NAE Chapter 2C

Environmental, Economic and Social Impacts of NAE Agriculture and AKST

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Key Messages

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1. Environmental effects of agriculture. AKST and policies leading to increased production in NAE have had negative effects on the environment. However, increased awareness of these effects has encouraged the development of tools to mitigate these effects. Their success has been variable. The greater awareness in recent years that farming has a multifunctional purpose, delivering ecosystem services as well as food (and energy) has changed attitudes and practices. The success of these mitigation practices depends on sound knowledge transfer systems.

a) Impacts of intensive cropping systems. Intensification of cropping has had varying impacts on the environment (water, biodiversity, soils). The following are examples: Soil quality has declined in much of the NAE over the last 50years. Intensive cultivation practices, aided by greater mechanization, have caused increased soil erosion. Intensification of production has had negative impacts on both biodiversity and water quality. Increased fertilizer use has resulted in raised levels in nitrogen and phosphorus in rivers and coastal waters. Increased pesticide use has resulted in some adverse environmental effects**.** Irrigation has led to salination and erosion. Increased mechanization and consequent changes in field sizes has resulted in the 'grain' of the landscape becoming coarser, with negative effects on biodiversity.

Specific issues: Bioenergy crops At present their environmental foot print is small but development of these crops should proceed with caution in order to maximize the carbon benefit and minimize any environmental effects. Substantial increases in the area devoted to energy crops may have a major impact on food production and prices. **Genetically engineered crops** The adoption of genetically engineered (GE) crops has so far not led to the creation of invasive species or had major impacts on non-target organism populations. However, there are concerns for negative impacts in the long term and a need for greater understanding of potential impacts.

b) Impact of intensive animal production systems. Greater intensity of animal production systems, combined with the increased spatial the segregation of crop and animal production units, has increased environmental effects. Manures (from intensive animal production) have increased nutrient levels and contaminated water systems. Greater intensity has also raised animal welfare concerns.

2. Impacts of Aquaculture. Expansion of the aquaculture industry, especially farmed salmonids, is leading to greater environmental impacts both directly through increased pollution and indirectly through depletion of fish stocks to create fishmeal for the farmed fish

3. Impacts of Forestry. The environmental quality of forests in the NAE has tended to decline in the 20th Century with some impacts on a range of species. However, as the quantity of forest is actually expanding in the NAE, this has the potential to have environmental benefits.

4. Agriculture and climate change. Greenhouse gas emissions from agriculture are in the range of 7-20% of total country emission inventories (by radiative effect) for NAE and are a contributor to climate change. Agricultural emissions are important for methane and nitrous oxide emissions. Approximately 30% of global methane is thought to originate from agriculture, of which enteric fermentation from ruminant livestock is by far the greatest contributor. Agriculture contributes at least one third of global emissions of nitrous oxide. The development and rise in the use of inorganic nitrogen fertilizers led to the increased emissions. Carbon dioxide emissions from agriculture are small, globally estimated to be 5%. Direct energy use only accounts for 1 and 2% of emissions

5. Food miles. The increase in food miles that has occurred in the NAE over the last 50 years has had negative effects on the environment, primarily because of increased energy use. Recent desires by consumers to source local food may reduce this in future

6. Economic impacts

a) Direct economic impacts. AKST operating with a changing economic and political environment has contributed to lower prices, benefiting consumers, but has led to pressure on farming communities and structural change in the food industry. In N. America and Western Europe (EU15) this has substantially increased the relative power of retail food business in relation to processors and farmers. Lower prices benefit consumers but there is increasing concern to source foods which are perceived to have improved quality/safety (e.g. organics, fair-trade). Farmers have faced reduced income and many families now depend on off-farm incomes to maintain living standards. Market power has shifted towards large retail organizations. Levels of waste (on farm inputs, food and packaging) have increased.

b) Impacts on structure of food and farming systems. Development of AKST has brought about significant changes in farm and food systems. Agriculture has become more capital intensive and less labor intensive. Large scale production raises the potential dangers of breaches in food safety leading to increased regulatory requirements and costs. The external impacts of agriculture on industries such as water and tourism have increased. AKST has raised major issues in relation to externalities. AKST has changed lifestyles within rural communities, resulting in more off-farm work, substantial migration within and between countries.

7. Social impacts. The increase in productivity achieved by NAE agriculture over the last 60 years, with the help of AKST, has contributed to provide people in NAE with more wealth, choice and

mobility. In most of the NAE there is today more food and a wider range of affordable food items available than ever before.

a) Food security and safety. Extensive testing of food for pesticide residues and for disease in food grown/reared or imported into the NAE indicates that few hazards exist to consumers. Developments in technology have allowed modern agricultural techniques to improve animal health. Increases in mechanization have resulted in redundancy in the farm labor force but the increased productivity/efficiency has enhanced worker environment by eliminating repetitive, dangerous and disliked tasks.

b) Migration of populations. The proportion of the work force involved in agriculture has declined dramatically in USA and W. Europe. The changes in Eastern Europe are more complex as the communist era greatly reduced the number of farming units, by collectivization. Following the demise of this system of land management in c. 1990 there has been a variable re-allocation of land to the former owners, resulting in fragmentation of the farming units

c) Equity. Drastic inequity prevails in food systems: between industrialized and developing countries, between urban and rural regions, and even between generations. Industrialization, globalization and consolidation have affected the ability of smaller producers to effectively compete with larger corporate entities with consequential effects on rural community structure and dynamics. A declining share of the consumer food 'Euro' is allocated to producers. There has been a growing interest in much of the NAE in 'alternative' food systems, in response to the numerous concerns related to industrialized agribusiness. These systems are currently still small in scale but are increasing.

d) Distancing of consumers from production. There has been an increase in both the spatial and social distancing between the stages of the food chain, separating consumers from production. Social distancing has contributed to detachment of consumers' understanding of the production system and food chain.

e) Nutritional consequences of NAE food systems. Obesity and associated diseases (diabetes, hypertension) have become increasing concern in much of the NAE (USA, Western Europe) as a result of agriculture providing more than adequate nutrition. Despite this situation of general abundance of food, some sections of the population whilst provide with an abundance of food, do not consume a sufficiently healthy diet and as a result develop dietary related diseases. A minority of the NAE, mainly Eastern Europe and the Commonwealth of Independent States still have an inadequate diet.

8. Impacts outside NAE. NAE has had a major impact on agriculture in the rest of the world, both directly by importing food and raw materials from the rest of the world and indirectly, through the

impact of NAE AKST. This impact of the NAE import requirements has had environmental and economic consequences for the rest of the world. Research undertaken in NAE has also had a global impact. Whilst other countries have derived some benefit, the focus of research has not been on their problems. The development of international research capacity via the CGIAR institutions has sought to balance this by research relevant to the needs of developing countries However, the intellectual paradigm that determines the conduct and direction of research remains powerfully influenced by the model of research in NAE countries.

2C.1 Environmental impacts of agriculture and AKST within NAE

Agricultural productivity depends for its success on the provision of adequate resources of water, nutrients, soil, and atmospheric carbon dioxide to deliver crops and animals for human consumption. Endeavors by man over many millennia have sought to exploit these resources to enhance food production. In the last 50 years AKST has promoted changes in mechanization, farm structure, cropping and management practices which have allowed farmers in NAE to dramatically increase agricultural productivity. This has provided the basis for improved heath, choice and mobility of the people of this region and has also provided food for other areas of the world. This intensification has wider environmental effects and it is a strongly debated issue as to whether such practices are environmentally sustainable in the long run. Future generations need to learn from the past to increase the sustainability of agriculture for the future. Previous subchapters of this report have presented information on how productivity has increased. This subchapter examines the environmental consequences and considers how changes in practices in recent years have started to reduce impact and increase sustainability. Some of these issues have already been discussed in the Millennium Ecosystem Assessment (MA, 2005), as agriculture is such a key component of the world's environment. This subchapter starts with comments on the impact of agriculture on soil, water, and biodiversity and then reviews the role of agriculture in relation to climate change. Subsequent subchapters then explore the impacts of specific agricultural changes on the environment (e.g. changes in fertilizer use, increase in mechanization, pesticides and irrigation, changes in farm size)

An important issue that must be mentioned at the outset of this chapter relates to education and knowledge transfer. In order to minimize environmental impacts it is vital that best practice is adopted by all farmers. This needs really effective knowledge transfer. There is some concern in the NAE that as food production has become increasingly successful and food shortages uncommon for much of the population (it is still an issue in some E. European states) government support for knowledge transfer has declined. Consequently KT has become increasingly the role of the private sector. There is some doubt as to whether the environmental goals identified in this chapter can be met by the private sector.

2C.1.1 Impact of agriculture on soil quality

Key message: Soil quality is the basis of agricultural productivity but it has been adversely affected by agricultural practices, resulting in soil degradation which may or may not be reversible. Agricultural land uses and management developed over the last 50 years have however helped to redress these adverse effects by stabilizing or improving soil quality.

Soil is one of the most basic of natural resources, serving as a critical link between agricultural productivity, economic progress, and environmental quality (Lal, 1998). While certain natural processes can damage soil quality, human activity in agriculture can initiate or accelerate soil degradation. The major threats to soil functions have been identified to be erosion, a decline in organic matter and overall soil nutrition status, local and diffuse contamination, sealing and crusting, compaction, a decline in biodiversity and salinization (CEC, 2002; Van Lynden, 2000). These threats are discussed below. It should also be noted that issues raised in this subchapter also relate to the subchapters on environmental impacts of fertilizer use and irrigation (see subchapters 2C.1.5.2; 2C.1.5.4).

Resulting soil degradation may or may not be reversible, and if reversible, the necessary actions or practices needed may range from relatively easy, quick, and inexpensive to impractical, slow, and expensive. Some agricultural land uses and practices developed over the last 50 years, e.g., various tillage methods, cropping systems, and nutrient management plans, can help stabilize or improve soil quality (Gregorich, 2002). It must be noted that agriculturally induced soil degradation is inextricably linked to the characteristics of the affected soil and the climate.

In both Europe and North America agriculturally induced soil degradation has been a major concern over the last 50 years and, indeed, was of considerable importance in the earlier decades of the 20th Century (e.g. the Dust Bowl in the Great Plains of the USA in the 1930s). It is still a major issue today. For example, in the EU-15, an estimated 52 million hectares, representing more than 16% of the total land area, are affected by some kind of degradation process (CEC, 2002). In the accession countries (EU-10), this figure is around 35% (GLASOD, 1992).

2C.1.1.1 Soil compaction

Human-induced soil compaction has increased dramatically over recent decades, largely related to mechanical stress caused by off-road wheel traffic and machinery traffic (Hakansson and Voorhees, 1998). This trend is related to increased mechanization and use of larger more efficient farm vehicles, leading to greater soil densification and corresponding reduction of productivity in some regions (see subchapter 2C.1.5.6). Reductions in organic matter related to over tillage and extensive use of inorganic fertilizers have also been related to increased susceptibility to compaction. It has been estimated that 4% of European soil suffers from it, being of higher importance in some East European countries (Batjes, 2000; CEC, 2002).

There have been observations of soil compaction and associated yield reductions since the 1930's, with increasing literature on this topic over the last 30 years (Hakansson and Voorhees, 1988). However, because of complex and interrelated soil, management, and climatic factors, the challenge has been to directly and quantitatively relate compaction to yield reductions and resulting economic impact. Gill (1971) estimated U.S. on-farm losses through land compaction at US$1.2 billion per year. Eswaran et al (2001) concluded that soil compaction caused yield reductions of 25 to 50% in North America

While the various causes and effects of soil compaction are interrelated and often difficult to assess, it is generally considered that this process and its amelioration is understood well enough that systems for its management on the farm can be reasonably formulated. Controlled traffic systems (tramlines) and appropriate cultivation practices (e.g. sub-soiling to break up sub-soil compaction) can be used to resolve compaction problems.

2C.1.1.2 Salinization

Salinity is an issue in soils both in Europe and North America. It is a common occurrence in U.S. semiarid and arid regions, i.e., where evapotranspiration exceeds rainfall, resulting in salt accumulation in the rooting zone (Derici, 2002). However, the salt problems of greatest importance to agriculture occur when previously productive soils become salinized as a result of agricultural activities such as improper or excessive use of irrigation (high in salts and/or Na relative to Ca and Mg); use of low-quality irrigation water (even good quality irrigation water has some salts); inadequate or no drainage system; land conversion from perennial species to annual crops with lower transpiration rates resulting in the raising of water tables; and actions promoting formation of saline seeps (Derici, 2002; Rhoades, 2002). This topic is most relevant in relation to irrigation use and is discussed in subchapter 2C.1.5.4.

2C.1.1.3 Erosion

Soil erosion can be caused by both wind and rain, their relative importance depending on climate. The Dust Bowl of the 1930's is perhaps the most famous example in the U.S. (Bonnifield, 1979; Worster, 1979; Hurt, 1981). In general, soil erosion is more severe in North America than in some countries in Europe, due to in part to differences in climate, e.g. higher intensity rains and climatic extremes (hot summers, cold winters) increasing the soil's susceptibility to water erosion (Lal, 1990). Other reasons are related to intensive land use, mono-cropping without frequent use of soil-conserving cover crops, continuous cropping, and the excessive and often unnecessary use of heavy machinery (Lal, 1990).

Accelerated erosion by running water has been identified as the most severe threat to soil in Europe (Kirkby et al., 2004), and is on the increase (Van-Camp et al., 2004). According to expert estimates based on non-standardized data (GLASOD, 1992), 26 million hectares in EU suffer from water erosion and at least 1 million hectare from wind erosion. The Mediterranean region is historically the most severely affected by erosion (the first reports date from 3000 years ago) and in more than one third of the total land of Mediterranean basin, average yearly losses exceed 15 tons per hectare (CEC, 2002), while a yearly loss of 1 ton hectare can be considered as irreversible within the time span of 50 to 100 years. There is also growing evidence of significant erosion in other parts of Europe (e.g. Denmark, Austria, Czech Republic and the loess belt of Northern France and Belgium). In the Central and Eastern Europe (CEE), erosion is a major environmental issue. Areas affected range from 5% to 39% of the total surface (Van Lynden, 2000). In 1991, the direct cost impact of erosion in Spain was estimated at ECU 280 m per year, including the loss of agricultural production, impairment of water reservoirs and damage due to flooding

(ICONA, 1991). In addition, the cost of attempts to fight erosion and restore the soil was estimated at about ECU 3000 m over a period of 15 to 20 years.

In 2003, USDA data on soil erosion on U.S. cropland indicated soil losses of 1.75B tons, with sheet and rill erosion of 971M tons per year, and wind erosion of 776M tons per acre (Fig.2C, 1.1), USDA-NRCS, 2003). However, these figures also demonstrated a dramatic decline of 43% since 1982 from an overall value of 3.06B tons.

Erosion has been exacerbated by changes in land structure (disappearing of landscape elements such as hedges, shelterbelts, field margins with permanent vegetation, increased field sizes and surface modeling for machinery), plowing of permanent pastures, separation of livestock from arable production, the conversion from mixed rotations to continuous arable cropping and monocultures, and to high stocking rates and overgrazing even on uplands. Adoption of other practices, which cause decline in plant-cover and soil organic matter and increase soil tillage and soil compaction, have all aggravated erosion.

Adoption of soil protection measures such as different cropping patterns and rotations have succeeded in reducing erosion both in North and South Europe, even on soils under intensive production. (Van-Camp et al., 2004) Similarly, in N. America developments in AKST have provided guidance to farmers on how to minimize the risks of erosion, particularly through the use of conservation tillage.

[Insert Figure 2C.1.1: Erosion on cropland by year in the U.S.]

2C.1.1.4 Effects on soil organic matter, soil nutrients and soil pH

Intensive agriculture can have great effects on soil fertility. This can manifest itself in loss of nutrients and organic matter and in soil acidification. Many practices can cause these effects including: intensive cropping with inadequate or no return of crop residues, heavy tillage systems which accelerate organic matter decomposition and increase nutrient release, inadequate, excessive or inappropriate application of fertilizers and lime and irrigation. With increased AKST considerable advances have been made in resolving these issues, but problems remain both in North America and in Europe.

Significant progress was made in the USA in the 1940's in addressing soil acidification through increased application of liming materials. This increase was largely due to farm subsidies and when these were discontinued there was a decline in the demand. In 1975 it was estimated that 88 million tons of limestone were required annually, but only 24 million tons had been applied (Tisdale and Nelson, 1975). In more recent years, this trend has been reversed in some parts of the U.S. (Jackson and Reisenauer, 1984; Lathwell and Reid, 1984; McLean and Brown, 1984). Higher fertilization rates, especially N, causing the production of high grain yields, have actually resulted in a higher depletion rate of nutrients and lime reserves (McLean and Brown, 1984). Advances in plant breeding and management practices have resulted in higher-yielding crops, leading to increased nutrient demand (e.g., N, P, K) and inducement of micronutrient deficiencies (Karr, 2006). Many U.S. soils are naturally low in available levels of one or more micronutrients and heavy crop demands over time increases the severity of the deficiency (Karr, 2006).

[Insert Figure 2C.1.2: Concentration of organic carbon in the top soils of western and central Europe. A map compiled by European Soil Bureau (Jones et al., 2005)

Similar issues have arisen in Europe. A recent estimate of the quantity of soil organic matter (presented as soil organic carbon (SOC)) in the soils of Europe has been recently published (Fig. 2C, 1.2). It shows that there is a decreasing trend in SOC concentration from north to south, due to natural factors. Carbon sequestration potential in soils of Europe has also been evaluated (Sauerbeck, 2001; Freibauer et al., 2004). According to the European Soil Bureau, based on the limited data available, nearly 75% of the total area analyzed in Southern Europe has a low (3.4%) or very low (1.7%) soil organic matter content. Soils with less than 1.7% organic matter can be considered to be in pre-desertification stage. Land use changes from forest or grassland to arable agriculture have been and still are a significant source for the release of former plant and soil carbon into the atmosphere (Sauerbeck, 2001, with references).

Changes in agricultural practices over the last 30 years have slowed this decline in soil organic matter. For example, conservation tillage has been a major part of the U.S. conservation program since the 1970's and its use to sustain or increase SOM have been continually re-evaluated and adapted over the years to reflect its need and effectiveness under different U.S. climates and soils (Bruce et al., 1990; Havlin et al., 1990; Wood et al., 1991; Reeves and Wood, 1994; Franzluebbers et al., 1994; Aase and Pikul, 1995). Similarly, the introduction of no-till and reduced till techniques has increased the carbon content of arable soils in Europe (Arrouays et al., 2002). However, in England and Wales, the percentage of soils with less than 3.6% organic matter rose from 35% to 42% in the period of 1980 to 1995, probably due to changing management practices. In the same period, in the Beauce region south of Paris, soil organic matter has decreased by half for the same reason (CEC, 2002), indicating that not all changes in practices are beneficial to soil organic matter. It should be noted that differences in SOM (and hence carbon sequestration) response to reduced cultivation will be influenced by climatic and soil factors. A recent review by Baker et al (2007) has concluded that more rigorous interpretation of experiments looking at the interactions between tillage, and SOM and carbon sequestration leads to the conclusion that the evidence 'that reduced tillage promotes carbon sequestration is not compelling'. So, although reduced cultivation may have other benefits (e.g. reduced energy use, less impact on soil invertebrates), its effects on soil carbon levels are not altogether clear.

2C.1.1.5 Soil Pollution and Contamination

The introduction of contaminants into the soil may result in damage to or loss of soil functions and cross contamination with water. Diffuse soil contamination is of major importance in Europe and is generally associated with atmospheric deposition, certain farming practices and inadequate waste and wastewater recycling and treatment (CEC, 2002). Atmospheric deposition is due to emissions from industry, traffic and agriculture. Deposition of airborne pollutants releases into soils acidifying contaminants (e.g. SO_2, NO_x), heavy metals (e.g. cadmium, lead, arsenic, mercury), persistent pesticides (e.g. lindane, DDT, aldrin) and organic compounds (e.g. dioxins, PCBs, PAHs). Nitrogen deposition, often originating from agriculture (mainly NH_3 emissions), also causes soil enrichment decreasing biodiversity. In some European forests nitrogen input has reached extreme values of 60 kg N per hectare annually, while pre-industrial deposition was below 5 kg (UN and CEC, 2000). Acidification is affecting about 35% of Poland and Hungary, and Latvia and Lithuania are also affected (Van Lynden, 2000). Clearly, excessive application of mineral fertilizers or manures can cause negative effects on soils and on the wider environment. These are discussed in the subchapter 2C.1.5.2 on fertilizer use. .

Heavy metals (e.g. cadmium, copper, zinc) in fertilizers, municipal wastes (as amendments), agricultural biosolids (manures from poultry and swine), and animal feed may become enriched in soils and they, like the antibiotics in feed, may get into the food chain. The effects of these on soil functions are not fully understood (CEC, 2002). A wide variety of synthetic organic and inorganic chemicals are also used in agriculture to control a variety of plant, insect, or animal pests. There are concerns over the persistence (decomposition), transport, and fate of these applied products, especially as many of these compounds and their decomposition products end up in surface and groundwater (Thurman et al., 1992). Pesticide use is widespread but despite the authorization process and regulation of their use, they are found in the food chain and in groundwater and surface water (CEC, 2002). Many ground water supplies in the EU 15 periodically exceed the Drinking Water Directive (Directive 98/83/EC) maximum of 0.1 μg/l for a single pesticide (EEA, 2002). Similarly, pesticides have been found in water extracted for irrigation from the High Plains (Ogallala) aquifer in the USA (Spalding *et al.,* 2003).

2C.1.1.6 Soil Sealing and Crusting

Soil susceptibility to rainfall induced sealing and crusting depends upon a combination of physical, chemical, and biological processes, highly affected by climatic and soil conditions prevailing during seal formation (Bradford and Huang, 1992). In general, cultivated soils are structurally unstable and surface seals and crusts are common phenomena of these soils (Shainberg, 1992). These phenomena are considered major contributing processes to agricultural and environmental degradation in the Western, North Central, and Southeastern U.S. (Sumner and Stewart, 1992). Sealing and crusting are particularly prevalent on irrigated soils (see subchapter 2C.1.5.4 on irrigation) and in dryland farming under marginal precipitation. Loss of organic matter from soils inherently low in these materials, (e.g. through overgrazing of rangelands and intensive cultivation) increases the soil's susceptibility to surface sealing and crusting (Smith and Elliott, 1992). A number of soil management practices (e.g. no-till, winter cover crops) and irrigation practices (Singer and Warrington, 1992; Rhoades, 2002) have been used to reduce or ameliorate crusting problems in the West of the USA.

Thus, agricultural practices have resulted in significant adverse effects on soil quality over the last 50 years, depending on the type of agriculture, the soils affected and the climate. However, increased awareness arising through appropriate AKST has facilitated the development of techniques that can reduce these adverse impacts.

2C.1.2 Impacts of agriculture on water

Key message: Water is a vital component of all agricultural production systems. Over the last 50 years there has been increasing demand and usage of water, contributing to higher production in NAE, but resulting in increasing pressure on supplies of water both from rivers and from aquifers and increased levels of water pollution. The second critical element of agriculture, after soil, is water. Agriculture is a major user of water, as discussed elsewhere in this report and the conflict between demands for water for agriculture and demands for human consumption will increase. Enhancement in crop production in many parts of the world depends on irrigation and the environmental consequences of irrigation are discussed below (see subchapter 2C.1.5.4). Agriculture also impacts on water quality, as excess fertilizer, pesticides and other products of agriculture in drainage water can pollute water supplies, rendering them unusable, without appropriate purification, and causing appreciable environmental damage by degradation of the quality of both fresh and salt waters. Water impacts are inextricably linked to those of soil and have already been mentioned above in the subchapter on soil quality. They are also discussed in the relevant subchapters on the environmental impacts of a wide range of agricultural inputs described below (e.g. subchapter 2D 1.5.3 on pesticides and 2C.1.5.2 on fertilizer).

Water quality has been degraded across the whole of the NAE over the last 50 years, as a result of the intensification of agriculture. Also demands of agriculture for water have caused appreciable depletion of underground aquifers. For example, the High Plains (Ogallala) Aquifer under the mid West of United States has declined substantially over the last 50 years (http://co.water.usgs.gov/nawqa/hpgw/journals/DENNEHY1.html), causing concerns as to the future.

More sustainable use of water will be needed in future to reduce the adverse effects of agriculture.

2C.1.3 Impacts of agriculture on the atmosphere: climate change and air quality

Key message: Agriculture is a small but non-trivial contributor to greenhouse gas emissions, especially of methane and nitrous oxide. The final component of crop productivity, after soil and water, is carbon dioxide, which is the basic building block for all carbon based materials (sugars, proteins etc).

But agriculture also impacts on the atmosphere through its use of energy and release of greenhouse gases. The practices of agriculture have effects on the atmosphere at global, regional, and local levels.

At the global level, agriculture is a factor in the budgets of gasses, increasing the atmospheric greenhouse effects leading to global warming. Local and regional effects include odor problems and emissions of ammonia which contribute to regional nitrogen deposition, a factor in acid rain and eutrophication of water bodies.

Agriculture affects the budgets of three greenhouse gasses that are subject to change by human activities, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_20). Carbon dioxide, concentrations have increased by 30%, CH_4 by 151% (i.e. 2.5 times pre-industrial), and N_20 by 17% over pre-industrial levels. The primary greenhouse gas is CO_2, having a concentration much higher than the other two. Methane (CH_4) and N_20 have a stronger greenhouse effect than CO_2 on a molecule per molecule basis, but are present in the atmosphere at low enough concentrations that CO_2 is responsible for most (about 60%)of the human-induced greenhouse effect while CH_4 and N_2O represent 20 and 6% respectively (as of late 1990s, IPPC, 2001). Although greenhouse gasses emitted by agriculture are relatively small they are non-trivial, additions to the total emissions in the NAE region. In the EU, agriculture represents 9.9% of total EU emissions. Agriculture accounts for 6.3% and 19.2% of total emissions for the U.S. and Canada, respectively (IPPC, 2001; also see Franzluebbers and Follett, 2005).

2C.1.3.1 Carbon Dioxide (CO_2)

The clearing of forests to create farmlands releases carbon that was bound in the trees into the atmosphere as CO_2. However, land use programs of afforestation/reforestation/forest management in North America and Europe have contributed to terrestrial ecosystems becoming a net sink in these regions (Millennium Ecosystem Assessment chapter 13 “Climate and Air Quality”). In recent decades the total amount of forest cover in NAE has been relatively stable, with clearing in some areas being balanced by expansion of forests in others.

The amounts of CO_2 held both as plant matter and soil organic carbon in agricultural fields is often much lower than that found in native vegetation and soils. Conventional plowing agriculture reduces the amount of organic carbon in soils resulting in a net release into the atmosphere. Farm machinery and heating of farm buildings is also largely dependent upon fossil fuels, with consequent release of CO_2 to the atmosphere.

[Insert Table 2C.1.1: Summary of soil organic C decline with cultivation, soil organic C sequestration, in response to agricultural management among five regions in North America (Taken from Franzluebbers and Follett, 2005)]

After decades of conventional plowing cultivation soils may lose well over 50% of their native organic carbon (e.g. Paustian et al., 1997). With the large areas committed to agriculture in NAE, these changes in local carbon content of vegetation and soils are a significant component of the global carbon budgets. Where agricultural lands are abandoned and forests allowed to regrow, there is a net transfer of CO_2 from the atmosphere back to the land. Where traditional plowed agriculture is replaced by a no-till or reduced tillage practices, the amounts of soil organic carbon can increase with a net transfer of CO_2 from the atmosphere to the soil (Table 2C.1.1).

Other sources of CO_2 emissions from agriculture include emissions from burning of fossil fuels used in mechanization and use of farm machinery, energy use for irrigation pumps, temperature control in indoor and glasshouse units, the burning of agricultural waste, and drying of agricultural crops for storage. Since the mid 1960's the primary direct energy use on US farms has shifted from gasoline (petrol) to diesel powered engines. Farm energy use in the USA has been estimated to be 9.2 and 3.5Tg C02-C equivalent for diesel and gasoline respectively (Lal et al 1998). However, relative to other sources of CO_2, these sources are small. Estimated CO_2 emission directly from agricultural energy use in the USA in 2001 is only 2% of total CO_2 emissions (USDA, 2004). Similarly, UK statistics suggest that emissions due to such agricultural fossil fuel and lime use accounted for less than 1% of total CO_2 emissions in the UK (MAFF 2000). There are also several indirect implications of agriculture on CO_2 emissions in NAE, such as the manufacturing of fertilizers and pesticides and the packaging and distribution of agricultural products.

A major technological change that can result in farm energy savings is the adoption of conservation tillage. Through the use of herbicides to reduce competition from weeds instead of plowing, and by direct seeding, the amount of farm energy use can be reduced substantially. Change from traditional tilling to no-till agriculture can reduce total farm energy use (for North American farms) by as much as 80% (e.g. Lal. 2004). It has the added benefit of also increasing levels of organic carbon in soils. Although from energy and general ecosystem viewpoints no-till and min-till approaches to crop establishment are very beneficial, their reliance on herbicides to manage weeds does increase usage appreciably, with consequent environmental risks.

2C.1.3.2 Methane (CH_4)

Methane is introduced to the atmosphere from a variety of sources, both natural and anthropogenic. Agriculture is a significant contributor of methane through its generation in soils in rice paddies, by enteric fermentation in the digestive systems of livestock, and methane loss from manures. Methane is generated in nature by bacteria in environments where there is a lack of oxygen to completely convert the energy in organic carbon sources completely to CO_2 (such as sediments in wetlands, landfills, and manures).

Husbandry of ruminant animals is the major source of increased agricultural emissions of CH_4 (including lagooning and management of waste) (Prather et al 2001). It is estimated that ruminant livestock production (including cattle and sheep) accounts for 90% of agricultural methane because of their unique digestive system allowing them to digest course plant material. The most recent UK estimates are that 80% of emissions are from enteric fermentation and 20% from animal waste (Anon, 2006). Table 2C.1.2 shows the CH_4 contributions from enteric fermentation of different groups of livestock in the USA, with beef and dairy cattle combined accounting for over 90% of the emissions. In the UK cattle alone account for 75% of these enteric emissions. Manipulation of the diet in these concentrated animal feeding operations (CAFO's) is one of the major methods available to manage these emissions (MAFF 2000).

[Insert Table 2C.1.2: Methane emissions from enteric fermentation (Gg)]

Where methane can be collected, as from systems to collect methane from manure, the methane can be used as an energy source to generate heat and electricity (e.g. Williams and Gould-Wells, 2004). Extraction energy from the conversion of methane to CO_2 reduces the greenhouse effect, as CO_2 is not a strong a greenhouse gas as is methane. Such manure management also reduces potential for runoff pollution from manure wastes, and may also reduce odor problems.

2C.1.3.3 Nitrous Oxide (N_2O)

Nitrous Oxide is produced by bacteria due to inefficiency in the bacterial conversions of ammonia to nitrate (nitrification) and the conversion of nitrate to nitrogen gas (denitrification). Human activities have greatly increased the amount of nitrogen in soils through application of synthetic fertilizers, by the planting of legumes, and by nitrogen deposition from the atmosphere. The increased soil nitrogen availability leads to greater N_2O production. Globally, production of N_2O from agricultural sources and represents about 60% of all anthropogenic sources.

This relatively high N_2O contribution from agriculture is found especially in NAE countries. For example in Greece, agriculture represents the largest anthropogenic source of nitrous oxide emissions (65.2% approximately of the total nitrous oxide emissions in 2002). However, actual emissions from this sector have decreased by 9.2% since 1990, mainly because of new agricultural practices that have modified fertilizer use (National Observatory of Athens). In Poland, agricultural emissions of N_2O in 2003 accounted for approximately 68% of the country's total emissions (National Emission Centre, Poland), while this is estimated to be 72% for Canada.

2C.1.3.4 Additional impacts of agriculture on climate change and air quality

Agricultural operations cause change in the reflectance (surface albedo) of solar radiation back into the atmosphere from the earth's surface. Agriculture land (particularly darker soils of moister climates) and vegetation (agriculturally bred for dense canopy cover and hence high leaf area index) often trap light and reduce reflectance and aid atmospheric cooling. Increased cultivation can lead to increased evapotranspiration and therefore also lead to local cooling. Simulation models have show that such intensive agricultural cultivation activities in the East and Midwest of the USA in the last century have caused cooling in this area by an estimated 1 to 2^{o}C (Bonan, 1999). Another example is the draining of wetlands in Florida for agriculture which has had the effect of reducing the protective effect of moisture in the air and hence has created a greater probability of damaging freezing events (Marshall et al 2003)

Dust from agricultural management and erosion with tillage operations causes air quality problems such as respiratory effects in humans and reduction in visibility. Dust particles in the atmosphere also impact on the climates through modifying the reflecting and trapping of solar radiation. There has been a move in recent years to reduce these emissions in agriculture through for example a move towards conservation tillage management in the dust bowl regions of North America.

Other land-use related activities associated with agriculture can cause the emission of aerosols into the atmosphere such as mineral dust, and nitrates which have a much shorter lifespan in the atmosphere and therefore a greater regional impact close to their source (Houghton et al 2001).

2C.1.4. Impact of agriculture on biodiversity and ecosystem services

Key message: Increased farming intensity over the last 50 years, although leading to appreciable increases in production per unit area, has had a negative impact on components of the ecosystem, such as biodiversity and quality water supply.

2C.1.4.1 Ecosystem services

Agriculture both depends on ecosystem services and generates them. Agricultural ecosystem services can be grouped into three categories: direct support for agricultural production, direct contributions to the quality of life of humans and contributions towards global life-supporting functions (carbon sequestration, supply of fresh water (e.g., Björklund, 2004)). Although the natural environment of agriculturally managed areas will generate ecosystem services for the benefit of agriculture (e.g. parasitoids to attack crop pests, plants to support pest predators), agriculture, especially intensively managed can drastically reduce overall biodiversity and also reduce ecosystem services.

Assessment of ecosystem services was adopted as an integral part of the Millennium Ecosystem Assessment (MA, 2005). The attempts to manage ecosystem services are of great interest for the future sustainability of world agriculture. Actions to increase food production often cause degradation of other ecosystem services: conversion of ‘natural’ habitats to crop production; increased demand for plant nutrients and water; water pollution; reduced biodiversity; and the spread of invasive species (MA, 2005). There is considerable debate about the most appropriate approaches to reduce imbalances in ecosystem services. The 'ecological' emphasis implicit in ecosystem service approaches has been questioned by those who favor increasing intensity of production in some areas and thus conserving other areas for off-farm biodiversity (land sparing) (Green *et al.,* 2005; Vandermeer and Perfecto, 2005). The study of Pretty et al. (2006) indicated that this debate may miss important opportunities for achieving win-win solution between productivity and ecosystem services.

2C.1.4.2 Agriculture and biodiversity

Agriculture (including forestry) is the dominant land use throughout much of Europe. As a consequence agriculture has a huge footprint on the overall ecosystem, especially in intensively farmed countries such as France, The Netherlands and UK, where agriculture and forestry occupies the majority of the land surface. There have been widespread declines in the populations of many groups of organisms associated with farmland (e.g. arable plants, invertebrates, farmland birds) since the 1940s in Britain and North-West Europe. A review of 18 studies investigating changes in wildlife in arable farmland in Great Britain confirmed the decline of many taxa investigated. In only two studies (on butterflies) was there evidence of an increase over the survey periods (Robinson and Sutherland 2002). Similar results have been found in Portugal (Stoate *et* al., 2001).

At a wider European level decline in farmland bird populations have been related to agricultural 'intensity' (Donald *et al*., 2002). At its simplest there is a link between average cereal yields (FAOSTAT) and the rate of bird decline (Fig 2C.1.3). Other data support this, suggesting that bird declines are linked to increased use of pesticides, high input cereal farming, increased field sizes, loss of habitat diversity, loss of hedges, changes in sowing times and harvesting, and the replacement of hay by silage. A similar study on invertebrates has reported on changes in bees and hoverfly populations in Britain and the Netherlands pre and post 1980, concluding that there has been a decline in bee diversity in most of the assessed areas in both countries since 1980 (Biesmeijer *et al.* 2006). This decline seemed to be linked to declines in pollinator plants, which may well have become less common as a result of agricultural intensification (Preston *et al.,* 2002). The overall conclusion for Europe, east and west, is that increased farming intensity over the last 50 years, although leading to appreciable increases in production per unit area, has had a negative impact on the environment and ecosystem services (Tilman 1999). A further complicating issue relates to the impact of land abandonment in some areas of East and southern Europe on biodiversity. Economic pressures have resulted in fields not being farmed and as a consequence scrub has started to invade, degrading the habitats' suitability for many farmland species, though it does increase its suitability for others.

[Insert Figure 2C.1.3: The relationship between mean farmland bird population trend and cereal yield across Europe

Concerns about the impact of food production on ecosystem services loom less large in N. America, although American-based ecologists are as concerned as European scientists about the impact of agriculture on the ecosystem (Tilman 1999). Agriculture has a much smaller ‘footprint’ in N. America, as in the USA it uses less that 50% of the land surface and in Canada less than 10% (FAOSTAT, 2006). In general, management strategies of U.S. natural resources have moved toward land or ecological-based systems which recognize the important role of the soil (Robertson et al., 1999). There has also been a changing philosophy to rangeland management in the U.S. over the last 50 years (Orr, 2006). Rangeland use has evolved from grazing systems, to domesticated livestock production (Sampson, 1923); to a more scientific approach incorporating soil science, geomorphology, climate, ecology, and animal science. These recognize the need for “resource rehabilitation, protection and management for multiple objectives including biological diversity, preservation, and sustainable development for people” (Heady and Child, 1994, Stoddart *et al*., 1975). Despite this changed philosophy more than one-half of all U.S. rangeland ecosystems have lost 98% of pre-settlement flora, to agricultural use. The amount of U.S. grazing land and rangeland is expected to continue to decline slowly over the next 50 yr, with the land use shifts away from grazing use but there is no indication that endangered rangeland ecosystem types are being lost except for desert grasslands (Mitchell, 1999, Van Tassell, 1999). Advances in technology are not expected to significantly change the overall forage supply.

A further element in the USA response to concerns about impacts of agriculture on biodiversity was the establishment of the Conservation Reserve Programme in 1985. This aims to encourage farmers to convert erosion and environmentally sensitive crop land to areas suitable for the conservation of biodiversity. It has been credited with the regional recovery of several animal and bird species (USDA, 1996). An issue of particular concern in N. America, though it is also relevant in Europe, relates to the spread of introduced invasive species. Not only do invasive pests cause huge losses to agricultural production, they also threaten the native ecosystems (Carruthers 2003, Pritekel *et al.,* 2006).

The decline of biodiversity can be at least partly attributable to the changes in farming systems which advances in agricultural technology have made possible. For example:

- the widespread use of pesticides has impacted on non-target species (this is discussed in more detail in subchapter 2C.1.5.3),
- the development of machinery capable of establishing crops on soils not previously amenable to crop production (see subchapter 2C.1.5.6),
- the increased size of machinery aimed at increasing efficiency has resulted in field amalgamations and losses of hedges and other wildlife habitats (see subchapter 2C.1.5.7)
- Simplification of rotations so that only a limited number of crops are grown, thus decreasing the planting of those with different biology and planting times, that formerly provided a greater range of habitats for wildlife

- The replacement of hay crops by the earlier harvested silage, for intensive animal production

However, AKST has also provided tools and expertise to assess impacts of agricultural changes on wider biodiversity.

2C.1.5 Environmental consequences of changes in agricultural practices and production systems

The following subchapters review the impacts on the environment arising from various key components of agricultural change over the last 50 years, ranging from changes in inputs, to changes in farm organization to overall increases in intensity of production.

2C.1.5.1 Environmental consequences of changes in land use (cropping, production systems)

Key message: The huge changes in agricultural production systems over the last 50years in the NAE have had major impacts on the environment. AKST has provided 'tools' (e.g. pesticides, machinery) to facilitate these changes. In general, change has been in the direction of increased intensity of production, but there has been growing recognition of an increasing need to balance production increases against the environmental impacts. All changes in the way land is farmed have the potential to change the overall agricultural ecosystem. AKST over the last 50 years has provided tools to permit a wide range of farming systems to be developed. Different production systems (crop, animal, forestry) have differing impacts on the ecosystem. For example, returning plowed cropped land to grassland will increase soil organic matter content, decrease erosion potential and decrease pesticide inputs, but it could increase risks of nitrogen, phosphorus and bacterial pollution from the animals grazing the new grassland. Similarly, switching production from one crop to another can increase or decrease the threats to various elements of the arable ecosystem. For example, cotton requires high levels of pesticide use, horticultural crops often require high levels of fertilizer, wheat crops can be established with minimum soil disturbance (minimum tillage), and root crops can impact on soil structure, because of the soil disturbance at harvest. In recent years there has been much debate, at least in W. Europe, about the relative environmental impact of different crops and indeed on how those crops were grown. Farms maintaining diversity through growing a variety of crops, that practice integrated pest management, are pesticide free, or are organic, are often viewed as having less impact on the environment than monoculture and high-intensity cropping. The main issue is that as a result of AKST and economic drivers, there has been increased intensification of production across the NAE area. Many of the issues associated with this greater intensification are covered in more detail in subsequent subchapters (e.g. increases in bioenergy crops, expansion of aquaculture)

2C.1.5.2 Environmental consequences from the increased use of fertilizer (particularly inorganic fertilizer)

Key message: Inorganic fertilizer use has had significant effects on the environment through such impacts as ground water contamination and eutrophication of rivers, lakes and coastal

environments. However, good agricultural practices can help to reduce nutrient loss very significantly. This will continue to be an issue of concern in the future. The increase in the use of inorganic fertilizer has environmental and potential human health consequences. The traditional use of organic fertilizers (especially manures) has declined as a result of increased specialization of producers. Mixed farms with both animal and crop production, where manure could easily be used as fertilizer, have declined. Much livestock is finished in feeding operations which import feed and produce large amounts of manure, creating a local oversupply of organic fertilizer. Hence crop farmers without animals must rely on inorganic fertilizers, and animal feeding operations must deal with an excess of organic fertilizer.

Not all the nitrogen and phosphorus applied to agricultural fields ends up in the target crops. It is estimated that on average for the U.S. only 65% of the nitrogen is harvested (NAS 2000) and 20% is leached to water. A small portion of the nitrogen is volatilized to the atmosphere (2%) and the remainder is either building up in soils or is denitrified. This leads to huge increases in the amount of fixed nitrogen and phosphorus that can severely affect aquatic and marine ecosystems. Phosphorus from agriculture can contribute to eutrophication of fresh waters, and agricultural nitrogen contributes to it in coastal marine waters. The eutrophication of water bodies has led to increased plant growth, with the consequence that decaying plant matter sinks to the bottom of water bodies and strips oxygen from the water creating hypoxic zones, making the system far less suitable for desirable organisms. In recent decades concern over eutrophication has been focused on effects in coastal waters, as there are numerous hypoxic zones on in the coastal waters of North America and Europe (UNEP 2004). The contribution of agricultural nitrogen to coastal eutrophication in different watersheds is quite variable (NRC 2000) and depends upon the relative amount of atmospheric deposition of reactive nitrogen from combustion sources and point sources in the watershed. Nevertheless, it is clear that agricultural nitrogen is often a significant, if not the major source.

In 2000, the European Union announced the establishment of an all-embracing ‘Water Framework Directive’ (http//ec.europa.eu). This requires that all inland and coastal waters within defined river basin districts within the EU must reach at least *good status* by 2015 and defines how this should be achieved through the establishment of environmental objectives and ecological targets for surface and ground waters. This is focusing very strongly on the impacts of nitrogen and phosphorus. There is still much debate as to what is defined as ‘good status’, but reductions in levels of nitrogen, phosphorus (and pesticides) in ground and surface waters are clearly a primary objective. Use of appropriate on-field farming practices can make major reductions in fertilizer runoff without significant reductions in agricultural productivity. Table 2C.1.3 lists a few examples. Further runoff prevention can be achieved through use of uncropped ‘set-aside’ areas as buffer zones and wetlands, or pastures to process runoff from croplands adjacent to surface waters (Table 2C.1.4). The performance of wetlands depends significantly upon the length of time the water sits in the wetland before it flows out. Overall, the performance of wetlands averages about 60-70 % removal of total nitrogen (Peterson, 1998). Buffer practices will remove some productive areas from field crops but these zones do not need to represent a complete loss. A properly managed buffer can support tree crops for timber or fruit or nut production or become a refuge for beneficial invertebrates. This can provide some diversity to the farmer's income. The outer zones of the buffer zones may be used for grazing.

[Insert Table 2C.1.3: Examples of the magnitude of benefit of different on-field agricultural practices]

[Insert Table 2C.1.4: Examples of the magnitude of the benefit of different off-field management practices]

It should be noted that although many of the eutrophication problems arising from fertilizer use are linked to inorganic fertilizers, inappropriate and over-use of organic manures derived from intensive animal production units, can also cause similar problems. These issues are discussed in more detail in the subchapter on animal production systems (2C.1.5.9).

2C.1.5.3 Environmental consequences from the use of pesticides and other agricultural chemicals

Key Message: Pesticide use has increased greatly in the NAE resulting in some adverse environmental effects. But changes in products to less environmentally hazardous ones and increased regulation has reduced impacts on water, soils and biodiversity, though some problems still remain. The general category of pesticides includes chemicals used to target a variety of different groups of organisms. The majority of pesticides are insecticides, herbicides and fungicides. This subchapter will also briefly consider the effects of agricultural pharmaceuticals on the environment. The potential toxic or other adverse effects of pesticides on farm workers, members of the public near pesticide applications (e.g. downwind or exposed to overspray), and persons handling pesticide containers, and the issues of pesticide residues on foods and in drinking water sources are important topics, but are not addressed in this subchapter.

A general concern with pesticides is that they may affect organisms other than those that are causing the impediment to agricultural practice or harvest (e.g. Somerville and Walker, 1990). Many of the chemicals which target a particular insect, for example, are also toxic to insects which are not problems for agriculture. For example, some insecticides are toxic to pollinating honeybees, which if not pollinators for the crop they are being sprayed on, may well be pollinators for nearby plants, both cultivated and wild. Pesticides running off farmers fields may have direct toxic effects on aquatic organisms. Herbicide runoff may influence the species abundance of plants in aquatic systems.

In addition to the direct toxic effects to pesticide exposure, there may be consequences to organisms which are exposed to very low levels of pesticides through food chain exposure. (A description of the processes responsible for the concentration of pesticides and other chemicals in certain organisms can be found in Hinga et al., 2006) The case of the chlorinated, persistent, pesticide DDT being concentrated in predatory birds and leading to reproductive failure is well known. It is the potential for similar not-easy-to-predict effects, or perhaps not-even-easy-to-identify the cause of the effects which are taking place, that is a continuing concern. Also of concern are the food-chain effects caused by use of agricultural chemicals. Pesticides can change the populations of food sources for higher level organisms (tri-trophic interactions). For example, the control of insects may directly (in the case of an agricultural pest) or inadvertently reduce insect prey populations, which in turn limit the size of a bird population which feeds on the insect. Similarly, herbicides may limit certain plants that are the foundation for specific food chains. These indirect effects of pesticides on the environment have become of increasing concern. Identification of indirect effects is difficult because of the large numbers of contributory factors that may be affecting populations of non-target organisms. However, there are some examples; Rands (1986) demonstrated that herbicide and fungicide use on arable fields decreased the breeding success of grey partridge and Hart et al., 2006 have shown that insecticide use on arable farmland depressed yellowhammer breeding performance. Both these examples demonstrate that affects of pesticides on plants or on insects had a negative indirect effect on birds, through the availability of food during the breeding period. Boatman et al., (2004) have reviewed the available European data on indirect effects of pesticides on birds, concluding that populations of four farmland bird species had been affected. These issues are raised again in the Subchapter on the effects of agriculture on biodiversity (2C.1.4).

The concern over indirect effects extends to GM (GE) crops. There has been considerable discussion about the acceptability of GM (GE) herbicide and insecticide tolerant crops. A huge research project was undertaken to endeavor to establish whether herbicides used on GMHT crops had a greater environmental impact than the conventional products they were replacing (e.g. Hawes et al., 2003). The conclusion was that the outcome depended on which herbicide(s) was used on the HT and conventional crops (see Subchapter 2C.1.5.5).

The unwanted effects of pesticides can be mitigated in a number of ways. Primary of these is advances in pesticides themselves. For example, throughout the 1950's to about 1970 insecticides were primarily DDT and other chlorinated hydrocarbons (Aspelin, 2003). While these had a relatively low direct human toxicity, they are extremely persistent in the environment so the concentrations built up sufficient to cause problems with non-target organisms throughout the globe. Chlorinated hydrocarbons have been largely phased out and replaced with insecticides with far less persistence and therefore represent much less potential for harm to non-target organisms. However, the replacements for chlorinated hydrocarbons, especially organophosphates, can have a much greater toxicity to workers, birds and other mammals. It is a general maxim that good farm practice is needed to reduce unwanted exposures. These include measures such as choosing appropriate equipment to reduce overspray, timing of spraying (to avoid winds and rain) and using well-maintained machinery. Further, treatment should only be used when needed rather than as an automatic preventative measure. Discussions on impending changes in European pesticide legislation are attempting to decide on the feasibility of increasing the evaluation of non-target effects of pesticides, so that it becomes possible to have a better understanding of the wider environmental impact of new products.

Use of biopesticides and integrated pest management techniques, such as traps with chemical lures, may reduce pest damage sufficiently to avoid general treatment of the whole field, greatly reducing the amount of pesticides used. Further use of crops modified through genetic engineering to contain a natural insecticide, toxic to certain invertebrate species, can reduce the total amount of pesticide used (Brookes and Barfoot, 2005: Fernandez-Cornejo, 2006) and the natural toxin incorporated into the plant only provides an exposure to insects directly feeding on the plant (its pollen when the toxin is in the pollen). For plants bred with herbicide tolerance, it is important that the herbicide that is being used is not persistent in the environment to prevent it from affecting off-farm areas (see 2C.1.5.5).

Agricultural pharmaceuticals

Farming, ranching, and aquaculture facilities may use various drugs in order to keep animals healthy or to simulate growth. However, the residues of such pharmaceuticals once excreted by the animals may escape the livestock facility through runoff and be dispersed in the environment. Of particular concern is the routine use of antibiotics. It is a near certainty that microbes will develop a tolerance if given steady exposure to low levels of antibiotics, eventually rendering the antibiotics ineffective for treatment of disease (see for example, Cohen and Tauxe, 1986). A more direct pathway for environmental damage is the direct toxic effects of pharmaceuticals on carrion feeders. For example, vulture populations in Asia appear to have been severely impacted by toxic effects of the veterinary drug diclofenac in carcasses of treated cattle (Green et al., 2006). There are also concerns for the hormones that may be excreted by livestock, especially where they are held in dense populations, or where manure is spread (e.g. Jenkins et al., 2006). (This is a problem shared with human wastes.) While hormones are not especially persistent in the environment, they can affect organisms at very low concentrations. Estrogenic compounds may affect the growth, behavior, sexual development, and hence breeding ability of organisms. Where breeding capability is reduced, the populations may not be able to maintain their normal levels.

The control of problems associated with agricultural pharmaceuticals requires prudent use of the materials, and good practices on the farm to prevent the export of the pharmaceuticals to nearby aquatic or terrestrial ecosystems. Many of the practices which can be used to control agricultural runoff, such as buffer zones and wetlands, are effective in retaining and degrading agricultural pharmaceuticals so they are not released to the wider environment (e.g. Shappell et al., 2007, Lorenzen et al., 2005).

2C.1.5.4. Environmental consequences of crop irrigation and drainage

Key message: Extensive, poorly managed, irrigation with improper and/or inadequate drainage has resulted in soil degradation in some areas in NAE. Although irrigation has had tremendously beneficial effects on crop yields, irrigation systems can have detrimental environmental, economic and social effects upstream of the system, at the site of the irrigation system and downstream (Hillel and Vlek, 2005). Similarly, although artificially drained soils provide some of the most productive agriculture in the NAE, it can be a major contributor to off-site environmental impacts (see also subchapter on Soil Quality 2C.1.1).

On-field effects

Poorly managed irrigation can cause problems of salination, water-logging, erosion, and soil crusting. Irrigation water applies water-borne salts to the soil surface and if these accumulate they can markedly reduce the fertility of the soil. Sometimes the soil can become completely sterile. Soil salinization affects an estimated 1 million hectares in the EU, mainly in irrigated fields of Mediterranean countries, and is a major cause of desertification. Similarly, there are approximately 10 million ha in the Western U.S. affected by salinity-related yield reductions, which has brought very high costs to the Colorado River basin and the San Joaquin Valley (Barrow, 1994; Kapur and Akca, 2002). If too much water is applied the water table of the site will be raised, thus rendering the site water-logged and decreasing its ability to remove the salts and to provide a medium for healthy plant growth. In the last half of the last century, extensive work has been carried out in the U.S., and globally, to research, diagnose, improve, and manage salt-affected soils on irrigated agricultural lands (Miles, 1977; Moore and Hefner, 1977; Ayers, 1985; Hoffman et al. 1990; Rhoades, 1990a-b; Tanji, 1990; Rhoades et al., 1992; Umali, 1993; Sinclair, 1994; Rangasamy, 1997; Rhoades, 1998, 1999; Gratan and Grieve, 1999; etc.). Modern management techniques are being deployed to improve water use efficiency to overcome these problems, by targeting the water more accurately and by using the most appropriate application technologies. Productivity can often be maintained in salt affected areas through careful application of appropriate practices (Hoffman et al., 1990; Miles, 1977).

Erosion has also been related to irrigation practices. For example, yield reductions have been reported in southern Idaho due to erosion on undulating irrigated lands (Carter et al. (1985; Carter, 1986). Approximately 75% of the fields had whitish subsoils exposed on their upper ends caused by erosion after 80 seasons of furrow irrigation. Some soils had lost all of their topsoil and some of their subsoil near the upper end; most fields had lost about 20 cm of topsoil; topsoil thickness had increased on down-slope parts 60 to 150 cm; and crop yields were estimated to be at 75% of what they could have been without erosion.

Central Valley of California offers one of the best examples of water logging associated with irrigation practices. Drainage problems began in this area soon after irrigation began in the 1870's, As a result of the drainage problems, construction began in 1968 on the San Luis Drain, connected to the Kesterson Reservoir, which started receiving irrigation runoff water in 1973, subsurface drainage by 1978, and tile drain water by 1981 (Letey et al. 1986). However, all drainage into the reservoir was terminated in 1985 due to bird deformities resulting from selenium in the drainage water (Letey et al., 1986). The practices also led to salination and by 1983 more than 10,000 ha had an elevated saline water table within 1.5 m from the surface; 47,500 ha between 1.5 and 3 m; and 36,800 between 3 and 6 m (Letey et al., 1986).

Soil crusting has been related to the use of certain irrigation systems. Center-pivot sprinkling irrigation in the Coastal Plain area of the U.S (Miller and Radcliffe, 1992) resulted in soil crusting from the sprinkler drop impact energy. The water application rates of this high energy impact irrigation system are often limited by low infiltration rates due to crust formation. Different practices may reduce this problem (Singer and Warrington, 1992; Rhoades, 2002).

The review by Hillel and Vlek (2005) concludes that irrigation is sustainable but at a cost. They suggest various strategies are needed to ensure long-term sustainability of irrigation:

a) "focus irrigation on high value crops such as fruits and vegetables
b) employ sophisticated technology and sound management to ensure accurate use of water, applying required amounts in the most effective way possible
c) avoid inefficient technologies
d) exploit the potential of crop biotechnology to develop crops that require less water and nutrients and which can tolerate higher salt levels."

It should be noted that not all stake holders would support the use of biotechnology to improve salt and drought tolerance. The issue of GM (GE) crops is discussed in more detail in subchapter 2C.1.5.5.

Improved drainage is often associated with irrigation, being needed to prevent the rises in water tables and risks of salinity discussed above. It can help resolve some of the problems associated with irrigation but also it is generally agreed that drainage will increase peak run-off rates, sediment loss and nutrient loss (Skaggs *et al.,* 1994). An example of problems arising from drainage of irrigation areas in California have been described above. There is also concern that drainage has greatly reduced natural wetland areas in NAE over the last 50 years with consequent adverse impact on the ecology of associated plants and animals. For example, in the UK, over 300,000 ha of wet grassland were lost between 1970 and 1985 (Bradbury and Kirby, 2006). The UN Ramsar Convention on Wetlands (www.ramsar.org) was established in 1971, with the aim of protecting the world's vulnerable wetland sites, drainage being one of the key issues. There are now over 1600 Ramsar sites, worldwide.

Off-field effects

Creation of dams to provide water can cause huge environmental changes and the larger schemes can also have major sociological impacts. Abstraction of water from rivers can cause major reductions in water flow with consequent negative impacts on river and associated wetland habitats. The drying and salination of the Aral Sea as a result of abstraction of water for irrigation from the main rivers feeding the sea is a particularly stark example of off-site impacts (Micklin, 1994, 2006). Similarly, abstraction of water for irrigation from boreholes can cause a lowering of the water table with adverse effects on neighboring natural wetland areas. Lemly *et al* (2000) have reviewed the impact that irrigation schemes can have on wetland habitats, and highlight the need for society to assess the overall impact of irrigations schemes, not just the agricultural cost and benefits. Following irrigation, surplus effluent water is often returned to the river systems, downstream of the irrigation site. Such water can contain high levels of nutrients, salts and pesticides and consequently can have a major effect on the water quality of the affected water bodies.

Drainage also causes off-site effects as it speeds water flow from arable land, resulting in increased risks of flooding in the lower reaches of river catchments. It also can increase the risk of loss of nutrients (this is discussed in Subchapter 2C.1.1) and other pollutants. Suitable management, such as buffer strips, can reduce these impacts but there is still much to be learnt and drainage induced run-off, whilst not as significant as normal erosion, can still cause serious off-site problems.

2C.1.5.5 Environmental consequences of the adoption genetically engineered crops

Key message: The adoption of genetically engineered (GE) crops has so far not led to the creation of invasive species or had major impacts on non-target organism populations. However, there are concerns for negative impacts in the long term and a need for greater understanding of potential impacts. Currently, most GM crops are either insect resistant (though only to specific groups of insects) through the use of a Bt protein or are tolerant to a herbicide (HT). There are also virus resistant varieties in production and a number of other types of traits utilizing genes transferred from other organisms are in development.

There are two main environmental concerns with the current Bt and herbicide tolerant (HT) GE crops, their effects on non-target species and the development of herbicide tolerant weed species which could become invasive. A review of the 10-year history of cultivation and testing of genetically modified crops concludes that there is no scientific evidence that the commercial cultivation of GM crops has caused environmental harm (Sanvido et al., 2006) though they note that there are no requirements to monitor for potential effects where GM crop varieties have been approved for unregulated use. However, because of the nature of the technology it has raised greater public and governmental concerns than 'conventional' plant breeding, resulting in closer scrutiny of potential environmental effects (see subchapter of GE crops for a discussion of ethical and related issues). As all forms of agriculture have effects on the environment, it is more appropriate to compare the benefits and risks of genetically engineered crops to the environmental impacts of existing cropping systems.

Current GE crops have to undergo an extensive environmental risk assessment throughout NAE (see e.g. Directive 2001/18/EC for EU requirements and http://usbiotechreg.nbii.gov/lawsregsguidance.asp for US requirements). These regulatory systems impose a cost on the development of new varieties.

An issue which has been extensively studied is the risk of cross-pollination of GE crops to wild relatives or other varieties of the crop. GE contaminated wild or feral populations and traditional crop varieties may persist. In some areas the risk of gene-flow to wild relatives needs to be extensively assessed carefully for each new GE event and the particular geographical region before release (Haygood et al., 2003). Where the risk of cross-pollination to wild relatives is considered too high, restrictions have been applied (Wozniak, 2002).

GE insect and herbicide resistant crops each have potential environmental impacts. For GE insect resistant crops these include toxic effects on non-target or beneficial organisms (Sears et al., 2001, Dively et al., 2004) but these need to be compared to the effects of using conventional pesticides or biocontrol agents. Another concern is the persistence of insecticidal proteins in the soil ecosystems, particularly over cold winter periods, although no negative impacts on non-target soil organisms have been found so far (Stotzky, 2004). For herbicide tolerant crops the concerns include a reduction in the broad-leaf weed flora (Heard et al. 2003), potential toxic effects of herbicides on ecosystems (including soil microflora) and weed resistance [1].

The potential for pest or weed resistance to GE crops emerging is a major issue, and affects both target and non-target species. To address this risk in relation to insect resistant GE crops, various resistance strategies have been implemented in the US since they were first commercialized. In Spain Bt maize has been grown on a small scale for several years without insect pest resistance problems arising. There are concerns whether this will continue [reference?]. Weed resistance to Roundup (glyphosate) is now a serious concern in the US and other places where Roundup Ready crops are grown on a large scale (Roy, 2004; Baucom and Mauricio, 2004; Vitta et al., 2004). The scale of production of Roundup Ready herbicide resistant crops in some countries may be increasing the use of mixed herbicides now necessary for weed control (Nadula et al., 2005). This return to the use of cocktails of products starts to reduce the environmental benefits arising from the use of glyphosate, as this herbicide has a lower environmental impact than the products it replaced (e.g. Brimner *et al.,* 2005).

[1] In the U.S., this is an important issue. In the summer of 2006 researchers at the University of Missouri confirmed tall waterhemp as the sixth glyphosate-resistant weed in the U.S. and the ninth such weed in the world. Resistant weeds can be found at this registry: http://www.weedscience.org/in.asp.

The extent to which these concerns would be, or are being realized remains limited. An FAO Expert Consultation (FAO, 2003) found that:

- The cultivation of GE crops with their benefits and potential hazards to the environment should be considered within broader ecosystems and their effects on the environment should be assessed on a case-by-case basis.
- The scientific understanding of the effects of GE crops at the agro-ecosystem level remains limited. This is partly due to the limited number of crop seasons and numbers of generations of crop-associated species for which data have been collected so far.
- The possible long-term and large-scale environmental effects of GE crops need to be quantified. Some of the main areas of interest would be
    - Gene flow and introgression into populations of plants other than crops,
    - Changes in agricultural inputs and practices associated with GE crops, and
    - Changes beyond agro-ecosystems (e.g. other biota located within common landscapes).
- Practical tools and appropriate information are needed to evaluate and address the possible environmental effects and farm-scale management of GE crops. The potential hazards of GE crops with novel traits like pharmaceutical products need to be better characterized.

The use of GE crops has implications for the way pesticides are used. Evidence from the US where GE crops now play a significant role in agriculture suggests that they have reduced pesticide use (ERS, 2006, Brookes and Barfoot, 2005), but, other reviewers have concluded that this is not necessarily so (Benbrook, 2001). However, the evidence increasingly supports the view that so far there has been a reduction in pesticide use in GE crops, with the greatest reductions in Bt cotton production. The adoption of herbicide tolerant soybeans is also largely associated with conservation tillage (ERS, 2006). There is a controversy as to whether the herbicide use associated with the no tillage and GM in crops negates any environmental benefits (Pimentel, 2005; Nadula et al., 2005).

2C.1.5.6. Environmental consequences of increased mechanization

Key message: Advances in engineering have permitted the mechanization of many previously manual operations. Machinery size and sophistication has increased, encouraging the creation of larger farm units and bigger fields. Although mechanization has tended to increase the environmental effects of farming this can be mitigated by the greater precision of operations that is now possible. Technological sophistication has increased in different sectors of agriculture since the Second World War. The environmental impact of mechanization is multifaceted. At the farm level much depends on the husbandry skills of the operator. The changes in mechanization in agriculture have resulted in the completion of tasks (processing and transportation of supplies and products) much more quickly and with less labor. There have been several advantages to this including increased productivity, allowing farmers to manage for bottlenecks in labor, cutting out of unpopular repetitive jobs and introduction of on-farm processing.

The introduction of powerful engine driven plows opened up areas for crop production that were previously difficult to work due to less tractable soil conditions. One consequence has been large-scale removal of hedges to create larger fields to assist maneuverability of the large machinery (Wilson and King 2003). Additionally, deep plowing can increase soil erosion, but mechanization has also increased the potential for less environmentally damaging minimum tillage soil cultivation practices. The ability to spread more fertilizers or pesticides, resulting from developments in mechanization, may pose dangers of run off into streams and rivers resulting in water and air pollution beyond the farm gate. However, the greater precision of modern machines has tended to reduce some environmental hazards (e.g. reduced spray drift, more precise fertilizer application). Frequent passes of heavy machinery in fields causes damaging soil compaction (see subchapter 2C.1.1), which is exacerbated where the crop is harvested in the winter months on wet ground, as can be the case in Northern Europe (Culshaw and Stokes, 1995). Farm machinery uses energy and releases of CO_2 into the atmosphere.

In animal production automation of husbandry techniques (e.g. feeding), harvesting and processing of farm products have resulted in increased production of animal-derived foods and value-added products (European Commission 2001). Mechanization has enhanced efficiency of management of animal waste, resulting in reduced potential for negative impacts on the environment, but the use of mechanization to increase intensity of production can counteract these benefits, by producing much greater quantities. Increased mechanization has also assisted the shift from haymaking to silaging to feed grassland-based cattle, a change which has led to reductions in non-grass biodiversity in pastures and meadows (Johnson and Hope 2005). Development of technology has allowed modern agricultural techniques to minimize human involvement, increase yield, and improve animal health. Livestock producers must continue to utilize technologies that result in maximization of efficiency of resources in order to meet the rapidly increasing demand while reducing to the need for and risk to existing natural resources.

One additional criticism resulting from the mechanization and consolidation of modern agri-food systems is that it has led to unnecessary food miles in meeting the needs of consumers. [2,3]

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[2] BBC Food Miles http://www.bbc.co.uk/food/food_matters/foodmiles.shtml

[3] The Validity of Food Miles as an Indicator of Sustainable Development Report for Defra by AEA Technology Environment Harwell B154 Didcot Oxon OX11 0RA July 2005

2C.1.5.7 Environmental consequences of changes in farm size and structure

Key message: Amalgamation of farms and the increase in unit size has tended to make the 'texture' of the landscape coarser. Fine grained landscapes with small fields are more beneficial to the natural environment. One of the changes in farm structure over the last 50 years across the NAE has been the increase in sizes of fields and farms, and the simplification of cropping systems. In Europe changes in farm sizes are often associated with other changes in agricultural practice, which it turn can have environmental impacts. The critical issue seems to be that the fine grained nature of traditional landscapes, with small fields separated by hedges, trees, walls and ditches, and with small semi natural areas between fields, has become coarser with the loss of many of the traditional boundary features that are often the key to the success of indigenous plants, invertebrates, mammals and birds. (Roschewitz et al, 2005; Herzog et al., 2006)

Intensification of production in Eastern Europe during the communist era has resulted in greater negative environmental effects, than has occurred in Western Europe. Although crop yields were increased, politically driven, central management has resulted in greater erosion, salination and chemical pollution (Bouma et al., 1998). Changes since 1990 are now endeavoring to limit adverse side-effects from agriculture.

2C.1.5.8. Environmental consequences of growing more bio-energy crops

Key message: Bio-energy crops have environmental value in providing an alternative energy source to fossil fuels. At present their footprint is small but development of these crops should proceed with caution in order to maximize the carbon benefit and minimize any environmental effects arising from their production. One incentive for the use of biofuels and biomass crops is their replacement for fossil fuels (see subchapter 2C.1.3). While any burning of fossil fuels (without sequestration) contributes to increases in carbon dioxide in the atmosphere, production of bio-energy should be neutral as the carbon in the bio-energy crops came from the atmosphere. However, it has been pointed out that modern agriculture is energy intensive and the emissions saved by use of biofuels and biomass crops is significantly reduced by the fossil fuels used directly (e.g. running farm machinery) or indirectly (energy used in the production of fertilizer and agrochemicals) during the production of the crop. There are some estimates that the current production of biofuels is actually carbon negative in that it takes more fossil fuel to produce biofuel than the petroleum it is intended to replace (e.g. Pimentel and Patzek, 2005) though the consensus seems to be that there is a positive net carbon balance in the production and use of biofuels (e.g. Farrell et al., 2006; Worldwatch, 2006). Biofuels could be used to replace the fossil fuels in the agricultural practices used to produce biofuels. However, this would even further expand the areas needed for biofuel production or further limit their total production capacity.

An issue of concern in Europe has been the environmental footprint of bio-energy crops. There is already much concern about the negative impact of intensive agriculture on ecosystem services (See 2C.1.4) and extensive cultivation on large areas of oilseed rape for biodiesel, or biomass crops such as elephant grass (*Miscanthus*) and coppice willow might have an even greater negative effect on the landscape than the crops they are replacing.

The prospects for greater production of biofuels without greater impacts on the environment will rely on a second generation of biofuel sources. It is expected that in the relatively near future that it will be possible to produce ethanol from the non-starch and non-sugar components of plants (Gray et al, 2006). This lignocellulosic material is presently agricultural waste. Improvements in industrial processes are needed in order to economically convert the sugars bound in the cellulose and hemicellulose in plants into fermentable sugars. Future developments may also entail breeding of food crop varieties and non-food plants specifically to increase their utility for biofuels production. Non-food crops may include hardwood species such as poplar, switchgrass, and even algae. It should be noted that ethanol and biodiesel are not the only prospects for second generation fuels. Butanol can also be produced by (bacterial) fermentation of sugars and may have significant advantages over ethanol as a gasoline replacement (Ramsey and Yang, 2004). Biogas may also be produced from plant materials.

An unresolved issue that impacts on the environmental effects of bioenergy crops relates to the conflict between using land for energy crops and using it to grow food. One outcome could be the further expansion of crop production into natural and semi-natural habitats to meet both requirements, to the detriment of the world's ecosystem. This applies as much to the NAE as it does to the rest of the world.

2C.1.5.9 Environmental consequences of changes in animal production

Key message: Greater intensity of animal production systems, combined with the increased spatial the segregation of crop and animal production units, has increased environmental effects. Greater intensivity has also raised animal welfare concerns Awareness of these problems has encouraged mitigation practices to reduce them. There are three distinct animal production systems in the NAE (and elsewhere in the world) (Seré et al, 1996): grazing, mixed farming and industrial systems. Each has potential environmental impacts, especially the latter. The increased specialization that has occurred in the last 50 years has resulted in many areas in polarization of production into 'crop production areas' and 'animal production areas'. As a result the number of mixed farms has declined.

Grazing systems: These are based on animals fed mostly on native grassland, with no or small amounts of other plants and rarely including imported inputs, resulting in low calorific output per hectare (Jahnke, 1982). Environmental impact is low.

Mixed farming systems: These integrate livestock and crop activities and have traditionally been the dominant approach to agriculture. By-products (crop-residues, manure) from one enterprise can serve as inputs for the other, resulting in environmentally friendly systems. Thus, the detrimental environmental impacts from fertilizers can be minimized by efficient use and recycling of nitrogen and phosphorus. However, even in mixed farming systems animal by-products can cause environmental damage, if they are not recycled efficiently, and excessive quantities are applied to land resulting, in nutrient run off and leaching into water supplies (Hooda *et al.,* 2000). The greater the intensivity of the system the greater is the risk of environmental damage.

I*ndustrial production systems*: Intensive, industrial production systems have evolved from the less intensive mixed farming systems in response to increased demand for meat, resulting in animal concentrations that are greater than the waste absorptive and feed supply capacity of the land and can cause major pollution problems and human health risks (Henning et al). Indoor production systems are now predominant for pigs, poultry, and veal cattle. These agricultural systems are controversial because of: the amount of waste produced, odor problems, the potential for groundwater contamination and animal welfare concerns. In intensive livestock farming areas excessive loss of nutrients and farm effluents in surface run-off and /or leaching, are the principal causes of degradation of water quality (Hooda *et al.,* 2000; Tamminga, 2003).

Technological developments have made it possible to intensify animal production in the NAE over the last 50 years. Livestock producers need to minimize risks to natural resources while remaining efficient and meeting demand. Awareness of the environmental impacts of some animal production systems, especially in relation to phosphorus and nitrogen pollution of water and the presence of antibiotics, pesticides and micro-organisms in manures, has resulted in the development of more sustainable management practices. In some European countries changes in management have been supported by legislation restricting the way manures are processed. An evaluation in 2003 of the Danish National Action Plan for the Aquatic Environment showed that nitrogen leaching (primarily from intensive pig farms) had declined by 50% since 1989 (Grant *et al.,* 2006). In The Netherlands a range of measures have been introduced, including a manure phosphorus quota which has been allocated to every farm, limiting the amount of P that can be applied to the land (Kuipers and Mandersloot, 1999). It has also been agreed that nitrogen application should not exceed 170-250 kg/ha/year on Dutch farms, depending on the land use (Tamminga, 2003). This, it is believed, will not exceed the carrying capacity of the land, and thus will not cause major pollution problems. Land-less animal producers must contract with arable farmers, for the disposal of their manures. In the UK a range of management options have been introduced to encourage reductions in water pollution from livestock farms Hooda *et al.,* 2000). Further legislation on the impact of nutrients on water is included in the EU's Water Framework Directive (http//ec.europa.eu), currently being promulgated across Europe. All countries in the NAE are endeavoring to reduce the effects of animal manures on the wider environment.

A range of new technologies are also being developed, especially in the USA, to minimize the environmental impact of animal production. For example, tools of molecular biology (e.g. electrophoresis and real-time polymerase chain reaction (RtPCR)) are now being used to develop optimized feeding strategies and the identification of feed additives that could improve the efficiency of utilization forages and crop residues, while reducing methane emission, which may lead to more sustainable and environmentally friendly livestock production systems (Makker and Viljoen, 2006 (from FAO/IAEA symposium)). Current FAO studies of the influence of livestock development practices on the natural resource base will provide information to predict and prevent possible negative impacts of intensified production and enhance positive ones,. These livestock studies involve feed quality, use of biomass for animal fodder, avoidance of overgrazing, manure management, animal waste disposal, domestic animal genetic diversity, plant and animal wildlife diversity, and integration of cropping and livestock systems (FAO/IAEA, 2003-2006a).

Although manures and the nutrients from them are considered to be the main environmental problem arising from animal production, methane is also of concern, as ruminant animals are major producers of this greenhouse gas. This is discussed in the subchapter 2C.1.3, on climate change.

2C.1.10 Environmental consequences of a larger aquaculture sector

Key message: Expansion of the aquaculture industry, especially farmed salmonids, is leading to greater environmental impacts both directly through increased pollution and indirectly through depletion of fish stocks to create fishmeal for the farmed fish. The increases in aquaculture production seen in Europe over the past thirty years, especially in farmed salmonid and sea fish output (FAO 2000), are causing concerns about the environmental impacts of fish farming. Aquaculture is increasingly competing for resources such as high quality water and high protein feed based on fish meal. There is evidence not only of pollution at production sites but also depletion of sea fish stocks such as sandeels, pilchards and sardines used to feed the farmed fish (Muir 1996, Rosenthal 1997).

Fish farming is now strictly regulated in Europe with a number of Directives and domestic legislation covering water use and pollution control, the use of disease control measure (including pesticides), and feed regulations. There are also rules and regulations relating to the processing and marketing of aquaculture products (Varadi et al 2001).

There has also been an increase in the amount of research centered on dealing with the environmental problems caused by aquaculture such as:

- Pollution of the sea caused intensive cage systems in coastal waters

- Pollution of rivers and streams caused by trout farming units
- Pesticide residues in fish flesh and the impacts of pesticide use in the marine and freshwater environment
- The impact on marine ecosystems of large-scale supply of sea fish for aquaculture feed, for example the 1990s near-collapse of food webs dependent on sandeels in parts of the Northwest Atlantic

2C.1.11. Environmental consequences of changes in forest management

Key Message: The environmental quality of forests in the NAE has tended to decline in the 20th Century with some impacts on a range of species. Awareness of this has resulted in changes in management aimed at reversing these trends. However, as the quantity of forest is actually expanding in the NAE, this has the potential to have environmental benefits. Forests cover an appreciable proportion of the land surface of the NAE, especially in parts of N. America and in Russia and so changes in management have the potential to have appreciable environmental impacts. Environmental concerns about forestry have resulted in changes in approaches to tree production and to management. This is exemplified by changes in the USA since 1970. In the 1970s public concern about the effect of current clear-felling and re-forestation practices led to the 1976 National Forest Management Act (NFMA). One of the important developments following the passage of this Act was the establishment of the Long-Term Soil Productivity (LTSP) research program (Williams, 2000) to explore the environmental effects of forestry practices. Since the launching of the program the Canadian Forest Service, British Columbia Ministry of Forests along with universities and industrial forest companies have become LTSP cooperators. The findings of the first decade's work on the impacts of organic matter removal and soil compaction have recently been reported for the 26 oldest installations in the nation-wide network of LTSP sites. Complete removal of surface organic matter led to declines in soil C concentration to 20 cm depth and to reduced nutrient availability. The effect is attributed mainly to the loss of the forest floor. Forest productivity response to soil compaction depends both on soil texture and the degree of understory competition, as production declined on compacted clay soils, increased on sands, and generally was unaffected if an understory was absent (Powers et al., 2005).

Adoption of ecosystem-based approaches to manage national forests and grassland has changed the way public/Federal land managers in the U.S. and Canada administer natural resources. In the United States, ecosystem management on National Forest System Lands was officially launched in 1993 with the Forest Ecosystem Management Assessment Report. In 1997 the "Natural Resource Agenda" was issued. In keeping with the intent of the Organic Act of 1897, this new agenda put protecting the national forests as the primary goal of management, followed by providing abundant, clean water, and finally allowing multiple resource management on areas that can sustain intensive activities (Williams, 2000). In 2003 the four main threats to the delivery of clean air and water and wildlife habitat were considered 1) fire and fuels, 2) invasive species, 3) loss of open space, and 4) unmanaged recreation (Bosworth, 2004). The efforts over the last decade show a growing need to address ecological processes while still meeting human wants and needs. Providing commodity uses, i.e., timber, forage, energy, on public lands in the United States will continue to be a major focus of land managers. But there has been significant shift in how commodities are managed and delivered. Competing interests for limited resources will only grow more complicated as the human population of the United States expands and its resource needs increase.

High-quality riparian areas trap sediments, slow runoff, provide habitat for wildlife, fish, and plants (USDA-USFS, 1999). Degradation of these areas have resulted from public use, forage for livestock, recreation, mining, roads, and railroads. Recent surveys show only 37% of grassland riparian areas currently meet national forest plan objectives, and nearly 50% of all riparian areas in both forests and grasslands need aggressive management (USDA-USFS, 1999). Over 65% of southwestern animals depend on riparian habitats, and many southwestern residents use these areas for agriculture (USDA-USFS, 1999). Structure and composition have changed due to irrigation diversions, reservoirs, farming, grazing, and human settlement. Loss of biodiversity, species invasion, and channel functions, e.g., sediment transport, are important issues posing major challenges to the USDA Forest Service and other Federal agencies and cooperators.

Thus, changes in practices arising from AKST have had some success in the last 30 years in ameliorating some of the negative environmental effects of forestry in the USA. However it must also be noted that new technologies developed since the second world war allow faster and more efficient harvests and access timber in areas previously considered too fragile for harvest, thus expanding the potential managed forest areas.

Air pollution, e.g., acid rain and ground-level ozone, impacts certain forest ecosystems in the Eastern United States (USDA-USFS, 1999). In addition, nitrogen deposition poses a potential shift in composition of some forests. The USDA Forest Service in cooperation with its partners monitors air pollution impacts across the country, with the Forest Health Monitoring Program currently monitoring ozone effects in forests in 33 states. The USDA Forest Service has identified how ozone damages tress and has screened tree varieties less susceptible to ozone damage. Studies are on-going to identify ozone-sensitive trees in areas of ozone exposure, increasing our understanding of how to manage forest resources (USDA-USFS, 1999).

In Europe, the replacement in the last century of mixed aged stands of often deciduous woodlands with uniform age conifer plantations has had negative effects on biodiversity, especially ground flora and mammalian fauna, and sometimes on soils and surface waters (Hartley, 2002; Humphrey *et al*., 2002; MA, 2005; Spiecker, 2003). Bird populations may also be adversely affected but in some cases, conversion and intensive management has boosted populations of birds and some mammals (such as crossbills (*Loxia curvirostra*) red squirrels and pine martens in Scotland, where 90% of woods are plantations) that were previously rare in primary forest (Marquiss and Rae 1994). BirdLife International (www.birdlife.org) estimate that about 40% of the hundred European 'priority' forest bird species are in unfavorable conservation status, mainly due to declines in old-growth forest. Coniferous plantations also appear to increase the acidity of precipitation falling on them, leading to reductions in pH of streams, rivers and lakes within forested areas (Spiecker, 2003). Although the area of forested land in Europe is increasing, most of the increase is made up of plantations and secondary woodland and this does not necessarily offset the reductions in flora and fauna caused by conversion of natural forests to intensively managed plantations. Awareness of the negative impacts of uniform age conifer plantations has resulted in much debate in Europe as to the economic viability of replacing them with mixed species stands, with both conifer and deciduous species (Spiecker, 2003). Despite declines in natural forest quantity and quality in W. and some E. Europe countries, European forests remain one of the most important refuges for wildlife on the continent.

A final environmental issue arising from forestry is the introductions of species of tree that then become invasive. This is a serious issue in for example South Africa where Eucalyptus from Australia has become seriously invasive, but is less of an issue in NAE, although there are examples from North America (Richardson, 1999)

2C.1.12. Environmental consequences of the increase in food miles

Key message: The increase in food miles that has occurred in the NAE over the last 50 years has had negative effects on the environment, primarily because of increased energy use. Recent desires by consumers to source local food may reduce this in future. Increased geographical distance between producer and consumer, together with the regional specialization of agriculture has resulted in the availability of a wider selection of apparently cheap food for consumers, but at the cost of longer transport with the attendant consequences of greater energy use and deleterious effect on global climate. Distancing and regional specialization has encouraged less diverse production systems, complicating recycling of nutrients and carbon from animal husbandry back to crop production and from demand chains back to agriculture. In addition, distancing and regional specialization allow concentration of big units of animal production in limited areas, which increases the severity of environmental emissions while reducing the ecosystem's buffering capacity (see subchapter 2C.1.5.9). Further, distancing consumption from production hinders feedback from the ecosystem to the human community, affecting the land-use, thus impeding adaptive management (Vergunst, 2002; Deutsch, 2004; Sundkvist et al., 2005).

The increase in food transportation has a significant impact on energy use, climate change, pollution, traffic congestion and accidents. Road transport generates six times more CO_2 emissions compared with shipping, and airfreight 50 times more (Jones, 2001). The dramatic increase in transportation has resulted in a rise in the amount of CO_2 emitted by food transport: 19m tons of carbon dioxide were emitted in 2002 in the course of getting food to consumers in UK, which was a 12% increase on 1992 (Smith et al., 2005). The cost of food miles is £9bn a year to the UK. This is greater than the total contribution of the agricultural sector to GDP (£6.4bn). Several studies show that shorter supply chains would be less detrimental to the environment. Transportation is responsible for a considerable proportion of the total energy consumption especially for fresh products, exceeding the energy consumed for cultivation of apples, for example (Jones, 2002). The use of fossil energy and climatic effects of transportation of more local food were smaller, even when taking into account the smaller amounts transported at a time (Granstedt et al., 2005; Poikolainen, 2004; Carlsson-Kanyama, 1999). This was the case even if the domestic apples had to be stored long periods, in contrast to the imported ones (Blanke and Burdick, 2005). According to Pretty et al. (2005), the external cost of transportation in local food systems (food basket sourced from within 20 km of retail outlet) would be less than one tenth of the current one in the UK, depending on transport vehicles. Pirog et al. (2001) reported from the USA, that depending on the system and truck type, the conventional food system used 4 to 17 times more fuel and released 5 to 17 times more CO_2 than the Iowa-based regional and local systems.

The environmental consequences of distancing are complex. If food supply chains are identical except for transportation distance, reducing transportation increases sustainability (Smith et al., 2005). However, differences in food supply systems often imply trade-offs between various ecological, economic or social sustainability. Transport mode, transport efficiency (vehicle size and loading), differences in food production systems and food storage, all affect the final outcome. The total effect depends, for example, on the energy input to production and post-harvest processes. If production is clearly less energy-intensive when performed outside the region (Cowell and Parkinson, 2003), as it can be for greenhouse vegetables (Poikolainen, 2004) and for cereals with higher yields and lower energy need for drying in warmer regions (Sinkkonen, 2002), the benefits of reduced transportation may be more than offset by the increased energy costs for production. Therefore, a simple calculation of food miles is not a valid indicator for sustainability (Seppälä et al., 2002).

2C.2 Economic impacts of agriculture and AKST within NAE

All changes in agricultural production in the NAE over the last 50 years have economic drivers and consequences, from the field to the 'plate'. This sub-chapter looks at the changes that have occurred in production systems, partly as a result of advances in AKST but also due to other technological and societal changes that have occurred during this period.

2C.2.1 Economic context linking advances in AKST to production

Within North America and Western Europe most decisions about farming practice are made by individual farmers. These range from small family businesses where the labor is supplied mainly by family members to large scale corporate activities involved for example in poultry production or beef lots. The motivation of these decisions varies. For some farmers the amenity benefits of living on a farm may be more important than its earning capacity. For others, benefits from land ownership may include capital appreciation and the avoidance of some forms of tax. In the USDA classification these would probably be the 'retirement' and residential /lifestyle' categories of farm. Together these classes account for 56.7% of the number of US farms but only 6.7% of farm production. However for many farm businesses profit is central, it is the major, if not the only, source of household income. For such farmers new technology is assessed in terms of what it can do to reduce costs and add to output, leading to higher profit.

As more farmers adopt productivity increasing technologies supply tends to grow more rapidly than demand and real prices to fall. In such a situation those who did not use the new methods have had to adopt them, find a new niche market for their products or face falling real income. Income earned outside farming may cushion this or even make it of no great importance but where these strategies cannot be used, many working farmers and their children will have to leave farming. Although rural populations have started to stabilize and more recently to grow in some areas, the decline in the farm labor force in the second part of the 20th Century has been dramatic. The farm labor force in 2000 was only some 16% of its size in 1950.

[Insert Figure 2C.2.1: Agricultural and Rural Population in North America and Europe (Data from FAO)]

The pressure upon the centrally planned economies of the Eastern European communist states to adopt technical innovations was enormous. Failure to supply sufficient and reliable food was a major problem for the Soviet Government. Some countries in Eastern Europe, such as Poland, retained many very small farm holdings. Here it was more difficult to apply the larger scale investments associated with new farm technology. In contrast, as in Hungary where private holdings were merged into collective farms, large scale farming businesses looked for innovation and invested in production related research. A failure to keep pace with AKST technology across the food industry as a whole weakened the relative position of the centrally planned economies to those of the west. Consumers had fewer choices, products were often of lower quality than elsewhere in Europe and the centrally planned economies became less able to compete in global markets except by cutting prices. Although substantial investments in new technology were made these did not overcome the relative lack of competitiveness. Compared with market driven economies the intensity of production and the levels of productivity usually remained lower although output continued to grow.

The effect of the pressure to adopt new technology is seen in the sustained and substantial improvements in productivity that were achieved (See Sub-chapters 2B.2 and 2B.3). Measurements of this are complex. Yields per hectare of major crop products, as presented in Fig 2B.1 are a first and very rough proxy for productivity. Aggregated data of this nature conceals a good deal of variation but the overall message is clear. Yields have increased in every area and whilst the rate of improvement slowed in the 1980's it has recovered. The substantial gap between the USSR and other areas has not been removed. It reflects underlying natural conditions. However, even here cereal yields have virtually doubled over the 40year period.

The response of agriculture to improved technology is reflected in the rising trend of GDP per worker. In practice in Europe and North America GDP seems to have risen faster in agriculture than in the economy as a whole. In contrast to many assumptions, GDP per person engaged in agriculture tends to be higher than in the economy as a whole in most NAE countries.

[Insert Figure 2C.2.2: Gross Domestic Product (GDP) per Capita ($) and agricultural GDP per economically active person in agriculture (2002)]

2C.2.2 Impact of AKST on supply and demand

In the past 50 years agricultural output in NAE has grown more rapidly than demand. (See Chapter 1 and Chapter 2 B) This has been made possible by better understanding of science, applied in the form of new technology and supported by increased understanding by farmers. One result has been a trend for real prices for farm products to fall. (See evidence from FAO, 2005; EU, 2003; UK, 2005a) Domestic protection has mitigated but not prevented this in markets such as the EU and USA. External markets, which have had to absorb varying levels of surplus from the protected markets, have been volatile but have experienced a sustained tendency for real prices to fall.

Changed technology has also led to a transformation in the way in which food reaches the consumer. In much of NAE traditional local supply chains have given way to systems in which a high proportion of food comes from international markets in processed form through a relatively small number of supermarket chains (Regmi and Gehlhar, 2005). The degree of concentration and the proportion of processed food differs amongst countries within the NAE area but in most situations the distance between consumers and producers has increased both in terms of geography and in the consumer's awareness of where food has come from and how it is produced (UK, 2005b; USDA, 2005)

Agricultural policies in Europe and North America have tended to protect producers, leading to a growth in supply greater than the domestic market can absorb. Until 2003 most of the subsidies in the EU were commodity related. More recently they have become 'decoupled' enabling farmers to survive even though income from farming may be very low. Support led to a situation in which substantial export subsidies has been needed to enable domestic production to compete in world markets. As Fig 2C.2.3, which includes both intra and extra EU trade, shows the EU as the largest agricultural trader. Even when intra EU trade is excluded, it remains a major player in the market for many important commodities (Table 2C.2.1).

[Insert Figure 2C.2.3 Agricultural Imports and Exports in Europe and North America (from FAOSTAT 2004)]

[Insert Table 2C.2.1: External Trade of EU 15 in 2002 in eight selected products]

Export subsidies mean that relatively modest shifts in consumption or production spill over into the world market where they may influence world prices. The effect of growing productivity within NAE countries, driven by AKST, has thus been to depress world prices. The impact of improving productivity, combined with subsidies on exports is illustrated in the falling trend of commodity real prices shown below (Fig 2C.2.4).

[Insert Figure 2C.2.4: Changes in Real Commodity Prices - prices are deflated by the United States Consumer Price Index 1995 =100 (FAO, 2004)]

Falling prices benefit consumers, especially poorer consumers who spend a relatively large share of their income on food. They also benefit net importing countries but may give rise to increased dependence on foreign supplies, and reduced investment in local agriculture and its support services. This has had the effect of making import prices low and volatile for importing countries. For developing countries low import prices benefit consumers but reduce returns to domestic producers. Because imported food prices are also volatile, they can give rise to unpredictable and unaffordable trade deficits.

Some consumers within NAE have reacted to anonymous low priced and highly processed and packaged food by seeking alternatives that represent for them higher quality. The response is multidimensional. It includes: -

i. A growing market in organic food. USDA reports (Dimitri and Greene, 2002) growth in retail sales of 20% per annum since 1990. In the Western Europe, too, demand for organic food is growing at a rapid rate. The EU Commission reports that the area organically farmed increased at a rate of 25% per annum between 1993 and 1998 and since 1998 by 30% per annum (European Commission, 2005). However in 2000 it still represented only 3% of the total EU utilized area

ii. An increased requirement for farmers to demonstrate that livestock (Defra, 2004) products have been produced in welfare friendly systems. Regulations vary considerably within NAE. In the USA regulations relating to animal welfare only apply to animals used in research, testing teaching or exhibition (USDA, 2007) In Western Europe regulations govern the slaughter, transport and housing of farm animals. The European Union included a protocol about farm animal welfare in its Treaty of Amsterdam (e.g. European Commission, 2002)

iii. A concern to acquire food from local sources, based in part on convictions about freshness, community solidarity and quality and in part on anxieties about the environmental impact of transporting food over long distances. (F3, 2007)

iv. A desire to ensure that farmers in low-income countries that supply NAE markets are treated fairly. These concerns are articulated by the Fair Trade movement which promotes equitable standards for international labor, the environment and social policy in areas related to the production of 'Fairtrade' labeled and unlabelled goods. The movement focuses on exports from developing countries to developed countries (Fairtrade, 2007).

2C.2.3 Impacts of advances in AKST on the growth of output and on farm businesses

Improved AKST has enabled farmers to increase yields. It has also resulted in a fundamental restructuring of the industry. According to the American Farmland Trust, small and part time farms accounted for 86% of all farms in North America and almost half the farmers had full time jobs elsewhere (Thompson, 1986; Miljkovic, 2005). Most of the output, however, came from a minority of large and very large farms. Analysis by the EU Commission suggests that in the Southern member countries nearly half the farmers and more than half the farm workers are part time. (Barthelemy 2007) Speaking in London in January 2007 the Commissioner for Agriculture suggested that a growing number of farmers will have to get second jobs when subsidies from the CAP are slashed in 2013. (Fischer-Boel, 2007) The changes in farm structure have been discussed in more detail in sub-chapter 2B.

Farmers have also sought to secure their position by diversifying their businesses to include activities that are not limited to agricultural production. Farmers markets enable some farmers to sell directly to consumers, capturing part of the return from distribution. Farmers Markets are increasingly organized on a national scale. Revenues based on the assets the farm already owns can be generated from activities such as tourism, campsites or outdoor leisure activities. In some cases farm buildings may be converted for housing, for office use or for small-scale manufacture, generating income in economic sectors that prosper as economies grow. For many farms a minority of income now comes from farming. UK Data suggests that more than 50% of farms have income from diversified activity, income from these sources accounts for more than 50% of total income for 43% of the farms concerned(Defra, 2007).

In the years between 1945 and 1989 many farmers in Eastern Europe were collectivized and in some countries State Farms were established. Where this was not the case very small scale farming persisted, often using traditional technologies. On the large Collective and State farms modern methods were used although the number of workers employed did not decline as rapidly as in the West. In the post 1989 period as central planning gave way at varying paces to competitive markets, adjustments are taking place in the structure of farming, the level of agricultural employment and the relationship between producers and consumers (Borzutzky and Kranidis, 2005). In many of these countries subsistence farming remains important (European Commission. 2006) (Fig 2C.2.5).

[Insert Figure 2C.2.5: Semi-subsistence farming among New Member States. Eurostat 2003]

Farmers in countries that have recently become members of the EU now have to compete with existing members. This will impose a need to employ AKST both on the farm and in the processing sector in order to reach the levels of quality and productivity that market demands. EU data suggests that there is still a relatively low level of participation in further education and training in agriculture among the new member countries (European Commission, 2006).

2C.2.4 Impacts AKST driven growth in output on processors and distributors

In NAE most food reaches consumers through processors and retail distributors. These organizations benefit from lower farm gate prices, arising from increased production, but AKST has offered them the means to secure other goals. By using AKST products can be made more uniform, freed from visual blemishes, delivered when needed, available throughout the year and able to show a known provenance. These attributes can make the offerings of processors, caterers and retail supermarkets more competitive in a discriminating market. Information at the tills provides strong evidence of what consumers prefer and an indication of what is needed to seek or sustain market share. AKST is also critical in ensuring the safety of the foods these companies sell. Food borne diseases are a matter of alarm where mass distribution increases the number of people who may suffer if products are infected or contaminated. On the farm this means attention to issues such as biosecurity and the use of pesticides and in the food processing direction to methods of preparation and presentation, including the provision of information about ingredients to which some customers may be allergic. For major distributors their most valuable asset is their reputation. AKST, including Information Technology is needed to safeguard this through ensuring production of that can is consistent, can be branded and safe and where any failure can be rapidly identified (Horniman and Fearn, 2005). The impact on the role of processors and distributors has led to developments in the supply chain. Traditional arms length markets are replaced by coordinated plans for production and delivery. These minimize some elements of market risk and are a channel through which new technologies may be encouraged and supported on farm (Duffy, 2005). This development has been closely linked to progress in transport and the use of information technology to monitor performance at all stages of the food supply chain.

2C.2.5 Impacts on market power

The technologies that have developed from AKST tend to encourage concentration at all levels of the agriculture and food sectors. Although farms in general remain small businesses, a high proportion of output comes from the largest units (McAuley, 2004). By spreading the costs of investment over a larger volume of output the unit cost of production can be reduced. Independent farmers may seek to lower costs by sharing equipment and labor and sometimes by merging parts of their own farm enterprises such as milk production. Beyond the farm gate the concentration of the industry has advanced much more considerably. In Europe supermarket and retails chains in the produce market dominate sales, with 96% in Sweden, 85% for Denmark, 85% for Finland, 85% in the UK, Germany with 78%, France with 70% and Italy with 46% (Wiel 2007). In the UK four major supermarkets; Tesco PLC, Wal-Mart Stores Inc.'s Asda Group Ltd., J. Sainsbury PLC and Morrisons Supermarkets PLC) control almost 75 percent of the domestic market. This has given rise to concern about the impact on competition and the relatively weak position of businesses that supply these companies. This has led the Competition Commission to examine the food supply chain, pricing and the land banks owned by these companies (Wardell, 2007). An important repercussion of this has been a sense among both farmers and consumers that they are helpless in the face of the businesses with which they deal. This has enhanced the importance of farmer co-operatives and of direct marketing to consumers. The proportion of product sold via co-operatives varies considerably amongst the countries of NAE. In the Netherlands and Denmark co-operatives account for a much larger market share than, for example in the UK. Direct marketing includes traditional open markets in local towns, still a major avenue of distribution in France and the South of Europe or farmers markets that may take place on farms within reach of towns or sometimes within open spaces in town. Farm shops that may have started to sell the produce of the farm often develop to sell a diversity of products and services not produced on the farm itself but offering to the urban customer an attractive shopping experience.

The agricultural and food system that AKST has made possible requires substantial packaging, temperature control, processing and ahs appreciable delivery costs. All this enables food to be kept in edible condition for long periods and to be safely transported over long distances. Packaging is needed to protect the product and to keep it wholesome. It is also a vehicle for selling the product to consumers, so that attractive presentations, which convey relevant information and are in convenient sizes, are an important sales aid. These represent costs that have to be absorbed within the supply chain and born by the consumer.

There is concern that this may lead to environmental costs as a result of excessive packaging and problems of waste disposal. Losses may also occur when food is discarded because temperature control has failed or where the 'sell-by' date has been past either within the food industry or in domestic kitchens. For packaged goods supermarkets sell products in predetermined pack sizes. These may not match the requirements of small households who find they do not fully use all the items in a package before its 'use-by' date has past. Whilst these sources of waste are of concern, it should be noted that substantial wastage occurred before modern AKST systems were used as seasonal surpluses could not be safely preserved by many households.

AKST has also enabled consumers to access a huge range of products throughout the year relying on imports to supply markets out of season. Combined with low cost air freight this has lead to a sharp debate about 'food miles' and the impact on the environment of sourcing fresh food from distant markets. Rich Pirog and Andrew Benjamin of the Leopold Center for Sustainable Agriculture at Iowa University quote evidence from US studies suggesting that the average food miles covered between leaving the farm and being consumed in the US was between 1346 and 1500 miles (Pirog and Benjamin, 2003). A study by Defra discusses the complexity of assessing the environmental impact of food miles. It shows that in the UK Food transport accounted for 25% of Heavy Goods Vehicle traffic and estimated the direct environmental, social and economic cost of food transport as in excess of £9 billion per annum (Watkiss, 2005).

2C.2.6 Structural change induced by AKST

The way in which resources are organized into businesses, the structure of an industry, is determined by many factors including the competitiveness of different technologies. Among these other factors, affecting the food and agricultural sector are rising labor costs, the development of communication systems, the operation of banking systems and the availability of transport systems. Even without changes in the state of AKST, changes in these areas would lead to changes in the sort of technology that was used in the sector.

[Insert Figure 2C.26: Share of economically active workforce in the NAE in agriculture]

AKST has facilitated change, anticipating and responding to changes in the market in order to increase labor productivity. Mechanization, agricultural chemicals, improved seed varieties all increase productivity. Improvements in communication have enabled processors and retailers to access producers directly, reducing the number of intermediaries such as wholesalers and traditional markets. Industries that supply new technology operate on an international scale. Farm machinery, pharmaceuticals, pesticides, herbicides, seeds and animal feeding-stuffs are all international businesses. At the farm level, the most obvious structural effects have included fewer workers increased specialization and there is a tendency for full time farms to become bigger, whilst smaller farms become part time. The number of farmers and farm workers has declined (Fig 2C.2.6). In some cases the statistics may not fully represent the degree to which decisions have been concentrated, as farmers share resources such as machinery or labor and in some cases run a single large enterprise on more than one 'farm'. The decline in the farm labor force has profound implications for rural communities. In areas where agriculture was the major source of employment the rural economy can be undermined. Community services such as schools, medical facilities and transport are no longer able to operate at an economic level. Village shops may disappear and the informal, voluntary activities that often form a crucial part of the social support system for village residents may decline. In regions close to urban centers this impact may be diminished. Instead of working on farms former farm workers may commute to towns. Where the urban economy is buoyant, city dwellers may move into villages, raising the price of village houses and creating new and different communities. In this type of situation impacts measured in average data tend to show these communities as relatively affluent although they contain many poorer people who once depended on farming for their incomes.

2C.2.7 Impacts of changes in production driven by AKST on trade

Falling incomes presented a major problem for some NAE governments. Powerful farm lobby groups demanded support for farm incomes. In response, policies provided subsidies that prevented returns to farmers falling in response to the excess levels of production resulting from greater productivity. The EU and the USA subsidized farmers, limited imports and subsidized exports. A widely used indicator of support is the PSE; this showed that as a percentage of gross farm receipts in 2003 support in OECD averaged 32% of gross farm receipts, in the EU it amounted to 37% while in the US the figure was 18% Japan and Switzerland have much higher figures, at 58% and 74% respectively. (OECD, 2004) Fig 2C.2.7 shows the substantial level of support that has been sustained despite the conclusion of the Uruguay Round in 1995

[Insert Figure 2C.2.7: Producer and Consumer Support Estimates as measures of support for agriculture – OECD 2004]

The chart below (Fig 2C.2.8) shows the dramatic effect of changes in the level of support taking place after the break up of the Soviet Union. From the mid 1990s however, support had declined to levels below those of most other developed countries

[Insert Figure 2C.2.8: Support for farming in the Soviet Union and Russia – OECD]

Producers in other countries faced depressed prices some cases total loss of markets as a result of subsidies in NAE. This became the major issue in international trade negotiations. Its impact extended far beyond agricultural trade itself because countries refused to make progress on trading issues without an agreement on agriculture. The debate included the level of domestic subsidies, the demand to remove export subsidies and to reduce all sorts of barriers to market access. In return for progress in these areas the NAE countries sought tariff reductions on manufactured goods; trade in services and agreements relating to intellectual property (WTO, 2005).

The Uruguay Round made substantial progress. Participating countries agreed to convert barriers such as quotas and variable import levies, to tariffs that could be 'bound' and negotiated downwards. Internal supports were classified into those that directly affected production such as price support; payments that were not related to specific products and those that had no impact on production (were de-coupled). The first group was to be reduced over a period of time; the second were allowed to continue subject to review; the decoupled payments were regarded as non-trade distorting. Export subsidies were limited in terms of volume and expenditure. Substantial trade distortion continued but the important outcome was to bring agricultural trade within the system of rules and dispute settlement established in the WTO.

Agricultural issues remain critical in the current, Doha round of negotiations. After protracted negotiations the Secretary General reported on December 18th 2005 that significant progress had been made on agriculture including an agreement to end export subsidies by 2013. However, in a statement on July 24th 2006 the Secretary General reported that the trade negotiations would be suspended because of lack of progress. He said, "From the discussions over this weekend, it is clear that the main blockage is on the agriculture legs of the triangle of issues the G6 has been trying to address." At the heart of the debate was a failure to agree terms for access of developing country exports to developed country markets or to reach a settlement on domestic support (WTO, 2006). Informal negotiations between the parties have continued and there is some prospect that this will lead to a further formal round of negotiations at which progress in relation to agriculture can be made.

The impact of a successful outcome to the Doha round is debated among authorities. Globally the most significant issue is the impact on international trade as a whole. For developed newly industrialized countries the potential gains from non-agricultural issues, including trade and intellectual property, greatly outweigh those related to farming. The implication is that their agricultural industries will have to adjust to the impact of higher productivity resulting from AKST. In launching the current round of negotiations the participants said. "International trade can play a major role in the promotion of economic development and the alleviation of poverty. We recognize the need for all our peoples to benefit from the increased opportunities and welfare gains that the multilateral trading system generates. The majority of WTO Members are developing countries. We seek to place their needs and interests at the heart of the Work Program adopted in this Declaration." The impact of AKST applied in developed countries has been disadvantageous to the economy of farmers in less developed countries as a result of the agricultural policies of NAE countries, which have depressed world prices. However, removing this distortion may not offer an unequivocal benefit to developing countries. Net importers would face higher prices. Where Modern AKST methods applied within developing countries to supply exports to NAE markets, may attract resources away from the food needs of local populations. NGOs have played a growing role in trade negotiations (Charveriat, 2002; Lin, 2004; Teegen.et al 2004).

2C.2.8 External Economic Impacts of the application of AKST

The impact of AKST upon the environment has been discussed in sub-chapter 2.4.1 of this chapter. These environmental and social costs do not figure in the accounts of the businesses concerned but do represent real economic benefits or costs to other individuals. They are externalities and may be positive or negative. The incidence of these costs is diverse. Some can be calculated with relative ease. For example, water quality may suffer as a result of farming practice. The costs of restoring water to a satisfactory condition for drinking will fall upon the water industry. Less easily assessed are environmental losses occurring where plant nutrients or pesticides contaminate water courses (see sub-chapter 2C.1.2). The use of AKST in devising and using veterinary medicines, pesticides, herbicides and in the management of more intensive stocking of livestock can raise public health issues. Food borne diseases represent costs to affected individuals and to medical services. For the industry, market collapses as a result of food scares can destroy the value of goods already produced. Governments seek to minimize risks to human health but the costs can be very large (see sub-chapter 2C.3.1 Food security and safety). For example the gross total cost to the UK and the EU budgets of measures to combat BSE between 1996 and 2006 are reported below (Table 2.4.2.2) (Defra, 2006).

[Insert C.2.2 Net UK costs of managing the outbreak of BSE 1996-2005]

Similarly, UK government costs to manage Avian flu between 1998 and 2002 are presented in Table 2C.2.3.

[InsertC.2.3: Net UK costs of managing Avian flu 1998-2002]

The cost of introducing a new medicine or pesticide involves substantial expenditure by the company concerned on testing to the approved standards. Increased public concern has led to a progressive tightening up of standards in both the EU and the USA (Tait, 2001). A range of institutions are involved, in the UK the Pesticide Safety Directorate and the Veterinary Medicines Directorate are agencies of the Department of the Environment and Rural Affairs. Within the EU the European Medicines Agency governs both veterinary and human medicines whilst the Health and Consumer Protection Directorate General is responsible for the licensing and monitoring of pesticides. (European commission 2005a)

2C.2.9 Impacts of AKST driven changes in production systems on traditional food production systems

Traditional food production systems embodied practices that provided some assurance of food safety. These were sometimes embodied in religious rules or taboos but often no more than accepted custom and practice. The application of new technologies based on AKST may make some of these rules irrelevant and require others that may not be intuitive. To cope with this there is a growing body of regulation relevant to food.

Regulation involves costs for government, in devising rules that offer a satisfactory level of protection and in their administration and enforcement. Failures may occur infrequently and irregularly creating a need to set up and resource contingency arrangements. This implies further cost that has to be borne by the public purse.

Regulations also impose significant costs on private businesses. The creation and maintenance of an audit trail is fundamental to rapid recognition and assessment of disease outbreaks, to detecting and remedying episodes of pollution and to assessing the impact of farming practice on wildlife, the management of water and the landscape. Rules may require new skills and need to reflect the diversity of farming situations. Governments attempt to assess the cost benefit of proposed regulations through impact assessments (European commission 2002a).

2C.2.10 Impact of AKST on the agricultural and food economy

The translation of AKST into action has required changes in economic systems on the farm and in the industries that supply inputs and process and market farm outputs. New systems have replaced many which were traditional. They have greatly increased the supply of food, in the countries of NAE outstripping the growth in demand as a result of rising income and growing population. AKST has interacted with economic growth so that for most people in a generally affluent NAE society there is little anxiety about food supply. Concern remains for less affluent citizens and for less wealthy countries but the focus of concern has switched towards issues relating to the safety of food, the impact on health of diet and the consequences of modern food supply systems for the environment.

The strong role played by NAE AKST in developing insights into production that apply on a global scale has stemmed from the emphasis given to these issues in a period of scarcity following the Second World War. At a global level these issues remain relevant but there is a risk that the change of emphasis in NAE may divert the development of AKST into areas of less immediate importance to other poorer regions of the world.

2C.3 Social impacts of agriculture and AKST within NAE

The increase in productivity achieved by NAE agriculture over the last 60 years with the help of AKST has contributed to provide people in NAE with more wealth, choice and mobility. In NAE there is today more food and a wider range of affordable food items available than ever before. People have also more choice in where they want to live and work than in the past. Rural regions have increasingly specialized in producing and exporting natural resource-based raw materials. At the same time local demand is being satisfied with food imported from outside the region. Much of the food processing and food distribution has been transferred to urban areas or even beyond national borders. Technological change as well as agricultural policy and liberalization of agricultural trade have led to a reduction in the number of farms and farming work force. This development has given rise out-migration and to major changes in social structures in the rural regions of the industrialized countries in Europe. Only a small fraction of the population works today in agriculture in most NAE countries. A side effect of these developments is that consumers have increasingly become not only more spatially removed from how their food is produced but also less familiar with the realities of farming. Ethical issues, such as animal welfare, have become a growing public concern in many regions of NAE, largely in response to increasingly industrialized farming practices. Disease outbreaks, such as BSE[4], have increased the public's concern about food safety and further reduced public trust in the efficacy of regulations and government information. Plentiful food supply is one of the factors contributing to people living longer lives in most parts of NAE but it has contributed to new health problems such as obesity. The following sections explore these issues in more detail.

2C.3.1 Food security and safety

Development of technology has allowed modern agricultural techniques to improve animal health as well as minimizing human involvement and increasing yield. Economics, quality and consumer safety all play a role in how animals are raised. These developments have led to regulations on drug use and feed supplements (or even feed type) to ensure yield is not increased at the expense of consumer health, safety or animal welfare. Application of agricultural technology to production practices vary around the world, for example growth hormone use is permitted in the United States but not in the EU or in countries selling meat/produce in the EU such as Australia and New Zeeland. Livestock may be branded, marked, or tagged to denote ownership or for inventory, breeding, health management, product identification and tracing, or other purposes. Radio Frequency Identification (RFID) technology use is increasing in wildlife and livestock tracking in more than 50 million pets and 20 million livestock worldwide. The Mad Cow scare in North America caused a push for adoption of the technology by the cattle industry (Psion Teklogix, 2004).

Molecular techniques have been used for detection and quantification of pathogens such as Escherichia coli O157:H7 and Salmonella in food products and for detection of probiotics and intestinal microbiota in monogastrics. These techniques assist the selection and breeding of preferred animals with natural resistance to gastrointestinal helminthic and trypanosomoses infections, or having the ability to thrive under climatic or nutritional stress. Improved understanding and application of the functional genetics as affected by nutrition and genotype could impact significantly on health, welfare and production of livestock species (FAO/IAEA, 2006).

[4] Bovine spongiform encephalopathy, commonly known as mad cow disease

Extensive testing of pesticide residues in meat from grazing animals reared or imported into the U.S. and Europe indicated that few hazards exist to consumers. Mean residues have been at 0.23 percent of acceptable daily intake with inspections at less than 0.43 percent (27). Consumers eating vegetables grown on soil fertilized with manure from animals treated with antibiotics may be unknowingly ingesting antibiotics. Resistant bacteria from farms can contaminate air, water and soil.

2C.3.1.1 GM resistance in Europe: Public attitudes

A key difference between North America and Europe is attitudes to GM foodstuffs. Whilst foods from GM crops are available and do not require labeling in North America, in Europe, foods derived from GM crops are generally not available, primarily due to consumer rejection and, where sold, are required to be labeled as containing GM ingredients. On a basis of “willingness to pay for or to avoid GE products, N. America consumers were considered neutral whilst those in Western Europe tended to believe that the risks of GE foods outweigh the benefits (Bryne, 2006).

In a unique undertaking, public dialogue in the UK showed that there are several different reasons for consumer rejection of GM foodstuffs. For UK consumers, the potential impact of GM crops on the environment was the issue that gave rise to most concern. The safety of GM food was less of an issue, but suspicion and concern still surround the subject. Although some people considered that GM could bring benefits in terms of nutrition, quality and price, others questioned whether GM food was necessary given the choice of food currently available. Consumers considered that further information on the safety assessment carried out on GM food needed to be made publicly available and they wanted to know more about the regulatory bodies responsible for safety. There was recognition that GM food has been consumed outside the EU for some years with no suggestion of any health problems. But there were concerns regarding the potential long-term health effects of eating GM food. (UK FSA, 2003)

Ethical debates about GM crops

The ethical debate about GM products reflects the diversity and range of opinion about other aspects of the technology. Arguments based on religious belief are deeply held values are acknowledged to be a key to debates (Nuffield Council on Bioethics, 1999). One article summarizes a common position taken by ethics specialists: “Any discussion based on objections to playing God is generally not accessible to logical argument. Respect for such beliefs usually involves ensuring that there are mechanisms in place to permit believers to choose not to use such products” (Kinderlerer and Adcock 2003). One of the key areas of debate is the impact that biotechnology will have on developing countries and the mechanisms that are in place for allowing developing countries choice over the new technology.

In May 1999 the Nuffield Council on Bioethics, an independent UK organization published a major report on: "Genetically modified crops: the ethical and social issues." The executive summary of the report states: "The application of genetic modification to crops has the potential to bring about significant benefits, such as improved nutrition, enhanced pest resistance, increase yields and new products such as vaccines. The moral imperative for making GM crops readily and economically available to developing countries who want them is compelling…" (Nuffield Council on Bioethics, 1999)

Kinderlerler and Adcock (2003) point out however that early development of the technology has not been with poorer countries in mind. Rather it has been aimed at securing profits for firms in industrialized country contexts selling products to relatively wealthy farmers. Whilst public private partnerships and international agriculture research centers may be developing crops more appropriate to developing countries, Kinderlerler and Adcock outline a range of factors that need to be taken into account including general welfare, justice and access. They argue strongly that an ethical position is one that allows each country the right to accept or refuse GM crops, a position that does accord with the science-based regulatory approach of the World Trade Organization.

Ethical issues in GM and animals

Ethical issues are a major consideration in discussions about biotechnology and animals. A distinction is made between 'intrinsic concerns' (genetic engineering as wrong or morally dubious due to the mode of production or the source of the genetic material or 'it is unnatural to genetically engineer plants, animals and foods) and 'extrinsic concerns' based on animal welfare perspectives (Kaiser, 2005) and environmental impacts.

Reviews such as those published by the Netherlands Advisory Committee Ethics and Biotechnology in Animals (1990) and the Royal Society (2001) stress the need to consider a range of health and risk implications of genetically engineered animals to humans but also our responsibility to the animals themselves.

2C.3.2 Social impact of increased mechanization

In all sections of agriculture increases in mechanization have resulted in redundancy in the farm labor force but the increased productivity/efficiency has also left more time for other work and enhanced worker environment by eliminating repetitive, dangerous and disliked tasks (Wilson & King 2003; Culshaw & Stokes, 1995).

Precision farming represents a means of harnessing both old and new technologies to improve production and to cope with a variety of environmental impacts. It is associated with agribusiness and with large scale enterprises. Its ability to secure lower costs implies growing pressures on small farms that cannot, or fail to, apply similar methods. Where communities depend on traditional agriculture as in many areas of Europe it is likely to increase pressure on farmers and farm workers to seek employment off the farm and accelerate the continuing decline of the farm labor force. The social and political consequences of this are likely to remain at the centre of agricultural policy thinking into the 21st Century.

In forestry one of the greatest impacts of the increase in mechanization has been on a reduction in accidents (Figure 2C.3.1). Forestry is an innately dangerous operation and in Sweden between 1970 and 1990 the number of accidents decreased from 8656 to 1469. The accident risk, expressed as accident frequency rate, was reduced from 90 to 35 accidents per one million man-hours worked (Axelsson, 1998).

[Insert Figure 2C.3.1 Accident frequency rate, i.e. number of accidents per one million man hours worked in Swedish forestry (1967 to 1995)]

2C.3.3 Migration from rural areas

In 1945, 16 percent of the total labor force in the United States was employed in agriculture, which dropped to 4 percent by 1970 and 1.9 percent by 2002 (Dimitri, et al., 2005). At the same time, primary farm operators begin to work more off-farm jobs. In 2002, 93 percent of farm households had off-farm income, a three-fold increase since 1945, when 27 percent of farmers worked off-farm.

Both farm population and rural population have decreased as a percentage of the U.S. total population, falling from to 1 percent in 2002 from 17 percent in 1945 and to 21 percent in 2000 from 36 percent in 1950, respectively (Dimitri et al., 2005). The decade of the 1950s saw the largest exodus from farming (Lobao 1990) while 600,000 farmers exited farming between 1979 and 1985 (Heffernan and Heffernan 1986), the latter characterized as the “Farm Crisis” of the 1980s that particularly impacted the economic base of rural communities in the Midwestern states.

The portion of rural dwellers in 1945 was nearly 50%of the population but by 2005, the rural population was only about 21%. This shift in the relative percentage is often perceived as an exodus from rural areas, but during this time the rural population has held relatively constant.

In Western Europe, as technology advanced during the 50 years following the Second World War, the number of farms and the number of farmers and farm workers has also declined dramatically. In 1950 England had farm labor force of 687,000 people. By 2000, the labor force on farms had declined to 375,000 (Defra, 2006a). Similar trends are apparent in other western European countries.

[Insert Table 2C.3.1: Employment by major economic sectors in a selection of countries in the NAE]

[Insert Table 2C.3.2: Urban and rural populations in NAE]

The changes in Eastern Europe are more complex as the communist era greatly reduced the number of farming units, by collectivization. In E. Germany, for example, in 1945 all large farms were broken up and given to the farm workers. This was not successful and by the 1950s many of these new farmers had left the land to work in the new factories and collectivization started, resulting in the establishment of large collective farms. Then, following the demise of this system of land management in c. 1990 there has been a variable re-allocation of land to the former owners, resulting in fragmentation of the farming units. In turn there has now been re-amalgamation of the small units to create more financially viable enterprises (Bouma et al., 1998).

In North America and Western Europe the population working in agriculture is today only a small section of a country's overall population (Table 2C.3.1). In contrast, in some countries in Eastern Europe the proportion of the population is still very significant (Table 2C.3.1).

The proportion of the population living in rural versus urban areas in NAE can be seen in Table 2C.3.2. The rural population is still declining in terms of percentage of the total population in most NAE countries.

2C.3.4 Equity (benefits, control and access to resources)

Food production per capita has been increasing globally, but major distributional inequalities exist. Global food production increased by 168% over the 42 years until 2005 (MA, 2005). Still, an estimated 852 million people suffered from chronic undernourishment in 2000-02, increased with 37 million even after the period 1997-99. This is mainly due to poor access to food and to the resources required for food production, which follow from poverty and lack of voice. Most of the hungry live in the developing world, while some 9 million live in industrialized countries (FAO, 2004a). Sub-Saharan Africa is the region of the largest share of undernourished people, and also the region where per capita food production has lagged the most (MA, 2005). Most of the poverty ravishes rural areas (FAO, 2004a) with declining value added for food production. Food systems have developed from ones relying on ecosystem services and other local resources towards industrial systems in which regulation by the carrying capacity of the ecosystem has been lost. The depletion of economically exploitable fossil energy, phosphorus resources and inherent soil fertility is accelerated, while environmental pollution and climate change intensify (see sub-chapter 2.4.1). Biodiversity and ecosystem services are in decline (MA, 2005). A drastic inequity thus prevails in food systems: between industrialized and developing countries, between urban and rural regions, and even between generations. In addition, current directions in the development of food systems have fundamentally changed the internal interaction and share of benefits in the food chains, disempowering local rural actors, such as farmers and small-scale processors. The share of retail for control and benefits in the food chains has increased.

2C.3.4.1 Drivers of change

North America and Europe (EU) are two of the world's largest agricultural producing, consuming and trading entities, so the influence of these two regions globally is significant. In both regions there has been a continuing pattern of transformation during the 20th century from labor intensive, small, diversified farms to large, mechanized and specialized farms (Dimitri et al., 2005; Poiret, 1999). In both North America and the EU, agriculture is declining as a contributor to gross domestic product and as a source of employment, however the more broadly defined food and agricultural sector (hereafter called agri-business) continues to play a prominent role. Agri-food supply chains in NAE have undergone important structural changes in recent decades that have altered the ways in which food firms do business. One of the most striking changes is the ongoing rise in the scale of operations of food firms at all points along the supply chain, most notably in food retailing (Connor, 2003; Dobson, 2003). Loosely aligned vertical integration processes have created clusters of alliances and resulted in the concentration of control over decision-making in global food systems to fewer and fewer transnational corporations (Lang, 2003). This trend describes the so called development of industrialized farming and a globalized food system comprising of specialization, consolidation and standardizations, which has led to increases of concentration of ownership and control by downstream market actors. The generative forces for pattern of change are largely attributed to changing market forces and technological innovation (Dimitri et al., 2005; Poiret, 1999).

2C.3.4.2 Equity in terms of economic benefits and value-added

The empirical evidence of *the impact of agricultural growth* on equity is ambiguous (von Braun, 2003; Deininger at al., 2004; Gallup, 2002; Fan et al., 2002). The continued food distributional inequalities despite food production per capita increasing globally, is explained by a set of factors. In low-income countries, in which agriculture has a large share in the economy and rural population has a high proportion, food production has critical equity impacts in the form, for example, of poverty alleviation, reduced inequalities in food consumption, improved nutrition and health, low commodity and food prices, and direct and indirect employment and income generation. According to von Braun (2003), the experience of the last few decades shows that the higher the food (and agricultural) output across regions and types of crops, the more equal the land distribution, the better the small farmers' access to inputs and markets (including the infrastructure and credits to the poorer farmers and in remote areas), and the less suppression of agricultural prices, the greater the positive impact on income and consumption distribution, poverty alleviation, and food security for the poor. The marginalization of vulnerable groups such as women and children is also a constraint to equitable sharing of benefits from farming (Quisumbing and Meinzen-Dick, 2001). Adequate research and extension is crucial.

According to a review of more than 200 theoretical and empirical studies about *the effect of trade liberalization* on sustainability, the effects on economic welfare and overall sustainability depend on the nature and extent of the flanking and other supporting measures that are taken (Kirkpatrick et al., 2004). Although there are often potential, aggregate economic welfare gains to be made from free trade and increased foreign investment inflows, these are not necessarily shared by all countries and all socio-economic groups within these countries. In many examples the social (and environmental) impacts are negative, where protection measures are insufficiently effective. In addition, the trends in global demand for food safety and processed products raise concerns about the long-term viability of small farms in developing countries in the conditions of free trade (Lipton, 2005). These trade effects have been contributed to by the disproportionately negative impact of structural adjustment policies on smallholders during the 1980s and 1990s. The impact of trade liberalization on distribution of income within developing countries varies, however, according to country-specific policy conditions and socio-economic structures. In Latin America, for example, the effects on equality in income have been positive in nine countries and negative in five countries (von Braun, 2003).

Rural regions have increasingly specialized in producing and exporting natural resource-based raw materials for, e.g., food industry (Siegel et al., 1995), while at the same time satisfying local demand with food imported from outside the region. The value added in input production, food processing and food distribution has been transferred to urban areas and, increasingly, beyond national borders. Besides liberalization of agricultural trade, the European Union's (EU) agricultural policy and the associated technological change have forced a rapid reduction in the number of farms. Because food production has always played a central role in rural vitality, and will do for a long time to come (OECD, 1996), this development has led to unemployment, out-migration and the disintegration of social structures in the rural regions of all industrialized countries in Europe. On the other hand, this has impeded sustainable development of urban areas, too, as well as the access to resources of food production.

It is argued that industrialization, globalization and consolidation affect the ability of smaller producers to effectively compete with larger corporate entities with consequential effects on rural community structure and dynamics. While the transformation to a more advanced stage of industrialized farming over the past 60 years has led to significant increases in productivity (primarily due to chemical use, mechanization advances and the restructuring of markets) with concomitant benefits to many consumers, it has simultaneously, in many rural areas, had an adverse effect on economic and social vitality and has been said to have reduced the somewhat idealized independence of farmers (Ikerd, 2002; Pretty, 2001; Goldshmidt, 1978; Lerza, 1983). In a moderating argument Buttel (1983) suggests that the above description of events is too sweeping and that although changes in social and economic structure of rural communities is continuing such changes have differential effects, creating opportunities for some and disadvantaging others. Such reasoning suggests that socio-economic effects of industrialization and globalization are variable and perpetually fluctuating in response to local and non-local driving processes.

It may also be indicative of a nostalgically laden view that idealizes how rural farming communities once were, before being destroyed by the ogres of agri-business.

The *rise of retail concentration* (see section II.3.1) has led to the concern that retailers may abuse their market power vis-à-vis other actors with smaller market shares, in particular farmers and consumers. Farmers have for a long time noted how small a share of the prices consumers pay for food and fiber products, is made up of the prices they receive for the raw commodity at the farm gate. The declining share of the consumer food Euro allocated to producers is reflected in rising retail-farm price margins. A factor contributing to this decline is the increase in consumer demand for off-farm or marketing services for food. Farmers' ever-increasing productivity has made agricultural products steadily cheaper in real terms; this alone would cut the farmer's share of retail prices if the margins for processing and retail distribution just kept up with inflation. But growing farm productivity is only half of the story. The farm-to-retail margins have risen significantly faster than overall food marketing costs. The rapidly growing retail margins may be variously explained in different markets (Reed et al., 2003). Reduced competition among retailers or (for some products) processors may produce monopoly profits, stifle cost saving innovation, and dull the efficiency of management; alternatively, fewer competitors may increase the importance of competition on things other than price. There may be more value-added at the retail level, including better service and a greater variety within the category. All farmers are facing a shrinking share of the retail dollar. With the ever-growing efficiency of production agriculture, and the continuing tendency of the marketing system to add more value for wealthier consumers, we may expect this trend to continue (Kinsey and Senauer, 1996).

2C.3.4.3 Equity in access to resources

Industrialization and NAE-driven development of agricultural technology based on external, purchased inputs has affected equity: poor farmers especially in developing countries often do not have the option of introducing modern methods for ecosystem services because of the lack of market integration and infrastructure or heterogeneity of environment, or because they cannot afford the external inputs. The nutrient case illustrates the more general consequences: Large areas of field soils of NAE, especially in Europe, have been enriched with phosphorus originating the rock phosphate deposits, and only a fraction of the industrially fixed nitrogen is retained in food products. This leads to eutrophication and biodiversity decline in both aquatic and terrestrial systems. Conversely, the soils of several cultivated systems especially in Sub-Saharan Africa are nutrient-depleted (Maene, 2003). This is especially problematic where fruits, vegetables and other crops are exported on a large scale from rural areas to urban centers, or from regions with nutrient-poor field soils to nutrient-enriched NAE. In fact, NAE relies for increasing part on food, feed and resources originating beyond its boarders (Deutsch, 2004). For example, only a third of African phosphate fertilizer production was used in Africa in 2002 (FAOSTAT, 2005).

There are also other kind of linkages between the impact of cultivation on ecosystems and equity. Climate change, the decline in ecosystem services and increasing environmental costs caused by agriculture, e.g., loss of inland water fish populations due to eutrophication and loss of habitat and biodiversity, often worst hit the rural poor (Bene et al., 2003). The landless rely more on wild sources of food (Grimble et al., 2002). Increasing emigration from rural areas can also be seen contributing to urban hunger in the form of lack of access to resources of food production.

The overexploitation and pollution of natural resources and decline in ecosystem services through the last decades have created inequity also between the generations. There are concerns about growing inequality with regard to the capacity to generate and gain access to new scientific information and technology (von Braun, 2003), because an increasing share of agricultural R&D is privately funded. Large companies have few incentives to focus on crops and technologies appropriate for poor farmers especially in the tropics, while having increasing proprietary rights over processes and technologies (Pardey and Beintema, 2001). When the investments in R&D in developing countries, excluding largest ones, are small despite of the significant role of agriculture in their economy, these trends widen the existing gap in scientific and technological capacity between NAE and developing countries further. This is contributed by trade liberalization, which emphasizes science and technology as the central resources for competitiveness.   .

2C.3.4.4 Equity in control and influence

The trend of vertical integration of food systems (described in Section II.2.6) has culminated recently in the rise of food retailer concentration especially in Europe, but also in the US (Gibbon, 2003; Pimbert et al., 2001; Vorley, 2003; Vorley, 2001; Ponte and Gibbon, 2005; Marsden, 1997:187). It is widely claimed that the current asymmetry of power relations enables large supermarket chains to exert pressure in one-sided negotiations to push the costs and risks of business down the supply chain to producers (Gibbon, 2003; Vorley, 2001). It is also asserted that this continued push for trade liberalization and demands to conform through buyer driven supply chains stipulating different food quality criteria has meant an increasing global standardization of price and quality and demanding terms of trade that favor a small minority of large-scale producers whose destinies are closely aligned through contractual arrangements with global agri-business. This current disequilibrium of power has had dire social and economic consequences for many primary producers in both poor and rich countries, who often have few alternative retail outlets, with closed supply chains rapidly replacing traditional arms length or spot markets (Vorley, 2001).

Critics concerned with the global equity of agri-business assert that powerful food retailers situated in the North largely dictate the social relations of production in the South and provide little opportunity to encourage local value capture (Marsden, 1997). Such processes are seen to be powerful drivers for divergence and marginalization in traditional farming communities (Vorley, 2001). Further, it is contended that the only way forward is for these localities to disengage and reintegrate into local and regional settings. Paradoxically, in some regions (e.g. Tuscany), these same phenomena described above have been the catalyst for stimulating vibrant new livelihood strategies (such as tourism) in traditional farming communities as they have endeavored to innovate and adapt to rapidly changing circumstances.

Historically, some of the effects of the trends described above have been mitigated in Europe and the US by costly market intervention to ensure price support, often under the policy guise of rural poverty mitigation, rural development programs or more recently nature conservation (Petit, 1997; Dimitri et al., 2005). The impacts of these policies are in the decline in the US, but due to effective lobbying and public support the agricultural sector in the EU was largely exempted from trade liberalization agendas until the Uruguay Round. However, clearly the continuation of farm subsidies (in one form or another) is an approach increasingly subject to public and political debate within both regions and indeed its effects resonate throughout the world. Proponents concerned with global equity argue that further trade liberalization in the agricultural sector would increase poor farmers' access to lucrative EU and US markets and stop the practice of 'dumping' of heavily subsidized exports on world markets. The contemporary countervailing argument, which still has political resonance in some areas, is that subsidies protect the socio-cultural fabric and environmental integrity of these rural areas. Internationally sponsored forums such as WTO and the World Bank promote the merits of the global free market as vehicle to deliver greater global equity (and efficiency), while at the same time overseeing the formation of trading blocks in the EU and the Americas that ensure the continuation of self protective trade barriers and the asymmetries of market relations between the richer and poor parts of the world.

Goodman and Watts (1997) describe how the global food economy is also increasingly differentiated in new sorts of ways at the levels of consumption. *'Some in poor countries are eating better, while others in Africa descend even deeper food insecurity, millions in California go hungry and others consumer 'designer organic vegetables shuttled around the world in sophisticated cool chain.'* This is occurring whilst food production has outstripped population increases, but there is no substantial contribution to increasing food insecurity or calorific intake in many parts of the world (especially Africa) (Fahlbeck, 2006).

Understanding the wants and demands of consumers within highly differentiated food markets has become a source of power within food systems. Related to this point, consumers are demanding more transparency and information (*read control*) about food production methods and labor relations on which to base purchasing decisions. Thus the role of knowledge and information is assuming more and more importance as a point of influence and control in food systems. Supermarkets and fast food outlets with their positional proximity to customers have a unique advantage to influence the rest of the production and food distribution chain. These powerful retailers continue to strive to meet consumer welfare concerns (price, quality and variety), often to the detriment of producer welfare. A recent spate of food controversies in North America and Europe has re-stimulated the continuing debate and concern about human and environmental health risks (the so-called food anxieties) associated with food production and consumption (Holloway and Kneafsey, 2004). The response is tougher more restrictive food quality criteria managed through resource intensive, producer responsible, certification processes to manage risk and quality. Clearly such demands are increasingly favoring larger scale producers.

2C.3.4.5 Rise of alternative food systems

Partly in response to the numerous concerns related to industrialized agribusiness (see section II.2.6) there has been a growing interest in 'alternative' food systems. Although still marginal in scale and impact compared to the dominant agribusiness many of the 'alternative' modes of food provision seek to 'reconnect' consumers, producers and food (Sage, 2003). A key motivation for this movement is the social welfare of rural communities - an issue that is closely related to sustainable wealth creation, or what might be regarded as value-capture locally (Marsden and Smith, 2004). Thus many communities in response to and as part of globalization processes are putting increasing emphasis on localizing food systems to develop resilient local economies to build capacity and create innovative synergies, so they can more readily adapt to current and future challenges (Marsden and Smith, 2004). Local food systems with their focus on their social and economic embeddedness can reduce risk for farmers and consumers and value-add locally, thereby supporting rural development (Sage, 2003; Winter, 2003). Although the benefits attributed to locally-oriented food systems are numerous, these models have also been criticized as benefiting primarily those who can choose based on education or income (Allen, 1999; Hinrichs 2003, Hinrichs and Kremer, 2002).

Conceptualizing the equity of food systems at different spatial scales generates different perspectives and responses. Local food systems projects based on regional identity (e.g. Tuscany) or branding (e.g. organics) have been promoted as rural development alternatives in NAE (Barham 2003). However, they may also serve the privileged at the expense of the poor (Allen, 1999), through the decreasing affordability of products - perhaps even magnifying existing unequal relations of consumption locally (Bellows and Hamm, 2000; Allen and Sachs, 1991). Furthermore a focus on the local may well take our eyes off global-scale inequities surrounding issues of food security and material welfare, although it may reduce local communities' (implicit) involvement as consumers in exploitative labor and environmental commodity chains. Endeavors to concentrate production and consumption locally may also restrict opportunities to import Fair Trade goods and therefore limit market access for developing country growers. Fair Trade initiatives have also been criticized for encouraging agriculture for export rather than to feed the populations of the exporting countries. In fact, extensive hunger has appeared even in important exporting countries (Parrott and Marsden, 2002), and "increased local food production remains critical to alleviating poverty and providing food security" (MA, 2005, p. 238).

The historical and continuing interactive trends of technological advances and liberalization of trade and vertical integration processes have been largely influential in the formation of the hegemonic US and EU buyer driven food chains of today that have significant local, regional and global implications. There tends to be an asymmetry of power relations within these food systems that favors downstream market actors over smaller scale producers. This phenomenon is exacerbated in poorer farming areas devoid of adequate capital (to increase efficiencies and scale up to meet demanded standards) and/or effective government intervention to ensure price support. In parallel and in some case in response to these processes there is also an emerging reflexive trend that features small-scale, locally value added horizontal food chains that seek to reconnect producers and consumers.

2C.3.5 Distancing consumers from production

Transport and trade of food has the potential to result in economic and social benefits such as, economic gains for both developed and developing nations and individual enterprises, reduced prices for consumers and increased consumer choice. On the other hand, the effects on food safety are often negative. The wider economic and social effects are, however, complex and very systems-specific. In addition, they are manipulated through the political-economic environment. Effects on local economy and communities and the consequent potential to equity among regions has often not been beneficial. Even if globalization and liberalization of agricultural trade lead to apparently more efficient production, underutilization of the released resources radically changes the effect. Transfer of the labor to other regions and sectors from declining agriculture is both a social problem causing inequity and an economic problem (Huan-Niemi, 2004).

The increasing emergence of vertical food chain (see sections II.2.6 and II.3.1) has extended spatial and social distancing between the stages of the food chain. This has caused dramatic changes in the voice among the actor groups. Higher equity in control among the actors of the food chain has been found in a local food chain as compared with the dominant system (Sumelius and Vesala, 2005; Kahiluoto et al., 2005). Social distancing has contributed to detachment of consumers' understanding of the production system and food chain. Issues of ethical, social and environmental concern are typically shielded from consumer view and may only be revealed if there are dramatic and direct societal consequences. As Marsden et al. (1999) illustrate the environmental effects of conventional agriculture and their social implications tend to be spatially bounded (rather than atmospheric or global) and often are remote from the end consumer. For example, a shopper in Sweden selects from bananas grown and transported from Costa Rica without having any inkling of (or having information about) the social or ecological implications or production and transport. Aside from the concerns about production methods cited above, globalize food commodities are often produced in ways that are exploitative of local labor relations and weak environmental regulation regimes. In this way consumption in a remote market is materially connected through the commodity chain to questionable production practices in poorer countries. In these circumstances price and convenience, which are still visible, have been the predominant determinant for consumers, while adverse social and environmental effects can be isolated from consumer view, therefore preventing active and critical consumer choice.

2C.3.6 Nutritional consequences of NAE food systems

The most direct and tangible benefit of food is its role in enabling individuals to pursue active, healthy, productive lives as a consequence of adequate nutrition (Food, chapter 8, Millennium Ecosystem Assessment). For these reasons access to adequate, safe food has been recognized as a basic human right. Decreased hunger and poverty and improved nutrition and human health are two of the Millennium Development Goals.

Although the food insecurity and prevalence of under nourishment and hunger has been reduced worldwide, there were still 9 million undernourished people in industrialized countries and 28 millions in countries in transition in 2000-2002 (FAO, 2004b). These data include 24 million people in the Commonwealth of Independent States (9 % of the population), 4 million people in Eastern Europe (former communist states within and without the EU) (3 % of the population), and 0.2 in Baltic States (2 % of the population).

On the other hand, economic development, an increase in consumer purchasing power, progress in food production methods and changes in the marketing of food products have dramatically altered the food situation in many countries of the European Union and in the USA in recent decades. A situation of general abundance of food available has developed, although some sections of the population do not consume a sufficiently healthy diet. Those on a low income spend a greater proportion of their income on food, but eat a diet of lower nutritional quality than those on a high income (European Commission, 2002b).

The emerging challenges in relation to nutrition and health are thus of a different nature than the ones experienced some decades ago. North America and Europe are currently experiencing a high prevalence of non-communicable diseases, such as cancer, cardiovascular disease, diabetes, certain allergies and osteoporosis, due to the interaction of various genetic, environmental and lifestyle factors (including smoking, diet and a lack of physical activity). Numerous studies suggest nutrition is important in maintaining health and preventing many of these major diseases (Ferro-Luzzi and James, 1997; WHO, 2003).

For the European Union, estimates have been made of the total burden of ill health, disability and premature death from all causes experienced by the population, and the factors most responsible for this disease burden (European Commission, 2002). Of a broad range of causes, diet-related factors are believed to be responsible for nearly 10 % of the total disease burden —including overweight (3.7 %), low fruit and vegetable consumption (3.5 %) and high saturated fat consumption (1.1 %). Together with lack of physical exercise (1.4 %), these factors account for a greater proportion of ill health than tobacco smoking (9.0 %).

[Insert Table 2C.3.3: Obesity and overweight among adults in a sample of countries within European Union]

[Insert Table 2C.3.4: Change in obesity (percentage of adult population with a BMI>30 kg/m2) from 1980-2003 in the NAE]

The relatively recent situation of food abundance has a main drawback: obesity. The prevalence of overweight and obesity is commonly assessed by using body mass index (BMI), defined as the weight in kilograms divided by the square of the height in meters (kg/m2). Persons are considered as "overweight" when their BMI exceeds 25 kg/m2 and as "obese" when their BMI exceeds 30 kg/m2. (WHO, 2003a; International Obesity Task Force, 2005) In recent years, overweight and obesity have been growing at a very fast rate and today obesity represents a real threat to the public health of certain groups in North America and Europe, as shown by data from IOTF and OECD (Tables 2C.3.3 and 2C.3.4).

In the next 5 to 10 years obesity in the European Union will probably reach the high level of prevalence in the United States today, where one third of people are estimated to be obese and one third to be overweight. Another big concern is the rapid rise in childhood obesity (Fig. 2C.3.2). In many countries there is a 10-15 year lag behind the USA, but nevertheless European countries are narrowing this gap.

Figure 2C.3.2: Rising prevalence of overweight children in NAE

Overweight and obesity lead to adverse metabolic effects on blood pressure, cholesterol, triglycerides and insulin resistance. The non-fatal, but debilitating health problems associated with obesity include respiratory difficulties, chronic musculoskeletal problems, skin problems and infertility. The more life-threatening problems fall into four main areas: CVD problems; conditions associated with insulin resistance such as type 2 diabetes; certain types of cancers, especially the hormonally related and large-bowel cancers and gallbladder disease. The likelihood of developing Type 2 diabetes and hypertension rises steeply with increasing body fatness. Overall, this leads to heavy economic, public and social costs. According to WHO (2003a), obesity accounts for 2-6 % of total health care costs in several developed countries, with some estimates being as high as 7 %. The true costs are certainly much greater as not obesity-related conditions are included in the calculations.

Obesity is most commonly due to an imbalance between energy intake and energy expenditure (i.e. over consumption of energy rich foods combined with a lack of physical activity (WHO, 2003b). Favoring healthy diets and educating the consumer to choose an appropriate diet and increase physical activity is a great challenge involving a range of long term strategies (WHO, 2003a; European Commission, 2002 and 2005b; USDHHS and USDA, 2005). This corresponds to the necessity of a behavioral change as described by Popkin (1998) to get rid of malnutrition leading to nutrition-related non communicable diseases. Unfortunately, under-nutrition and malnutrition can co-exist, as it is the case in countries displaying “nutrition transition” patterns, leading to a phenomenon described as “the double burden of disease”.

2C.3.7 Welfare of farm animals

Intensive livestock production raises several significant ethical issues. Treating animals as items on a production line offends many who feel this is an unacceptable relationship between humans and other species. The welfare of farm animals has become an area of increased significance for policy makers (Defra, 2004a, Webster, 2005; USDA, 2003). The mass production of animals to specification undermines traditional livestock businesses, reducing local employment and undermining the economic survival of some communities. In an area in which emotions often play an important part in determining attitudes there are a wide range of pressure groups who criticize many aspects of intensive livestock production (Compassion in World Farming 2007).

Livestock kept in intensive systems such as those widely practiced in Europe are prone to outbreaks of disease, illustrated by the periodic outbreaks of foot and mouth disease and encephalopathies such as BSE and scrapie, and viral diseases in cattle, sheep and pigs, and epidemics of viral and bacterial poultry diseases. These epidemics have sometimes devastated livestock sectors in Europe and have largely been controlled by a slaughter policy, although for some pig and poultry diseases vaccination and the routine use of antibiotics has become common practice since the 1950s. There is serious concern about the routine use of antibiotics as growth promoters and disease control agents in European livestock because this has led to the rise of antibiotic resistant bacteria in humans (Mellon 2000).

Livestock farming in Europe is strictly regulated by sets of rules and regulations that developed in the early 20th Century, mainly as a response to the needs of intensive livestock systems. These cover animal welfare, disease prevention and control, the use of chemicals in husbandry and processing, and worker health and safety. Since the 1960s many EU Directives have developed, giving rise to Member States’ domestic legislation regulating livestock production and processing.

The FAO has collaborated with animal welfare organizations to initiate joint activities to promote humane treatment of slaughter animals while heightening the quality of meat products and by-products. Also, to improve the efficiency of village-level meat processing by developing modular designs for slaughtering and processing facilities based on affordable, easily available materials and selected and adapted to the needs of users. These activities were focused on reducing losses and limiting contamination while increasing employment especially for rural women and the income to small producers.

2C.3.8 Loss of traditional farm buildings

Traditional farm buildings represent one of the more long lasting features of landscape in most developed countries.[5] Their replacement by purpose designed modern buildings changes the appearance of the countryside and since by the standards of traditional building they tend to be large there have been complaints that they are inappropriate. Still more pressure groups have sought to preserve old buildings as part of the heritage of the countryside.[6,7] Maintaining buildings that have no economic function is a costly activity that farm businesses will wish to avoid. One solution has been to modify them so that they may be used for new purposes. Thus old barns and cottages may be modernized and add to the stock of housing in rural areas. In some cases old farm buildings, including byres and barns have been used for light industrial purposes or turned into offices. With minimal expense some buildings may be used to store non-agricultural items such as caravans or old motor cars. Again this can represent a new source of economic activity in rural areas.[8]

2C.4 Impacts of NAE agriculture and AKST outside NAE

2C.4.1 Impacts of NAE AKST on developing countries

This section provides an overview of key events since 1945 in transferring and adapting research from the “rich” or industrialized countries in NAE for improving productivity in crop, forestry and fisheries systems in Africa, Latin America and Asia. From 1961 to 2003, global food production increased by 168% but despite this increase c. 852 million people were undernourished in 2000-2002, of which nearly 96% lived in developing countries (Wood et al., 2005). These figures indicate that despite the efforts by international research organizations to boost food production, there is still a large divide between the aspirations of scientists and policy makers and the apparent lack of improvement in agriculture.

Knowledge transfer has long followed a “top down” approach, from universities and research institutes as providers of new technologies and principles, which were passed down to experimental stations, extension agents and finally to farmers and producers. However, criticisms of this top-down system approach led to more multi-disciplinary and participatory approaches, attempting to engage scientists with farmers in a flow of ideas and knowledge exchange (Broerse and van de Sande, 1995).

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[5] See Museum of English Rural Life http://www.rdg.ac.uk/rhc/interface/public/countryside/landbuild/landbuild_farm_buildings.html

[6] Traditional Farm Buildings English Heritage - http://www.english-heritage.org.uk/server/show/nav.001002005008009008

[7] Silos and Smokestacks National Heritage Area P. O. Box 2845 Waterloo, Iowa 50704-2845 (319) 234-4567 info@silosandsmokestacks.org

[8] Michigan State University - How are Farms and Ranch Diversifying their Revenues? http://www.prr.msu.edu/agdiversity/paper.html

In many developing countries, National Agricultural Research Systems (NARS) developed from experimental stations originally established by colonial occupiers. These stations concentrated on export crops, such as cotton, sugar cane, and tea, with little attention to food crops. Initially senior scientists and administrators tended to be predominantly expatriates, even after countries gained independence (Arnon, 1989; Buhler et al., 2002). From the 1960s to 1970s, NARS in many developing countries did not function effectively because of financial constraints and the low priority given to agriculture by their governments (Farrington and Howell, 1987). Population increases caused a need for more production of food, which in the 1960s and 70s resulted in organizational changes in agricultural research at national, regional and international level (Von der Osten, 1982).

The Consultative Group for International Agricultural Research (CGIAR) was founded in 1971 with the aim of increasing food production (primarily cereals). CGIAR worked with NARS to build individual and institutional research capacities (Buhler et al., 2002). International Agricultural Research Centers (IARCs) were founded under CGIAR to provide regional centers, and each originally had specific crop mandates (see also [insert reference to Helena's piece on institutions here]).

The first IARC was the International Rice Research Institute (IRRI) founded in 1960 in the Philippines to work on the improvement of rice yields. Others followed, including the Centro Internacional de Majoramiento de Maz y Trigo (CIMMYT, Mexico) and the International Institute for Tropical Agriculture (IITA, Nigeria). Currently IARCs also cover non-crop research, such as livestock (International Livestock Research Institute, ILRI, Ethiopia), forestry (e.g. Center for International Forestry Research, CIFOR, Indonesia) and food policy (International Food Policy Research Institute, USA) (see Buhler et al., 2002).

2C.4.1.1 Institutional structures outside CGIAR

In 1945, at the same time as the wheat breeding program was started in Mexico (which led to the founding of CIMMYT), the United Nations established the Food and Agriculture Organisation (FAO) as a specialist agency for developing country agriculture. More recently, in 1996, the Global Forum on Agricultural Research (GFAR) was founded to coordinate research and development amongst IARCs, NARS, other research organizations, farmer groups, NGOs, private companies and international donors. Both GFAR and FAO work with a very broad range of partners and research organizations for information transfer, capacity building and research coordination.

NAE universities have long played an important role in the transfer of AKST to developing countries through training of postgraduate students who often occupy senior positions on their return home. Most countries in NAE have aid organizations which transfer AKST to the developing world. These include Sweden's SIDA, Denmark's DANIDA, Germany's GTZ, France's CIRAD, the NL's DGIS, the UK's NRI/DFID, the US's USAID and Canada's CIDA. In addition a number of charitable foundations play an important role in transferring NAE AKST to developing countries. They include the Rockefeller Foundation, the Ford Foundation and Gatsby Charitable Foundation. In recent years, a plethora of regional networks have also been developed. In Africa, for example, networks include ASARECA for East and Central Africa, CORAF/WECARD for West Africa and SADC/FANR for Southern Africa (coordinated by the Forum for Agricultural Research in Ghana).

Trade bodies such as the International Agriculture and Technology Centre organize missions for potential commercial partnerships between UK companies and companies or parastatal organizations in the more advanced agricultural sectors, such as meat processing or export horticulture. Farmer organizations in industrialized countries appear to play little role in the transfer of AKST to developing countries. In the UK, there do not seem to be any types of exchange or training arrangements by farmers' organizations or levy boards with any other equivalent overseas organizations.

Within developing countries, private or commercial companies can often be providers of technology and advice for farmers, e.g. supplying seeds, fertilizers, and pesticides. These companies can range from small family run enterprises to larger national organizations, possibly working with regional branches of multi-national pesticide businesses. The environmental and human problems associated with pesticide misuse have long been documented (e.g. Bull, 1982), and proper training of farmers and extension staff is a key but neglected element in preventing "pesticide pollution". Financial indebtedness to seed and pesticide companies has led to cases of suicide by farmers (e.g. in India).

Since the 1990s, national governments have privatized extension services, so farmers and farmer groups need to choose who to pay for advice. In some countries, such as Uganda and Ethiopia, NGOs and charities act as the advisory service. However, this change from independent or government-backed advice to privatization can lead to obvious conflicts for example in recommendation of pest control products.

2C.4.1.2 Reform of institutions in AKST

One could question the degree of overlap/ complementarity occurring through international (FAO, GFAR, CGIAR), regional/ subregional networks and aid organizations based in individual industrialized countries. Regional networks may be essential to oversee local adaptations of technology transfer and measure impacts. However, there must be a more efficient way to group experts, intermediaries and end-users in different regions, so more aid money goes directly to improvement rather than administration. The use of Information and Communication Technology (ICT) in virtual networks through the internet should be accelerated.

2C.4.1.3 CGIAR and agriculture AKST

Crop Breeding

The Cooperative Wheat Research Production Program started in 1944 to increase wheat yield in Mexico. The program involved the Rockefeller Foundation and the Mexican Ministry of Agriculture. The four principle scientists were from the US and included Norman Borlaug, who was largely responsible for research into breeding high yielding, disease resistant and semi-dwarf wheat varieties. The program involved combining improved varieties with changed agricultural techniques such as the use of artificial fertilizers, irrigation and pesticides. The work was accelerated through field trials in central Mexico during the summer, followed by further testing in northern Mexico. This shuttle breeding system took advantage of the two growing seasons and tested varieties at different altitudes and temperatures. As a result of the program Mexico became a net exporter of wheat by 1963. Norman Borlaug also applied the same approach in Pakistan and India. Between 1965 and 1970 wheat yields nearly doubled in these countries, greatly improving their food security. These collective increases in yield have been labeled the Green Revolution, and Borlaug is often credited with saving over a billion people from starvation. He was awarded a Nobel Prize in 1970 in recognition of his contributions to world peace through increasing food supply. The program led to breeding programs for wheat (at CIMMYT) and rice (at IRRI) (Hedden, 2003; Buhler et al, 2002).

IRRI's first major activity after its establishment was to breed rice lines that would respond to application of higher doses of fertilizers and be less photosensitive. The use of these varieties doubled or even tripled yields but they tended to be more susceptible to pests than older rice varieties. The use of the new rice varieties were thus combined with an increased use of pesticides as well as synthetic fertilizers, a practice that became dominant in rice cultivation in several Southeast Asian countries within a few years. Similar development was seen for wheat (Evenson and Collin, 2003) and maize.

Other components of the Green Revolution were large-scale irrigation systems, soil cultivation, harvest and post-harvest technology. After the initial enthusiasm, critics against green revolution developed, initially with a focus on social issues and later an increasing concern about negative environmental impacts (Van Keulen, 2006). Criticisms include claims that the use of substantial quantities of chemical inputs did not lead to an increase in efficiency, that small farmers became dependent on money-lenders and traders and often lost their land and that many practices were not appropriate or accessible and that credit was not necessarily available for small scale farmers. Irrigation required big dams, often involved the flooding of previously settled areas and fertile farmland, and the efficiency of the large irrigation networks was controversial. It has been suggested that the green revolution technology was a less stable and riskier strategy, due to e.g. compensation of heterogeneous crops with monocrops of a single variety, and due to market integration, taken fluctuating markets and prices. Concerns were raised about pollution of the environment and harm to wildlife through the use of chemicals, about replacement of landraces through high yielding varieties, perceived as causing genetic erosion and genetic vulnerability. There is also concern that the agricultural intensification further worsens soil degradation (salinization, acidification) and increases dependence on external, non-renewable energy sources. The success of the Green Revolution led to a situation where farmers disregarded other means of yield improvement. Growing crops for subsistence gave way to the production of cash crops.

After the success of the first Green Revolution in Asia in increasing crop production, and despite criticisms in some quarters about the effects of the technological transformation, there were high hopes in translating the Green Revolution to Africa, but to date these attempts have failed, possibly because farmers goals in African agricultural systems are very different to those in Asia (Conway, 1997; Lipton 1988), and where small-scale farmers produce a range of locally adapted crops with very few inputs other than manual labor (Herren, 1994).

Therefore, approaches which pay attention to the multidimensional effects of the technologies, such as farming systems research (FSR) and participatory research methods, integrated pest management (IPM), sustainable agriculture, on-farm conservation and integrated rural development became common in the 1970s and 1980s (Mann, 1997). Official programs to compare methods using high external inputs with traditional practices started to gain ground again in the 1990s. The problems linked with the Green Revolution raised the notion of the Doubly Green Revolution with an objective of sustainable agriculture with the approach of sustainable use and/or adaptive management (Pretty, 1995; Conway, 1997; von Braun, 2000; Ashley and Maxwell, 2001).

An improved rice variety, NERICA (New Rice for Africa), was introduced by the Africa Rice Centre (WARDA) in the 1990s. This hybrid was obtained through conventional tissue culture and combines traits from African varieties for resilience to abiotic conditions (drought tolerance, poor soil nutrition) with the high yielding qualities of Asian rice varieties. NERICA is reported to increase yield by 50% without any fertilizer and more than 200% with fertilizer (Nwanze et al., 2006). NERICA-derived lines could become important in African upland rice-based systems for maintaining soil fertility (Nguyen and Ferrero, 2006).

In recent years, the use of genetic modification (GM) techniques to accelerate plant breeding have resulted in several research projects grouped around the provision of better food quality using the "golden rice" GM technology. This was originally devised to provide beta carotene biosynthetic pathway into rice endosperm, so that vitamin A intake would be increased by consumers with the aim to reduce infectious diseases and eye problems in humans. The gene technology has been made available without any patent restrictions for use by other researchers and new "golden" crops such as yams and maize are currently being evaluated (Beyer et al, 2002: Potrykus, 2001). Although GM technology is controversial, especially in "industrialized" countries where there is a disconnection between food production and food availability, many developing countries have active government sponsored GM crop and livestock programs at national research organizations and universities. Cultivation of pest tolerant Bt cotton in China, for example, has been reported to improve yields and yield security as well as reducing insecticide use and cases of pesticide poisoning in farmers.

Crop Protection

As with crop breeding, CGIAR, NARS and universities have been involved in crop protection programs. A key example where these three groups worked together are the biocontrol program against cassava mealy bug, an insect pest introduced from South America to Africa in the 1970s. By the 1980s, cassava mealy bug was causing an average 40% yield loss in cassava tubers. CIAT, IITA and GTZ started a research project in 1981, which involved surveys in South America to identify potential biocontrol agents. A species of parasitic wasp was identified as a potential key mortality agent and was shipped to IITA after quarantine at CABI Bioscience in UK and then mass produced in West Africa for large-scale releases in the cassava growing areas of west, central and southern Africa (Neuenschwander, 2001). The successful establishment by the wasp led to mealy bug control within 10 years. Monetary savings of US$7971 to $20,226 million were estimated, and a cost-benefit ratio of about 1:200 was calculated when cassava was valued at world market prices, and the ratio was 1:370–740 when African trading prices were considered (Zeddiesa et al., 2000). Since the end of the project, no further interventions have been needed against cassava mealy bug. Networking, capacity building and training was a central element to the project, leading to dissemination of biological control and plant health management concepts in African NARS and universities.

A biological control project against African locusts and grasshoppers was initiated in 1990 due to the concerns of environmental pollution and effects on biodiversity and human health after insecticides were used between 1985 and 1989 to control the desert locust (the biblical plague locust). An insect-pathogenic fungus, a biocontrol agent of the desert locus, was developed for use in conventional ultra-low volume spray equipment, normally used by African pest control organizations, after 12 years of research costing US$17 million (Shah and Pell, 2003). The work to develop this product (called “Green Muscle”) involved researchers from IITA, CABI Biosciences, DGIS and NARS, mostly in West Africa. In many cases, costs of supplying the product are ultimately covered by donor agencies, as national governments did not have sufficient resources to pay for the biocontrol fungus product. FAO has included the product on a list of recommended compounds but widespread use has still to occur, partly because of the lack of uniform regulatory frameworks in Africa (Neuenschwander, 2004). A report which contained some adverse observations about mixing the fungal product during a field trial highlighted an important aspect in knowledge transfer and technology adoption. Chemical companies carry out “product stewardship” in overseeing possible misuse of their pesticides, especially newly introduced compounds. In public sector research, communication of information within the different strands of the research community needs to be better managed, especially involving technologies targeted at low-input systems.

A final example from Africa concerns the simultaneous control of the major parasitic weed *Striga* and insect pests which bore into the stems of cereals such as maize and sorghum. Work by Rothamsted Research in the UK and the International Centre for Insect Physiology and Ecology (ICIPE), in Kenya, has produced a habitat management strategy involving the intercropping of cereals with a legume which prevents growth of Striga and repels the insect pests. The adult insects are attracted to grasses grown at the edges of the crop, which also attracts natural enemies of the pests. However, the caterpillars of the insects are unable to develop on the grasses because of a gummy plant sap which impairs insect feeding. The grass is harvested to feed cattle kept in stalls and any surplus meat or milk is sold, providing a direct economic boost to the household. This "push-pull" technique is spreading throughout the Lake Victoria basin area of central Africa with assistance from non-governmental organizations, and is estimated to have been adopted by about 2-3,000 farmers. The technique can be viewed as optimizing crop and non-crop diversity for pest and weed control with the added benefit of improving livestock production for smallholder farmers. No external inputs are needed except the grass which is distributed through NARS.

Forestry and soil erosion

A World Bank-financed project, the Loess Plateau Watershed Rehabilitation project, is being promoted as a model for soil erosion control. The Loess plateau in northwest China covers 640,000 km^2 of which about 67% is estimated to have severe soil erosion. Environmental degradation caused by centuries of overexploitation of natural resources driven by unsustainable farming led to soil erosion and desertification. The Chinese Government and the World Bank devised a project in 1993 with the local population to re-forest vast areas by tree planting and to promote suitable farming practices by forming terraces, restricting goat grazing and only farming in certain areas.

The project concentrated on one small part of the Loess plateau which was identified as being important for watershed rehabilitation for flow of the Yellow River and where there was high local commitment to environmental improvement, since manual labor was needed for tree planting and terracing. Vegetation cover was increased from 10 percent to 42 percent through reforestation and establishment of shrubs and pastures. The produce from fruit orchards is sold nationally and has contributed to rural incomes. A network of training centers was established for farmers to encourage demand-driven technology transfer.

Within seven years, the project has reported to have helped improve the livelihoods of one million people, stopped soil erosion and improved the ecology of the plateau area. The cost of the project was estimated at US$9 million at 1993 prices (World Bank, 2003).

The principles for improving agriculture and ecosystem functioning are now considered useful and could be adapted to marginal lands in other parts of the world, for example in Africa. If this dissemination is successful, then it could be viewed as technology transfer between "south-south" partners.

Institutional factors and current status

Changes in research organizations in industrial countries have affected AKST because of changes in funding priorities brought about by government policies, leading to a gradual erosion of appropriately qualified scientists able to work in agricultural research for developing countries. There has also been a fragmentation of the researcher skills base, so that experts are spread amongst a large variety of research institutes, universities and non-governmental organizations, rather than a small number of specialized departments.

Changes in the institutional structures in the UK (see Table 2C.4.1) provide a good example of AKST moving from colonial to post-colonial phases, and organizational mergers in more recent times, leading to job losses and diminished science capacity.

[Insert Table 2C.4.1: Changes in research institute structures in the UK 1894-1996]

The UK now has now recognized locust research group, a devastating loss considering that the ALRC was a highly effective organization in researching locust ecology and preventing crop damage through pest forecasting. These activities are now largely covered by FAO.

The UK Department for International Development (DFID) has been severely criticized for its role of overseeing research and development to benefit developing countries (Science and Technology Committee, 2004). In response, a Chief Scientific Advisor was appointed by DFID to help formulate the next science strategy.

Since the 1990s, there has been a reduction in funding and a fragile career structure for UK scientists wishing to work on overseas agriculture. This resembles the situation within plant protection and development organizations in many developing countries. The drive to short-term funding has led to the almost complete decline of curiosity-driven research and almost a "lost generation" of UK scientists with overseas experience. Given recent and forthcoming retirements by specialists and continued job losses, the expertise in UK for developing country agriculture is seriously compromised. Expertise focused around small research groups located within larger universities or research institutes, or within private consultancy companies, has led to considerably more fragmentation than existed previously. The decline in expertise is exacerbated by the closure of undergraduate courses in agriculture in several UK universities.

2C.4.1.4 Capacity building for developing countries

A central element for KT undertaken by nearly all research and donor organizations is the need to provide advanced training so that individuals and institutions in developing countries become more self-reliant in identifying and executing research and AKST. Capacity building is generally targeted to individuals, e.g. scholarships and fellowships. Examples include IARC Fellowships (CIMMYT, Vavilov-Frankel/IPGRI, etc.), Generation Challenge (CGIAR), UN, TWAS, IFS, Commonwealth Scholarship and Fellowship Plan (CSFP) and fellowships through research organizations (e.g. Rothamsted International) and universities. A criticism is that although money is provided for training, there is usually no funding to help the scientist on return to their home institute for equipment or other funding, which would help continue the work and training received in an international centre.

2C.4.1.5 Conclusions

Changes in spending on public, rather than private, spending on worldwide agriculture indicates that developing countries will have to be more reliant on development of suitable agricultural technologies, and the biggest hurdle will be in the application of biotechnology (Pardey et al., 2006).

The divide between the aspirations of the scientists and policy makers in helping developing countries become more self-reliant in food security and the actual worldwide situation could be attributed to different research agendas (especially life sciences vs. social sciences), mismanagement or over-management, and poor vision by both scientists and policy makers. All of these may have contributed to inadequate transfer of AKST to developing countries.

However, one should note the degree of debate and controversy *within* industrialized countries on the role and extent of KT, involving government, universities, research councils and industrial organizations. For example, despite all of the past advances in S&T, policies for effective KT are still being formulated within the UK, requiring a balance between science and industry (Research Fortnight, 2006).

2C.4.2 Impacts of NAE AKST through international trade

2C.4.2.1 Agricultural Trade Flows between NAE and other parts of the world

The North American and European Region accounts for rather more than a quarter of trade in Agricultural Products**.** The European Union and the United States are major players. Trade flows with the Russian Federation are much smaller

[Insert Table 2C.4.2: Trade in Agricultural Products – 2003 (1000$ US)]

Trade has been growing. The data in Table 2C.4.2, based on FAO data reflect the period between 1986 and 2003. During this period substantial changes in trade flows were associated with the break up of the USSR. Beyond it the EU became 25 countries rather than 15.

[Insert Figure 2C.4.1: Trade (imports and exports) in NAE from 1986-2004.]

The diagram (Figure 2C.4.1) shows that through this period the US has been a net exporter whilst the EU, has been a net importer. The EU has provided substantial subsidies on agricultural exports whilst the US support system for farmers, combined with Food Aid programs has helped to support farm exports. Subsidized exports damage low cost producers in both developed and developing countries whose markets are depressed and may even be lost to products that are effectively dumped into the world market. The damage done by export subsidies and policies that have similar effect has played a major role in trade negotiations. With the creation of WTO agriculture was brought more effectively within the multilateral trade negotiating scene and pressure has grown for export subsidies to be reduced and eventually removed and for greater access to developed country markets for the produce of developing countries.

[Insert Figure 2C.4.2: EU Agricultural imports and exports (Source: European Commission: Eurostat and Directorate General for Agriculture)]

The largest volume of agricultural trade in the EU is between its member countries. The pattern of external trade shows that much of this takes place between the US and the EU. Diagram 2C.4.2 shows the major trading partners of the EU.

Many of the EU imports, particularly from the US and Brazil are feedstuffs for the livestock industry rather than finished product.

For the US the most important destination for exports are the neighboring countries Mexico Canada within the North American Free Trade Area. Outside this free trade area Japan and the EU represent the major destinations for North American Exports. China has markedly increased imports since 2002 and is expected to continue to do so in the future. A major question that may lead to a significant change in the flow of exports from North America is the prospect that an increasing share of the Maize crop will be used to produce bioethanol rather than enter the food chain.

There is a similar concentrated pattern for US imports (see figures 2C.4.3 and 2C.4.4). Here the EU has recently overtaken Canada as the largest supplier. Imports from Mexico have risen relatively rapidly benefiting from the North American Free Trade Area. Among the four largest suppliers only Australia secures its market without subsidies or preferential access to the market.

Agricultural trade flows can act as a catalyst for the diffusion of AKST to exporting countries. Importers may invest in production and processing activities that employ technologies developed within their own countries to meet market needs. As markets are established imported technologies can be adapted to local circumstances developing skills within the local community. {More on trade related investment}

Trade also plays an important role in making effective public and private initiatives to encourage the development of agricultural knowledge, science and technology in the developing world. Private initiatives such as the Ford and Rockefeller Foundations have supported research directed specifically at the problems of production in low income countries. Many of the aid agencies such as Christian Aid, Oxfam, Farm Africa and World Vision have supported the development of education and the application of new technologies in farming. Whilst the focus of much of this activity has been to improve the productivity of traditional farming activities in developing countries as production moves from local self-sufficiency to meet market needs whether at home or abroad there is a need to employ technologies that cope both with the needs of storage and transport.

[Insert Figure 2C.4.3 U.S. Exports Destinations from 1989-2005 (Source ERS/USDA)]

[Insert Figure 2C.4.4: U.S. Imports of Agricultural Products 1989-2005 (Source ERS/USDA)]

[Insert Figure 2C.4.5: US Trade in Processed Food 1997-2005 (Source US Department of Commerce)[9]]

Much of the final value of agricultural products is embodied in processing. Imports of processed products have been increasing and this represents an opportunity for developing exporting countries that requires depends upon the use of appropriate technology (see Figure 2C.4.4.5). This must meet the safety requirements of importing countries and respond to the needs of their retailers and caterers. Production and transport is often organized by developed country suppliers who oversee production, handling and transport through to their final customers.[10]

European livestock production and trade

For the past 30 years Europe has been producing far more meat and dairy products than it needs becoming one of the world's leading exporters. The search for more market sector has led to dumping of these products in less wealthy countries with consequent damage to the economic status of their agricultural producers. There are several well documented cases of disruption of, and damage to, developing country agricultural markets as a result of this European strategy. As a result of rigorous CAP reforms in the 1990s, European production of beef and veal has fallen rapidly from around 50% over-production (EU-15) in the 1990s to around 96% self-sufficiency in 2004 (Table 2C.3.3)

[9] http://www.trade.gov/td/ocg/outlook06_processedfoods.pdf
[10] One such firm is Vitacress in the UK http://www.vitacress.com/uk/difference_SUB1.htm

The large increases in European livestock production between 1960 and 1990 relied heavily on animal feed imported from Brazil, Argentina, North America and the Ukraine. In 2005 the EU 25 imported 30 million tons of animal feed, over half coming from Brazil and Argentina (data from Eurostat). Animal feed is the largest imported (aggregated) product for the EU-25 (European Commission 2006). Total imports, expressed in values reached € 5 099 million during the 1st semester of 2005, i.e. a decrease of 27.2 %, with Brazil having the largest share with € 1 834.1 million (-34 %). EU-25 exported a total of € 670.4 million during the 1st semester of 2004 and € 997.5 million during the 1st semester of 2005, with Algeria (€ 111.2 million and € 140.6 million) as the most important destination.

Pig meat is still being over-produced in EU-25 by about 8%, making Europe a net exporter of pig meat products, mainly to Russia and Japan. The EU is a net importer of sheep meat (EU-25 is only 78% self-sufficient in sheep and goat meat) and dairy products, mostly from New Zealand, and also imports large quantities of poultry meat from Brazil and Thailand, where production costs are much lower than in Europe. Somewhat perversely the EU also exports large quantities of poultry meat and offal to Russia and the Ukraine, and parts of the Middle East.

[Insert Figure 2C.4.6 Livestock and meat: total world trade and WEU market share 1991-2000]

[Insert Table 2C.4.3 Net balance of external trade (EU) in meat products]

Next to India, the EU is the second largest producer of milk and milk products, exporting around 800,000 tons per year to a variety of global markets, including Africa (mainly Nigeria and Algeria), China and Russia and parts of the Middle East, especially Saudi Arabia. Exports of cheese and curd currently run at around 300,000 tons per year, going mainly to the USA, Russia and Japan (Eurostat Agricultural Trade Statistics data).

The Common Agricultural Policy is moving away from production-led subsidies towards a more market-led and environmentally friendly system, but there is still a substantial subsidy paid to most livestock sectors that reduces the competitiveness of developing countries.

2C.4.3. Relationship of the NAE to world supplies of raw materials for agriculture (an example of phosphate exploitation)

Agriculture in the NAE has exploited raw materials from other countries in the world to increase output. A typical example of this is the use of phosphate to provide good crop nutrition. Phosphate rock (PR) is the primary raw material for producing P fertilizers. Currently, 90% of world phosphate rock production is utilized by fertilizer industry (Van Kauwenbergh 2003). Consumption of P fertilizers reached 5 Mt P in 1960 and peaked in 16 Mt P in 1988 (Smil, 2002). After a 25% decline in 1993 the global use began rising once again (International Fertilizer Industry Association, 1999 (Fig. 2C.4.7). The world use is projected to grow, especially in China, India and in the developing countries of Asia and South America (Jasinski, 2000).

[Insert Figure 2C.4.7: Consumption of inorganic phosphatic fertilizers 1900-2000]

In contrast to the concern often presented, FAO report (2004c) concludes: "On the world-wide basis, there is ample supply of high-quality PR for chemical processing and direct application for the foreseeable future." The contrasting view is presented by Castillon (2005) based on the same data who concludes that at the present rate of exploitation the economically available deposits risk to be exhausted in about a hundred years. Most estimates for the sufficiency of the resource are between 50 and 100 years.

In the developed world, use of phosphate fertilizers was at highest in the end of the 1970s, while in the developing countries the rate is still increasing (Fig. 2C.4.8). In Western Europe the peak was in 1973, in North America in 1978 and in Eastern Europe in 1984. In Eastern Europe, an abrupt drop took place in 1991, and the use has not recovered since. Only in Western Europe has consumption already dropped below that in 1961 (the first year in FAO statistics). During the 1990's, global applications of inorganic fertilizers averaged just over 10 kg ha-1 of arable land, with continental means ranging from a mere 3 kg ha^{-1} in Africa to over 25 kg ha^{-1} in Europe (International Fertilizer Industry Association, 1999). These figures hide enormous inter- and intra-national differences.

The production of phosphate fertilizers in the North America is higher than the consumption and in Europe production approximately corresponds to consumption. USA was the leading producer (29%) and consumer of the world in 2000 (Jasinski, 2000). Decades of relatively high P applications and the gradual release of a part of the initially fixed P have resulted in considerable surpluses of available P in many fertilized agro-ecosystems especially in the affluent world (Edwards et al., 1997). The major part of the world phosphate fertilizer production is used in developing countries. Extensive tracks of land in the tropical and subtropical regions of Asia, Africa and Latin America contain highly weathered and inherently infertile, acid soils with low inherent P fertility (Lal, 1990; Formoso, 1999) and with high P-sorption capacities. Substantial P inputs are required for optimum growth and adequate food and fiber production (Date et al., 1995). Because manufactured fertilizers are imported to most developing countries, they are often in limited supply and represent a major outlay for resource-poor farmers. Therefore, the direct application of indigenous PRs mainly of sedimentary marine origin (80% of world PRs), which are more reactive, to replenish soil P status, is very appropriate in many conditions in developing countries. This is the case especially in Africa where the soils are extremely poor in P, in many cases the P field balance is negative and P the limiting nutrient for crops (Maene, 2003) - in spite of numerous PR deposits (FAO, 2004).). In those regions of the world where mineral P use is the key to raising food production, industrial fertilizers or rock phosphates are hardly used (Runge-Metzger, 1995). In 2002, for example, the last year for which the figures are found in FAO statistics, only a third of African phosphate fertilizer production was used in Africa.

[Insert Figure 2C.4.8: Consumption and production of phosphate fertilizers in 1961-2002]

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