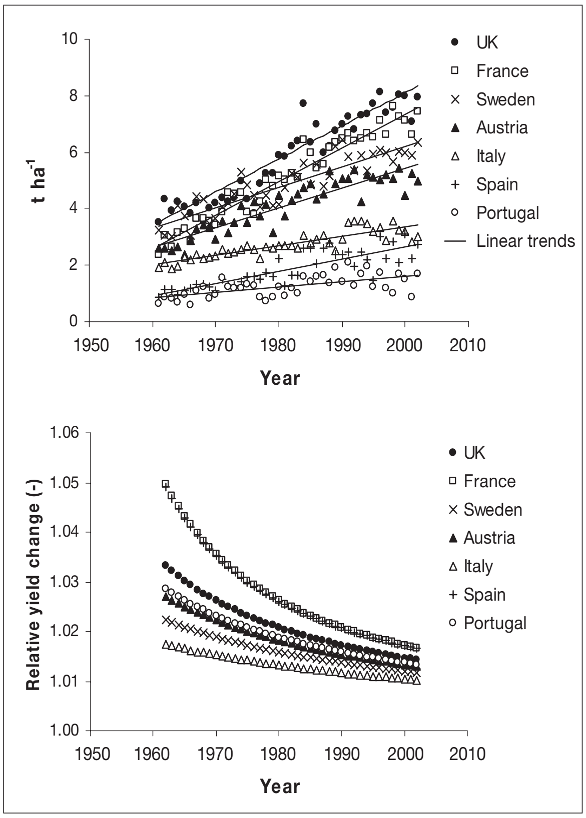


Figure 4.4b. Observed (FAO, 2003) (a) grain yields and (b) relative yield changes of wheat in selected countries in Europe (Source: Ewert et al., 2005)

Table 4.4. Land use and selected yield statistics for major European crops. Rates of yield change are in 0.1t ha^{-1} yr^{-1} (Source: Ewert et al., 2005)

Crop	Harvested area		Yield average (t ha^{-1})		Rate of yield change[a] (t ha^{-1} year^{-1})	Relative yield change[b] (%)
	ha (×10^{6})	% of arable area	1961-1970	1991-2000		
Cereals (all)	37.8	51	2.6	5.27	0.88	1.6
Wheat	18	24	2.4	5.54	1.02	1.74
Barley	10.7	15	2.9	4.29	0.47	1.06
Oats	1.9	3	2.37	3.28	0.29	0.84
Rye	1.2	2	n.a.	4.17	0.96[c]	2.05
Triticale	1.0	1	n.a.	4.87	1.45[d]	2.56
Maize	4.2	6	3.19	8.32	1.69	1.89
Potatoes	1.3	2	19.65	32.64	4.4	134
Sugar beets	1.9	3	36.53	55.31	6.43	1.1
Rapeseed	3.0	4	1.92	2.88	0.34	1.1
Sunflower	1.9	3	1.17	1.54	0.18	0.9
Sum/average	45.9	53	–	–	–	1.51[e]

Scientific name of selected crops are *Trilicum aeslivum* (wheat), *Hordeum vulgare* (harley), *Avelia Saliva* (oats), *Secak cereak* (rye), X *Trilicosecale* (triticale), *Zea mays* (maize), *Solanum tuberosum* (potatoes), *Bera vulgaris* (sugar beets), *Brassica napus* (rapeseed), *Helianthus annuus* (sunflower). n.a.: not available.

[a] Calculated from measured yields between 1961 and 2002.
[b] Calculated from estimated yields for 1999 and 2000 (see Eqs. [1] and [2]).
[c] Based on available data from 1979 to 2002.
[d] Based on available data from 1986 to 2002.
[e] Value refers to area weighted average.

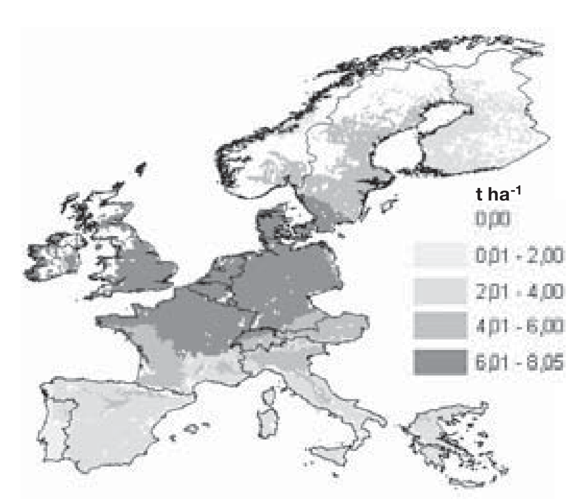


Figure 4.5. Wheat yields in EU-15 in 2000, based on Eurostat (Source: Ewert et al., 2005)

Region		Wheat productivity (2004-2006)	Cows' milk collected (2004-2005)
		ton per ha per region	ton milk per cow per year
1	Nordic	5.02	7.93
2	British Isles	8.03	6.15
3	Western	7.15	6.60
4	Mediterranean	3.23	5.92
5	Alpine	5.17	5.82
6	North Eastern	4.19	4.61
7	South Eastern	3.53	3.79
8	Baltic	3.20	4.45
	EU-27	5.26	5.88
	EU-15	5.98	6.43

Table 4.5. Agricultural output in different regions of Europe based on EU statistics. (Source: Eurostat)

Table 4.6. Selected farm management indicators for field crops farms (EU farm typology types 1 and 6) and for different combinations of the land use and intensity dimensions with which the EU farm typology has been extended. UAA = Utilised Agricultural Area. (Source: Andersen et al. 2007)

	Share of UAA (%)	Share of farms (%)	Wheat Yield (kilo/ha)	Barley Yield (kilo/ha)	Fertiliser use (Euro/ha)	Crop protection use (Euro/ha)	Set aside & Fallow/ UAA (%)
All field crop farms	100	100	6218	4312	99	92	10
Intensity							
Low-intensity	25	18	3455	3048	50	22	18
Medium-intensity	69	66	6701	5168	108	103	7
High-intensity	5	16	7181	5252	216	275	4
Land Use							
Arable/Cereal	50	44	6403	4815	107	96	6
Arable/Fallow	24	16	4972	3324	65	45	25
Arable/Specialised crops	10	18	7689	5690	149	180	4
Arable/Others	16	22	6308	4543	94	90	5
Intensity and land use							
Low-intensity cereals	8	7	3343	3123	64	30	7
Medium-intensity cereals	41	35	6697	5337	113	107	6
High-intensity cereals	1	2	7141	5470	162	180	5

Table 4.7. Selected farm management indicators for dairy cattle farms (EU farm typology type 41) and for different combinations of the land use and intensity dimensions with which the EU farm typology has been extended. UAA = Utilised Agricultural Area; LU = Livestock Unit. (Source: Andersen et al. 2007)

	Share of UAA (%)	Share of farms (%)	Stocking density (LU/ha)	Fertiliser use (Euro/ha)	Crop protection use (Euro/ha)	Milk yield (kilo/LU)	Permanent grass/ UAA (%)	Rough grass/ UAA (%)
All dairy cattle farms	100	100	1.7	82	24	6408	45	2
Intensity								
Low-intensity	2	1	0.4	13	1	3491	40	28
Medium-intensity	73	64	1.3	78	21	5952	46	2
High-intensity	25	36	2.9	98	32	6939	44	0
Land use								
Dairy cattle/ Land independent	1	3	7.7	133	63	6327	15	1
Dairy cattle/ Permanent grass	41	37	1.6	77	14	6229	74	5
Dairy cattle/ Temporary grass	16	15	1.4	76	19	6483	9	1
Dairy cattle/Others	42	45	1.7	87	34	6555	32	1
Intensity and land use								
Low-intensity permanent grassland	1	1	0.5	15	1	3815	50	39
Medium-intensity permanent grassland	31	26	1.4	74	13	5667	74	5
High-intensity permanent grassland	9	11	2.5	99	19	7176	77	1

Source: FADN-CCE-2003 DG Agriculture/A-3; SEAMLESS adaptation.

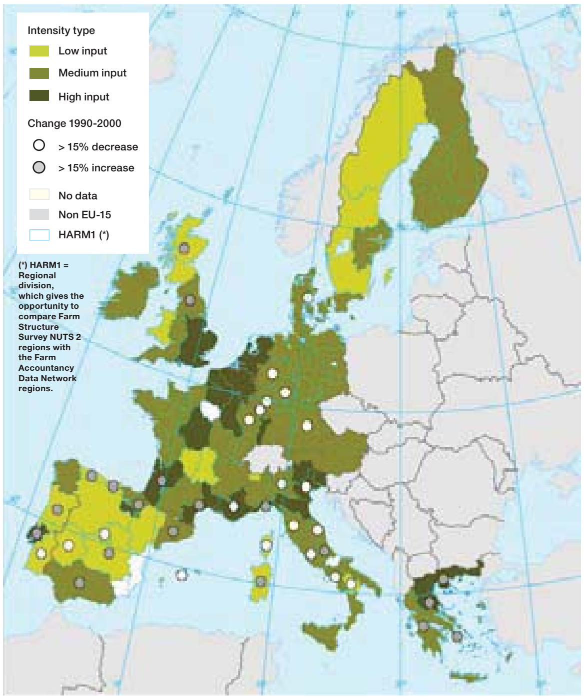


Figure 4.6. Regional importance of low-input, medium-input farming and the trend 1990-2000 (Source: EEA, FADN, Eurostat, LEI)

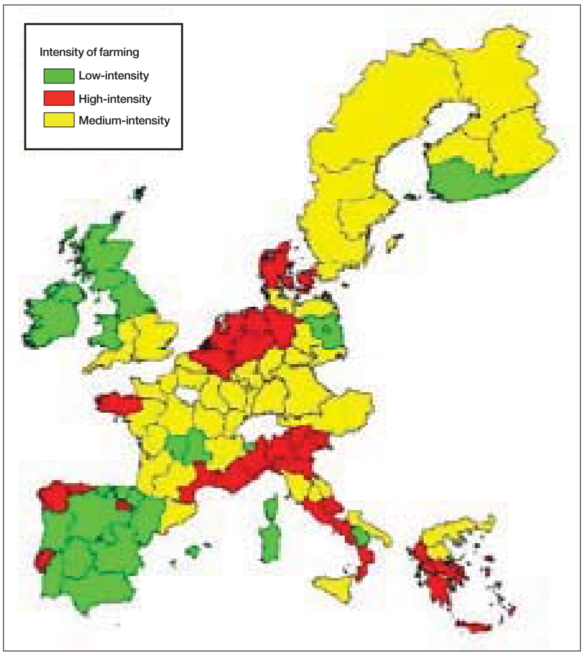


Figure 4.7. Regions where low- or high-intensity (based on outputs) farms manage more than 25% of the agricultural area (the highest shown if overlap) and with the remaining regions indicated as medium-intensity (Source: FADN-CCE-2003 DG Agriculture/A-3; SEAMLESS adaptation, Andersen et al. 2007)

At regional level there is a positive relation between the intensity of farming and the number of livestock units in a region (compare Figures 4.6 and 4.7). There are indications that input use per hectare has decreased somewhat since 1990, probably mostly on the intensive farms (i.e., lower nutrient and pesticide input), which points to increased use efficiencies of inputs.

Organic agriculture is a specific form of extensive agriculture. Its area has increased substantially over the past decade; in the EU-15 it increased from 1.8% in 1998 to 4.0% in 2003, totalling 5.3 million ha (EEA, 2005; EC, 2005), which is in relative terms still fairly small. At EU-25 level the share was 3.6% in 2003. Another category of agricultural land which is usually managed in an extensive way is "high nature value" (HNV) farmland; these are more extensive than organic agriculture. These are the farmland areas which contain the most biodiversity – rich areas of farmland. The estimated share of HNV farmland is 15-25% of the total agricultural area in the EU-15 (EEA, 2004; EEA, 2005).

When analysing intensity levels of farming, it is relevant to consider synergies between inputs. Figure 4.8 illustrates this principle for water and other inputs: irrigation is much more effective (also per drop of water) when other input levels have been optimised (De Wit, 1992).

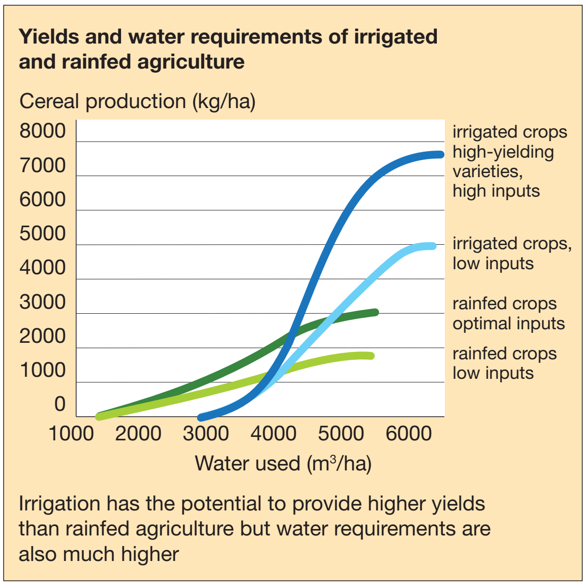


Figure 4.8. Synergy between inputs: well-managed crops use water more efficiently (Source: FAO, 2007)

Energy

In terms of energy use, agriculture is only a small economic sector: both in Europe and the USA it accounts for only ca. 2.4 and 1.1%, respectively, of the total energy use (Schenkel, 2006; Schnepf, 2004). This refers to the direct use only, and excludes consumption through fertiliser and pesticide production (and production of machinery and building). Inclusion of these energy sources increases energy use by about 50% (EEA, 2005); this still does not make agriculture a prime energy consumer. Energy use of agriculture in the EU-15 ranges between 0.5 and 6.5% of total energy use (OECD, 2007; EEA, 2005). Major sources of direct energy use are the use of oil products and electricity for heating and fuel for farm machinery. As a result of this, agricultural sectors differ a lot in energy consumption. Protected horticulture in countries such as the Netherlands is the dominant energy user, followed by intensive livestock sectors. Even though greenhouse horticulture in the Netherlands uses just a small fraction of the total area (0.5%), it accounts for 76% of the direct energy use in agriculture. Evidently, this shows the scope for energy-saving or efficiency-increasing measures in different agricultural sectors. Developments in, for instance, the Dutch horticultural sector demonstrate that much has been and can be gained; despite the fact that the area of horticulture under glass grew by 4% in the period 1995-2003, the energy use decreased by 10% (LEI, 2005). Figure 4.9 shows an even more drastic increase in efficiency in the 1980s.

Apart from great differences in energy use across sectors, energy use and energy-use efficiency differs between different production methods within a sector (e.g., intensive versus extensive systems; Table 4.8) and within a population of farms using similar types of systems. A study comparing sugar beet systems in the UK (Tzilivakis et al., 2005b) showed that different production systems (differing in soil type, production intensity and conventional versus organic) vary in energy use between 15.6 and 26.8 GJ/ha, and 0.26 and 0.54 GJ/ton of sugar beet. Generally, organic production systems use much less energy per hectare, but per ton of product the figures of organic and conventional systems are much closer, though organic still slightly outperforms conventional systems in most cases (Bailey et al., 2003; Tzilivakis et al., 2005b; Tzilivakis et al., 2005a; Gronroos et al., 2006). This is mostly due to the fact that organic systems do not use chemical fertiliser, which requires a lot of energy for its manufacturing (40-50 MJ/kg N – Tzilivakis et al., 2005a; Meul et al., 2007).

Variation in energy use (and efficiency) across farms within similar systems is very high. For instance, the top

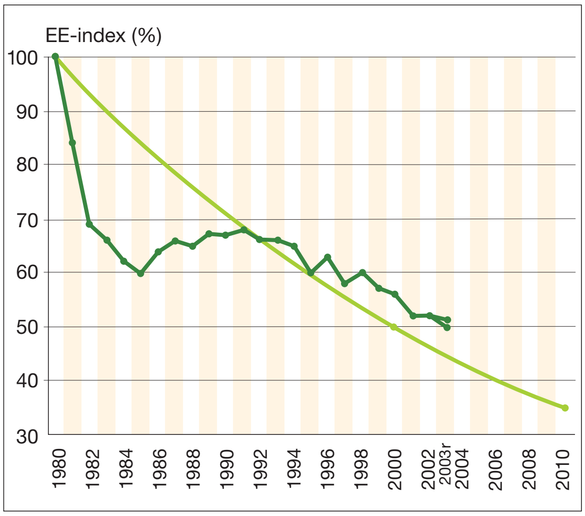


Figure 4.9. The Energy Efficiency (EE) index in Dutch greenhouse horticulture (corrected for temperature) in the period 1980-2003. The EE-index is defined as the primary fuel use per unit of product, using the 1980 value as 100%. The smooth line indicates the EE-index policy targets for the EE-index.
(Source: LEI and Van der Knijff et al. 2004)

Table 4.8. Examples of energy use in different agricultural sectors and production methods

Type of farming	Unit of Energy use	Conventional	Integrated	Organic	Source
Arable: rotation	GJ/ha	21.0			(Meul et al., 2007)
Arable: rotation	GJ/ha	14.7	13.4		(Bailey et al., 2003)
Arable: rotation	GJ/ton	Ca. 2.0	Ca. 2.0		(Bailey et al., 2003)
Arable: sugar beet	GJ/ha	23.8		19.0	(Tzilivakis et al., 2005b)
Arable: sugar beet	GJ/ton	0.48		0.42	(Tzilivakis et al., 2005b)
Pigs	GJ/FPE*	3.6			(Meul et al., 2007)
Dairy-milk	GJ/ha	36.4			(Meul et al., 2007)
	GJ/1 000 l	3.7			(Meul et al., 2007)
	GJ/1 000 l	6.4		4.4	(Gronroos et al., 2006)

*FPE = Fattening Pig Equivalent

Table 4.9. Crop water productivity (CWP) benchmark values per unit of water depletion according to "FAO33" (Doorenbos and Kassam, 1979), CWP ranges according to the literature study by Zwart and Bastiaanssen (2004) of the data sets by crop (Source: Zwart and Bastiaanssen, 2004)

Crop	CWP-range ("FAO33" kgm^{-3})	CWP-range* (this research kgm^{-3})	*n*	Minimum	Maximum	Mean	Median	S.D.	CV
Wheat	0.8-1.0	0.6-1.7	412	0.11	2.67	1.09	1.02	0.44	0.40
Rice	0.7-1.1	0.6-1.6	105	0.46	2.20	1.09	1.02	0.40	0.36
Cottonseed	0.4-0.6	0.41-0.95	126	0.38	1.70	0.65	0.58	0.23	0.35
Cottonlint	Not given	0.14-0.33	66	0.10	0.37	0.23	0.23	0.064	0.28
Maize	0.8-1.6	1.1-2.7	233	0.22	3.99	1.80	1.60	0.69	0.39

*Defined as the 5 and 95 percentiles of the entire range.

performing farms in Flanders reached a 170% and 163% higher energy productivity for dairy and pig production, respectively, than average farms (Meul et al., 2007). For arable farming this figure was even higher (205%), but this was partly due to differences in crop rotations, i.e., some crops are more energy efficient than others: winter wheat, for example, has an output/input ratio of 14.4 versus potato 4.3 (Hulsbergen et al., 2001).

In summary, historical trends and variation across farms within a sector show that energy use and energy-use efficiency have improved and can still be improved further. In absolute terms, the largest gains can be achieved in horticulture and intensive livestock systems. However, given the large number of arable and dairy farms, scope for improving energy use in these sectors is also significant. This should be assessed jointly with issues such as the role of agricultural systems in carbon sequestration and biofuel production. This will be further discussed in the Outlook part of the paper.

Water

Irrigation is the main source of water use in agriculture, and it causes agriculture to be a major user of water, i.e., between 7 and 60% of our total water use in Northern and Southern Europe, respectively (EEA, 2005). Table 4.2 (page 36) provides the irrigable area per member state and region; across the EU-15 the irrigable area amounts to 9% and across the EU-27 to 7%. In the EU-15, 85% of irrigated land is in the Mediterranean area (France, Spain, Italy, Portugal, Greece; Appendix 3). In the acceding and new member states, Romania and Turkey are the major users (93%). The water use in the EU-15 for agricultural purposes has been fairly stable (EEA, 2005); this is the net result of an increase in irrigable area (France, Greece and Spain) and a decrease in application rates per hectare. Figures on annual water allocation rates point to a likely reduction in water use per ha of irrigated land, while yields have not decreased but rather increased (between 1990 and 2000, the mean water allocation rates in France, Greece, Italy, Portugal and Spain decreased from 6578 to 5500 m^3/ha/year (EEA, 2005). This points to an increase in water-use efficiency.

Zwart and Bastiaanssen (2004) reviewed the recent literature (the past 25 years) and summarised the crop water productivity (in kg/m^3), defined as the actual marketable crop yield divided by the actual seasonal crop water consumption by evapotranspiration. Few of the 84 references are from Europe, but there is little reason to assume that variation in Europe is much less than in other parts of the world. Table 4.9 shows this variation for wheat, rice, cotton and maize. The main reasons for the variation in crop water productivity are climate, irrigation-water management and soil-nutrient management. The data underpin the scope for improving water-use efficiency through irrigation, optimising irrigation-water management and other crop management, including fertilisation.

Nutrients

Nutrient use is another indicator of agricultural production and its intensity, as well an indicator for environmental effects. The amount of mineral nitrogen fertiliser consumption in the EU-15 has decreased by ca. 15% between 1995 and 2005 (Eurostat); trends differed significantly across countries, to some extent depending on their level of fertiliser use. In the Netherlands the use of fertiliser-N decreased by ca. 25% over the past 10 years. In countries such as Italy and Portugal, fertiliser inputs tended to increase rather than decrease. For phosphate mineral fertiliser, consumption in the EU-15 decreased by 35% in the 1990-2001 period.

Nutrient balances are a much better indicator for possible environmental effects than nutrient use per se. At EU-15 level this gross nitrogen balance decreased from 65 to 55 kg N/ha over 1990 to 2000 (EEA, 2005). Interestingly, this decrease is mainly due to higher outputs and not so much lower inputs – hence the nutrient-use efficiency has increased drastically. Figure 4.10 shows

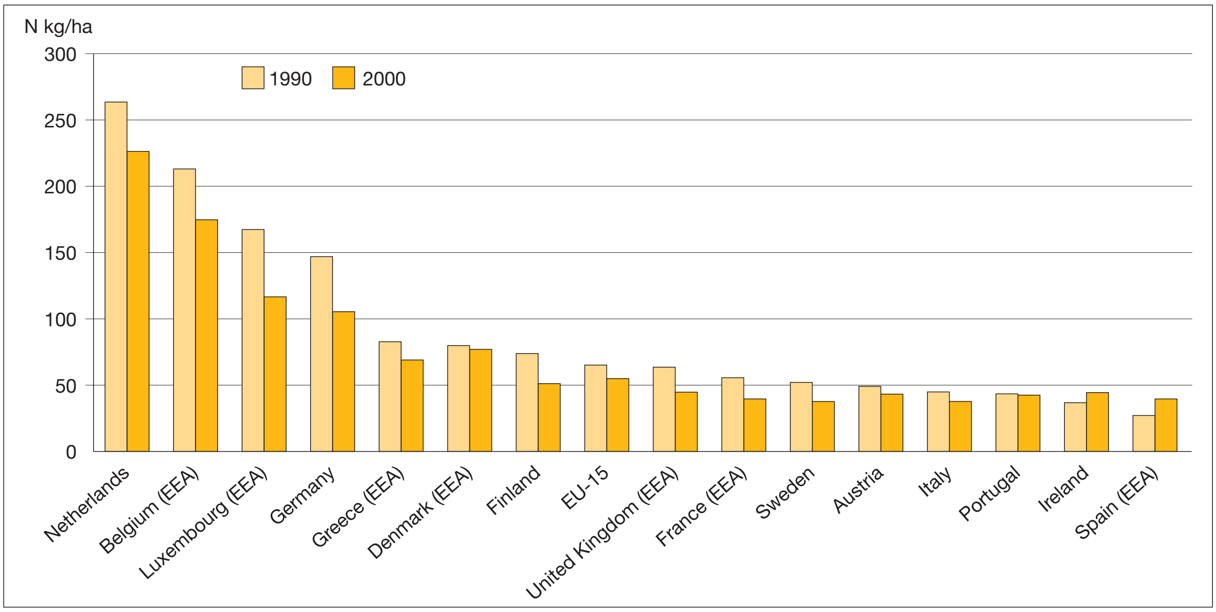


Figure 4.10. National gross nitrogen balances (kg/ha) in 1990 and 2000. In Belgium (Flanders) the first calculation is for 1998; in Sweden the first calculations are for 1995. The country name followed by (EEA) indicates balances that have been calculated by the EEA on the basis of EU-level data. (Source: EEA 2005)

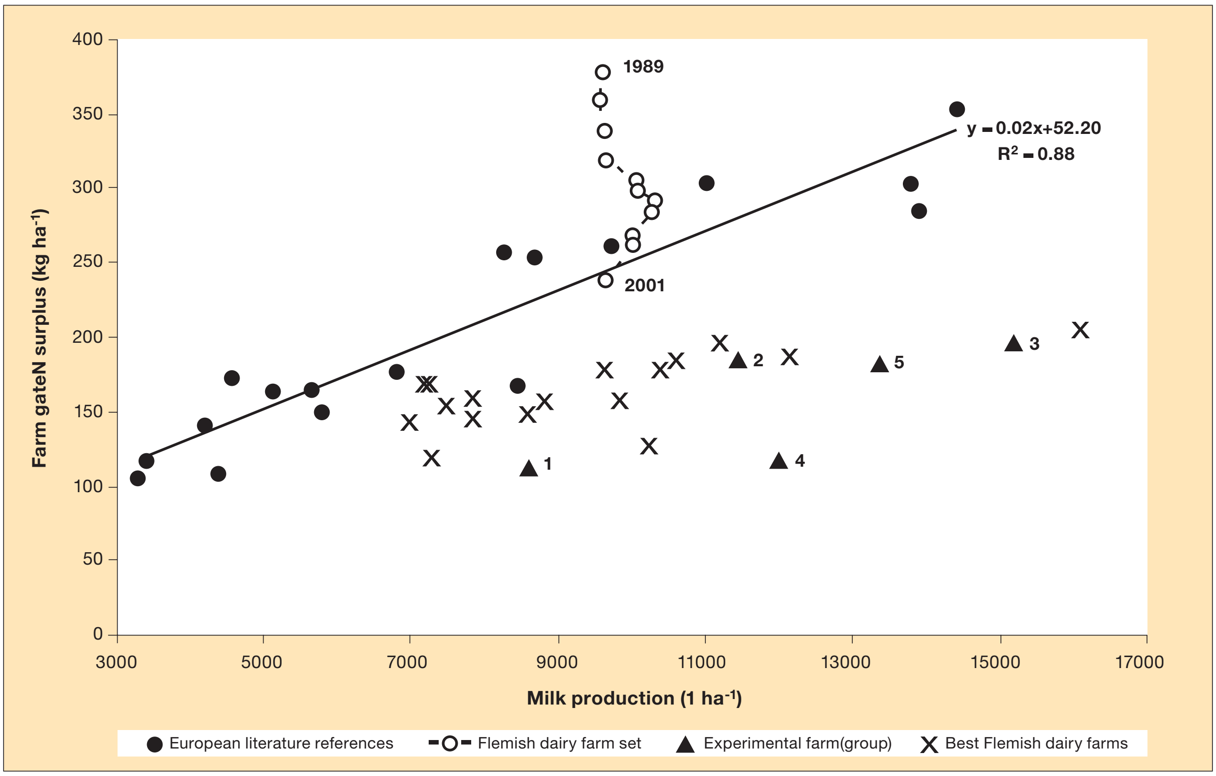


Figure 4.11. Farm-gate N surpluses in relation to production intensity. Data of literature references, average of the Flemish specialised dairy farm set (1989-2001), progressive Flemish dairy farms (2000 and 2001) and Dutch experimental farms (1. Bioveem; 2. Vel and Vanla; 3. Koeien en Kansen; 4. De Marke; 5. A.P. Minderhoudhoeve). (Source: Nevens et al. 2006)

the enormous variations across countries, as well as the significant decreases in surpluses in some countries over the 1990-2000 decade. This is mainly due to large differences in net nitrogen input through manure, which varied between 31 N kg/ha (Spain) to 206 N kg/ha (the Netherlands); fertiliser rates varied between 35 N kg/ha (Austria) and 179 N kg/ha (the Netherlands). Other nitrogen inputs refer to atmospheric deposition, biological nitrogen fixation and seed and planting material: this source ranges from 8 to 44 N kg/ha (Portugal and the Netherlands, respectively).

Variation of nutrient surpluses and nutrient-use efficiency across farms illustrates scope for improving nutrient-use efficiencies (Appendix 4). The variation is high, not only across all farm types, but also within a farm type and within a group of so-called forerunners. Nevens et al. (2006) regressed the farm-gate N surpluses versus the milk production per hectare for dairy systems across Europe (Figure 4.11); clearly, farm-gate surpluses increase with milk production per hectare. At the same time the figure shows how, without sacrificing production, Flemish farms have become much more nutrient-use efficient between 1989 and 2001; this was achieved mainly through reducing N fertiliser input and, second, through reducing concentrate input (Table 4.10). Further, data from progressive (forerunner) farms and experimental farms show that N surpluses can be further decreased substantially. N-use efficiency (N in farm output over total N-input) increased from 15% to 22% between 1989 and 2001 in the Flemish farms and varies roughly between 20 and 40% on forerunner farms in the Dutch Cows and Opportunities project (Oenema and Aarts, 2005).

(b) Environmental effects associated to resource use and resource-use efficiency

Various environmental effects were implicitly or explicitly covered in the previous sections, but some deserve an explicit mention here.

Greenhouse gas emissions

The important greenhouse gases related to agriculture are carbon dioxide, nitrous oxide and methane. Per ton of gas, nitrous oxide is 310 times more powerful in terms of global warming than carbon dioxide; methane is 21 times more powerful than carbon dioxide. In 2004, the share of agriculture in total greenhouse gas emissions in the EU-15 amounted to 9%; this was 10% lower than in 1990 (EEA, 2005; EEA, 2006b). This may be attributed particularly to lower nitrous oxide (minus 8.2%) due to lower N-fertiliser use and to lower methane emissions (minus 9.4%) due to lower number of cattle, the prime source of methane. Reduction of the third source of greenhouse gas emissions, carbon dioxide, is less significant and mainly related to energy use. Agriculture also makes a further contribution to reducing greenhouse gas emissions through production of bio-energy (presently it produces 3.6% of total renewable energy).

Soil erosion

Soil erosion is particularly evident in arid regions in Europe (southern and western Spain, northern Portugal, southern Greece and central Italy), where long dry periods are followed by heavy, erosive rains falling on steep slopes with fragile soils (EEA, 2005), and where soil cover is only partial in space or time (i.e., for important parts of the year the land is fallow). In these regions erosion may exceed 5 tons/ha/year.

Table 4.10. Average characteristics of the specialised dairy farms in the Flemish Farm Accountancy Data Network and of a subgroup of 18 progressive farms with regard to the N-use efficiency (data for 2000 and 2001) (Source: Nevens et al. 2006)

Topic	Unit	Progressive group *n* = 18	All dairy farms *n* = 148	Progressive group compared to all	
				Absolute	Relative (%)
Utilized area	ha	34.2	32.3	+1.9	106
Stock density	LU ha^{-1}	2.92	3.01	−0.09	97
Milk production	1 ha^{-1}	9399	9831	−432	96
Milk production	1 cow^{-1}	5552	5925	−373	94
N surplus	kg ha^{-1}	163	250	−87	65
N use efficiency	%	38.3	22.0	+16	174
Mineral ferlilizer use	kg Nha^{-1}	87	139	−52	63
Concentrate use	kg Nha^{-1}	78	96	−18	81
Share of heifers	%	31	34	−3	91
Yearly income	€ per labour unit	31059	27478	+3581	113

Ammonia

Ammonia emissions in Europe are mainly the result of volatilisation from livestock urine and manure. Between 1990 and 2002 these emissions decreased by 9%, which is likely to be caused mainly by a reduction in livestock numbers (EEA, 2005). In countries with high livestock densities and very intensive systems, such as the Netherlands, ammonia emissions decreased in the same period by ca. 45%. This is the result not only of reduction in the number of animals, but particularly also of manure application legislation and improved housing.

Pesticides

The number of crop protection agents is very high and moreover the active ingredients change over time. This makes it extremely difficult to draw unambiguous conclusions about the total use of pesticides in agriculture and their environmental impact. Amounts of active ingredients may remain fairly constant whereas their environmental impact may decrease substantially, due to less toxic components, and vice versa. In the Netherlands (atypical in the sense that pesticide use is relatively high in the Netherlands), total use of active ingredients of pesticide decreased by 50% between 1990 and 2003 (LEI, 2005), due to changes in cropping systems, new varieties, more precise application techniques, new active ingredients and better disease monitoring. The decrease in use of soil fumigation agents takes the largest share; for other types of pesticides the decrease is only modest. For a real comparison of pesticide impact in time, toxicity of the various components to soil, water and air must be considered and data are largely lacking to do this properly.

Biodiversity

Biodiversity and landscape are interrelated with agricultural practices. Figure 4.12 provides a hypothetical relationship between intensity of agriculture and biodiversity (EEA, 2004). This scheme provides rationale to political concern for High Nature Value (HNV) farmland. However, relationships between intensity of agriculture and biodiversity are typically scale-dependent and must be studied at multiple scales. This is reflected in issues such as an Ecological Main Structure, for which not just local biodiversity values (on agricultural land) count, but typically the biodiversity that can be obtained at entire system level. Intensive systems are generally more productive and this requires lower areas to produce a certain amount of food. Hence, at European level less land is needed for agriculture and more land can be used for nature conservation purposes (cf. Rabbinge and Van Latesteijn, 1992).

Farmland bird populations are assessed to have decreased by ca. 20% over the past two decades, though they have tended to stabilise recently (Figure 4.13). This decrease is associated with an intensification and specialisation of agricultural systems and practices with increased external inputs (nutrient and pesticides), a decline in habitats and less variability in landscape. Reidsma et al. (2006) reviewed the relationship between types (including intensity) of farming and ecosystem quality (Table 4.11). Ecosystem quality is defined here as the mean abundance of species originally present in a natural ecosystem relative to their abundance in undisturbed situations.

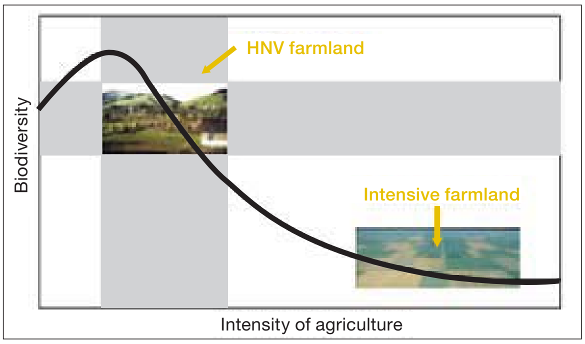


Figure 4.12. Hypothetical relationship between agricultural intensity and biodiversity; HNV farmland = High Nature Value farmland. (Source: EEA, 2004; adapted from Hoogeveen et al. 2001)

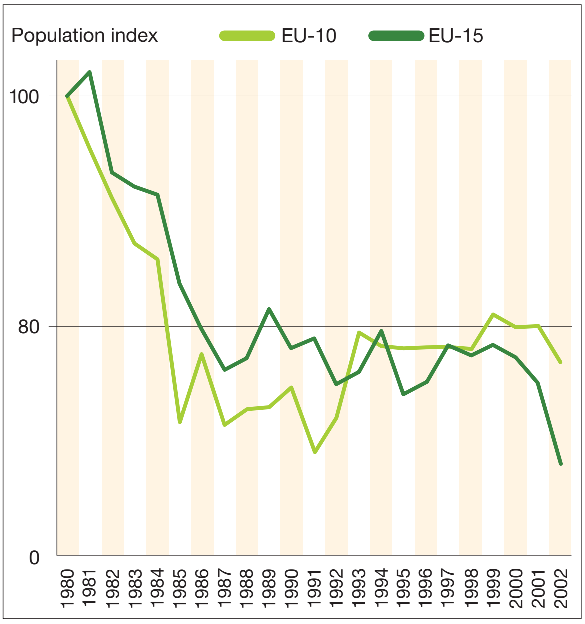


Figure 4.13. Common farmland bird trend from 1980 and 2002 in EU-15 and EU-10 member states (Source: EEA, 2007 – http://dataservice.eea.europa.eu/)

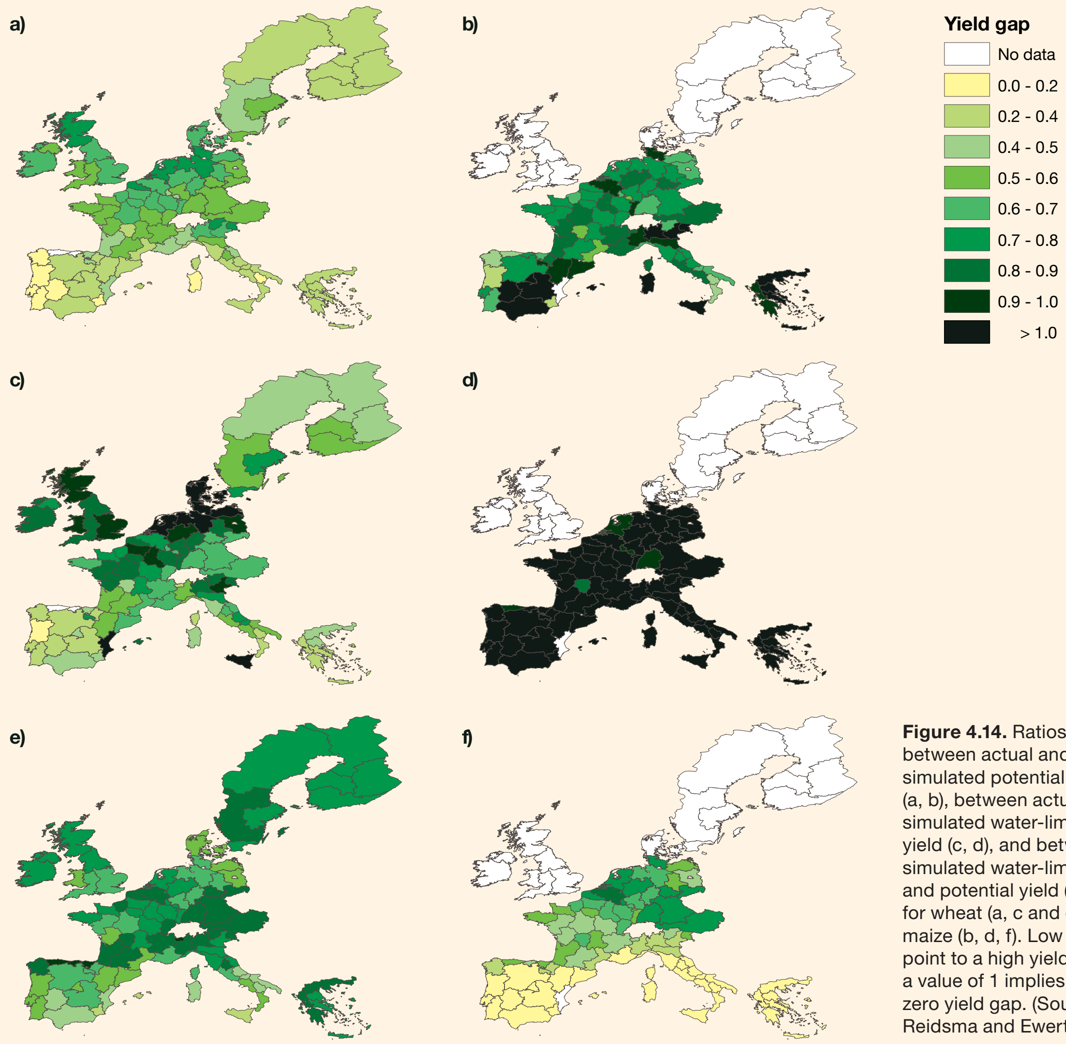


Figure 4.14. Ratios between actual and simulated potential yield (a, b), between actual and simulated water-limited yield (c, d), and between simulated water-limited and potential yield (e, f) for wheat (a, c and e) and maize (b, d, f). Low values point to a high yield gap; a value of 1 implies a zero yield gap. (Source: Reidsma and Ewert, 2005)

Table 4.11. Classification of (annual and permanent) cropping systems (Source: Reidsma et al. 2006)

	Criterium Organic	Criterium Irrigation	Criterium Intensity[a]	Class[b]	Ecosystem quality
Irrigated	Non-organic	Irrigation		17 (37)	5%
Highly intensive	,,	No irrigation	> 250 €/ha	16 (36)	5%
Intensive	,,	,,	80-250 €/ha	15 (35)	10%
Extensive	,,	,,	< 80 €/ha	11 (31)	25%
Highly intensive organic	Organic	Irrigation OR	> 250 €/ha	14 (34)	15%
Intensive organic	,,	No irrigation	80-250 €/ha	13 (33)	20%
Extensive organic	,,	,,	< 80 €/ha	12 (32)	35%

[a] Intensity = costs of: fertiliser and soil improvers, crop protection products and feeding stuffs for grazing livestock.
[b] Classes without brackets are for cropping systems, with brackets for permanent cropping systems.

(c) Yield gap analysis

In the previous section we have presented and analysed trends. In a few cases we have started with the outlook, by assessing what the best farmers or forerunners already achieve. A more science-driven approach to underpin outlooks is provided through the principles of production ecology. Production ecological knowledge and insights allow computation of potential yield levels, given genetic characteristics of plants/crops, temperatures and carbon dioxide concentrations in the atmosphere. This is under the assumption of no yield limitation due to water and nutrients and absence of reducing factors due to weeds, pests and diseases (Van Ittersum and Rabbinge, 1997). The absence of yield limitations and reductions can be achieved through perfect management. Although it may be difficult or uneconomic to realise such perfect management in reality, the potential yield (or water-limited in case of absence of irrigation and assuming rain-fed agriculture) provides a benchmark for productivity of current agriculture and scope for improvement in terms of agricultural management. The ratio between actual and potential or water-limited yield is defined as the yield gap (low values point to a high yield gap; a value of 1 implies a zero yield gap) and provides an indication for the scope of improving land productivity through agricultural management. The ratio between water-limited and potential production points to the potential gains in productivity through irrigation.

Figure 4.14 provides an example of such yield gap analysis for wheat and maize. Note, that in some regions the actual yields of maize are higher than the computed potential yields. Theoretically this is not possible, but the simulations were performed with relatively old varieties and related crop parameters, so potential and water-limited yields of present varieties have been underestimated.

Relative to water-limited yields, yield gaps of wheat are small for NW Europe and substantial for Scandinavia and Mediterranean countries (Figure 4.14c). It suggests that for wheat the potential of further improving nutrient management and crop protection is particularly significant in Scandinavia and southern regions. The ratio between water-limited and potential yield levels (Figure 14e) suggests the potential of irrigation: this is clearly very significant for Mediterranean regions, but also for some regions in France and Germany.

For maize the picture is quite different: Figures 14b and d suggest that maize is often irrigated and that the maize crop could further benefit from irrigation where it is currently not irrigated.

In theory, similar reasoning and analysis could be applied to livestock systems (cf. (Van de Ven et al., 2003), though in practice this is far more complicated and has not been done so far.

For the wheat crop, similar conclusions were drawn by Rabbinge and Van Diepen (2000), but these analyses were also performed for new member states and European countries outside the EU. Yield gaps are generally even larger in these countries, i.e., generally actual yields are less than 60% of water-limited yields and in some countries even below 40%. Yield gap analyses provide an insight into the scope for increasing land productivity in various regions in the EU, but can also be used to provide an indication of how much more could be produced at aggregated level. Rabbinge and Van Diepen (2000) did this for Europe (including Ukraine and Russia) and concluded that wheat production at aggregated level has only reached 43% of its water-limited levels. That indicates an enormous scope for further increase in productivity, even within the current agricultural areas (i.e., without expanding agricultural areas).

(d) Use of Genetically Modified crops in agriculture

Due to the EU's very conservative policy towards the use of Genetically Modified crops (and organisms), the use of GM crops in the EU is very low compared to several other countries (Table 4.12). Figure 4.15 shows the main crops for which GM varieties are currently used and their share in the total area with GM crops.

(e) Relative cost prices of agriculture in the EU

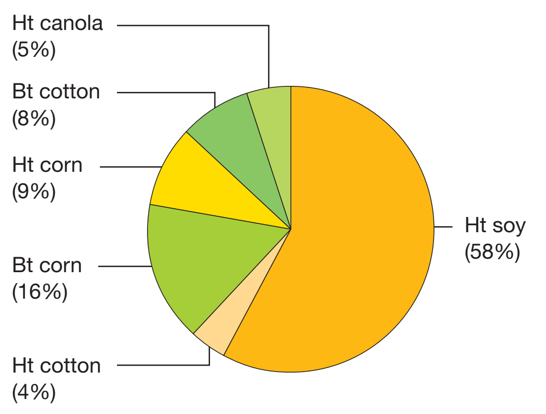
Various factors are important to assess international competition: cost prices, scope to improve productivity and efficiency from an economic point of view (including economies of scale) and scope to improve productivity and efficiency from an agri-environmental point of view. For international competition the relative cost price of producing agricultural commodities is important. The "cash costs" of production are important in establishing competitiveness in the short-run, whereas in the longer-run also other economic costs, such as family labour, owned land and own capital, as well as economies of scale are relevant. Figure 4.16 presents the cash costs for milk production, expressed per 100 kg of product for selected EU and non-EU milk producers. A more comprehensive picture of cost prices and the scope to improve these is important to assess future competitiveness of European agriculture.

Table 4.12. Global area of Genetically Modified crops in 2006 by country (Source: ISAAA, 2006)

Rank	Country	Area (million hectares)	Biotech crops
1*	United States of America	54.6	Soybean, corn, cotton, canola, squash, papaya, alfalfa
2*	Argentina	18.0	Soybean, corn, cotton
3*	Brazil	11.5	Soybean, cotton
4*	Canada	6.1	Canola. corn, soybean
5*	India	3.8	Cotton
6*	China	3.5	Cotton
7*	Paraguay	2.0	Soybean
8*	South Africa	1.4	Corn, soybean, cotton
9*	Uruguay	0.4	Soybean, corn
10*	Philippines	0.2	Corn
11*	Australia	0.2	Cotton
12*	Romania	0.1	Soybean
13*	Mexico	0.1	Cotton, soybean
14*	Spain	0.1	Corn
15	Colombia	<0.1	Cotton
16	France	<0.1	Corn
17	Iran	<0.1	Rice
18	Honduras	<0.1	Corn
19	Czech Republic	<0.1	Corn
20	Portugal	<0.1	Corn
21	Germany	<0.1	Corn
22	Slovakia	<0.1	Corn

* 14 biotech mega-countries growing 50,000 hectares, or more, of biotech crops.

Source: ISAAA Brief 35-2006 – Global Status of Commercialized Biotech/GM Crops: 2006.



Sources: Various including ISAAA, Canola Council of Canada, CropLife Canada, USDA, CSIRO, ArgenBio

Figure 4.15. Global areas sown under Genetically Modified crops in 2005 (Source: ISAAA, 2006) Bt corn: corn with a small amount of genetic material from the soil bacterium, *Bacillus thuringiensis*; the gene of interest produces a protein that kills Lepidoptera larvae, in particular, European corn borer. This is an alternative to spraying insecticides for control of corn borer. Ht crops: herbicide tolerant crops.

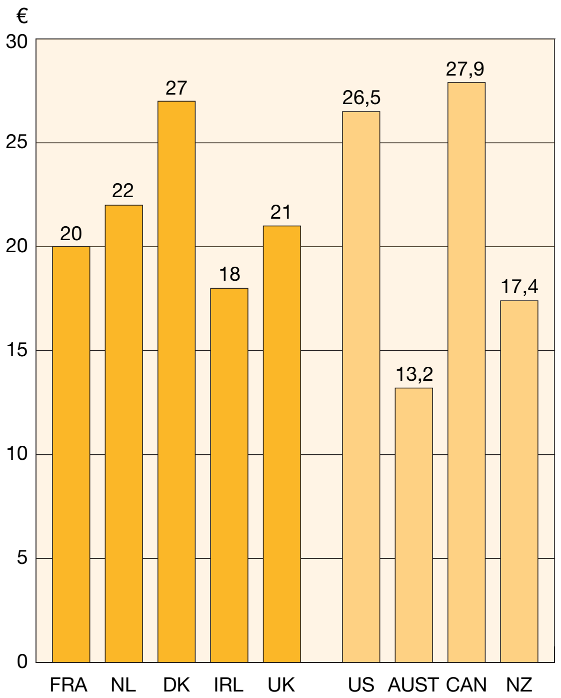


Figure 4.16. Dairy production and its cash costs in the EU and non-EU countries, expressed in €per 100 kg product volume, 1998-1999 (Source: Boyle, 2004)

4.1 Current systems and future scenarios for food production activities

4.1.4 Important drivers for agricultural production in the EU

4.1.4.1 Introduction

Recently the European Commission commissioned a scenario study, Scenar 2020 (Nowicki et al., 2007), that identifies and analyses the future trends and driving forces framing the European agricultural and rural economy with a time horizon of 2020. In this report the exogenous (to agricultural systems) drivers were assumed to be demographics, (macro-)economic growth, consumer preferences, agri-technology and world markets. Policy-related drivers were Common Agricultural Policy (market policies, direct payments and rural development policy), biofuels, enlargement, WTO and other international agreements and environmental policies. We took these drivers as a starting point for this section, but with some modifications. The aim of the ESF/COST Forward Look is to define a research agenda for the production, processing and consumption aspects of European food systems. By definition, such a research agenda must address strategic issues, which have a longer time horizon than 2020. Hence, we believe climate change should be part of the driving factors. Further, we combined macro-economic growth and world markets. Consumer preferences will be dealt with separately in another chapter of this report. Finally, we singled out “biofuels” as they have such obvious implications for agricultural production. Below we briefly discuss these factors which play a role in the defined scenarios and are important to arrive at a robust research agenda.

The driving forces are presented from a European perspective in a global context. Clearly, agricultural production is not a major concern in the EU presently. Also, future scenarios with respect to changes in cropland and grassland tend to indicate major declines in areas needed to feed the European population (Rabbinge and Van Latesteijn, 1992; Rounsevell et al., 2005). However, we assumed first that significant research investments will be needed to realise such predicted changes, and, secondly, that Europe also has to play a role in terms of research and development to solve challenges at a global scale.

4.1.4.2 Demographics

The European population is predicted to decrease from 731 to 709 million in 2030 and 664 million in 2050 (United Nations, 2006), while the median age of the population will increase drastically from 39 years in 2007 to 46 and 47 in 2030 and 2050, respectively. This contrasts with global developments. In 2007 the world population was 6.7 billion individuals, while this number is predicted to increase to 8.3 billion in 2030 and 9.2 in 2050; the median age increases from 28 years to 34 and 38, respectively. Until 2030 almost 100% of the population growth will occur in lower- and middle-income countries.

These figures ignore inward migration from Africa and non-EU parts of Europe. Currently this is adding about 0.3 million per year but, while important in some countries, is unlikely to affect the overall population decrease.

4.1.4.3 Economic growth and world market

Actual scope for productivity increase of agriculture depends on biophysical *and* on economic factors: prices and total costs of production may well lead to the fact that lower yield levels are more profitable than attainable from a biophysical viewpoint. At more macro-economic level, Hafner (2003) found in a global study of historical cereal yields of 188 nations that productivity growth is correlated to per capita GDP, next to latitude (which corresponds to climate). Effects of GDP may be interrelated with availability and affordability of inputs, perhaps presence of agricultural subsidies and the level and quality of research, education and extension. It is thus likely that yield gaps will become smaller in new member and southern member states of the EU when their per capita GDP increases (see also Figure 4.4b).

Per capita GDP is also highly correlated to meat consumption. It is predicted that global consumption of animal foods may double between 2000 and 2050 (Steinfeld et al., 2006). This much more affects the demand for biomass for food through the required feed inputs (Delgado, 2003; Smil, 2002). For instance, an affluent western diet, in which animal proteins have a significant share, involves a three-times larger input of grain equivalents than the adequate vegetarian diet that is still normal in many developing countries (Penning de Vries et al., 1995). Such developments will affect European agriculture through a higher global demand for feed.

Markets for food consumption (in terms of volume) in the former EU-15 may well be saturated, but it seems likely markets in the new member states and other parts of Europe will grow further, particularly because of changes in diets and higher consumption of beef with relatively unfavourable feed conversion coefficients. Global changes in demography and economic growth will increase demand for food at a global scale. This will have implications for Europe, the precise effect depending on the degree of liberalisation and globalisation (Rosegrant et al., 2001; Nowicki et al., 2007; Rosegrant et al., 2008), but for several commodities Europe seems competitive whereas for beef production, for example, this is not the case. Structural change (number and size of farms) will be a major effect of liberalisation.

4.1.4.4 Climate change

Effects of climate change are an interplay of effects of elevated carbon dioxide concentrations, temperature, rainfall and options for adaptation and mitigation. Van Ittersum et al. (2003) provide an example of a systematic analysis of each of these factors and their interaction for wheat crops in an area in Western Australia with a Mediterranean climate. The common denominator of studies (e.g. Olesen and Bindi, 2002; Maracchi et al., 2005) assessing consequences of climate change on European agricultural production suggests that in northern regions climate change may have positive effects on agriculture assisted through introduction of new crop species and varieties, higher crop production (effects of carbon dioxide and temperature rises) and expansion of suitable areas for crop cultivation. Disadvantages may be an increase in the need for plant protection, the risk of nutrient leaching and the turnover of soil organic matter. In southern areas disadvantages will predominate. The possible increase in water shortage and extreme weather events may cause lower harvestable yields, higher yield variability and a reduction in suitable areas for traditional crops. This vulnerability of Mediterranean regions is confirmed by Schröter et al., (2005a; 2005b). The question, stressed by many authors, then is whether options for mitigation and adaptation, particularly in southern parts of the EU, are adequate to counterbalance effects of climate change. Also, many studies do not account properly for the greater risks for extreme events.

4.1.4.5 Technology and research investments

Figure 4.4 is illustrative of the results of technological progress and development over the past decades. Some researchers project such historical trends into the future with slight variation under different scenarios (Ewert et al., 2005). This extrapolation is questionable and at least major investments in research and development will be required to maintain the yield increases at the levels observed over the past decades. In several places in the world and in Europe we can still expect great progress in productivity thanks to principles of the green revolution – the yield gap is still enormous (Section 4.1.3.2 (c)). In other places, where yields are usually closer to the potential levels, diminishing returns of input use are evident. Returns on nitrogen fertilisation, for example, are clearly diminishing or have reached a plateau; yield gains can only be achieved through mutual optimisation of inputs. From a genetic point of view, improved harvest indices no longer seem a promising route to increase yield potentials substantially (Shearman et al., 2005; Reynolds et al., 2005). Several authors argue that yield potentials of cereals are source-driven rather than sink-driven. In other words, yields of rice (and probably other crops) cannot be increased further through a reallocation of biomass within the crop through changing the architecture of plants and crops. In crops where breeding has been less prominent or with an indeterminate architecture, breeding for a different architecture may still offer ample scope (e.g., rapeseed – Berry and Spink, 2006).

In the major cereals, higher light-use efficiencies and hence photosynthesis are needed to boost yield potentials. The most prominent route proposed for rice, for example, is to target C4 rather than C3 rice (Sheehy et al., 2007). Breeding for, for instance, C4 rice is proposed as a route that must be investigated and, if successful, might lead to yield increases of up to 50%, considering differences in productivity between maize and rice crops grown under the same conditions and with similar growing seasons (Sheehy et al., 2007). Further, it would not only boost potential yield levels, but also be very beneficial for water- and nitrogen-use efficiency. However, even if successful, turning C3 crops into C4 crops will only be effective in relatively warm climates. So for many of the temperate regions in Europe breeding for C4 is not a viable route. Yet, we believe that from a global perspective, some drastic breakthroughs, such as turning C3 crops into C4 crops, are the only way we can cope with the enormous challenge of feeding the world with a 50% higher population, drastic increased demand for livestock products and, at least presently, demands for bio-energy. Europe has its role to play here, both in terms of production per se, and in terms of research capacity.

Yin and Struik (2007) critically assess some of the pathways of using C4 biochemistry and physiology in C3 plants; they argue that some perspectives may look promising at a particular experimental level (short time span and at plant or crop level with a certain leaf area index), whereas they may not hold up when scaling up processes to a growing season or full crops. Negative feedback may well compensate positive effects at micro level. Yet, a large international consortium is currently formed to take up the challenge of developing C4 rice, or at the very least some alternative non-C4 possibilities to raise yields (Mitchell and Sheehy, 2007). Yin and Struik (2007) suggest that crop systems biology is needed to take advantage of modern functional genomics and traditional sciences (such as crop physiology and biochemistry) in understanding and manipulating crop phenotypes relevant to agriculture. This not only applies to the case of C4 rice, but applies to all kinds of breeding attempts in which genomics plays a role — the need for scaling up such knowledge and its potentials to the crop and cropping system level is urgent.

The case of C4 is presented here as a complex example to make the point that trend breaks are needed to face global challenges and that breakthroughs are needed from biotechnology, hand in hand with progress at systems level, i.e., the field, crop, animal and production system level. Other challenges for breeding, biotechnology and agricultural management relate to coping with abiotic stresses, especially climate change, resistance to biotic stresses, coping with new diseases in response to pathogens and vectors moving in response to climate change and transports across the globe, development of integrated crop and livestock management systems that efficiently cope with multiple environmental stresses.

Koning et al. (in press) show that growth rates of investments in agricultural research have declined over the past 10-20 years. They also point out the risk of short-sighted expectations: food production at global scale and in all developed countries has not been and is not yet an issue of political concern. The long-term perspectives that this may change do not affect investments in research and development at present, whereas breakthroughs require a really long-term perspective. Cassman and Liska (2007) also plead for rapid action to improve global targeting of research and development funds to assure an acceleration in food production capacity while protecting natural resources and environmental quality.

4.1.4.6 Policy-related drivers

In various parts of the world, agricultural policies increasingly evolve as integrated policies, or even become part of integrated policies, such as for instance environmental or rural development policy programmes. This may occur within the larger frame of agreements on sustainable development. In Europe the share of so-called first pillar policies (Common Agricultural Policy), though still very substantial, is decreasing at the expense of second pillar polices (Rural Development). Within the first pillar, subsidies have been substantially decoupled from production prices towards farm subsidies since the latest Common Agricultural Policy reform in 2003, and it seems likely this will continue. Subsidies are partly coupled to meeting certain management requirements or conditions, for instance related to nutrient or pest management (cross-compliance). Globally, within the frame of World Trade Organisation negotiations, direct support of production is decreasing, generally in favour of other farm-based, environmental or rural development policies. Future evolutions of policies are hard to predict and largely depend on world views and developments. This driver therefore recurs very prominently in the definition of scenarios (see Section 4.1.6). Recent developments as to supporting biofuel production demonstrate the strong effect policies can have on agricultural production and prices (see below). The current increase in prices of major agricultural commodities, due to a combination of increased demand for biofuel production, low harvests in various parts of the world and increased demand for feed and food from China, has already led to discussions on lowering set-aside areas, and increasing milk quota.

4.1.4.7 Energy scarcity and biofuels

Renewable energy sources currently account for 6% of the total EU-25 energy consumption; prime sources are biomass (ca. 2/3 of renewables), waste and hydro; the contribution from solar energy is still very minor. Most of the biomass comes from wood or wood waste and only a very small fraction (3% of the renewable energy) came from biofuels in 2003. The target for renewable energy sources in 2010 is 12%, which requires a substantial rise in the use of biomass. The share of renewable electricity in the EU-25 was 12.8% in 2003; here large-scale hydropower is the dominant contributor (EEA, 2006a) and biomass contributes only ca. 15%. The EC's biofuel directive aims at a 5.75% share of biofuel in total fuel for transport (transport energy accounting for ca. 30% of the total energy consumption in the EU-25).

All these figures point to great pressure on agricultural land to contribute to biomass production in the near future. In 2003, the agricultural sector contributed 2.23 million tons of oil equivalent (Mt OE), including 67% biofuels, 13% short-rotation forestry, 3% biogas and 17% use of straw. In 2003, 1.6 million ha of land were used for biofuel production. To give an indication of the possible pressure, the Biomass Action Plan of the EC proposes a number of measures to increase the production and use of biomass for energy use to reach some 150 Mt OE in 2010 (EC, 2005; EEA, 2005). It has been estimated that even the objective of realising 5.75% biofuel of total fuels would require close to 10% of the EU-25 agricultural land (Nowicki et al., 2007). Internationally, claims for maize for bio-ethanol in the USA are estimated to reach 30% of the maize crop, while Indonesia and Malaysia, for example, are planning to use 40% of their current palm oil output for production of biodiesel, both for the year 2010 (Biopact, 2006; Food and Agricultural Policy Research Institute, 2006).

It will be important here to discriminate between short-term policy aims (say up to 2020) and longer-term developments and the need to focus on other renewable energy sources rather than biomass.

Analysis of energy-use efficiency of agriculture (crops and feed production) around the globe indicate a fairly low efficiency in the EU-15 compared with other parts of the world, in particular Canada, Argentina and, to a lesser extent, USA and Australia (Slesser and Wallace, 1982; Bonny, 1993; Conforti and Giampietro, 1997). The output/

input ratio in the EU-15 was estimated at 1.5 whereas that in Australia, Canada and USA was 2.1 on average. Output/input ratio was much higher in Argentina (ca. 10). This may indicate a relatively high vulnerability of European agriculture to high energy prices.

For the coming 15 years or so, there will be a need to make agriculture more energy-efficient to be competitive internationally in the face of high energy prices and to manage its contribution to greenhouse gas emissions. At the same time, agriculture will face implications of high demands for biomass production for bio-energy, at least in the short and medium term, until alternative and more efficient renewable energy sources have been sufficiently developed and made economically attractive. First generation bio-energy technology will compete directly with food and feed, whereas second generation bio-energy might compete (also) with soil fertility as waste and residue products are the prime source for this technique.

4.1.5 The three questions

In this section we relate the information on current agricultural production (Section 4.1.3 – Table 4.2) and the drivers (Section 4.1.4 – Table 4.13 below) to the three overarching questions presented in the introduction of this paper. As indicated, answering the questions is equivalent to speculation, due to uncertainties as to exogenous drivers, but we will hint at evident trends and indicate what kind of analysis and information is needed to answer the three questions. A scenario approach, as presented in the final section, assists in further investigating the three questions.

1. Will there be substantial changes in agricultural resource use in Europe as a consequence of intensified production systems and policies on energy security/diversity?

It is likely that intensification in European agriculture will continue. As a consequence, some areas currently producing food crops and animals will come out of food production, i.e., less land will be needed in Europe for food production in the decades to come (Rabbinge and Van Latesteijn, 1992; Rounsevell et al., 2005). At the same time the demand for biomass to produce biofuel will increase; land that might be reverted to forest and/or recreational space may be used for this. The degree of land abundance for food production and reversion to biomass production for biofuel will largely depend on political choices within the EU (e.g., quota systems, set-aside policies and subsidies on biomass for biofuel) that also intervene with technological development and the

Table 4.13. Relative importance of the drivers on the three questions underlying this chapter on future scenarios for food production activities

Driver	Question 1	Question 2	Question 3
Demographics		×	
Markets and economic growth		×	
Climate change	×		
Technology and research	×	×	×
Policy development	×	×	×
Energy scarcity and biofuels	×	×	×

actual use of new technologies. In the short to medium term, biomass production for bio-energy will have substantial effects on land use. Given its intensity, European agriculture is fairly susceptible to higher energy prices; it will have to become more energy efficient. Clearly, data as shown in Figures 4.9, 4.10 and 4.11 show there is ample scope for a more resource-use efficient, yet intensive agriculture. Finally, shortage of water for irrigated agriculture in the Mediterranean region combined with warming in northern latitudes will result in production of some high-value horticultural and vegetable crops moving north.

2. Will changes in global food markets (resulting, for example, from industrialisation in China, India and South America, energy security policies in the USA, and climate change in sub-Saharan Africa) result in changed production systems in Europe?

Globally, it seems very likely there will be higher demand for food and non-food production from European agriculture. There are three reasons for this: (1) population growth in developing countries; (2) economic development and its effect on consumption of animal proteins; (3) increasing demands for non-food production. Increased demand for food by China is already affecting world trade; this is likely to continue. In India the situation is different because of a greater focus by the government on self-reliance. The switch to maize production for biofuel has had a short-term effect on markets but the longer-term consequences are uncertain, given that more land may come back into production as a consequence of higher cereal prices. The proximity of Europe to Africa is likely to have effects on European production, especially if the USA uses cereals that have historically gone to Africa during times of famine. The degree to which such issues will manifest themselves will be highly dependent on global developments, political choices and precise demographics.

Production potentials are there, both at European (e.g. Rabbinge and Van Diepen, 2000) and global level (Penning de Vries et al., 1995), but their exploitation requires significant investments to overcome yield gaps and improve resource-use efficiencies. European agriculture is typified by a high number of very small farms. Partly as a result of this, its cost price seems to be relatively high. Comparative analyses of international cost prices of major agricultural commodities seem scarce. Such analyses would be even more useful when extended with negative and positive externalities associated with the production. A comparison of cost prices and a systematic life cycle analysis of agricultural goods across the globe would be helpful to reveal optimum production systems (optimum from various perspectives related to sustainable development) under patterns of globalisation and regionalisation. That in turn can provide a basis for policy development.

3. Will new technologies be adopted, in Europe or elsewhere, that result in "best" methods of food production, enhanced environmental management and healthy foods?

Answering this question very much depends on how new technologies are defined, but overall the question must be answered positively. New technologies in terms of new cultivars, integrated crop-, water-, nutrient- and pest-management practices are continuously adopted. If new technologies refer to genetically modified crops or organisms, it is obviously a political choice driven by public opinion that determines their adoption. Evidently, pressure for adoption of genetically modified organisms (and hence changing European policies as to this subject) will increase.

New cultivars with durable disease resistance are being developed. A significant impact of genomics on this in field production is some 15-20 years away. Better nutrient and water management will increasingly be adopted, especially if energy costs push fertiliser costs higher. Public policy requirements for sustainability and biodiversity will ensure that new technologies need to be developed to achieve the policy goals. Genetic modification is only one of several technologies that will play a role here. The precise type of new technologies may differ between future developments towards either further globalisation or regionalisation. In the former case, emphasis may be more on high-tech and resource-use efficiency, whereas in the latter case prevention of local emissions may be a prominent objective.

4.1.6 The Forward Look scenarios coloured for agricultural production

The four scenarios that have been defined in the ESF/COST Forward Look were named after the buttons of a tape recorder: what could happen to European food systems if we press the button "fast forward", "pause", "rewind" or "play"? The assumption behind this approach is that it provides a means of identifying a research agenda which anticipates discontinuities, considers wider contextual developments, and is relevant to the design of policy concerning European food systems (see Chapter 3 by Wilkinson et al.). The four scenarios are related to the driving forces described in Section 4.1.4, in particular to the drivers on economic growth and global markets and policy development. Below we attempt to characterise ("colour") the four scenarios by describing their possible implications for agricultural production. This is a highly speculative exercise, but it is relevant to keep in mind that its purpose is not to predict any future, but to map the uncertainties within which a robust research agenda must be drafted.

Scenario A
Fast Forward (Continuing 2007 for another 20 years)

Under this scenario there is a strong continuation of intensification of agricultural production; farming systems will further specialise (separation of different production sectors on-farm, but at higher levels they may well mix) and scale up in size. Current trends will continue and agricultural production will concentrate in areas and regions where this can be done in the most efficient way (efficient mostly from an economic perspective). Resource-use efficiency will be a key concept here, but it is likely resource use will be expressed predominantly in monetary terms. Systems may well be vulnerable to large-scale epidemics because of a globalising agriculture with large trade flows and a narrowing of the set of cultivars or varieties in use. In this scenario, it seems likely that much land will be freed up for other purposes than food production due to a high productivity.

Scenario B
Pause (Globalising markets and higher perception of risk)

In this scenario, society responds actively to perceived risks, which can be of various kinds (environmental, social and economic) as a result of global drivers such as climate change, large-scale epidemics, obesity and resource depletion and scarcity. The need for "trust" in the food system is crucial. This probably results in higher cost prices because of a focus on more (quality) control in food production systems. People will be much more cautious about what they eat and drink. Tracking and tracing, supported through life-cycle assessments, give incentives to efficient, yet low-risk production systems. This has enormous implications for the entire food chain, including processing, packaging, retailing and consumption. Also in this scenario it is still likely that in several parts of the world (including Europe) land can be freed up from food production purposes. Resource-use efficiency will be approached from multiple angles, not just economic. Net effects on biodiversity may well be positive, as agriculture is concentrated on relatively small areas.

Scenario C
Rewind (Global crisis, act local)

Agricultural food production will regionalise. Trade and transport flows decrease and people prefer food from within the region (which can still be fairly large, but generally food comes from the same continent). Seasonality of availability of products will increase and there will be less diversity. Also enormous efforts will be needed to prevent local food shortages (not so much in Europe but in, for instance, parts of Asia). As in Scenario B, trust in the food system is important and this is achieved through a combination of extensive tracking and tracing and local production. Food miles will be low; food self-sufficiency of regions is an important aim and protectionism prevails. Production does not take place in the most suitable places nor in the most efficient way. Food production will require much more land than in the previous scenarios, which has implications for other functions of land. Also, overall resource-use efficiencies will decrease. Requirement of agricultural labour is much higher in this scenario (and scenario D) than scenarios A and B.

Scenario D
Play (Regionalised markets and low perception of risk)

The assumption in this scenario is that production systems with low use of external inputs will prevail. This could be organic production or a Tuscany-type of agriculture. Certainly on a hectare basis energy use will be relatively low, though this may be less evident for the entire sector. For most resources their use efficiency will be relatively low in this scenario. Locally, biodiversity may benefit from this type of production; globally, food production will require much more land than in Scenarios A and B and this is at the expense of nature conservation and land available for, for example, biomass production. Agro-biodiversity (i.e., the pool of genes used in agricultural cultivars, varieties and breeds) will be relatively high. Multifunctional types of agriculture will probably flourish. Trust in food is less of an issue in this scenario than in the previous – it is mainly obtained through the assumption that organic and locally-grown food is safe. Production methods are relatively labour-intensive in this scenario.

A characteristic of the scenario approach as applied here is that it seeks answers to predominantly reactive developments. In other words, it does not focus on shaping the future of food production systems by actively formulating policies, measures or allocating research funds to reach a particular end. If so desired by society, areas for agricultural production and means of agricultural production can fulfil various roles. Apart from delivering food, they can also have a recreational function, support the conservation of biodiversity, or be a supplier of bio-energy. Moreover, specific targets could also be formulated as to the function of agriculture as a source of food. Foods with improved sensory properties could be targeted, or more importance could also be attached to the production of foods with health-promoting components, and breeding could be supported to achieve this.

In retrospect, we feel that the scenario approach applied in this ESF/COST Forward Look has not sufficiently opened up our analysis of possible future developments in food production activities. Some of the assumptions ascribed to the scenarios seem arbitrary and lack scientific underpinning, e.g., the proposition that low-input or high-input agriculture have particular implications or that society would become highly perceptive to eventual perceived risks of various kinds (environmental, social and economic) and act on that. By contrast, recent history has shown that although consumers react immediately and violently to the occurrence of a food scare, for instance bovine spongiform encephalopathy (BSE), they usually return to their trusted behaviour, a process that is facilitated by providing the public with proper information.

4.1.7 Towards a research agenda

Based on Sections 4.1.3-4.1.5, we suggest the following research topics are robust to the differences between the four scenarios. In other words, we expect these research topics to be relevant in any of the four future scenarios and hence in any imaginable future.

The five research topics below have the purpose: (1) to better understand the pros and cons of the present systems from an integrated perspective, while adequately accounting for different scales and economic, environmental and social aspects; (2) to increase resource-use efficiencies such that yield levels at fixed levels of resources can be lifted (or the same yield levels can be achieved with less input); (3) to lift potential yield levels; (4) to adapt the layout and management of production systems, at different levels of scales, to mitigate factors of global change; (5) to design and develop production systems that have dual purposes in terms of food and feed production, bio-energy, biodiversity, landscape and resource conservation. The proposed topics 3 and 4 can be understood in the frame of the production ecological concept (Van Ittersum and Rabbinge, 1997), a concept that discriminates between yield defining, limiting and reducing factors.

Concretely, we propose the following overarching research topics:

1. Characterisation of production systems with respect to productivity and efficiency, environmental impact and socioeconomic implications at different scales: integrated assessment of agricultural systems at field, farm, regional and global level (including life cycle analysis: all aspects of production, transport and consumption);
2. Enhancement of resource-use efficiency, viz. of water, fertiliser and energy (Gregory et al., 2002), at different levels;
3. Assessment of the possibilities to stretch the yield potential further (both to make it possible to achieve higher potential yields and to achieve intermediate yield levels "more easily", i.e., with less input or effort) (see Section 4.1.4.5);
4. Determination of proper adaptation strategies of production systems at different scales, i.e. field, farm and land use level, with respect to global changes: this refers to climate change, greater risks for epidemics in livestock production sectors, for example, sudden and perhaps temporary rises in demand for agricultural products such as presently with demand for biofuels (see Section 4.1.4.4 and 4.1.4.7);
5. Development of production systems with higher dual contributions, i.e., to both food production and aims such as bio-energy (for example, when second generation techniques become available and residues can be used for this, the trade-off between soil fertility and bio-energy may become urgent), landscape and biodiversity values, etc. (Section 4.1.4.7).

We strongly advocate a follow-up to this ESF/COST Forward Look that takes a wider perspective with an integrated scenario analysis not only based on current drivers but also on societal aims and ambitions that a dedicated research agenda could help to realise.

Acknowledgements

We thank Professor Rudy Rabbinge, Dr. Peter Gregory, Dr. John Ingram, Dr. Anita Linnemann and Dr. John Porter for their helpful comments and suggestions.

References

Andersen, E., B. Elbersen, F. Godeschalk and D. Verhoog (2007). Farm management indicators and farm typologies as a basis for assessments in a changing policy environment. *Journal of Environmental Management* 82: 353-362.

Bailey, A.P., W.D. Basford, N. Penlington, J.R. Park, J.D.H. Keatinge, T. Rehman, R.B. Tranter and C.M. Yates (2003). A comparison of energy use in conventional and integrated arable farming systems in the UK. *Agriculture, Ecosystems & Environment* 97: 241-253.

Berry, P.M. and J.H. Spink (2006). A physiological analysis of oilseed rape yields: past and future. *Journal of Agricultural Science* 144: 381-392.

Biopact, 2006. Palm biofuel survives low crude oil prices-official, http://biopact.com, September 2007.

Bonny, S. (1993). Is agriculture using more and more energy? A French case study. *Agricultural Systems* 43: 51-66.

Boyle, G. (2004). *Competitiveness concerns at the production and processing level: the example of the dairy sector*. In: Workshop on Enhancing Competiveness in the Agro-food sector: making policies work. Vilnius, Lithuania.

Cassman, K.G. and A.J. Liska (2007). Food and fuel for all: realistic or foolish? *Biofuels, Bioproducts and Biorefining* 1: 18-23.

Conforti, P. and M. Giampietro (1997). Fossil energy use in agriculture: an international comparison. *Agriculture, Ecosystems & Environment* 65: 231-243.

De Wit, C.T. (1992). Resource use efficiency in agriculture. *Agricultural Systems* 40: 125-151.

Delgado, C.L. (2003). Rising consumption of meat and milk in developing countries has created a new food revolution. *Journal of Nutrition* 133: 3907S-3901S.

Doorenbos, J. and A.H. Kassam (1979). *Yield response to water*. FAO irrigation and drainage paper no. 33, Food and Agriculture Organization of the United Nations, Rome, Italy.

EC (2000). *Communication from the Commission to the Council and the European Parliament, Indicators for the Integration of Environmental Concerns into the common agricultural policy*. COM (2000) 20 final.

EC (2005). *Biomass Action Plan*. Communication from the Commission. European Commission, Brussels.

EEA (2004). *High nature value farmland – characteristics, trends and policy challenges*. EEA report, European Environment Agency, Copenhagen, Denmark.

EEA (2005). *Agriculture and environment in EU-15 – the IRENA indicator report*. EEA Report, No. 6/2005, European Environment Agency, Copenhagen, Denmark.

EEA (2006a). *Energy and environment in the European Union – Tracking progress towards integration*. EEA Report, European Environment Agency, Copenhagen, Denmark.

EEA (2006b). *Greenhouse gas emission trends and projections in Europe 2006*. EEA Report, European Environment Agency, Copenhagen, Denmark.

Eurostat (2006a). *The agricultural economy, the 2006 Agricultural Year*. http://ec.europa.eu/agriculture/agrista/2006/table_en/en31.htm, September 2006.

Eurostat (2006b). *The 2006 Agricultural Year 3*. Economic data 3.1 The agricultural economy, http://ec.europa.eu/agriculture/agrista/2006/table_en/en31.htm.

Eurostat (2006c). *Statistical and Economic Information – Report 2006*. Rural development in the European Union, http://ec.europa.eu/agriculture/agrista/rurdev2006/index_en.htm.

Eurostat (2006d). *Rural Development in the European Union*. Statistical and Economic Information Report 2006
http://ec.europa.eu/agriculture/agrista/rurdev2006/index_en.htm.

Eurostat (2007). Eurostat Home page http://epp.eurostat.ec.europa.eu, September 2007.

Ewert, F., M.D.A. Rounsevell, I. Reginster, M.J. Metzger and R. Leemans (2005). Future scenarios of European agricultural land use: I. Estimating changes in crop productivity. *Agriculture, Ecosystems & Environment* 107: 101-116.

FAO (2007). AQUASTAT, http://www.fao.org/nr/water/aquastat/main/index.stm, September 2007.

Food and Agricultural Policy Research Institute (2006). *Baseline update for U.S. agricultural markets*. FAPRI-UMC Report #12-06, University of Missouri-Columbia, September 2007.

Gregory, P.J., J.S.I. Ingram, R. Andersson, R.A. Betts, V. Brovkin, T.N. Chase, P.R. Grace, A.J. Gray, N. Hamilton, T.B. Hardy, S.M. Howden, A. Jenkins, M. Meybeck, M. Olsson, I. Ortiz-Monasterio, C.A. Palm, T.W. Payn, M. Rummukainen, R.E. Schulze, M. Thiem, C. Valentin and M.J. Wilkinson (2002). Environmental consequences of alternative practices for intensifying crop production. *Agriculture, Ecosystems and Environment* 88: 279-290.

Gronroos, J., J. Seppala, P. Voutilainen, P. Seuri and K. Koikkalainen (2006). Energy use in conventional and organic milk and rye bread production in Finland. *Agriculture, Ecosystems & Environment* 117: 109-118.

Hafner, S. (2003). Trends in maize, rice, and wheat yields for 188 nations over the past 40 years: a prevalence of linear growth. *Agriculture, Ecosystems & Environment* 97: 275-28

Hoogeveen, Y.R., J.E. Petersen and P. Gabrielsen (2001). *Agriculture and biodiversity in Europe*. Background report to the High-Level European Conference on Agriculture and Biodiversity, STRA-CO/AGRI (2001) 17. Council of Europe/UNEP, Paris.

Hulsbergen, J.J., B. Feil, S. Biermann, G.-W. Rathke, W.-D. Kalk and W. Diepenbrock (2001). A method of energy balancing in crop productivity and its application in a long-term fertilizer trial. *Agriculture, Ecosystems & Environment* 86: 303-321.

ISAAA (2006). *Global status of commercialized biotech/GM Crops:2006*. ISAAA Brief.

Koning, N., G. Becx, T. van Boekel, W. Brandenburg, J. van den Broek, G. van Hofwegen, M.K. van Ittersum, R. Jongeneel, H. Schiere and M. Smies (in press). *Long-term global availability of food: continued abundance or new scarcity?* Wageningen University, The Netherlands.

LEI (2005). *Land- en tuinbouwcijfers 2005*. LEI Wageningen UR and Centraal Bureau voor de Statistiek, The Hague, The Netherlands.

Maracchi, G., O. Sirotenko and M. Bindi (2005). Impacts of present and future climate variability on agriculture and forestry in the temperate regions: Europe. *Climatic Change* 70: 117-135.

Meul, M., F. Nevens, D. Reheul and G. Hofman (2007). Energy use efficiency of specialised dairy, arable and pig farms in Flanders. *Agriculture, Ecosystems & Environment* 119: 135-144.

Mitchell, P.L. and J.E. Sheehy (2007). *Surveying the possible pathways to C4 rice*. In: Sheehy, J.E., Mitchell, P.L., Hardy, B. (Eds.), Charting new pathways to C4 rice. Los Banos (Philippines): International Rice Research Institute, pp. 399-412.

Nevens, F., I. Verbruggen, D. Reheul and G. Hofman (2006). Farm gate nitrogen surpluses and nitrogen use efficiency of specialized dairy farms in Flanders: Evolution and future goals. *Agricultural Systems* 88: 142-155.

Nowicki, P., H. van Meijl, A. Knierim, M. Banse, J. Helming, O. Margraf, B. Matzdorf, R. Mnatsakanian, M. Reutter, I. Terluin, K. Overmars, D. Verhoog, C. Weeger and H. Westhoek (2007). *Scenar 2020 – Scenario study on agriculture and the rural world*. Contract No. 30 – CE – 0040087/00-08. European

Commission, Directorate-General Agriculture and Rural Development, Brussels.
OECD (1993). *OECD core set of indicators for environmental performance reviews: a synthesis report by the group on the state of the environment*. Environment Monographs, Organisation for Economic Cooperation and Development, Paris.
OECD (2007). http://www.oecd.org, September 2007.
Oenema, J. and H.F.M. Aarts (2005). *Koeien & Kansen – Hoe efficiënt worden de mineralen benut in "Koeien & Kansen"?*. Report Plant Research International, Wageningen.
Olesen, J.E. and M. Bindi (2002). Consequences of climate change for European agricultural productivity, land use and policy. *European Journal of Agronomy* 16: 239-262.
Penning de Vries, F.W.T., H. van Keulen and R. Rabbinge (1995). *Natural resources and limits of food production in 2040*. In: Bouma, J., Kuyvenhoven, A., Bouman, B.A.M., Luyten, J., Zandstra, H.G. (Eds.), Eco-regional approaches for sustainable land use and food production, Proceedings of a symposium on eco-regional approaches in agricultural research, 12-16 December 1994, ISNAR, The Hague.
Rabbinge, R. and C.A. van Diepen (2000). Changes in agriculture and land use in Europe. *European Journal of Agronomy* 13: 85-99.
Rabbinge, R. and H.C. van Latesteijn (1992). Long-term options for land use in the European community. *Agricultural Systems* 40: 195-210.
Reidsma, P. and F. Ewert (2005). *The adaptive capacity of European agriculture under different climate and management conditions*. In: Proceedings from the NJF Seminar No. 380, Adaptation of crops and cropping systems to climate change. Odense, Denmark.
Reidsma, P., T. Tekelenburg, M. van den Berg and R. Alkemade (2006). Impacts of land-use change on biodiversity: An assessment of agricultural biodiversity in the European Union. *Agriculture, Ecosystems & Environment* 114: 86-102.
Reynolds, M.P., A. Pellegrineschi and B. Skovmand (2005). Sink-limitation to yield and biomass: a summary of some investigations in spring wheat. *Annals of Applied Biology* 146: 39-49.
Rosegrant, M.W., M.S. Paisner, S. Meijer and J. Witcover (2001). *Global food projections to 2020: emerging trends and alternative futures*. IFPRI, Washington, DC.
Rosegrant, M.W., S. Msangui, T. Sulser and C. Ringler (2008). *Future scenarios for agriculture: plausible futures to 2030 and key trends in agricultural growth*. Background paper for the World Development Report. IFPRI, Washington D.C.,
Rounsevell, M.D.A., F. Ewert, T. Reginster, R. Leemans and T.R. Carter (2005). Future scenarios of European agricultural land use. II. Projecting changes in cropland and grassland. *Agriculture, Ecosystems & Environment* 107: 117-135.
Schenkel, Y. (2006). *Energy as a driver for European agriculture and forest, bioenergy and bioproducts*. In: SCAR paper. 42 pp.
Schnepf, R. (2004). *Energy use in agriculture: background and issues*. CRS Report for Congress, Congressional Research Service (CRS), The Library of Congress.
Schröter, D., W. Cramer, R. Leemans, I.C. Prentice, M.B. Araujo, N.W. Arnell, A. Bondeau, H. Bugmann, T.R. Carter, C.A. Gracia, A.C. de la Vega-Leinert, M. Erhard, F. Ewert, M. Glendining, J.I. House, S. Kankaanpaa, R.J.T. Klein, S. Lavorel, M. Lindner, M.J. Metzger, J. Meyer, T.D. Mitchell, I. Reginster, M. Rounsevell, S. Sabate, S. Sitch, B. Smith, J. Smith, P. Smith, M.T. Sykes, K. Thonicke, W. Thuiller, G. Tuck, S. Zaehle and B. Zierl (2005a). Ecosystem Service Supply and Vulnerability to Global Change in Europe. *Science* 310: 1333-1337.
Schröter, D., W. Cramer, R. Leemans et al. (2005b). Ecosystems Service Supply and Vulnerability to Global Change in Europe. *Sciencexpress*. pp. 1-11.
Shearman, V.J., R. Sylvester-Bradley, R.K. Scott and M.J. Foulkes (2005). Physiological processes associated with wheat yield progress in the UK. *Crop Science* 45: 175-185.
Sheehy, J.E., A.B. Ferrer, P.L. Mitchell, A. Elmido-Mabilangan, P. Pablico and M.J.A. Dionora (2007). *How the rice crop works and why it needs a new engine*. In: Sheehy, J.E., Mitchell, P.L., Hardy, B. (Eds.). Charting new pathways to C4 rice. Los Banos (Philippines): International Rice Research Institute, pp. 3-26.
Slesser, M. and F. Wallace (1982). *Energy consumption per tonne of competing agricultural products available to the EC*. Information on agriculture, (Commission of the European Communities), 85.
Smil, V. (2002). Eating meat: evolution, patterns, and consequences. *Population and Development Review* 28: 599-639.
Steinfeld, H., P. Gerber, T. Wassenaar, V. Castel, M. Rosales and C. de Haan (2006). *Livestock's long shadow; environmental issues and options*. FAO, Rome.
Tzilivakis, J., D.J. Warner, M. May, K.A. Lewis and K. Jaggard (2005a). An assessment of the energy inputs and greenhouse gas emissions in sugar beet (Beta vulgaris) production in the UK. *Agricultural Systems* 85: 101-119.
Tzilivakis, J., K. Jaggard, K.A. Lewis, M. May and D.J. Warner (2005b). Environmental impact

and economic assessment for UK sugar beet production systems. *Agriculture, Ecosystems & Environment* 107: 341-358.
United Nations (2006). *World Population Prospects: The 2006 Revision* and *World Urbanization Prospects: The 2005 Revision*. Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat. http://esa.un.org/unpp, August 31, 2007.
Van de Ven, G.W.J., N. de Ridder, H. van Keulen, and M.K. van Ittersum (2003). Concepts in production ecology for analysis and design of animal and plant-animal production systems. *Agricultural Systems* 76: 507-525.
Van der Knijff, A., J. Benninga and C. Reijnders (2004). *Energie in de glastuinbouw van Nederland*. Ontwikkelingen in de sector en op de bedrijven t/m 2003, report no. 3.04.13, LEI, The Hague, The Netherlands.
Van Ittersum, M.K. and R. Rabbinge (1997). Concepts in production ecology for analysis and quantification of agricultural input-output combinations. *Field crops research* 52: 197-208.
Van Ittersum, M.K. and J. Wery (2007). *Integrated assessment of agricultural systems at multiple scales*. In: Spiertz, H., Struik, P.C., Van Laar, H.H. (Eds.). Scale and complexity in plant systems research: gene, plant, crop relations. Springer, pp. 303-317.
Van Ittersum, M.K., S.M. Howden and S. Asseng (2003). Sensitivity of productivity and deep drainage of wheat cropping systems in a Mediterranean environment to changes in CO2, temperature and precipitation. *Agriculture, Ecosystems & Environment* 97: 255-273.
Van Ittersum, M.K., F. Ewert, T. Heckelei, J. Wery, J. Alkan Olsson, E. Andersen, I. Bezplepkina, F. Brouwer, M. Donatelli, G. Flichman, L. Olsson, A.E. Rizzoli, T. van der Wal, J.E. Wien and J. Wolf (2008). Integrated assessment of agricultural systems – A component-based framework for the European Union (SEAMLESS). *Agricultural Systems* 96: 150-165.
Venturi, P. and G. Venturi (2003). Analysis of energy comparison for crops in European agricultural systems. *Biomass and Bioenergy* 25: 235-255.
Yin, X. and P.C. Struik (2007). *Crop systems biology*. In: Spiertz, J.H.J., Struik, P.C., Van Laar, H.H. (Eds.). Scale and complexity in plant systems research: Gene-Plant-Crop relations. Springer, Dordrecht, The Netherlands, pp. 63-73.
Zwart, S.J. and W.G.M. Bastiaanssen (2004). Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize. *Agricultural Water Management* 69: 115-133.

Appendix 1 (detailed data of Table 4.2)

Land use and output in different regions in Europe based on EU statistics up to 2005

Region			Agricultural area (2004)				% of agricultural area	
Number	Name	Country	1 000 ha per MS	1 000 ha per region	% of land per MS	% of land per region	Arable[1] (2005) per MS	Arable[1] (2005) per region
1	Nordic	Finland	2 253	5 407	7	7	99	93
		Sweden	3 153		7		90	
		Norway						
2	British Isles	Ireland	4 307	21377	61	68	28	38
		United Kingdom	17069		70		40	
3	Western	Belgium	1 394	52765	46	52	61	66
		Denmark	2 664		62		92	
		France	29632		54		62	
		Germany	17020		48		70	
		Luxembourg	128		50		46	
		Netherlands	1 927		52		57	
4	Mediterranean	Cyprus	158	46355	17	45	64	51
		Greece	3 960		30		70	
		Italy	13159		44		53	
		Malta	10		30		85	
		Portugal	3 819		42		38	
		Spain	25249		50		49	
5	Alpine	Austria	3 254	3 254	39	39	42	42
		Switzerland						
6	North Eastern	Czech Republic	3 631	21867	46	50	75	75
		Poland	16301		52		76	
		Slovakia	1 935		39		70	
7	South Eastern	Bulgaria	5 331	26008	48	56	92	72
		Hungary	5 862		63		77	
		Romania	14324		60		63	
		Slovenia	491		24		35	
8	Baltic	Estonia	770	5 017	17	29	71	66
		Latvia	1 642		25		63	
		Lithuania	2 604		40		66	
	EU-27	EU-27	182 048		42	42		61
	EU-15	EU-15	128 989		40	40	57	57

[1] Cyprus, Bulgaria, Romania: 2003 data

					Horticulture		Irrigable area		Organic farming	
	Perm.[1] crops (2005) per MS	Perm.[1] crops (2005) per region	Perm.[1] pasture (2005) per MS	Perm.[1] pasture (2005) per region	Horti-culture[2] (2001-2004) per MS	Horti-culture[2] (2001-2004) per region	Irrigable area (2005) per MS	Irrigable area (2005) per region[3]	Organic farming (2003) per MS	Organic farming (2003) per region
	0	0	1	7	0.7	0.5	70500	4.4	7.1	10.5
	0		10		0.3		167 000		13.0	
							117 140			
	0	0	72	62	0.2	0.7	0	1.0	0.7	3.4
	0		60		0.8		208 380		4.3	
	2	3	37	31	5.1	1.6	21710	10.0	1.7	2.9
	0		8		0.5		432 030		6.2	
	4		34		1.7		2 706 480		2.0	
	1		29		1.0				4.3	
	1		52		1.8				2.3	
	2		40		5.1		407 920		2.0	
	27	21	1	27	14.8	10.9	45850	21.6	0.1	4.6
	30		0		33.1		1 593 780		6.2	
	17		30		10.8		3 972 670		8.0	
	10		0		3.4		3 020		0.0	
	21		40		6.3		616 970		3.2	
	22		28		8.1		3 765 130		2.9	
	2	2	56	56	0.7	0.7	119 420	3.7	10.1	10.1
	1	2	24	22	1.0	2.9	47030	1.6	7.0	1.6
	2		21		3.6		124 200		0.3	
	1		27		1.1		180 140		2.5	
	3	3	4	24	3.5	3.6	111 600	4.1	0.1	0.7
	3		18		3.8		152 750		2.6	
	3		33		3.7		808 370		0.3	
	6		60		1.7		4 430		4.3	
	1	1	28	32	2.4	2.0		0.1	5.4	1.8
	1		36		1.6		790		1.6	
	1		31		2.2		4 420		0.9	
		7		32	4.3	4.3			3.4	3.4
	9	9	34	34	4.7	4.7			4.2	4.2

[2] 3 to 4 year average

[3] some countries no data

Appendix 2

Area under arable crops (1 000 ha), by crop, 2004. (Source: Eurostat, 2007; Eurostat, 2006b; Eurostat, 2006c)

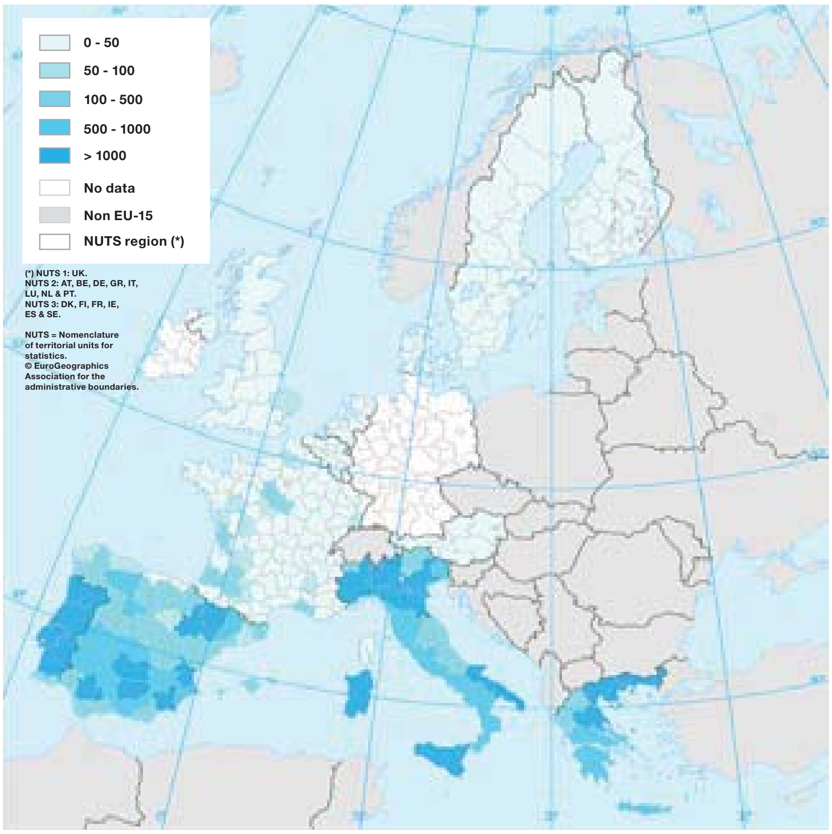
	Wheat	Rye	Barley	Oats	Corn	Potatoes	Sugar beet	Silage maize
Belgium	213	1	39	.	52	67	88	167
Czech Republic	863	59	469	59	88	36	71	216
Denmark	675	32	707	61	.	41	50	130
Germany	3 101	621	1 974	227	454	293	439	1 290
Estonia	76	9	128	***34***	.	23	0	1
Greece	839	10	90	43	251	36	33	4
Spain	2 152	91	3 170	477	480	98	103	90
France	5 231	33	1 626	124	1 796	***157***	384	1 451
Ireland	103	0	183	20	0	13	30	0
Italy	2 338	3	307	147	1 194	73	217	269
Cyprus	***5***	.	.	***0***	.	***6***	.	.
Latvia	166	42	138	54	.	46	***14***	***2***
Lithuania	355	56	293	53	1	69	23	14
Luxembourg	12	1	9	2	0	1	0	12
Hungary	1 173	45	331	69	1 234	31	62	103
Malta	.	.	.	.	.	2	.	.
Netherlands	139	3	48	2	22	165	98	224
Austria	290	46	191	30	179	22	45	76
Poland	2 311	1 550	1 014	520	412	713	292	286
Portugal	189	29	13	57	135	48	8	108
Slovenia	32	1	15	2	46	7	5	27
Slovakia	369	33	224	25	147	24	35	96
Finland	225	27	532	326	.	27	30	.
Sweden	404	24	393	226	.	31	48	5
United Kingdom	1 994	4	1 006	***122***	0	147	154	117
Bulgaria	1 040	9	329	43	383	31	1	30
Romania	2 296	22	425	208	3 239	266	21	34
EU-27	26591	2 750	13652	2 930	10116	2 472	2 252	4 751

Data from previous year

Source: Eurostat.

Appendix 3

Regional water abstraction rates for agriculture (million m^3/year) during 2000



The map illustrates the IRENA 22 sub-indicator that estimates regional water abstraction rates for agriculture, calculated by weighting national reported water abstraction rates by regional irrigable area. The 41 regions with the highest use of water for agricultural purposes (more than 500 million m^3/year) are all located in southern Europe. United Kingdom estimations are based on 1997 data for irrigable area and reported water abstraction rates. Ireland, Luxembourg and Germany do not provide data on irrigable area for NUTS regions. (Source: EEA, OECD, Eurostat).

Appendix 4

Farm-gate N surpluses in relation to production intensity: Flemish dairy farms in 1989-1990 (solid circles) and in 2000 and 2001 (open circles). Dutch experimental farms or farm groups (triangles). Isoquants of eco-efficiency (q, l milk/kg N surplus). (Source: Nevens et al., 2006)