Chapter 2A

Changes in agriculture and food production in NAE since 1945

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Key messages

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In NAE, there have been an increased number of technologies and tools available to agriculture primarily developed through advances in AKST. AKST has provided farmers with knowledge systems that enhance crop and livestock productivity and quality. Efficient knowledge transfer systems developed in the governmental and private sectors allowed for the dissemination of these new tools. Developments in AKST have primarily been more efficient use of fertilizers (including the development of synthetic fertilizers), technological sophistication and scale of agricultural mechanization, development of novel, more effective agrochemicals, and use of antibiotics. The development of plant breeding technologies including hybrids and genetically engineered varieties, have had widespread impacts both within the region and the rest of the world. Technological breakthroughs have been made in both saltwater and freshwater fish farming leading to spectacular increases in productivity. New technologies have also been introduced into forestry to meet increased demands for timber resulting in more efficient harvesting and processing and better access to remote areas. These tools and technologies have developed in parallel with policies and subsidies that have aimed to increase productivity as well as advances in research.

The application of these tools and technologies has greatly increased the productivity of cropping and livestock systems, forestry and aquaculture in NAE. Production of arable crops has at least doubled over the last 50 years in the NAE particularly in output per unit area. These increases are due to increased mechanization, new breeding techniques, and changed management systems (e.g. the use of fertilizers, herbicides, pesticides, and decision support). Development of more and better irrigation and drainage, coupled with the conversion of pasture to permanent cultivation also contributed to these increases. Uptake of genetic engineered crops has differed markedly in the region and has been applied in just a few cropping systems (soybeans, corn, canola and cotton) in North America. Although it is now largely stable, livestock productivity and output in NAE has increased enormously since 1945 with beef, pig meat and milk production almost doubling, and a four-fold increase in numbers of poultry, driven by policy (including subsidies)and increased demand resulting from a growing and wealthier population.

This productivity has been driven by improved animal breeding, improved pest and disease control (including the use of antibiotics), increases in pasture output per unit area, and the development of intensive rearing systems. Aquaculture output has and continues to increase, mainly due to saltwater finfish production. NAE is the only world region where there has been an increase in forest area since the 1960s, partly as a result of increased plantations and partly resulting from natural re-colonization. Demand for forest products has increased dramatically because of a larger and wealthier population. In the past twenty years, especially in Europe, there has been a trend away from productivity-driven management systems towards systems aimed at multi-use, especially for the provision of biodiversity and leisure activities. This trend is opening up new arenas for AKST.

This increased productivity has led to a situation of surpluses in much of the NAE, where supply has outstripped demand in crops, livestock, aquaculture and forestry. NAE has become a major exporter of these products which has led to market distortions throughout the rest of the world.

The concerns over the application of these new tools and technologies, and the changed production systems resulting from them, have led to a growing environmental, social and health awareness in NAE. Crop and livestock production in the NAE is among the most intensive in the world and this has had to serious adverse impacts on the environment. Crop and livestock enterprises have become fewer and larger due to economies of scale and this trend is likely to continue. Growing environmental, social and health awareness has resulted in the rise of environmental regulations (which mainly resulted from concern over the widespread use of agrochemicals), new tools and technologies and alterations in how they may be used, and the development of alternative production systems, including organic agriculture. This awareness has led to recent changes in agricultural policies away from production-led subsidies towards more market-led and environmentally friendly systems, but there are still substantial direct or indirect subsidies for most agricultural sectors that reduce the competitiveness of developing countries.

There has been a trend from public sponsorship of AKST towards private ownership of AKST, particularly where it produces products that have intellectual property that can be protected. There has been privatization of knowledge systems, particularly in genetic engineering. Where new technologies have emerged that can produce products that have protected intellectual property rights (IPR), industry consolidation has tended to occur. Consolidation may create efficiencies but may also limit the technological options as smaller firms which can often bring dynamism to a sector find it hard to compete. Tension within the international agreements regarding IPR need to be resolved because if affects farmer practice, profitability and affects the ability of farmers in poorer parts of the world to maintain profitability.

2A.1 Structural Changes in NAE

In the past few decades agriculture in North America and Europe has gone through an exceptionally dramatic structural change. There has been a decrease in the number of farms, reduction in the agricultural labor force, increased specialization geographically and at the farm level, and a loss of self-sufficiency at the farm level.

Technological change has been rapid in NAE, and the introduction of any new agricultural technology has implications for markets, producers, and consumers (Hayami and Ruttan, 1985; Kislev and Peterson, 1986). In most of NAE, technological change has favored capital intensive technologies and economies of scale. Mechanization has increased, generally allowing for larger average farm sizes although there is considerable heterogeneity in farm size and scale in NAE. Most NAE farmers have attempted a scale of operation having the lowest cost per unit of output. The average unit cost follows an L-shape function; the unit cost at first decreases sharply with size but then reaches a plateau (Hall and Leveen, 1978; Nehring 2005). The evidence for diseconomies of size is weak or non-existing. In spite of the fact that the average size of farms has increased in most of NAE, they are mainly managed by private farm families, most of which rely on off-farm income in addition to income from farming activities (Hoppe and Banker 2005).

The decreasing number of farms, combined with increasing total output has led to concentration of production. It can be measured by the number of farms necessary to produce a particular share of output (e.g. from 1989 to 2003 the fraction of U.S. farm production by large scale family and non-family farms increased from 57.7 percent to 72.8 percent). In Western Europe the farm size in hectares is only one tenth of that in the U.S. Thus, the number of farms is much higher but it is decreasing rapidly. From 1983 to 2001 the number of farms decreased in EU-12 from about 9 million to 6.5 million, but farms grew larger, especially in the livestock sector. Because of the small farm size in Europe, an even a larger portion of the farms than in the U.S. are operating on a part-time basis.

Economic growth also contributes to farm structure (Heady 1962). Other things being equal, including the labor share of inputs, the scale of farm businesses must increase in proportion to the increase in non-farm labor earnings. The growth of other sectors of the economy has driven labor from agriculture to more productive sectors in most parts of the NAE.

Specialization, an important aspect of productivity growth in NAE agriculture, has improved the spatial organization of the food chain and lowered production and transportation costs (Chavas, 2001:275). In Western Europe and North America, specialization occurred largely because of the economies of scale, larger economic forces and technological change discussed above. When economies of scale (the unit cost decreases with size) overcome economies of scope (synergies between products and by-products), specialization increases followed by the increasing size of production units. This leads to the regional specialization and concentration. However, government policies may also influence farm size and numbers. Agricultural policies after World War II directly promoted specialization through incentives (e.g. Pirog et al., 2001). Still the larger trends mentioned earlier have usually overshadowed the impact of policy programs on farm structure.

Farm specialization is particularly pronounced in North America and central and eastern European areas that experienced collectivization. Approximately 50 percent of U.S. farms produced only one product in 1999. Specialization differs by farm size, with smaller farms the most likely to produce one commodity. For example, many farms with less than $50,000 in sales specialized in beef cattle because of the low labor requirement (Cash, 2002). Financially successful farms have tended to be more diversified (Hoppe, 2001). More than 25 percent of very large family farms are specialized in hog and poultry and closely linked to processors (Hoppe and Korb, 2005).

[Insert FIGURE 2A]

[Insert FIGURE 2A.2]

Specialization in the eastern part of NAE has followed a different path due to collectivization after World War II. Collectivization led to the establishment of large collective or state farms following the principles of planning economy. These farms were highly mechanized and specialized but often also inefficient in their use and allocation of resources. In the former Soviet Union, collectivized sector of agriculture (99.6 percent of agricultural producers were collectivized by 1955) witnessed a significant growth over the post-war decades (Matskevich, 1967). After World War II, the CEE countries of the former Soviet Union were the main suppliers of grain and meat to Russia and the CIS countries. Compared to the more arid regions of the Soviet Union soils were relatively productive and a system of large collective farms was developed in the 1930s (Wheatcroft and Davies 1994). This system was only economically viable under the centralized and subsidized agricultural economies of the Communist era.

[Insert FIGURE 2A.3]

In many CEE and CIS countries, the farm structure was dualistic, with numerous small self-subsistence plots but also large-scale farms producing most of the gross output. For example, Soviet agriculture essentially branched into two sectors. One, the collectivized sector, was characterized by state-control, large-scale, reliance on off-farm inputs, mechanization and hired labor, and centralized processing and distribution of outputs. The other branch was the private household-managed sector, characterized by micro-scale, lack of state support or inputs, manual labor provided by the household, and with a goal of self-provisioning (Sharashkin and Barham 2005). The latter was authorized by Soviet authorities at the beginning of war to fight impending food shortages, and quickly spread throughout the country (Lovell

2003). This household-based sector continued to grow and by the mid-1950s accounted for 25 percent of the country's agricultural output (Wadekin 1973). Throughout the Soviet period, the authorities have maintained an ambivalent attitude to household producers; their importance to food security was tacitly recognized, yet the government refrained from providing any support to household production so as not to encourage any "capitalistic", private ownership tendencies (Lovell 2003).

[Insert FIGURE 2A.4]

After transition of the CEEC to democracy in the early 1990s the collective farm system rapidly broke down, partly because the system became uncompetitive once CEEC economies were opened to world markets, and partly because the Soviet markets for grain were no longer easily available to the transition countries. Large farms were privatized, which led to a rapid fall in agricultural output in many countries. Large farms remain a feature of many CEE countries, although many of these are now owned by corporations (Lerman et al 2004a). Production stabilized at the lower level but has started to recover in connection to the EU membership. Still, in places like Russia, where household enterprises have been particularly important, small household producers produce nearly all vegetables and potatoes, and over 50 percent of meat and milk products.

[Insert FIGURE 2A.5]

2A.2 Changes in Soil AKST and Use Since 1945

Soil is one of the basic natural resources, and is critical for agricultural productivity across NAE, a region with extensive amounts of productive soils. Thus, knowledge of soil is critical to agriculture. Traditionally, knowledge of soil type on a particular farm passed from one generation of farmer to the next and traditional practices of manure application were followed to improved soil productivity. The initiation of formal soil classification took place in Russia at the turn of century. Soil surveys were first authorized in the United States in 1899 (Soil Survey Division Staff, 1993), and shortly thereafter in the UK and rest of Europe (Bridges, 1970). Across NAE before 1950, the primary application of soil survey was farming, ranching, and forestry. In the 1950’s and 1960s’, as non-farm uses of the soil increased so did the applications of soil survey, e.g., urban development, highways and other engineering projects (Bartelli et al., 1966). In the 1970’s the authorities for soil survey were expanded to urban lands. More recently soil survey has been used in environmental studies. The modern soil survey utilizes many disciplines (Jenny, 1941; Baver, 1956, Jackson, 1958; Alexiades and Jackson, 1965; Rhue, 1975; Small, 1975; etc.). Extensive and detailed mapping of U.S. and European soils was initiated following World War II, and today has evolved into comprehensive, digital national maps of soils in many countries across NAE.

In response to concerns such as nutrient depletion and acidification, soil testing programs were established in the late 1930's to early 1950's at land grant colleges, universities, agricultural institutes and colleges of agriculture, providing testing services to help farmers make decisions about fertilizer and lime applications (e.g. Olsen et al., 1954; Mehlich, 1984). During the 1970's extension soil testing laboratories began to fulfill a broader mission, providing other tests and services (e.g. pollution). There was renewed emphasis on the efficient use of agricultural inputs such as fertilizers, largely due to the energy crisis, and an increased public concern for the protection of water quality and prevention of pollution from chemical fertilizers.

In recognition that saline and alkali soil conditions reduced the value and productivity of considerable areas of land in the U.S., the United States Salinity Laboratory was created in 1947 (United States Salinity Laboratory, 1954). Over the last three decades, there has been an evolution to, assemblage and development of long-term soil resource assessment technologies that are land or ecological based and away from managing individual resources (e.g., soils). This is especially applicable to forestry management in both the U.S. and Canada (Hills, 1952; Major, 1969; Wertz and Arnold, 1972; Bailey, 1976, 1996; Jordan, 1982; Rowe, 1980, 1984; Jones, 1983; Driscoll, 1984; Pregitzer and Barnes, 1984; Spies and Barnes, 1985; Cleland et al., 1985; O'Neil et al., 1986; McNab, 1987; Smalley, 1987, 1988).

Since the end of the World War II until the 1980s, soil science research was predominantly focused on soil productivity, aimed to increases agronomic yields. These were boom years for soil science, with large numbers of people being trained in and/or were actively working in the area of soil science and agriculture. Currently, however, soil science as a discipline underpinning agriculture is widely perceived to be in retrenchment in the US, as evidenced by decreased enrollments in undergraduate soil science curricula at land grant colleges of agriculture (Prunty, 2005). With the closure of some of these extension soil testing laboratories due to financial cut backs at the universities/colleges, the institutional knowledge about analytical methods for soils, water, and plant material is lodged more and more in the U.S. private sector.

In contrast, following shrinkage in the 1980s, soil science is re-emerging as vital component of agricultural and environmental sciences in Europe, with a current EC strategy and publicly-funded research program to protect Europe's soils from erosion and degradation and ensure sustainable use (EC 2006).

2A.2.1 Knowledge and application

Improvements in soil inventories and assessments have changed soil technologies and practices by facilitating appropriate land use based on its classification (e.g. rough pasture, arable land). Since 1945, there has been development and refinement of soil and water conservation technologies (USDA, 1957;

Troeh et al., 1980; Weeies et al., 2002; Tibke, 2002, USDA Soil Conservation Service 1935, USDA Natural Resources Conservation Service, 1994).

In the 1970's conservation tillage became a major part of the conservation program in the U.S., largely due to advances in herbicide developments in the 1960's. Since this time, its application has been modified and adapted to encompass a wide range of tillage practices, climates, and soils. Additionally, it has become integrated as one component of an overall soil management system and increasingly in North America is associated with the use of genetically engineered, herbicide tolerant crop varieties.

There is greater appreciation of the value of manures and sludge for providing both nutrients and organic matter to soils used for crop production. Proper application rates have been increasingly understood to minimize movement of nutrients off site, which could cause adverse ecological effects e.g. eutrophication elsewhere.

Trace elements (e.g. Cu, F) are crucial to human health and agricultural productivity, but can also be toxic at higher concentrations. Increased ability to analyze trace elements has changed the focus from merely characterization to environmental assessment. For example, the bioavailability (availability for uptake into a plant or animal) of a trace element can be assessed, the contribution of natural vs. anthropogenic sources can be assessed and recommendations given concerning shortages or excesses or trace elements.

2A.3 Changes in Cropping Systems in NAE

Increased productivity is the key change in NAE cropping systems. Arable crops, especially the major commodity small grain crops, such as wheat, barley, and maize along with the oilseed crops (soybeans, oilseed rape, sunflower), the legumes (peas, beans) and root crops (sugar beet, potatoes) have formed the backbone of crop production in the NAE. Fruits and vegetables, with their great range of crops, from lettuces to apple trees, make up the remaining production sector. While over the last 50 years there has been some change in the proportions of different crops grown, such as the increase in oilcrop production, the overall area of agricultural land has not increased during this period. In fact, data from FAOSTAT indicates an approximate 10 percent reduction in agricultural lands for the EU(15) and for the USA between 1961 and 2003, with a slightly greater decline in countries in eastern Europe (CEE) and a lesser one in Canada. However, production of virtually all crops has increased significantly – in some cases more than doubling – in NAE in this same time period, despite the decrease in arable land.

[Insert FIGURE 2A.6]

In the Soviet Union, by the mid-1950s cereal production exceeded the 1913 level and between 1950 and 1970 rose by more than 2.3 times to 186.8 million tons (Narodnoe khoziaistvo 1971). Although production lagged behind that in Western Europe and most of the world (see Figure 2A.4), the CEEC farms steadily increased arable production from 1945 to 1980 (Lerman et al. 2004b). After the breakdown of the collective farm system, there was a rapid decline in productivity from 1991, with large areas of arable essentially left unfarmed. For example it has been estimated that up to 40 percent of arable land in the Baltic States was abandoned in the 1990s, with a similar decrease in agricultural output (Lerman et al 2004b). This in turn led to a 38 percent decrease in per capita income in rural areas. Far less land was abandoned in Hungary and Poland where markets were more robust. There has been a recovery in production in most CEE countries, but production levels in the smaller countries are still only at 1960s levels (Lerman et al 2004b). Farmland in the larger countries, especially in Eastern Germany, Hungary and Poland, is seen by investors from Western Europe as having good potential for further increases in production by applying modern technology and having relatively low labor costs. Large areas of arable farmland in these countries are increasingly owned by Western consortia, including those aimed at developing organic production for W European retailers. Most CEE countries are now members of EU-25 and EU management of CEEC grain production is expected to increase by around 25 percent, an increase of some 50 million tons. This increase has already become apparent in for example Eastern Germany where yields of all grains now equal or exceed those in Western Germany.

The increases in production, particularly in Western Europe and North America, have been stimulated by the increasing demands for food from the rising NAE population during the last 50 years. This was particularly important in the 1950s, as there were real food shortages in many countries in the years following World War II. According to Medvedev (1987), the situation of agriculture in the post-war Soviet Union was dire, with famine conditions in 1946-47, and per capita production of grain and meat below 1913 levels. These conditions were due to the direct destruction of farming and food distribution resources in Central and Eastern Europe. In the western NAE, the continued momentum to increase production was encouraged by the politically driven agricultural financial support systems in Western Europe and USA, aimed at ensuring the continued viability of the rural economy. The Soviet Union turned to centralized planning, collectivization, and ultimately the Virgin Land Program, when 36 million hectares in dry areas were ploughed and sowed in the late 1950s to increase grain production.

A further factor requiring increased crop production has been the increasing demand for meat, (see livestock discussion in subchapter 2A.4) coupled with the increasing intensivity of meat production often resulting in intensive housed systems, requiring large quantities of grain, protein and oilseeds. It should also be emphasized that increased production was facilitated by, and to some extent stimulated by, the development of new cultivars and technologies aimed at increasing yields and decreasing yield threats from biotic and abiotic factors (e.g. pest and disease attack, weather impacts on crop growth and harvesting)

Research on crop production inputs and the dissemination of the information to farmers has played a key role in providing tools for farmers to increase their production. The major contributors to these yield increases are as follows:

1. breeding of higher yielding cultivars and the adoption of high-yielding hybrid seeds for planting
2. increased availability of fertilizers and increased knowledge of how to use them
3. development of new pesticides to control weeds, pests and diseases
4. better understanding of the biotic and abiotic factors constraining yields, leading to optimizing agronomic practices (e.g. sowing dates, plant densities, fertilizer timing)
5. improvement in machinery design and range to assist optimization of crop production
6. increased use of irrigation
7. enhanced mechanisms for technology transfer, such as development of national agricultural advisory systems
8. the delivery of information by the private sector, e.g. on the use of their products, it is as an important a source of information to farmers as is the public sector extension services and related public sector support.

These advances are summarized in data from the long-term Rothamsted wheat experiment, which clearly shows the role played by a number of different inputs in delivering higher yields.

[Insert FIGURE 2A.7]

While increasing productivity has been the main goal in the last 60 years, output is leveling off. In some of the curves in Fig. 2A.7 there is evidence of little increase in yields since 2000, suggesting that farmers may have reached economically optimal yield achievable with the cultivars available at the present time, in the current economic and policy arena. Similar responses can be identified for other major arable crops.

As well as the direct contribution of science and technology to increases in yields the establishment of effective technology transfer systems to ensure that the 'new' advice was conveyed to the farmer users was also of great importance. Such advisory systems have sometimes involved the public sector (government sponsored advice) and sometimes the private sector. In the U.S., development of an extensive public knowledge transfer system through the cooperative extension service of land-grant universities contributed greatly to agricultural productivity (Hildreth and Armbruster, 1981). However, today there is a transition from publicly supported technology transfer systems to private technology transfer systems. The former tended to be more holistic in approach whilst the latter has primarily associated with commercially viable products, whether it is a new agrochemical or a new cultivar (c.f. Fuglie *et al*, 1996).

2A.3.1 Increasing cropping systems productivity through inputs

As noted above, changes in outputs of cropping systems across the NAE reflect changes in production and management systems that utilize inputs such as mechanization, labor, seeds, genetics, nutrients and irrigation, in new and different ways.

2A.3.1.1 Mechanization

The last half of the 20th century saw dramatic changes in farming operation because of increased mechanization. Previously labor intensive jobs such as weeding, harvesting and threshing have now all been replaced by mechanization (Park et al., 2005). One of the most significant developments was the introduction of the diesel engine tractor to replace the steam plough. By the 1930s, hydraulic systems for attaching implements appeared and introduced a new generation of tractor design but it wasn't until the post war production boom in the 1950's that diesel engine tractors became more widely available in Europe. In the last two decades significant new developments have included more sophisticated hydraulic and transmission systems, increased use of four wheel drive, improved chassis strength and weight distribution enabling both front and rear mounted implements to be attached and better operator comfort (Park et al., 2005).

[Insert FIGURE 2A.8]

The post war period also saw the most significant increase in smaller compact combine harvesters. They had been designed as early as the mid 19th century to help deal with the vast areas of wheat in NA but were considered less well-suited to the damper and more cramped fields in the UK and other European countries. Improved efficiency and increase in machine scale may explain some of the decline in the number of harvesters and threshers observed in the USA in the 1960s, which has maintained a plateau since the mid 1970's. In contrast data for Europe showed a large increase in uptake during the 1960's and 1970's showing a continued investment in this machinery and reaching a peak in the number of machines during the mid 1980's.

[Insert FIGURE 2A.9]

New developments in mechanization also relate to precision agriculture, which seeks to improve performance by mapping the specific nutrient needs, or levels of pest damage to growing crops in such a way that differing treatments may be provided within the same field. To secure this, the map generated by global positioning service (GPS) needs to be translated into instructions that ensure machinery that is spraying a crop or depositing fertilizer recognizes where it is and regulates its output in response. This type of technology is at present best suited relatively large farms so that the capital cost of investment can be spread over a large output, primarily thus far in United States and Canada (Natural Resources

Canada 2006). Precision agriculture has also helped farmers meet environmental regulatory requirements.

In the eastern part of NAE, the collectivization of agriculture tried to exploit economies of scale, particularly in the fields of mechanization and in the use of agrichemicals. In the Soviet Union, productivity advances were largely achieved by government-mandated and government-sponsored industrialization of agriculture. Thus, between 1950 and 1974 the production of plough-tractors increased by 79 percent to 218,000 units per year, and the production of cereal harvesters increased by 91 percent to 88,400 units per year.

However, mechanization requires financing in some form or other, and this, plus the necessary individual incentives to improve performance, was often lacking (Meurs, 1999:20) in collectivized systems (e.g. Kovach (1999) noted that investment, especially in machinery, was limited by lack of state resources for the collectives and by lack of access to credit for the still-dominant private landowners).

Another agricultural sector that has seen significant mechanization advances is in glasshouse production. The use of glasshouses and other structures to protect crops enable horticultural crops to be protected from frost, irrigated as required, protected from pests and disease and brought to market out of normal season in first class conditions. Glasshouses are used for high value crops e.g. tomatoes, ornamentals. Since 1950 growing sophistication resulting from the use of automatic temperature, humidity and ventilation controls improved their performance and reduced the labor requirement. However, as transport becomes cheaper protected crops face growing competition from imports grown in climates that are more favorable. One response to this has been to devise cheaper ways of protecting crops, notably the use of plastic and polytunnels.

[Insert FIGURE 2A.10]

These changes in mechanization in agriculture have resulted in the completion of tasks much more quickly and significantly decreased the amount of labor involved in agriculture production. There have been several advantages to this, including increased productivity, allowing farmers to manage for bottlenecks in labor and cut out unpopular repetitive jobs. The introduction of powerful engine driven ploughs has also opened up areas for agricultural production that were previously difficult to work due to soil conditions. The negative impacts of these changes have included redundancy in the farm labor force, costs of maintenance and fuel. However, this modern machinery, as a direct result of their sheer size, has necessitated the large-scale removal of hedges and opening up of larger fields to assist their maneuverability (Wilson & King 2003).

The main drivers of mechanization have been the desire for greater productivity in the 1950-60s (European Environment Agency, 2003), the reduction of the labor leading to an increased quality of life, and increased economic needs. Moreover, AKST has provided mechanisms for the achievement of engineering improvements for agricultural and forestry equipment and more sophisticated handling of milking, as well as allowing for the development of computer management in animal feeding. Thus, mechanization is correlated with field size across NAE, changed management systems and increased flexibility of land use and management. All of these changes have had very important economic, environmental and social implications.

2A.3.1.2 Plant breeding, seeds and genetics

Another key contributor to productivity increases in crops has been the major advances in knowledge and technology that have been incorporated into crop breeding since the late 1930s, including the development of hybrid crops, cell fusion, embryo rescue and genetic engineering. Many of these new techniques are derived from new discoveries in biological sciences and major advances in the fields of genetics. These included the discovery of the structure of DNA and the understanding, at the molecular level, of genes as physical entities that could give rise to Mendelian-style inheritance. Post Second World War, the study of genetics lead to the development of new techniques to introduce inheritable traits into organisms, a subset of the broad set of methods known as biotechnologies designed to adapt living things for the production of useful products. These new techniques include genetic engineering (where a genetic “cassette” manipulated in vitro and containing a recombinant DNA gene for a desired trait is inserted into the organism) and marker assisted breeding (where the use of known “marker” sequences associated with a desired trait are used to determine if the desired trait is inherited in offspring from conventional breeding). Despite progress in new biotechnologies, the current seed varieties available in NAE for most crops have been developed largely through conventional breeding, where plants with desired traits are cross-bred and the resultant offspring contain the desired trait. Commercial hybrids are produced by the conventional breeding of two carefully chosen different high-quality true-breeding parental lines to yield progeny that themselves do not breed true, but that in combination give good yield (show vigor) and exhibit superior qualities, above those of traditional (open pollinated) varieties.

Hybrid varieties generally have increased vigor (hybrid vigor) over their open-pollinated counterparts. With the growth of mechanization of agriculture, hybrids could provide uniform characteristics amenable to mechanical (as opposed to hand) harvesting such as uniform maturity, concentrated fruit set etc., thereby increasing their attractiveness (and hence profitability) to farmers. At the end of World War II, the emphasis was almost solely on yield, rather than nutritional quality because of the food shortages in Europe. Later, this trend continued because of the rise of processed food where uniform standards were required. This emphasis has remained until very recently with the advent of foods with additional or extra vitamins or minerals.

Between 1940 and 1960, new corn hybrids were developed by private companies such as the forerunners to Pioneer Hi-Bred (Troyer, 1999) that were suited to the application of nitrogen fertilizers. Between 1950 and 1980, the amount of nitrogen fertilizer applied to corn in the USA increased by a factor of 17 (Kloppenburg, 2004). Changes in plant architecture brought about by hybridization allowed these plants to be grown more densely with higher rates of fertilizer application, and they were typically managed with the use of insecticides, fungicides and herbicides. Indeed, developments in crop protection have tended to parallel those in fertilizers.

Breeding, both using conventional techniques and biotechnologies have made considerable contributions to the development of non-cereal crops. The main targets for breeding have been developing agronomic properties such as crop pest and disease resistance and tolerances to biotic stresses (e.g. cold, heat, salt). However extending crop flavor, quality, nutritional characteristics, shelf life and seasonality are increasingly of importance in breeding programs for these high value crops. Some breeding programs are even targeted at improving harvesting and transport, e.g. genetically engineered tomatoes with increased flavenol that are damaged less by transportation (Muir *et al.,* 2001), or conventionally bred high glucosinilate broccoli. The change in emphasis in breeding priorities can be illustrated by the Scottish Crop Research Institute breeding program; this was originally focused on developing spring frost damage tolerance in top fruit varieties such as blackcurrants. However there is now greater emphasis on fruit quality (Brennan & Gordon, 2002). For vegetable cropping, quality has been the main driver of different breeding.

<u>Mutagenesis</u>

Radiation (usually gamma or x-ray) and certain chemicals have been used to induce mutations in plants as part of plant breeding for the past 50-60 years. Induced mutations are used to provide a general increase in genetic variation for use in plant breeding, or for the direct production of a variety with a certain characteristic. The techniques have been applied to almost all crops. New varieties of seed producing crops form the majority of new varieties produced through mutagenesis, but varieties of crops that can be reproduced vegetatively (.e.g. the banana, trees, ornamental flowers) can also be developed (Ahloowalia et al, 2004). Mutagenesis yields unpredictable effects and, following exposure, plants have to be grown to see if any useful mutants have been produced which can be multiplied and developed as distinct varieties or used in plant breeding.

Mutagenesis is reported to have resulted in the production of 2,252 varieties according to the FAO /IAEA mutation varieties database up to the end of 2000 (Maluszynski et al. 2000). It has been increasingly applied to ornamental plants and flowers. One factor favoring the use of induced mutants, has been the lack of intellectual property restrictions on access for use in cross breeding programs. One of the highest profile uses of mutagensis in plant breeding in recent years has been in the production of non-GE herbicide tolerant crops, e.g. for imidazolinone tolerance.

Marker assisted selection

DNA knowledge-based techniques, such as marker-assisted selection (MAS) and genetic engineering that rely on genomic characteristics and mapping have shown great promise over the past few years (Asíns, 2002). This is especially true for complex characteristics such as drought resistant as these tend to be controlled by multiple genes and therefore not amenable to the most straight-forward genetic engineering strategies. Furthermore, plants produced using MAS are considered conventionally bred in the U.S. and Europe and are not subject to the same consumer and safety concerns raised with respect to GE crops, although in Canada they are regulated in the same manner. Marker assisted selection can equally be performed by private companies or public institutes as varieties would be protected by plant breeders rights.

Genetic Engineering

In NAE, only North America has embraced genetically engineered crops since 1996. Predominantly herbicide tolerant and/or insect resistant GM varieties of soybean, maize, cotton and canola are grown. For the most part, European acreage is limited to field trials of GE crops (ISAAA, 2005).

[Insert FIGURE 2A.11]

According to USDA's Agricultural and Resource Management Surveys (ARMS) conducted in 2001-2003, the majority of U.S. farmers adopting GE corn, cotton, and soybeans indicated that they did so mainly to increase yields through improved weed or pest control. Other reasons for adopting these varieties were to save management time and make other practices easier and to decrease pesticide costs. In an USDA Economic Research Service report, Fernandez-Cornejo and Caswell (2006:9) report that "These results confirm other studies showing that expected profitability increases through higher yields and/or lower costs (operator labor, pesticides) positively influence the adoption of agricultural innovations". The actual impact on farm income appears to vary from crop-to-crop ; however, it is important to note that in some instances, at least, management time savings have offered farm families the opportunity to generate more off-farm income (Fernandez-Cornejo and Caswell, 2006). In the EU, the total area of commercially grown GE crops is less than 0.1 million ha of GE crops, accounting for 0.1 percent of the total maize crop (GMO Compass, 2006). Regulatory differences and differences in publics' attitudes towards to GE are a key to understanding the different patterns of growth and are touched on later in this section.

Changes in the organizational arrangements of seeds and genetics

Plant breeders turned to new genetic techniques for a variety of reasons, including major emphasis on increased production and productivity in the political arena across the whole of NAE (c.f. discussion of political emphasis on demand in Eastern Europe (Medvedev 1987)), as well as through market demand. Moreover, efficient and well-financed knowledge transfer systems (e.g. extension and private consultants) moved these new plant breeding technologies and techniques into widespread use. In addition, plant breeders were responding to the larger scientific arena that was pushing knowledge boundaries.

Such major transformations in technologies and techniques were accompanied by significant changes in the organizational arrangements of seeds and genetics. Even as hybrid maize was developed by public institutes such as USDA in the 1920s, it became clear that there was an economic dimension to their development. Because the grain harvested from hybrid plants cannot produce economically viable seed, the seed has to be brought each year by the farmer. This contrasts with open pollinated varieties where seeds can be saved from year-to year. Thus, the seed business developed from a public service to a profitable industry (Fernandez-Cornejo, 2004). At the same time, the number of varieties researched, developed and produced by public institutes waned.

A major driver of the shift from public to private research was the establishment of Plant Breeders' Rights (PBR). PBR are granted to the breeder of a new variety of plant to grant the control of the seed of a new variety and the right to collect royalties for a number of years. For several of the main commodity crops, farmers are not able to sell the seed that they produce but can use their own crops as seed. In 1961, the International Convention for the Protection of New Varieties of Plants, which restricted the sale of propagated protected varieties, was signed. Within Western Europe and the United States, national legislation was passed in the 1960s and early 1970s in accordance with the Convention. The WTO’s Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPs) and The International Union for the Protection of New Varieties of Plants regulate plant breeders' rights internationally.

The legislation concerning plant breeders’ rights was intended to stimulate private investment in producing new varieties. It certainly has done this but some maintain that there is conflict between these international agreements on plant breeders’ rights and the Convention on Biological Diversity which advocates “fair and equitable sharing of the benefits arising out of the utilization of genetic resources”. This has led to considerable continued discussion in a number of international forums.

This switch from public institutes to private companies as prominent providers of new varieties is one of most important shifts in agricultural research during the latter half of the 20th century. It is a source of discussion whether the public research effort waned because the increase in private interest made public research redundant, or whether public research declined at the influence of the industry, who viewed public research institutes as competitors (Fuglie *et al*, 1996). One of the most important drivers of this change, the development of hybrid varieties did start before the end of the World War II, but its impact increased greatly after the war. Since World War II, public institutions and private entities have increasingly collaborated. The decline in research and release of public varieties has continued until by the current day, where the seed development industry is predominantly controlled by just a handful of big companies, although a fairly large number of smaller seed companies exist to deal with much smaller, regionalized markets.

Globally, the seed industry is increasingly driven by NAE based transnational agrifood businesses (UNCTAD, 2006). Four NAE based transnational companies provide almost 30 percent of world's commercially available seeds. The European seed market, worth about $6.6 million annually, is the largest regional market in the world, with about 22 percent of the global market, according the International Seed Federation. Combined with the U.S. and Canada (which together have 21 percent of the global market of $30 billion), NAE accounts for 43 percent of the commercial seed market globally. France, Germany and Italy make up the majority of the European market.

[Insert FIGURE 2A.1]

In NAE, the U.S. has had the most heavily commercialized seed industry in the world, with a structure that has changed greatly in the last 50 years, anticipating changes in the rest of NAE. According to Fernandez-Cornejo (2004), over 150 companies formed in the 1930s to sell hybrid maize. By the mid-1960s, American farmers had essentially abandoned open-pollinated maize varieties with nearly all maize acreage planted to hybrid maize.

Maize supplied the kernels of the transformation the seed industry that occurred from the 1970-2000. Independent private seed firms essentially vanished, with more than 50 acquisitions of seed firms by pharmaceutical and chemical firms (Fernandez-Cornejo, 2004). By the 1980s, the maize seed market was dominated by Pioneer (now DuPont) and DeKalb (now Monsanto). As Fernandez-Cornejo and Schimmelpfennig (2004:18) state, "The share of U.S. seed sales controlled by the four largest firms providing seed of each crop reached 92 percent for cotton, 69 percent for corn, and 47 percent for soybeans in 1997." One contrast to this general trend was wheat, with more than 70 percent of the planted wheat in 1997 coming from varieties developed in the public sector. The same privatization trends are seen in Europe, and as a consequence, the private sector will become more important in the future.

One of the more striking features of industry changes in the last two decades has been the convergence of ownership between agrochemical and seed/genomic firms. This strategy has worked well "to better control and market proprietary lines of chemicals, genetic technologies and seeds, often sold in a single-bundled package" (UNCTAD, 2006:7). These bundles can be attractive to farmers and farmer managers as a purchased management tool. However, such packaged bundles can reduce flexibility of on-farm management strategies for pests and weeds, and increase reliance on purchased inputs (c.f. Hendrickson and James, 2005).

The way GE crops have been introduced into farming in NAE has in part depended on changes within agro-chemical and seeds industries. In the mid-1980s a new 'technological trajectory' based on biotechnology began to emerge for the agro-chemical and seeds industries (Parayil, 2003; Chataway et al, 2004). The combination of regulatory pressures, which made it more challenging and costly to bring new chemical based products to market, the existence of new science and a willingness on the part of industries to engage in large-scale change meant that biotechnology was adopted in research and development (R&D) in a radical way (Chataway, Tait and Wield 2004). However, the nature of change was such that adoption of new biotechnology based techniques (predominantly genetic manipulation) initially contributed to strengthening firms' abilities to produce chemicals rather than biotechnology-based alternatives to chemicals. Most multinational agro-chemical companies used biotechnology to speed up the screening process for agrochemicals and to improve its efficiency and targeting (Steinrucken and Hermann, 2000). Biotechnology is closely related to changed developments in pharmaceuticals (Malerba and Orsenigo, 2002) and relates to three main areas:

- Using genomics to validate targets for new pesticides;
- Using combinatorial chemistry to generate large numbers of new chemicals for screening; and
- Using high throughput screening to test very large numbers of chemicals, rapidly on a range of living targets.

These new methods are unlikely to increase the number of new chemical products reaching the market but they are expected to allow companies to meet increasingly stringent regulatory requirements while still launching one or two major new products a year (Tait et al, 2000)

It should be noted that the development of genetically crops is not entirely in the private sector in the NAE, but there are only two examples thus far of publicly developed GE crops that have been commercialized or are undergoing regulatory review (virus resistant papaya and virus resistant plum) (see www.agbios.com).

A key feature of the early evolution of biotechnology were efforts to create a 'life sciences' based industrial sector. Negative public opinion is one factor that impacted on these plans. The concept of life science synergies played an important part in agro-chemical and biotechnology industry managers' strategic planning (Tait et al 2000). Early interpretations of the term 'life science' assumed that, by using biotechnology to gain a better understanding of the functioning of cells across a wide spectrum of species, there would be useful cross-fertilization of ideas between the development of new drugs and of new crop protection products for agriculture. The vision was one of synergy at 'discovery' level, where a better understanding of genomics and cell processes, made possible by fundamental knowledge gained in the life sciences can lead to new drugs, new pesticides, GM crops and genetic treatments for disease.

These assumptions were accepted until the very early years of the 21st century without much questioning, partly to justify the continued retention within the same multinational company of two sectors with markedly different profit potentials, pharmaceuticals and agrochemicals. However, the original conception of a life science sector is now being reinterpreted.

The synergy worked well where both partners are interested in sources of *chemical* novelty, but not in the *gene* area. Functional genomics, as a platform technology, can help both sides invent novel and profitable chemicals but unlike pharmaceuticals, in the agro-biotechnology sector there are also major commercial opportunities in the creation of GM crops. The large scale marketing of genetically modified organisms is not a significant factor in the strategies of pharmaceutical companies. Although experience in the USA and other countries has indicated that GM crop development is potentially very profitable, the negative public reaction in Europe has created potential conflicts of interest between the two industry sectors (Tait et al 2000).

Over a medium and longer term timescale useful synergies between pharmaceutical and agricultural areas of biotechnology may again emerge, for example medicinal benefits and other health-related output traits from crop plants. However, it is not clear that a link between the agrochemical and pharmaceutical divisions of companies will be maintained and (Tait et al 2000) this could of course influence the direction on agriculture related science, technology and innovation.

It is clear that the development of important new technologies in plant breeding (i.e. hybridization, embryo transfer, genetic engineering etc.) has significantly increased productivity of cropping systems in NAE. Moreover, the shift from public institutions to private industry in the development of new varieties and technologies in plant breeding has been one of the most significant changes in agricultural research in NAE, and it has had considerable impact on the development of cropping systems across the region. Where new technologies and products were developed that could be protected through IPR, industry consolidation has tended to occur. Many firms combined to take advantage of strong demand complementarities between products (Just and Hueth, 1993). This industrial concentration may create efficiencies but it may also limit the technological options as smaller firms which often bring dynamism to a sector find it harder to compete. at the level of bringing products to market. However, they often arrange collaborations with larger firms in which they bring initial innovative research to a company with greater resources for product development and deployment. Similar arrangements are increasingly common between researchers in academia and large firms as well. This tension in the application of IPRs needs to be resolved because the uncertainties affect farmer practice and farmer profitability; clarification will be important for farmers in poor parts of the world to maintain profitability. The latter is important as the development of plant breeding techniques within NAE has had significant impacts on the rest of the world, particularly as many of these techniques and their resulting products have been transferred globally.

2A.3.1.3 Nutrients in cropping systems

The biomass of land plants, including agricultural crops, is drawn from three primary sources, the carbon dioxide from the atmosphere, water from the soil, and nutrients from the soils. While the carbon is replenished by the atmosphere, continuous harvest of plant material can eventually strip reactive nitrogen and phosphorus from the soils, impeding further plant growth. Agricultural production can also be limited by deficiencies of potassium and minor nutrients, but nitrogen and phosphorus are the main limiting factors for production.

Traditional fertilizers have been organic, but by the early to mid 1900s the use of inorganic sources of phosphorus, mined from phosphate rocks, and reactive nitrogen produced by industrial processes came into agricultural use. Nitrogen can also be provided by legume crops grown in rotation with other crops (See for example, Lavelle et al., 2005, or NAS, 2000.) After the end of World War II the use of synthetic fertilizers increased dramatically. Between 1950 and 1972 the supply of NPK fertilizers to Soviet agriculture increased by almost 10 times, and the rate of NPK application increased from 7.3 to 55.9 kg/ha per year (Narodnoe khoziaistvo 1975). The trends for North America and Europe are similar to the world as a whole, with the exception of a significant temporary decrease in fertilizer use in the CEE and CIS countries in the late 1980s due to the collapse of the former Soviet Union. While phosphorus use leveled off in North America around 1980, nitrogen use is still rising, though at a slower rate than pre 1980. This fertilizer use is partly responsible for the considerable gains in agricultural productivity (along with crop variety improvements, pesticide use to prevent losses, and improved farming practices) in North America and Europe since the 1950s.

[Insert FIGURE 2A.12]

[Insert FIGURE 2A.13]

2A.3.1.4 Pesticide usage in NAE cropping systems

The term pesticide covers a huge variety of products and uses including herbicides, insecticides, fungicides and nematicides. There are also pesticides used to control rodents, fish and bird species and other materials which may be used on farms such as wood preservatives, and biopesticides.

The control of pests, weeds and diseases in crops with synthetic chemicals was not widespread before the 1940’s. In the following 50 years the chemical industry has brought to market a huge range of chemistry for crop protection, such that the majority of crops now receive a whole series of treatments.

The most widely available data on pesticide use is that based on the tonnage of pesticide used in a particular country. For example, in 1997 approximately 350,000, 32,000 and 100,000 tons were used in USA, UK and France, respectively (FAOSTAT, 2006). Care should be taken to not over interpret the general trends as a direct indicator of environmental risk or health risk. Tons of pesticide used is also a rather unsatisfactory measure of pesticide use and environmental impact, as it amalgamates information on products used in undiluted form and. reflects neither the toxicity to different organisms nor the persistence of different chemicals The number of new pesticides being registered that are classified as low-risk and biopesticides (naturally occurring compounds) have both increased to be greater than the number of new chemical (conventional) pesticides (EPA 2005).

A program for registration of new pesticides was initiated in 1947 by the USDA, and is currently under the guidance of the USEPA (Pierzynski et al., 2000). Part of this USEPA regulatory strategy is groundwater assessments (Federal Register, 1996). Currently, there is a large amount of research by universities and federal agencies such as U.S. Geological Survey to better understand the fate and transport of pesticides applied to crops (Schraer et al., 2000; Thurman and Aga, 2001). There have been many improvements in the developments in pesticides in recent years include changes in formulations to lower amounts of active ingredients and to contain more readily degradable materials. There have also been user education programs to address changes in the application of these materials and timing of irrigation to increase the effectiveness and limit transport to groundwater (Spaulding, 2003). Canada instituted a government program called Food Systems 2002 in 1987 to reduce the use of pesticides in agriculture by 50 percent by the year 2002 (Gallivan et al., 2001). Based on data compiled from 1983 through 1998, there was a 38.5 percent decline due in part to reduction in crop area, but principally from reduction in mean application rates.

<u>Pesticide use in Europe</u>

Comparisons of pesticide usage between 1980 and 2004 in a representative sample of four EU countries indicate an approximately flat response for UK and Germany and a decline in the Netherlands and a slower decline in Denmark. These two latter countries both have legislatively driven pesticide reduction strategies.

[Insert FIGURE 2A.14]

As there was little pesticide use before 1950, there was a massive increase in pesticide use, to reach the tonnage levels recorded in the 1980s. Detailed changes in pesticide use over the last 50 years are difficult to access, but an example has been sourced from UK data for changes in pesticide use in cereals (Chapman *et al.,* 1977; Davis *et al.,* 1990; Garthwaite *et al.,* 1996, 2000, 2004; Sly *et al*., 1977, 1986). By the mid 1950s up to 50 percent of the cereal acreage was treated with herbicides based primarily on

MCPA (Russell, 1956). Over the next 5 years, further herbicides came onto the market for broad-leaved weed control in cereals and by the end of the decade approximately 90 percent of cereal crops (provided they were not undersown) were receiving a treatment (Dadd, 1962). UK national pesticide survey data shows that all cereal crops at this time received a herbicide and a seed treatment. In subsequent years there was a huge increase in the hectares treated with fungicides, and increases in insecticides and herbicides, whilst seed treatment has changed little. Over this period the area sown has also remained relatively static at a little more then 3M ha. By 2002 the number of pesticide treatments applied per hectare/year had increased from two (1974) to nearly nine. The overall trends in use do not show how product use has changed over time. Usage of old products has declined and they have been replaced by newer ones, often with a lower environmental footprint.

[Insert FIGURE 2A.15]

Pesticide usage in the USA

The use of conventional pesticides by U.S. agriculture grew rapidly to reach a peak in the 1980s and as in Europe has declined a little thereafter.

[Insert FIGURE 2A.16]

Agriculture typically encompasses 75 to 80 percent of total use of conventional pesticides in the U.S. The greatest amount of pesticide used on farms is herbicides. The growth of pesticide use through the 1950s and 1960s is primarily due to the growth in the use of herbicides. Fifteen of the top 25 most used pesticide active ingredients are herbicides in 1991 (Kiely et al, 2004). Herbicide use peaked around 1980, with atrazine being the most used active ingredient for many years. By 2001, glyphosate had become the most used active ingredient as a result of the wide adoption of glyphosate-tolerant crops produced by genetic engineering.

Insecticide used in agriculture peaked in the late 1970s and decreased by more than half between 1980 and 2000. This was primarily due to the replacement of organochlorine insecticides with insecticides that can be applied at much lower rates. 1n 1960, chlorinated hydrocarbons represented about 75 percent of insecticide use. By 1997, they represented less than 3 percent of insecticide use (see Aspelin, 2003). Another significant factor in the general reduction of insecticide use is the adoption of integrated pest management techniques. Most farmers of major crops now scout for damaging insects (NASS, 2006) and only apply insecticides when the projected savings from yield loss will outweigh the costs of the insecticide application. Some of the decrease since 1995 is also due to the use of insect resistant varieties of the major crops corn and cotton, produced through genetic engineering (Fernandez-Cornejo and Caswell, 2006 and references therein).

Role of AKST

The development of pesticides has depended almost totally on scientific advances in the private sector. The majority of pesticides have been produced by the multi-national agrochemical companies. However, the public sector has played a significant role in the regulatory approval for pesticides for minor or specialty crops where the small markets are not sufficiently economically viable to warrant conducting the necessary field tests. Science and technology has also played a key role in governmental regulation, as new tools and techniques, coupled with increased understanding of environmental consequences, has led to increasingly rigorous evaluation of new products.

Agricultural science has also provided tools to develop biocontrol agents, as alternatives to conventional pesticides. Improvements in application and formulation technologies have reduced off target effects and have enhanced performance on the target organisms.

The drivers of pesticide use in the NAE have been:

- Increases in crop yield and quality delivered by effective pesticides. This has increased profits both of farmers and of agrochemical companies.
- Increasing environmental concerns, both by regulators and the general public, resulting in increased regulation of approval of new products and greater restrictions of use of all products. A specific aspect of this has been the need to reduce levels of pesticides in both ground and surface waters, and to minimize levels in food.
- Increasing demands by the markets in the NAE for pest and disease free products resulting in increased pesticide usage in horticultural crops, in particular.

2A.3.1.5 Water control in NAE cropping systems

The control of soil moisture in agriculture has a large impact on yield and plant health. Root growth and function is impaired if soils are either waterlogged or droughted and this in turn affects the vigor of the plant above ground.

As many lowland soils are naturally waterlogged, especially during spring and fall, farmers have often drained their land either using ditches and channels, or since the 19th Century, by using buried pipes. These subsurface drains are highly effective at removing water from large areas of land. In 1945 drainage pipes were made of fired clay and their installation was labor-intensive and expensive. During the 1950s, plastic pipes became available in continuous lengths, and in both North America and Europe machines were developed that laid these pipes as the machine moved through fields.(Spoor and Leeds-Harrison 1997)) Large subsidies were made available to farmers to encourage soil drainage and from 1950 to 1990 vast areas were under-drained (for example in the UK (see Robinson and Armstrong 1988)), improving crop yields and increasing access to land for spring planting and harvesting at the end of the season. Access to land in fall also opened up the potential for winter cropping, now the norm over large parts of Europe and parts of the US. Whilst drainage on this scale certainly improved yields (examples?) it also gave rise to serious water pollution problems due to oxidation of iron and sulphur compounds in soils, and increased nutrient and pesticide run-off to rivers and streams (Sagardoy1993, EEG 1994, Ongley 1996, FAO 1997). Water pollution from agricultural drainage is now one of the largest factors in degradation of freshwater and marine biodiversity (especially in the Gulf of Mexico) throughout NAE, and special measures to try to address this pollution source have been introduced in both the US and Europe, although with limited success (WWF 1992, FAO 1997). Not only have surface and sub-surface drainage increased water pollution, but agricultural drainage been a contributor to increases in both the rates and rapidity of run-off from farmland, contributing to lowland flooding in many areas within NAE, most recently in Central Europe in 1997 and 2000 (Beckmann 2000). This increased run-off has also greatly increased sediment loads in freshwater systems, reducing general biodiversity and damaging reproductive capacity of fish populations especially in migratory salmonids (Dougherty and Hall 1995). Conversely in some areas drainage can lead to low river flows and damage to biodiversity in summer, exacerbated by increased demands for irrigation water for agriculture and horticulture (Dougherty and Hall 1995)

Irrigation is the process of applying water to soil, primarily to meet the water needs of growing plants. Irrigation has greatly increased yields of crops and also permitted their cultivation in arid areas where other climatic conditions may be suitable for plant growth. Across NAE, irrigation has also extended the cropping season and facilitated multiple cropping. While irrigation helps to maximize crop outputs, it needs to be managed carefully. Its value may well increase in the future, if predicted increases in world temperatures and changes in rainfall patterns actually occur.

In NAE, irrigation is used extensively in Southern Europe and the Western United States. Much of this use focuses on high value horticultural crops, although there is also appreciable usage in some of the major arable crops such as maize, soybeans and potatoes. Overall, within the EU (15), there has been a rise in the percentage of irrigated crops from 4% to 9% over the last forty years, increasing the potential irrigated area from nearly 7M ha in 1961 to more than 13M ha in 2001 (source FAOSTAT, AQUASTAT). This average value disguises the greater areas irrigated in the hotter southern countries and the much lower usage further north. Over 10M ha of the total 13M ha of arable land are irrigated in Spain, Italy, France and Greece.

In the United States, the area under irrigation doubled between 1949 and 1979 to 21 million hectares and by 1987 had more than doubled again (Rhoades, 1990a). In 1989, the Western Region had 15.2 million hectares of irrigated land, approximately 81% of the total U.S irrigated land (U.S. Dept. Commerce), using approximately 92% of all irrigation water (Sundquist, 2005). Of the 33.5 million hectares of arable land in

Canada, only 842,000 hectares are irrigated, mostly in Alberta, a 19% increase since 1991 (Canadian National Committee on Irrigation and Drainage, 1999). About 14% of the 2.13 million farms and ranches in the United States were irrigated in 2002 (USDA, 2004). Although irrigated land is only 18%, or 22 million hectares (55 million acres), of the total harvested cropland, farms with irrigated land receive 60% of the total market value of crops in the United States (USDA, 2004). Market value of crops on farms with all cropland irrigated was $US3480/ha ($1410/acre) in 2002 compared to $420/ha ($170/a) for non-irrigated farms. Irrigation not only increases crop value, it also increases water use efficiency (Howell, 2001) by increasing the mass of crop produced per volume of water.

Various irrigation methods have been developed over time to meet the irrigation needs of certain crops in specific areas. The three main methods of irrigation are surface, sprinkler and drip/micro. Water flows over the soil by gravity for surface irrigation, and has been the most common method in the U.S.

A major challenge for irrigated agricultural is increasing competition for water, primarily due to population increase (NRC, 1996). Irrigation water cost, or value, will increase with increasing competition for water supplies (CAST, 1996). Total water withdrawals in the US increased steadily from 1950 to 1980. While population has continued to increase, water withdrawals have been essentially constant 1985 to 2000 (Hutson et al., 2004). One reason for this is average irrigation application rate has declined from 1080 ha-mm per ha (3.55 acre-ft per acre) in 1950 to 756 ha-mm per ha (2.48 acre-ft per acre) in 2000.

The desired for increased productivity has been a major driver increasing the use of irrigation in the NAE, along with an increasing demand for products outside their normal production period (especially for fruits and vegetables), and the increased profitability of crop production using irrigation methods.

As in other parts of the world, drainage and irrigation of soils in arid regions of NAE has led to soil salinization, especially in some parts of the US and Southern and Central Europe, where agricultural production is severely curtailed. Irrigation in some areas has also led to increased pesticide and agrochemical runoff with subsequent damage to freshwater ecosystems.

2A.3.2 Agricultural products for energy and fuels

Due to a rapidly growing interest in developing alternate fuels for transportation, expectations are high for agriculture to produce liquid biofuels. The U.S. Energy Policy Act of 2005 calls for the use 7.5 billion gallons per year of biofuel (primarily ethanol) to be mixed into the U.S. fuel supply by 2012. (This is equivalent to 2 percent of the U.S. gasoline consumption in 2005, by energy content.) The European Union biofuels directive of 2003 sets a reference value of 5.75 percent for the market share of biofuels in 2010.

In the U.S. ethanol production capacity has increased from 1.6 billion gallons per year in 2000 to about 5 billion gallons per year in 2006, with an additional 6 billion gallon capacity under construction (Renewable Fuels Association, 2006). Biodiesel production (primarily using soybean as a feedstock) is currently much lower than ethanol, but rapidly expanding. As of 2005, there were 53 biodiesel plants with a capacity of 354 million gallons per year. Biodiesel capacity is expected to reach 1.2 billion gallons per year.

As in North America production of biofuels is increasing in Europe. Little was produced pre 2000 but in 2004 it had reached 2.4 Mt and the aim is to produce 18 Mt by 2010 (EU Commission 2006). Unlike the USA, most biofuel in Europe is biodiesel from oilseed rape and in 2004 2 Mt were produced. Assuming an average yield of 2.5t/ha this amount of biodiesel would have been produced by c. 300.000ha of oilseed rape. The remainder of the biofuel production was bioethanol, much of it derived from excess wine production in the EU.

The price for the crops at the farm gate increases with increased biofuel production and may be less volatile. In addition, the biofuel industry provides off-farm, rural employment opportunities while the byproducts of biofuel production (distilled grains and residue after oil is recovered) are considered quality feed supplements.

However, there are clearly limits as to how much biofuel can be produced, at least with current and foreseeable technologies. For example, in 2005, 14 percent of the U.S. corn crop was used to produce the equivalent of 2 percent of gasoline use in the U.S. (by energy content). (For comparison, the U.S. exports about 16 percent of its corn production). Using the same corn use to ethanol ratio, utilization of 100 percent of the U.S. corn crop for ethanol would produce fuel to replace only about 14 percent of the U.S. (2005) gasoline use.

While at least at a modest scale, biofuels production should benefit the NAE agricultural community, questions remain whether greatly increased production and use of biofuels will have detrimental environmental effects, or even meet the projected environmental benefits. To the extent that mandates to meet certain biofuel use targets cannot be met by domestic production, biofuels will need to be imported. This may negate some of the savings expected from import of petroleum products. Further, it may prompt increases in agricultural production elsewhere at detriment to the environment (e.g. Pearce, 2005).

One incentive for the use of biofuels is their replacement for fossil fuels. 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 to produce biofuels.

<u>Other agricultural-related energy sources</u>

Agricultural lands may make a contribution to energy in ways other than through production agriculture. For example, in the U.S. the richest wind energy resource, available in wide areas, stretches from the upper Midwestern plain states to Texas (Elliot et al, 1986). Farmers have leased the land for turbines, or have invested directly in their ownership. The potential of the Midwest wind resource has been recognized and the number of installed wind turbines and overall electricity production capacity is expanding (c.f. Wind Energy Association at, http://www.windustry.org/default.htm) (U.S. Department of Energy, 2007).

Forestry and other sources of plant material (eg biomass crops) are being increasingly used in Europe as a source of heat and energy, driven by the rising price of oil. In 2004 52.4 Mt (oil equivalent) was produced from these sources. A huge proportion of this was from forestry waste, especially in the well forested EU states, such as those in Scandinavia. However, the EU propose to greatly increase the 2 percent of energy from biomass crops such as coppice willow, and Miscanthus grass, so that it makes an appreciable contribution to the EU energy budget in the future (European Commission, 2005, 2007). As in the USA there are also considerable developments in the utilization of wind power. In 2004 the EU contributed 73 percent of the world's total capacity of 48 thousand MW. There is much debate as to the location of these wind farms and of their environmental impact, but they do offer an alternative source of income to farmers and other land owners.

2A.3.3 Organic cropping systems

<u>Europe</u>

Since the beginning of the 1990s, organic farming has rapidly developed in almost all European countries. Growth has slowed recently. In 2004 in Europe, 6.5 million hectares were managed organically by around 167,000 farms. In the European Union more than 5.8 million hectares are under organic management, and there are almost 140,000 organic farms. This constitutes 3.4 percent of the agricultural area. The country with the highest number of farms and the largest organic area is Italy. In most countries of Europe and particularly the European Union organic farming is supported with legislation and direct payments. Regarding the share of organic farmland in comparison with the total agricultural area, Austria, Switzerland and Scandinavian countries lead the way. In Switzerland, for example, more than ten percent of the agricultural land is managed organically1. Italy has a most relevant position at European level with the highest number of hectares organically cultivated and also of active organic farms. In fact the land under the organic certification has been largely increasing since 1994, i.e. when financial support was first introduced by the EU-Regulation 92/2078.

The support to organic production granted by the reform of the Community Agricultural Policy, i.e. enforcement of the EU Regulation 2078/92, (mis.A3+A4), constituted a fundamental step in this evolution and largely promoted the development of conversion to organic farming in the Southern regions of the European Union, even though the pioneers of organic agriculture were in the North and in the Central Europe. In the 1990s the regions in the South of Italy recorded the highest rates of growth of farms in conversion to organic farming. In the European Union, the European Organic Action Plan implementation process is now getting under way.

North America

In North America almost 1.4 million hectares are managed organically, representing approximately a 0.3 percent share of the total agricultural area. Currently, the number of farms is almost 12,000. With the US national rule in place, the organic sector has been able to provide a guarantee to consumers that those organic products using the new labeling mean that specific practices were followed. The US market has seen more and more organic products being introduced, the number of certification agencies accredited by USDA has grown, and talks are progressing to expedite international trade of organic products. Since 1999, the Canadian industry has had a voluntary Canada Organic Standard that is not supported by regulation. The organic industry continues to devote its energies toward implementation of a mandatory national organic regulation to help expedite trade relations with such major trading partners as the United States, European Union, and Japan.

2A.3.4. Summary of key changes in cropping systems and drivers

In summary, production of arable crops has doubled and in some cases tripled over the last 50 years in the NAE. These production increases have been mainly due to increases in output per unit area, as the area of arable land in the NAE has not increased and in many countries has decreased slightly. Production increases have been facilitated by the contribution of AKST, providing farmers with new tools to enhance crop production. These have primarily been more efficient use of fertilizers, mechanization and development of novel more effective agrochemicals and the breeding of new higher yielding cultivars. Dissemination of this new knowledge has depended on the development of efficient knowledge transfer systems, both governmental and private sector. Moreover, there has been increased technological sophistication in agricultural mechanization. The increased productivity/efficiency of cropping systems, has left more time for other work and enhanced the worker environment by eliminating repetitive, dangerous and disliked tasks. Despite the labor savings brought about by mechanization, there is still an appreciable use of hand labor in horticultural crops.

New tools provided enabling change or extension of farming practice. For example, larger field sizes to accommodate machinery, new areas under cultivation because of improved plough/cultivation capability, increased capability for minimum tillage, increased ability to cope with management and feeding of livestock at higher densities, shift from silage to hay. However, there are also negative aspects associated with soil compaction and structural damage resulting from frequent passes of large heavy machinery. Still, mechanization has increased the practicality of the production of some organic crops (e.g. new innovations in mechanical weeders).

Irrigation has played a major role in increasing food production in the NAE, especially in areas of limited rainfall. There has been increased crop value with irrigation. However, there is increased competition for water, primarily due to population increases in NAE. There has been an increase in total irrigated land but this is expected to decline in the future because of dropping water tables and higher energy costs. Increased use of irrigation has resulted in serious environmental problems (soil degradation, salinization, erosion, damage to natural wetlands, decline of natural aquifers). Irrigation has resulted in salinization of some U.S. soils through artificial elevation of water tables by extensive irrigation, with inadequate or improper drainage. AKST is playing a role in making irrigation more efficient and less environmentally damaging, is increasing water use efficiency by increasing mass of crop produced per volume of water, and the increased knowledge and technology for soil/irrigation sustainability and water quality.

There has been a huge increase in pesticide usage in the NAE since the 1940s. Sales of pesticides in N. America (NAFTA) and Europe in 2004 exceeded 16,000 M dollars (Croplife, 2006). During the 1950s and 1960s there was a rapid increase in the tonnage applied to fields but subsequently the quantities used have declined somewhat, as more modern, less environmentally damaging products have been introduced and greater regulation restricted usage (see below). Environmental concerns about pesticides both by governmental regulators and the general public have increased, resulting in greater regulation and the development of less environmentally damaging methods of use (e.g. Integrated Pest Management approaches) As it became increasingly difficult to discover and successfully develop new products, the companies of the agrochemical industry turned to molecular biology to develop genetically engineered crops that simplified weed control and delivered alternative methods of pest control.

2A.4 Changes in Livestock Systems in NAE

As in cropping systems, the key change in livestock systems in NAE has been significant increases in productivity in production of meat and dairy products. This has been driven by an increased demand for meat and dairy products among NAE consumers, but has been made possible by improved genetics and widespread access to superior genetics, changes in livestock feeding regimes, development of specialized production units for livestock, and improvements in food safety, particularly in the handling of meat. Recent changes in consumer demand for humanely treated livestock products (see Chapter 2B) as well as increased concern about environmental impacts of intensive livestock production have started to shift production practices across NAE, but particularly in Western Europe.

Across NAE, mixed farming systems predominated after World War II (e.g. lowland Europe was largely a region of mixed farming with livestock fed mainly by grazing and cereals produced on the same farm (Hodges 1999) while the U.S. had a more geographically dispersed livestock sector (McBride, 1997)). On the uplands in Europe, pastoralism was a way of life often using systems of summer grazing and winter long distance stock movements ('transhumance') developed in mediaeval times.

As a result of World War II disruption in production, distribution and storage, the livestock industry was unable to meet European consumer demand until the late 1950s, and between 1945 and 1955 rationing of meat, eggs and dairy products was widespread in all parts of Europe. Meat consumption per capita has generally increased since rationing ended in the early 1950s (Aumaitre and Boyazoglu 2000). During the post-war years almost every European government adopted subsidy-led measures to increase livestock production from a very low base (Hodges 1999).

In Europe, the mixed farm production of the 1940s has today almost completely changed to either arable or milk and livestock specialist production units, using high intensity production methods promoted by the EU Common Agricultural Policy and state subsidies, either in the form of direct subsidy of capital investment and/or productivity-related payments (de Haan, Steinfeld and Blackburn 1997). Although half of all EU farms still have livestock, around 90 percent of these are now specialist livestock producers, buying feed from global commodity markets (data from European Commission website). Europe now has one of the highest densities of livestock in the world (FAOSTAT), with a mixture of intensive grassland production and fattening and rearing units where livestock are fed on both home-grown and imported feed. The overall result has been a pattern of increasing numbers of livestock (although the density of livestock (LU/ha) in Europe has fallen some 10 percent in the past decade (FAOSTAT)) and increased productivity of all livestock and dairy products, leading to large-scale over-production in the cattle, pig and poultry sectors over the past twenty years.

[Insert TABLE 2A.2]

The U.S. and Canadian livestock sectors have also undergone extensive restructuring since 1945, but in different ways. One of the key developments has been the integration of the U.S., Canadian and Mexican livestock sector, accelerated by the adoption of NAFTA in 1994. This is particularly true in the beef and pork sectors (Farm Foundation 2004; Haley 2004; Young and Marsh 1998). Prices for beef and pork tend to move together in both wholesale and live animal markets, particularly in Canada and the U.S. (Vollrath and Hallahan, 2006) (e.g. eight percent of pork slaughtered in the U.S. now originates in Canada, a large increase over the last decade (Hahn et al 2005)). Poultry is the exception as it is not as well-integrated because it is a managed sector in Canada.

[Insert TABLE 2A.3]

In N. America the number of farms with livestock has decreased (McBride, 1997), while production of red meat, poultry products and dairy products has continued to increase. In the U.S., there have been significant geographic concentrations in beef and broiler production. Large feedlot operations for beef are concentrated in the Great Plains, while broiler production is heavily concentrated in the Southeast. In the 1980s, hog production shifted from the Midwest to large operations in the Southeast (see also Welsh, Hubbell and Carpentier, 2003).

[Insert FIGURE 2A.17]

At the same time, dairy production expanded in Western states away from the Northeast and Upper Midwest (McBride, 1997). Canada has seen similar geographic concentrations of livestock production with hog production shifting from Quebec and Ontario to the west, particularly Manitoba, while cattle production has become concentrated in Alberta (USDA-FAS, 1996).

[Insert FIGURE 2A.18]

2A.4.1 Trends in output and productivity since 1945

<u>Europe</u>

Four groups of animals produce over 90 percent of Europe's meat and dairy products; cattle for milk, beef and veal, pigs for meat, poultry for meat and eggs, and sheep and goats for meat, milk and wool. Meat, dairy products and eggs account for over one third of the total value of agricultural production in Europe. Beef sales declined during the BSE crisis from 1996 to 2001 but have now begun to recover (USDA 2005, Morgan 2001). Pig and poultry meat consumption increased due to the BSE-induced dip in beef demand, but have increased even further since the 1990s due to greater competitiveness with other meat production, partly as a result of CAP reforms that made cheaper cereals available for animal feed. Sheep meat production and consumption declined during the 2001 UK foot-and-mouth disease outbreak in 2001, but have now almost recovered to previous levels (data from Eurostat Agriculture: Livestock Production Statistics).

[Insert FIGURE 2A.19]

In response to growing demand from a larger and richer population production of all livestock increased very rapidly in Northern and Western Europe (EU-15) from 1961 to 2000, whilst production of meat and dairy products has fallen in the CEEC from 1990, mainly as a result of the transition from a centrally planned to a market economy. However in Hungary, Slovenia, Croatia and Romania production has either remained stable or increased slightly from 1993 to 2004 (EU 2004). Europe (EU-25) produces over three times as much meat per head of human population as the world average of 36 kg/capita (FAOSTAT Chartroom).

[Insert FIGURE 2A.20]

This productivity has led to over-production. Europe is more than self-sufficient in meat (see Table 2A.2), with a current net balance of around 105 percent for all meats (Eurostat data). As a result of rigorous CAP reforms in the 1990s, European production of beef and veal has fallen rapidly from around 50 percent over-production (EU-15) in the 1990s to around 96 percent self-sufficiency in 2004. Beef and veal consumption has risen in the past 4 years, with the European production deficit being made up by imports of around 250,000 tons per year from South America. Pig meat is still being over-produced in EU-25 by about 8 percent, making the EU-25 a net exporter of pig meat products, mainly to Russia and Japan.

[Insert FIGURE 2A.21]

The EU is a net importer of sheep meat (EU-25 is only 78 percent 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 (Eurostat Agricultural Trade Statistics data).

[Insert FIGURE 2A.22]

<u>North America</u>

North America (Canada and U.S.) accounts for 16 percent of the world total number of beef cows, eight percent of the world's pig crop, nearly one-third of the world's poultry meat production (although this has slipped from the early 1990s due to huge increases in Chinese and Brazilian poultry production), and nearly 15 percent of the world's milk (Farm Foundation, 2004; Adcock *et al* 2006). In 2004, North America produced over 11 million metric tons of pork and nearly 17 million metric tons of broiler meat (Farm Foundation, 2004). In the swine sector, productivity in breeding herds has increased significantly, with 3.2 million fewer sows in 2004 than in 1980 producing roughly the same amount of pigs. The U.S. and Canada have been able to increase milk output 19 percent and six percent respectively, even with fewer cows, due to significant improvements in milk productivity related to improved genetics (Farm Foundation 2004.

[Insert FIGURE 2A.26]

[Insert FIGURE 2A.27]

[Insert FIGURE 2A.28]

In the U.S. the value of livestock production increased nearly by a factor of eight between 1948 and 2005.

[Insert FIGURE 2A.23]

The pounds of red meat produced, defined as beef, veal, pork, lamb and mutton increased nearly 50 percent from 1963 to 2006.

[Insert FIGURE 2A.24]

[Insert TABLE 2A.4]

[Insert FIGURE 2A.15]

Beef and pork steadily increased in pounds produced. However, the production of lamb and veal declined very sharply, to the point where the U.S. now produces less than one-quarter of the lamb and mutton produced in 1963. The U.S. has also seen a marked increase in the amount of poultry produced in the last 20 years.

[Insert FIGURE 2A.29]

In Canada, pig slaughter has nearly tripled since 1976, while cattle slaughter declined and then started to increase in the last 15 years, due to the opening of new processing facilities by U.S. based firms (Cargill and Tyson). Sheep and lamb slaughter, while still very small has managed to almost double since 1976 a very different trend than the U.S.

[Insert FIGURE 2A.25]

Overall, livestock productivity and output in NAE has increased enormously since 1945 with beef, pig meat and milk production almost doubling, and a four-fold increase in numbers of poultry. Sheep and goat numbers and production of meats and other products from this animal stock have remained comparatively stable (data compiled from FAO, Eurostat and USDA).

2A.4.2 Drivers of increased livestock output and productivity

The spectacular rises in livestock numbers and productivity seen in NAE over the past 50 years result from four major drivers:

- Growth in population numbers and wealth, creating strong market demand for meat and dairy products
- A strong policy and strategic framework within European countries and the EU aimed at increasing livestock production
- Rules and regulations determining husbandry methods and processing of livestock products.
- Production-led subsidies that funded output and productivity increases
- The application of knowledge, science and technology to animal genetics and nutrition, including grassland management and feed formulation
- The development of the interstate highway system in N. America that has allowed animal production and slaughter to be situated more closely to major supplies of grain

<u>AKST in Livestock Systems</u>

The most important contributors to increased productivity have been changes in livestock genetics, livestock feeding and management systems. Animal breeding has always been a feature of farming systems, with selection taking place at the farm level until the end of the 19th Century. The result was adaptation of cattle, pigs, sheep, goats and poultry to specific (usually regional) farming and market situations (Hodges 1999). This led to a very wide variety of regional breeds, sometimes referred to as ‘landraces’. Yield was not the only goal of farm-based livestock breeding, especially in southern Europe, with more emphasis on selecting livestock that would thrive on particular types of land, climate and feed (CIV website). Farmer breeders were always trying to adapt livestock to the landscape and their socio-economic circumstances.

In the 20th Century livestock breeding was increasingly done in either state-owned or private institutions using genetic science. Coupled with advances in land and management such as drainage, fertilizer use and harvest and storage techniques, these breeding programs began to be more yield-oriented to cope with increased demands for food from a rapidly expanding urban population in Europe and desire for more meat consumption among North Americans. This drive for greater productivity accelerated in the 1950s as a response to the need to rebuild the food supply chain after World War II. Science-based livestock breeding typically produced annual genetic changes of around 2 percent of the mean of a trait (or trait-related index), especially in species with high reproductive rates like pigs and poultry (Simm et al

2005). Not only were yields from livestock varieties substantially increased, but standardized livestock systems were also developed where in cattle (and to some extent sheep) the landscape was adapted to the system. In pigs and poultry, and to some extent cattle in North America, the whole enterprise was taken off the land and into intensive housing and feeding systems. Varieties that maximized food conversion ratios were quickly developed, especially in pigs and poultry, using Europe-wide breeding schemes (Simm et al 2005), with cattle breeding focused almost entirely on high milk and meat production. In N. America in the 1960s and 1970s, the so-called “British Breeds” of cattle were replaced in much of the beef sector by Continental Breeds that introduced size and leanness, in response to consumer desire for leaner beef. The genetic techniques used to achieve these productivity gains include:

- Better statistical methods of estimating the breeding value of animals
- The use of artificial insemination that allowed producers at any level to access superior genetics
- Better techniques for measuring performance of new breeds
- Selection focused on quantitative traits, such as weight gain and disease resistance

In North America, AI came to the fore in dairy production in the late 1970s, beef production in the 1980s, and is now in widespread use in pork.

Despite the undoubted success of these science-based breeding programs, it is generally agreed that the maximum genetic potential of cattle, pigs and poultry has still not been reached, and intensive breeding programs are still maintained in Europe although the focus is now shifting away from continued productivity increases towards animal health and welfare traits (Garnsworthy 2005).

As a result of these breeding and husbandry techniques, the wide variety of landraces in 1945 was quickly replaced by a few high yielding varieties, such as Holstein/Friesian milking cattle (e.g. this breed comprised more than 85 percent of the Canadian dairy herd in 1999 (Kemp 2001)) or white lines of pigs used in intensive production facilities. Most livestock landraces have survived in small numbers either by the activities of ‘rare breed societies’ who try to maintain the genetic base of the ‘old’ livestock breeds, or by being used to produce niche market high quality products, mainly meat and cheeses.

The latest developments in breeding relate to genetic engineering in animal production. Its use is unpopular in Europe in general, but in North America, ancillary uses of GE technology—e.g., to increase milk production through the administration of recombinant Bovine Somatotropin (rBST) has been widely adopted. The reception in either North America or Europe of the first transgenic animals in the food supply remains to be seen. In Europe, however, even rBST use for milk production raised concerns about animal suffering and potential negative impacts on small farmers. In the context of surplus milk production in NAE, the benefits of this application continue to be debated.

While rBST may have hit the headlines, the main applications in this area relate to research in:

- *Livestock production and disease resistance*

  Assisted reproduction and GE potentially allow breeders to design and direct the reproductive course, disseminate desired traits and hasten genetic improvement. Generation interval can be reduced by combining artificial insemination with more recent techniques such as oestrus synchronization, superovulation, ovum pick from immature females and in vitro embryo production and transfer. The sex and genetic make up of the offspring can be selected by using sex-sorted sperm for insemination, marker-assisted selection, functional deletion or addition of specific genes to the offspring's genome, or somatic cell nuclear transfer or cloning (Basrur and King, 2005). These techniques, particularly marker assisted selection and selection of animals based on molecular characterization, also have the potential to breed disease resistance into livestock (WHO, 2005; Mackinezie et al, 2005). However, poor success rates and numerous scientific and technical difficulties (Basrur and King, 2005; Houdebine and Renard 2005; Wells, 2005) are slowing down application of these techniques. It is worth noting, however, that discussions in NAE over the use of somatic cell nuclear transplantation for the purpose of propagating desirable traits in populations ("cloning") are progressing. Both INRA (reference) and the U.S. Food and Drug Administration (2006) have published draft risk assessments regarding the safety of meat derived from cloned animals. To date, however, no final pronouncements on the safety of such meat have been made and no such animals have been approved for slaughter in NAE.

- *Diagnostic techniques*

- *Veterinary medicine*

  Vaccination is one of the most important and cost-effective methods of preventing infectious disease in animals (Rogan and Babiuk, 2005). Molecular tools and genomics, combined with a better understanding of which antigens are critical in inducing protection and an appreciation of host defenses that must be stimulated, opens up possibilities for safer and more effective vaccines.

Simultaneously with breeding for improved productivity, NAE scientists also focused on improving livestock feeding. A dramatic example of this is the change in weight gain of broiler poultry reared on a modern diet compared with those fed traditional grain in 1957. The weight gain at 56 days in 1957 was around 800g compared to a 3900g weight gain in 2001 (Havenstein et al 2003). Similar trends can be found for weight gain in pigs and for milk yields in cattle (Simm 1998). Breeding and nutrition technologies for sheep and goats have not been subjected to such intensive scientific attention as they are still mainly raised on marginal land throughout Europe, and the market is smaller. Grassland-based cattle systems have changed radically throughout most of Northern and Western Europe from haymaking to silaging using the highest fertilizer inputs in the world (FAOSTAT), with great loss of non-grass biodiversity in pastures and meadows since WW2 (Johnson and Hope 2005). Haymaking with low fertilizer use still survives in upland and marginal areas in N and W Europe and in many parts of the CEEC, especially where traditional breeds of livestock are used. However, in N. America, intensive grazing systems that rely on significant management skills are making a comeback in beef cow and dairy herds, with the goal of increasing profitability per animal, rather than maximizing productivity (Gerrish, 2004).

Technological innovation in the livestock sector has been largely been aimed at increasing productivity. Changes in management systems have provided additional efficiency and enhanced productivity. The post- World War II adoption of sub-therapeutic antibiotics in animal feed is one example which helped to increase rates of weight gains in commercial livestock by three to five percent (Khachatourians, 1998). However, the biggest change has been in the vertical integration of the livestock chain which sought efficiency through standardizing genetics, feeding systems, and housing units while increasing communication throughout the sector. In N. America this is particularly apparent in the poultry and pork sectors, and in Europe, high throughput automated housing, feeding, slaughtering and processing facilities have grown larger, replacing smaller family-owned businesses (European Commission 2001). Across NAE, many animal slaughter and processing units are operated by large consortia which control large parts of the food chain (see Chapter 2B for a fuller discussion of these changes), and even have large intensive livestock units at the farm level, increasingly out-competing family farms by means of their economies of scale and ability to influence market prices for livestock and products.

In the second part of the twentieth century major changes took place in animal production facilities, and investment in buildings and their use have become issues of growing importance for farmers and growers (Gay and Grisso, 2002). Traditional buildings associated with livestock production had usually been general purpose. They were generally small scale and reflected production systems that relied heavily on manual labor. Faced by rising labor costs, facilitated by a variety of technological developments in machinery, building materials and methods of controlling the environment a major transformation has taken place where modern high throughput facilities, such as dairy parlors, pig and poultry production units, have largely replaced traditional multipurpose buildings. These provide controlled environments with measured use of feed and prophylactic treatments to prevent disease. Such facilities are also very important in the vertical integration of the meat supply chain.

However, livestock kept in intensive systems 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. While epidemic disease has always been part of livestock production, the larger groups of animals and widespread transport to and from markets associated with intensive systems have increased risks of large epidemics, even though biosecurity at individual units has been improved (ref). It has been argued that intensive systems have also produced new and dangerous diseases such as E.Coli 0157 and BSE (refs). 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 NAE livestock production because this has led to the rise of antibiotic resistant bacteria in humans (Mellon 2000; Khachatourians, 1998).

These changes have been controversial because intensive livestock production raises ethical and environmental issues. Treating animals as items on a production line offends many NAE citizens who feel this is an unacceptable relationship between humans and other species. Farm animal welfare has become an important area for policy makers, especially in Europe (Webster, 2005). [12] 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 and consumers who criticize intensive livestock production.[3] Moreover, the development of confined animal feeding operations in NA have resulted in significant conflicts over air and water quality, land use issues (zoning) and regulatory control (Bonanno and Constance, 2006; Heederick, D. *et al,* 2007; Donham *et al*, 2007).

A less evident contributor to productivity in the North American livestock sector is the development of the interstate highway system in the U.S. that allowed animal feeding and slaughter to be concentrated more closely to feed sources, particularly in beef production. A parallel process was the introduction of vacuum packaging (boxed beef) in the late 1960s. This significantly altered the value chain for beef and other protein, since end users (supermarkets and groceries) could sell particular cuts of meat without the labor, storage and shrink costs involved with hanging sides of beef or pork (Duewer, 1984). These developments in genetics, management systems and meat handling, combined with the geographical shifts in production, allowed significant restructuring in the beef, pork and poultry sectors leading to the development of confined animal feeding operations, contractual relationships in marketing, and specialization in livestock agriculture.

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[1] See the New Animal Welfare Bill http://www.defra.gov.uk/news/issues/2004/animal07a.htm
[2] Animal Welfare Act and Regulations
Animal Welfare Information Center United States Department of Agriculture Agricultural Research Service National Agricultural Library http://www.nal.usda.gov/awic/legislat/usdaleg1.htm
[3] See Compassion in World Farming Intensive farming and the welfare of farm animals
http://www.ciwf.org.uk/education/resources/intensive_farming.html

Despite these advances in production, food safety issues remain particularly important in the meat industry in North America. In 1995, an outbreak of *E coli 0157:H57* killed several children who had eaten fast food hamburgers in Washington state. This event led to a revolution in food safety procedures in red meat, seafood and poultry in the U.S. with the creation and adoption of HACCP food safety rules (see chapter 2B for discussion). Food safety concerns about salmonella (like *E coli 0157:H57* inherent to the animal) and *listeria monocytogenes* (inherent to the slaughter facility) continue to be of primary concern to the livestock sector.

The advances in productivity in the livestock sector would not have been possible without public investments in AKST. In particular, many new genetic selection techniques (such as AI) were developed through public university and disseminated through extension services. Today, much of the actual genetics has been privatized, and is now maintained primarily in the private sector, although performance measures for stud selection are still provided in the public realm. In the same way, the research that developed HACCP approach to food safety was performed by public entities like USDA-Agricultural Research Service and enforcement is still performed through USDA. Finally, many of the engineering advances that allowed the development of large-scale climate controlled buildings for poultry and swine and for handling the wastes of those systems, was developed in the public sector and disseminated widely.

2A.4.3 Key changes in the NAE livestock sector

Livestock productivity and output in NAE has increased enormously since 1945 driven by policy (especially the CAP), government subsidies, and increasing population and wealth. AKST has been a key driver of growth in the livestock sector and is likely to remain so in the future. Europe and North America have been exporters of livestock sector AKST to the rest of the world.

For the past 30 years much of NAE has been producing far more meat and dairy products than it needs with the EU and NAFTA blocks becoming some of the world's leading exporters, particularly in pork (EU), chicken and beef (NA). 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. In common with the rest of the developed world, milk, beef, pig meat and poultry are among the most valuable agricultural commodities produced by European farmers (see FAO chart for 1985)

Much of European lowland and landless livestock production is the most intensive in the world and this has had serious adverse impacts on the European environment. Similar situations exist in N. America because of the increased geographical concentration of livestock production. Across NAE, livestock enterprises have become fewer and larger due to economies of scale and this trend is likely to continue especially in the CEEC region of EU-25.

In North America, the markets for beef and pork have become much more integrated with prices essentially moving as one across the region. Livestock production has been much more geographically concentrated. The development of the interstate highway system in the U.S. facilitated these changes as livestock production and slaughter were situated near large grain supplies, while the introduction of boxed beef allowed the shipment of meat over longer distances and revolutionized the way meat was distributed and marketed.

Developments in genetics, management systems and meat handling in North America, combined with the geographical shifts in production, allowed significant restructuring in the beef, pork and poultry sectors leading to the development of confined animal feeding operations, contractual relationships in marketing, and specialization in livestock agriculture.

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.

The European livestock sector remains a major employer in agriculture and food processing with at least 500,000 full-time jobs dependent on the sector. The livestock sector in the CEEC (and especially in the CIS) has declined since 1990 (due to declining spending power of CEEC consumers), but is now recovering. These countries may in future become leading producers of meat and dairy products in EU-25.

2A.5 Changes in Forestry Systems

Although it may sometimes seem that agriculture and urban sprawl are the main land uses in North America and Europe, forests and woodlands have always been the dominant vegetation cover, and that remains the case today. In both North America and Europe forests are largely derived from natural vegetation dominated by deciduous trees in the south and west, and vast areas of conifers towards the north and east that make up over 50 percent of total forest cover. With the exception of the Russian Federation and Canada, truly natural forests are rare in this region, where human influence has modified forests since Neolithic times.

For thousands of years in Europe and hundreds of years in America forests have been exploited by humans not only for timber supplies and for fuel, but also for the animals and plants that inhabit them, for food such as nuts, fungi and berries, for cork (the EU is the largest producer of cork with over 80 percent of the world market and 1.7 mha of cork oak forests), and for paper fiber,. Forests in this region still provide a significant proportion of the renewable energy used by both industrial and domestic consumers.

Forests also provide valuable and irreplaceable ecosystem services such as water resource protection, biodiversity and carbon dioxide fixation (for a detailed assessment of these services see Millennium Ecosystem Assessment 2005). For example, approximately 140,000 species of plants, animal, and micro-organisms are estimated to occur in Canada of which approximately 2/3 are found in the forests (Canadian Forest Service, 2003).

2A.5.1 Main trends in NAE forests and forestry production

North America and Europe is the only world region where there has been an increase in forest area since the 1960s. In 1630, when conversion of North American forests to agricultural land began, 50 percent of the U.S. lands were forests. Today, forests are approximately 33 percent (749 million acres), but since the 1980s have been increasing by 0.3 percent per annum. The U.S. growing stock volume increased 39 percent from 1953 to 2002.

[Insert FIGURE 2A.30]

[Insert FIGURE 2A.31]

[Insert FIGURE 2A.32]

The 415 million hectares of Canadian forests represent 10 percent of the world's forests, with 20 percent of the world's fresh water flowing from its watersheds. Forests cover 45 percent of the land mass of Canada (Lowe et al 1996) although it is unclear whether forest cover in Canada is stable or contracting (CANFI 2004) (INSERT TABLE 2A.5 AND INSERT TABLE 2A.6 HERE)

[Insert TABLE 2A.5]

[Insert TABLE 2A.6]

Forests in Europe have been expanding over the past 40 years by around 0.8 percent p.a., about 880,000 ha per year. This has been mainly due to an increase in plantations, reversion of agric land and decreased harvesting activity especially in the Russian Federation. The Russian Federation accounts for over 90 percent of an estimated 1.5m ha per year natural re-colonization of non-forest land in Europe,(GEO3 2000, Kuusela 1994**,** TBFRA–2000). In 2000, the Russian Federation had by far the largest area of forest cover in the NAE region. The Russian Federation has more than 7 times more forest cover than the European Union and almost double the combined forest area of Canada and the United

States. The Russian Federation also contains the greatest area of natural forest. (UNECE statistical yearbook 2003)

There has been a decrease in other wooded land (OWL – woodlands not dense or contiguous enough to be classified as forest) of approx 0.2 percent p.a. in Europe, similar to that of North America (TBFRA – 2000). Europe (not including Russian Federation) now has forest cover of around 35 percent (FAO statistics), similar to that of the US, after having reached a low of 25 percent during the 19th Century. Europe's total area of exploitable forest is 150 million hectares, out of a total of about 1.04 billion hectares of forest. Since the 1950s, there have been proportionately fewer fellings, when compared to the increasing forest growth and this has made it possible to supply more wood, while simultaneously increasing the growing stock.

Throughout NAE there been a steady increase in both deciduous and coniferous plantations since early in the 20th Century. This is now accelerating as planting technologies have improved and more agricultural land has become available for conversion to forest. There is a distinct trend towards a greater proportion of coniferous wood (now 69 percent in W Europe, 66 percent in CIS) being planted. European plantations make up 17 percent of world plantations with the Russian Federation having the greatest area in Europe. (FAO 2000,TBFRA-2000,UNECE/FAO 2000,) Extensive use of forest plantation is partly responsible for the growth of forest area in NAE. The United States has the highest annual average increase of 388 000 hectares of forest area. (UNECE statistical yearbook 2003)

Overall European and Russian forests sequester around 540 million tons of carbon per year, some 14 percent of the world's total sequestration, with US and Canadian forests sequestering about 200 million tons of carbon per year (UNECE/FAO 2000a) There has been an increasing trend for forests to be planted specifically for carbon sequestration, funded by schemes set up as a response to the Kyoto Protocol. (Bowyer and Ramsetstein 2004, Millennium Ecosystem Assessment 2005)

2A.5.2 Forest ownership and control

Over the past twenty years there has been a strong trend away from public towards private ownership of forests in W and S Europe, but almost all forest land remains in state ownership in the CIS countries and the Russian Federation, although this is changing towards private ownership in former Soviet states now in the EU-25.

[Insert FIGURE 2A.33]

Fifty-seven percent of all U.S. forest land is privately owned. Most of Canada's forests (94 percent) are under public ownership through provincial and territorial jurisdictions. Approximately 10 percent of U.S. forestland (77 million acres) is legally protected from commercial which is more than double that in 1953.

Around 66 percent of U.S. forest land (504 million acres) is classed as timberland, i.e., forest capable of producing in excess of 20 cubic feet per acre per year and not legally withdrawn from timber production. Since 1953 the area of timberland has had a net loss of 1 percent (5 million acres) primarily related to withdrawals of public timberland as reserved forest. Seventy-one percent of U.S. timberland is privately owned.

[Insert FIGURE 2A.34]

[Insert FIGURE 2A.35]

[Insert FIGURE 2A.36]

<u>Forest exploitation</u>

Timber harvests in U.S. National Forests increased 92 percent between 1952 and 1986, followed by an 84 percent decline between 1986 and 2001. In the 1920's, timber growth in the U.S. was about half the rate of harvest. In the 1940's forest growth rates improved and harvest rates declined resulting in timber growth and harvest being approximately equal. Timber growth has exceeded harvest since 1952.

[Insert FIGURE 2A.37]

The net growth rates have not been increasing as rapidly as in the past, while harvest levels have remained relatively stable since 1986 (see Figure 2A.37). Increased imports have addressed the additional resource demands. Additional information on the trends in growing stock harvested for timber products between 1952 and 2002.

[Insert FIGURE 2A.38]

The relationship of growth and removals can be used as an estimate of sustainable production, i.e., more wood growing than being cut implies that levels of wood production and standing volume are sustainable. However, this relationship conveys no information about quality, forest types, size, and other attributes of growth and harvest (Smith et al., 2002). In general, since 1960 the U.S. forest resources have continued to improve in condition and quality as measured by increased average size and volume of trees; however, if quality is measured as a function of optimum stand density, i.e., optimum number of trees per acres for stands of a given age, then the overall quality of many stands has deteriorated (Smith et al., 2002).

Canada is the largest exporter of forest products with total exports valuing $44.1 billion (Natural Resources Canada, Canadian Forest Service, 2000). In 2002, one in 17 jobs (361,300 Canadians) was directly or indirectly linked to forests.

Less than two thirds of the annual forest growth in Europe (excluding Russia) is harvested, so the volume of standing wood in forests is growing. In Russia only 14 percent of annual growth is currently being harvested, less than the proportion being harvested in the 1970s (TBFRA –2000).

The past thirty years have seen an increase in accessibility of forests through construction of new logging access roads into remote areas. Conservation protection legislation has also been applied to many inaccessible areas over the past thirty years. In W Europe over 85 percent of forest is now available for wood supply, in the CIS, where more forest is protected, 64 percent is available for wood supply. (TBFRA-2000)

<u>Biodiversity</u>

In both North America and Europe there has been an overall decrease in forest biodiversity due to reductions in areas of natural forest, illegal felling, increases in monocultural plantations, increases in serious fires and hunting activity in some countries, adverse effects of air pollution, and more urban access into forest areas. GEO3 (2000) reports that around 60 percent of Europe's forests are now degraded by the factors listed above. This degradation trend may be reversing in some more developed countries (UK, Germany, some CIS states) with higher levels of legal protection than the rest of Europe (> 10 percent of area protected) and development of new plantations that alleviate pressure on natural forest. In the NAE region, Canada and the CIS has the highest proportion of forest undisturbed by humans (in Europe 751m ha out of total of 856ma = 88 percent), whereas W Europe has lowest proportion (7 mha out of total of 176mha = 0.04 percent). (data from EUROPA website on forestry).

2A.5.3 Forestry as an industry

Demand for forest products in NAE has dramatically increased since the World War II, especially for industrial wood, with consumption and production more than doubling between 1961 and 2004 (UNECE/FAO 2003b). Demand and production of fuel wood has increased from 1990, and now exceeds 1960s levels, but is still only 20 percent of industrial wood production. This contrasts with world wood production where fuel wood slightly exceeds industrial wood production. There is a slight trend towards increasing the output and consumption of fuel wood in Europe. Wood production in Europe does not meet demand, leading to increases in imports from the 1960s (FAO 2000). In North America, following World War II, there was a rise in demand for timber to build houses and expand cities. There was also a timber supply shift from privately-owned forest lands toward federal lands. "During the 1950's timber harvests on national forests almost tripled, going from about three billion board feet in 1950 to almost 9 billion board feet at the end of the decade" (Williams, 2000).

The forestry industry has steadily grown over the past 50 years from a rural activity supplying urban areas with timber products to a major industry producing a wide range of added value products, especially wood-based boards where Europe is one of the world's major exporters. Nearly 3 million people in Europe gain a livelihood from forestry and forest-based industries. Not only has there been a significant rise in consumption of, and demand for, wood-based products derived from Europe, but there has also been a significant increase in the import of timber, especially fashionable tropical hardwoods, from other parts of the world, especially from Canada, S. America and the Far East. This import market has had an increasing impact on the forests of other continents and is an important factor driving forest loss in those areas. (FAO, Europa, UNECE)

In Europe over the past twenty years there has been a strong trend away from productivity-driven management systems towards more sustainable management aimed at multi-use, especially for leisure activities. This trend started in the more developed countries, driven by public demand, but is now becoming the mainstream paradigm throughout Europe (Hagner 1999). An exception to this trend is that timber production has fallen substantially in large parts of Russian Federation since independence, and forest strategy is still production-driven. European forests are rarely managed on a large-scale clear-fell rotation basis, but 'Plenterwald' labor intensive selective felling is the norm, producing high quality forest structure with sustainable yields.

Trends in forest mortality

Throughout NAE there have been significant increases in serious forest fires, mainly due to climate change and more human access into remote areas (e.g. EU disasters website, USDA Europe website). The Russian Federation has the main problem with up to 7 million hectares affected per year and in Southern Europe about 200,000 ha of forest are burnt annually. Forest fires in the US have continued to grow in size and intensity since 1945, threatening biodiversity and built development, and provoking controversy about how they should be managed (Williams 2000). These fires are a serious threat to biodiversity especially in biodiversity hotspots (e.g. in E Russia and the Mediterranean countries) and to forest productivity. There is likely to be an increase in incidence and severity of fires in next few decades, partly as a result of climate change. Climate change is probably also the driver of an increase in abnormal weather events such as drought and windstorms that have had a severe adverse effect on standing timber stocks throughout Europe, but especially in the West (Drouineau et. al. 2000). The hurricanes of the 1990s felled three years harvest over two days in parts of Western Europe.

Timber mortality from fires, pests, diseases and hurricanes in the U.S. increased in all U.S. regions from 1976 to 2001, but remains below 1 percent, with increases within the range of natural variation (Smith et al., 2002). In Canada, natural forest mortality rate from insects, diseases, and natural thinning varies from 1 to 3 percent. In both North America and Europe, growing global travel and trade has increased risks of introducing non-native organisms into forests, sometimes increasing mortality and reducing biodiversity. Air pollution, including acid rain and ground-level ozone, has damaged certain forest ecosystems in the Eastern United States (USDA-USFS, 1999) and in Central and Eastern Europe (UNECE 2003).

[Insert FIGURE 2A.39]

[Insert FIGURE 2A.40]

2A.5.6 AKST in forestry

Forestry science in Europe has a long history stemming from the late nineteenth century developments in agricultural science in focused on the developed countries especially Germany and the UK. In North America forestry science has developed since the early 20th century, initially modeled on European lines, but is now a distinct research and technology activity focused on specific North American forestry. Since 1945 forestry science has developed into a distinct discipline with increasing funding from state forest services, trade associations and state scientific funding bodies. In W and S Europe the main focus of forestry science has changed recently from the traditional productivist paradigm towards a scientific approach to sustainable multifunctional use, including the conservation of species associated with forests and the impacts of climate change. This trend is also found in parts of North America. Since the classification of American forests into ecoregions in the 1970s and 80s (Bailey, 1980,Bockheim, 1984, McNab and Avers, 1994), there has been a change in forest management away from exploitation for profit towards multifunctional sustainability (Johnson et al. 1999, Bosworth, 2004) focusing on four objectives; watershed health and restoration (USDA-USFS, 1999), sustainable forest management, public access, and recreation. These topics form the framework for most forest research in North America.

Since 1945 many new technologies have been increasingly applied to forest production, harvesting and processing. Increased pesticides use, especially on conifer plantation monocultures, has led to less insect and disease damage to forests. Drainage and ground preparation techniques have been adapted and scaled up from agriculture, resulting in conversion of more open uplands and wetlands to forest. New harvesting technologies have increased harvest rates and result in a higher proportion of felled wood being processed, with less waste. New processing technologies have given higher throughput of sawmills, a wider range of timber products, and better use of fibre products (e.g. for paper with lower environmental impacts) in the more developed countries.

Unlike in agriculture, crop varieties used in plantations for commercial forestry are largely derived from native stocks of trees but not necessarily grown in their native region. Some of these are taken from stands known to grow well in the prevailing conditions and to produce good quality timber. Domestication of trees is still at a very early stage largely because selective breeding is very difficult with plants that have long generation times and that only exhibit desirable traits close to maturity, typically after several decades. Biotechnology and genomic knowledge is beginning to open up the possibility of true domestication of trees, partly by producing varieties with shorter generation times, but mainly through increasing knowledge of the genes responsible for desirable traits.

Even using native tree varieties and labor-intensive forestry systems, foresters in Europe and North America have significantly increased productivity and production per unit area by employing new technologies for ground preparation (better drainage, fertilization, and tree protection using physical and chemical means), planting technology using mechanical planters, improved management of plantations, advanced rapid timber harvesting and extraction machinery, and high throughput processing (for paper, timber, and board production). The European timber industry also makes better use of fibre by-products (for board manufacture, insulation materials, and fuel) than before 1945, when many of these products were simply burnt in the open on site.

Much of this development was initiated from the state forest services, both in terms of funding and technical expertise. State services continue to have a major input into technology development, especially in the CIS countries, but in W and S Europe, forest technologies are dominated by a viable industry that exports machinery and knowledge for timber production and processing worldwide. In common with other manufacturing industries, production of machinery used in forestry and wood processing is increasingly shifting to the Far East, a trend that is set to continue.

The increase in timber production to meet increased demand within NAE was accomplished with the adoption of new machinery. The chainsaw replaced the axe and crosscut saw, gasoline and diesel powered crawler-tractors replaced horses and oxen to move logs in the forests, and the development of a system of roads for logging trucks replaced streams for hauling the logs to the mill. Additional innovations in logging systems were developed to allow for the harvesting of timber on steep mountainous slopes to protect fragile soil resources which included skyline, balloon and helicopter harvest systems. On flatter lands, hydraulic shears were developed that could cut a standing tree. “By the 1960’s, a variety of tractor-mounted shears were in use , with many machines designed not only to cut the trees , but also to remove bark and limbs, cut the tree to the desired length, and stack the log” (Williams, 2000).

Machinery used in all aspects of commercial forestry has increased throughput and scale of the production of timber and other forest products. Throughout NAE much of this development was initiated from the state forest services, both in terms of funding and technical expertise. These services continue to have a major input into technology development, especially in the CIS countries, but in W and E Europe, forest technologies are dominated by a viable industry that exports machinery and knowledge for timber production and processing worldwide. In common with other manufacturing industries, production of machinery used in forestry and wood processing in increasingly shifting to the Far East, a trend that is likely to continue.

Mechanization has significantly increased productivity in forestry in four main areas; ground preparation, planting, harvesting and processing. There have been major increases in production per unit area by employing new technologies for ground preparation (for example providing better drainage). Planting technology has also advanced considerably during the second half of the 20th century using mechanical planters. Similarly, new harvesting machinery have increased harvest rates and have resulted in higher throughput of sawmills, a wider range of timber products, and better use of fibre products (e.g. for paper with lower environmental impacts) in more developed countries. For example, in Sweden the introduction of the chainsaw and mechanization of logging operations resulted in total forest work productivity increasing between 2.3 and 12.5 m^3 per man-day between 160 and 1990 (Axelsson, 1998). Between 1970 and 1990, the degree of mechanization in final fellings increased from 25 percent to 85 percent and in thinning from zero to 60 percent (Frej & Tosterud, 1989).

One of the greatest impacts has been on a reduction in accidents. Forestry is an innately dangerous operation, however, 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 2A.41]

The negative impact has been that the larger scale mechanization has lead to a major decline in the number of forest workers. Another negative consequence is that in systems such as short rotation forestry, soil compaction can be an important issue when considering the mechanization. This can have a particular impact where the crop is harvested in the winter months on wet soils, as can be the case in soils of Northern Europe. In these regions the crops are frequently grown on soil that is saturated during the winter months and soil damage is more likely to be significant (Culshaw & Stokes, 1995)

2A.5.7 Forest institutions

Forest management in the United States and Canada has changed dramatically since 1945. In the United States, the USDA Forest Service (Forest Service) was formally established in 1905. Assisting private forest land owners with management was an early concern for the Forest Service. “By the 1920’s the U.S. Forest Service had twelve regional research stations with branch field (experimental) stations. Congress passed the McSweeney-McNary Act on May 2, 1928, legitimatized the experiment stations, authorized broad-scale forest research, and provided appropriations” (Williams, 2000). “One impetus for forestry research in the United States was the limited applicability of European models to the management of U.S. forests, especially in dealing with the threat that fire posed. European forests simply did not experience the fire danger that U.S. forests did” (Williams, 2000). The US and Canada collaborate over research on forest health, sustainability and soils (Lal et al., 1997; O’Neill et al., 2005, Powers et al., 2005)

These organizational developments are underpinned by many laws and regulations providing funding, strategic and institutional frameworks for forest establishment and management. Today, the US Forest Service administers approximately 194 million acres of forests and grasslands across North America.

Europe has a large number of institutions that underpin the development of forestry as an industry and a social resource (UNECE 2001). There are at least 150 forest research organizations and learned societies in Europe ranging from industry-sponsored research facilities, to academic departments (and entire ‘Forestry Universities’ in the CIS countries), and state-funded research institutions. These include at least 30 State Forest Services in Europe, some of them also responsible for wider land use issues such as agriculture and water resources. They are often powerful and influential organizations, with substantial funding, human and capital resources. Besides the training available through the organizations above, forestry is included in the general higher educational curriculum of many NAE countries, and there are dedicated training establishments for forestry and wood-based processing. Although Europe does not have an umbrella organization for the forestry industry, most countries have a number of associations representing and promoting forestry and wood-based industries. There are at least 24 European trade associations (Europa website 2006). As with agriculture, these organizations have had a powerful impact on national forestry policies and strategies.

There are also several forestry NGOs promoting sustainable use of forests and campaigning for better protection of natural forests. These include consumers of forest products who have also begun to question the ways in which their countries' forests are being managed and exploited. Consumer organizations are increasingly involved in lobbying for more sustainable forestry. This has led to the establishment and expansion of certification schemes throughout NAE, aimed at assuring consumers that the forests from which their products are derived from forests managed according to a published set of management rules and objectives.

Although many forestry societies, state forest services and research organizations were established over 100 years ago, these institutions have developed rapidly over the past 50 years, largely driven by the post-war need to increase timber and paper supplies to an expanding and increasingly wealthy North American and European public. They hold considerable political power and continue to be a key influence on the success of the forestry industry (World Bank 2005). Wood and wood products have been heavily marketed by the forest industry and state forest services as a response to alternatives provided by the plastics and metals industries. In recent years a key marketing tool has been to use the concepts of naturalness and renewability of forest products. If climate change and the use of fossil fuels become important drivers for consumer behavior we may see this trend increasing. The trade associations have played an important role in responding to consumer behavior and have been the prime movers in the trend towards forest certification and sustainable management of forests.

2A.5.8 Drivers of changes in forestry

Markets have always played an important part in forestry production, driven by demand for structural timber for rebuilding NAE infrastructure needed after World War II, meeting demand for increased timber and paper pulp due to an increasing population, and demand for fuel wood that is now increasing after a decline from 1950 to 1980. There has been a steady increase in global demand for wood-based boards used in construction and fitments and this is expected to continue in the 21^{st} century.

State ownership and subsidies have also played an important role in the development of NAE forestry science and technology, especially the increased use of modern soil preparation, planting and harvesting technologies and processing equipment, has enabled the increases in forest output seen in the past fifty years.

Rules and regulations have become increasingly important as drivers of forest management and protection, especially enabled by conservation legislation driven by EU Directives and North American statutes.

Due to increasing NAE human populations and a rise in wealth, from the end of the World War II to the 1980s management objectives were driven by a productivist paradigm, coupled with protection for key natural forest areas, delivered by nature conservation legislation (especially strict in Eastern and Northern Europe). In the 1980s public demand for greater access and use of forests for recreation and leisure has led to a trend towards multi-functional objectives, even for protected areas. This trend started in the US and S & W Europe, but is increasingly being adopted in the CEEC.

In NA, the main drivers of change in forestry have been the decreased demand for conversion of forestland to agriculture; increased demand and market pressures in North America and globally for wood and wood products; increased emphasis on non-timber products of forests, e.g., wildlife, range, water, outdoor recreation; and the increased recognition of the role of forests in climate change and protecting biodiversity.

<u>European Forests and Livelihoods</u>

Within the EU-15 area, some 2.7 million people are employed in forestry and forest-based industries such as woodworking, the cork industry, pulp and paper manufacture and board production. The industry produces an annual value of at least EUR 335 billion (UNECE/FAO 2003a, EU EUROPA website). The

EU is one of the world's largest traders and consumers of forest products, with a net income in this sector. The EU also imports large quantities of forest products, primarily roundwood from the Russian Federation and wood pulp from the Americas, where higher growth and lower production costs make forest products from this region very competitive. The EU excels in the production of high value wood products such as boards, cork and specialist papers and is a key exporter in this sector. (Bowyer and Rametsteiner 2004, EU EUROPA website)

At least 12 million people own forest holdings within the EU-15, mostly small scale owners with an average holding of 13ha, with most owning around 3ha, contrasting with the average area of 1,000ha for public holdings. Private owners occupy around 65 percent of Europe's forested land. Since enlargement of the EU large areas of previously state-owned forest holdings have been restored to private ownership. There is an increasing trend for private owners to supplement their incomes from urban-based incomes, with less dependence on income from forestry. (EU EUROPA website)

European forests are also economically and socially important because, besides providing the wood for industry, they also provide services such as leisure use (tourism, general recreation and hunting) and provide casual income for rural people from collecting valuable products such as fungi, berries and nuts. In Europe forests give many communities and individuals a strong sense of identity that is deeply ingrained in culture and societal values in many parts of Europe (e.g. rights to fuelwood, hunting, and the collection of forest foods).

2A.5.9 Summary of trends in NAE forestry

NAE is the only world region where forest cover is increasing. Total U.S. forestland remained relatively stable from 1880 to 1980 despite significant regional changes, but is now increasing by about 0.3 percent p.a. European forests are increasing in area at a faster rate of 0.8 percent. Indeed, timber growth in North America and Europe has exceeded harvest since the 1950s

Throughout NAE there been a steady increase in both deciduous and coniferous plantations since early in the 20th Century. Timber productivity has increased since 1945 to meet increased demand, but NAE continues to import large quantities of wood, including hardwoods from tropical forests. This has been partly responsible for reductions in cover and quality of forests in other world regions.

Since 1945 there has been a shift from private to state forest ownership in the US. This trend was also apparent in Europe, but here ownership is increasingly being privatized.

Forestry research and development has increased significantly since 1945. Technologies, especially mechanization, have been developed to achieve faster and more efficient harvests and to access and harvest timber in areas previously considered too fragile for harvest

Across NAE, there has been an overall decrease in forest biodiversity. However, 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. Forest management for multifunctionality is an increasing trend in Europe, with the exception of Russia where productivity is still the key driver of management.

Forestry institutions have developed rapidly, including the development of rules and regulations governing forestry and forest products.

Forestry management continues to provide livelihoods and a cultural focus for large numbers of people in NAE, and the forestry product industry has grown rapidly to accommodate increased demand for timber and other forestry-derived products.

2A.6 Changes in Aquaculture Production

2A.6.1 North American aquaculture

It is useful to divide aquaculture into two distinct types, freshwater and salt water. Figures 2A.42, 2A.43, 2A.44 and 2A.45 show the production of the major aquaculture species in North America. (Note the different scale for catfish in Figure 2A.42.) As a whole, Canadian aquaculture between 1986 and 2004 has grown at an annual rate of 20 percent.

[Insert FIGURE 2A.42]

[Insert FIGURE 2A.43]

[Insert FIGURE 2A.44]

[Insert FIGURE 2A.45]

In the U.S. modest amounts of fresh water aquaculture, dominated by catfish culture, have been practiced since at least the 1940s. In 2003, there were some 300 metric tons of catfish grown, representing 71 percent of all U.S. aquaculture, fresh and salt water by weight (NMFS, 2005) The rest is trout, talipia, crawfish and baitfish. Canadian freshwater aquaculture consists primarily of the rainbow trout and secondarily brook trout (Figure 2A.44).

In Canada, the major aquaculture crop is salmon. The majority of the cultured salmon, 55 to 60 percent, is exported to the United States, with the other two largest export markets, Japan and Taiwan, each representing less than 2 percent of production. Steelhead trout is the other seawater finfish aquaculture, but is produced in much lower amounts (Figure 2A.44). Through the late 1980s and 1900s there was a rapid expansion of clam and especially mussel aquaculture such that mussel is now the major shellfish aquaculture product by weight and by value (Figure 2A.45).

By contrast, before the 1990's U.S. salt water aquaculture was dominated by oyster culture. However, starting in the mid 1980s and continuing through the 1990s there has been a very large expansion of salmon aquaculture to become the dominant salt water product. Although, salmon is the currently largest salt-water aquaculture harvest by weight, the dollar value of oyster production ($63 million in 2003) is greater than that of salmon ($54 million).

Aquaculture products are growing in importance in both the U.S. and Canada, although they are less than 15 percent of wild fishery landings. (Aquaculture, totaling 420,169 metric tons in 2003, represented about 10 percent of U.S. wild fishery landings which were 4,312,000 metric tons. The total Canadian commercial landings of wild fisheries in 2004 were 1,071,182 metric tons, while aquaculture production was 145,840 metric tons, or 13.6 percent of the wild harvest. However, the opposite is true for salmon in Canada where the wild fishery landed just over 25 percent of aquaculture production, 25,613 MT in 2004 versus nearly 100,000 MT.) Further the U.S. is a net importer of seafood primarily from Asia.

2A.6.2 European aquaculture

The aquaculture sector in Europe has a very diverse production, processing and marketing structure, ranging from small traditional enterprises, through medium sized family fish farms, to the large-scale intensive businesses dominated by multinational companies (Varadi et. al. 2001, Varadi et.al. 2001, Fédération Européenne de Salmoniculture, 1990, MacAlister Elliott and Partners Ltd. 1999). Although there are structural differences between aquaculture sectors in different European regions, markets are now the determining factors of success and therefore the major driver in the aquaculture business with consumer demands, international competitiveness, health and environment issues and product quality all driving demand and price (Stirling Aquaculture 1996a, 1996b).

The total output from European aquaculture has increased steadily since 1945 (Tacon 1997). From the 1960s to the present the broad pattern of aquaculture development has been (data and trends from FAO 1996, FAO 2000, Eurostat website, Tacon and Barg 1998):

- High growth in Northern Europe and medium growth in Western Europe fuelled by the development of salmonid mariculture ,

- Low growth in Southern Europe with a focus on mariculture of sea fish
- Decline in Central-Eastern Europe due to general post-transition economic decline and changing consumer habits (Staykov, 1994; Szczerbowski, 1996).

Increases in the production of finfish and molluscs have almost always led to value reduction as the price falls. This has become a serious issue for the viability of salmonid farming in Northern and Western Europe, where ex-farm prices have dropped from 3.5 Euro/kg in 1997 to 2.4 Euro/kg in 2005. In Southern Europe the value of farmed sea fish has remained relatively steady. Overall production increases in European aquaculture have slightly outpaced falls in price per kilogram of fish, leading to an increase in total value from 3.4 MEuro in 1999 to 3.9 MEuro in 2005.

Subsidies from the EU have contributed to the development of the salmonid sector, but withdrawal of state support in Central and Eastern Europe may have contributed to the decline in cyprinid production. Other challenges for aquaculture include increasing concern from the public and from governments about the quality of fish produced in intensive systems and about the environmental impacts of fish farming, and the competition for resources such as high quality water, high protein feed based on fish meal, and labor.

<u>Freshwater production</u>

Freshwater production has grown since 1945, but remained almost static in the 1980s, largely because output from the CIS countries and Russia declined (FAO 1996). Increased fish consumption is expected, especially in Central-Eastern Europe, where per capita fish consumption still remains far below that of the EU-15 (Tacon 1997). Overall production from freshwater aquaculture is now increasing, albeit at a much slower rate than production from saltwater (FAO 1996).

<u>Saltwater production</u>

Aquaculture in saltwater has seen a spectacular rise in output since the mid 1970s, when farming salmon in sea cages began to develop in Norway, Scotland and Ireland. Salmonid finfish production now dominates the saltwater sector, overtaking mollusc production in 1995. The success of increasing output from the salmon industry has been tempered by a collapse in prices in the early 1990s, in turn leading to government intervention such as the destruction of smolts and feed quota systems introduced in Norway in the mid 1990s (Anon. 1996). Besides salmonid production, other higher value species of saltwater finfish such as bass, turbot, sea bream, cod and halibut are now being intensively farmed in European seas, lagoons and purpose built tanks in coastal waters of the warmer southern European countries such as Greece, Italy, and Spain (Tacon 1997). The industry is still developing from a low base in the 1980s but production has risen rapidly, with for example sea bream and bass production growing annually by over 40 percent (315 tons to 17,000 tons) from 1984 to 1995 (FAO 2000, FAO FISHPLUS website, Eurostat). Production rose to 120,000 tons in 2001, most of which was exported from Greece to Italy and Spain, but the market for these fish has now expanded to other European countries.

The main finfish species groups cultivated in the region are salmon and rainbow trout, with total annual production of almost a million tons (around 85 percent of total farmed finfish production) (Eurostat & FAO). Salmonids freshwater cyprinids (mostly carp and eels) constitute the second major finfish species group cultivated in the region (around 12 percent of total farmed finfish production (ref)). (Varadi and Jeney. 1994). (Voronin and Gavrilov 1990, Dushkina 1994, Zaitsev 1996). Production of mussels and oysters and other molluscs is still a major part of total aquaculture output in Europe. There has been a slow decline in output of molluscs since the mid 1980s driven by a combination of disease problems (Figueras et.al.1997), changing consumer habits and competition from other aquaculture sectors. Europe is the leading world producer of farmed turbot (100 percent), eels (99 percent), mussels (70 percent), sea bass and bream (68 percent), salmon (60 percent) and trout (54 percent).

From a low base at the end of World War II, European mollusc production increased rapidly until the 1970s since when output has remained relatively static, with some evidence for a decline of about 4 percent in the past twenty years. Blue Mussel production in France illustrates this trend with output at 8,500 tons in 1950 rising to 47,000 tons in 1977, a level that is the average maintained since then (FAO FISHPLUS website). Mussels remain the dominant species in this sector (60 percent of total output), with oysters making up around 25 percent output and several species of clams the rest. The main mollusc production regions are in France (35 percent of total), Italy (26 percent), Spain (17 percent) and the Netherlands (13 percent). Mollusc production makes up around 25 percent of the total monetary value of aquaculture in Europe (Tacon 1997, FAO 2000).

<u>Institutions in aquaculture production in Europe</u>

National organizations representing the aquaculture industry have grown rapidly since the 1960s in the Northwestern European countries, handling policy, advice, marketing and research. Some of these, like the Fiskeoppdretternes Salgslag in Norway are effectively production and marketing monopolies, but most others are NGOs independent of the industry. For producers there is a European wide organization, the Federation of European Aquaculture Producers (FEAP), representing all national associations at EU level. In most Eastern European countries, aquaculture is usually organized and advised by the Ministries of Agriculture and Food, with the exception of the USSR where it is in a separate Ministry of Fisheries. This state intervention is rapidly changing as private companies are beginning to gain market share within the Central and Eastern parts of EU-25.

Public investment in fish farming has been, and still is, a major factor in the development of European aquaculture. In Central and Eastern Europe, public funding has come via state intervention, whereas in other parts of Europe, state and EU subsidies and development programs have played a significant role in developing both the fresh and saltwater aquaculture industries. Thus, although policy has historically been a driver of aquaculture development, state intervention is declining and markets are becoming more important drivers.

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 opf aquaculture products. There is a trend towards stricter regulation and monitoring that adversely affects small family-owned enterprises (Varadi et al 2001).

2A.6.3 Science and technology in aquaculture

Since 1945 major breakthroughs have been made in fish farming techniques, including:

- The intensive hatching and rearing of sea fish in the southern countries
- Control of density dependent fungal and bacterial diseases in finfish
- Techniques for rearing salmonids in salt water
- The development of fish food processing and supply, including better formulation, the development of specialized feed, and automatic feeding

These developments have enabled the spectacular increases in production seen in Europe over the past thirty years, especially in farmed salmonid and sea fish output (FAO 2000). Most of this research and development has focused on high value finfish production, with far less work being done on mollusc and carp production, where production is mostly from units using traditional methods developed over centuries.

However, now research in aquaculture has changed to helping production systems address environmental issues including:

- 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

2A.6.4 Summary of key changes in aquaculture

Aquaculture, while practiced for centuries across NAE, has grown in importance since the 1940s, in most parts of the region except for Central and Eastern Europe. In Canada, for example, the industry is growing at 20 percent per year. There have been very large increases in aquaculture – both freshwater and saltwater – across NAE, propelled in part by explosive growth in salmon production. Despite this growth, North American aquaculture represents 15 percent or less of wild fishery landings by weight.

In the U.S., salmon has overtaken oysters as the major saltwater aquaculture and is the most important aquaculture crop in Canada. Salmon production is very important in Northern Europe, fuelled by good prices in the 1970s and 1980s. However, by the late 1990s, prices had dropped precipitously.

Due to developments in AKST, intensive rearing methods came to dominate aquaculture production. These production systems required the development of specialized feeds, and control of fungal and bacterial diseases. Increases in salmon production were possible because of new techniques for saltwater production. However, the environmental impacts of these intensive production systems has caused aquaculture research to shift to addressing pollution concerns, pesticide residues and impacts on ecosystems.

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