WORKING PAPER

FUTURE LAND USE PATTERNS IN EUROPE

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IIASA
International Institute for Applied Systems Analysis

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FOREWORD

One of the objectives of IIASA's Study *The Future Environments for Europe: Some Implications of Alternative Development Paths* is to characterize the broad-scale and long-term environmental transformations that could be associated with plausible scenarios of Europe's socio-economic development over the next century. Special attention is being given to a few low-probability, high-impact transformations. The future development of European land use is one of the key issues.

The present Working Paper contributes to the discussion of future land use patterns. Changes in technologies and environmental transformations such as climatic change are vital factors for future land use patterns. The paper has been prepared as an input to IIASA's Workshop on *Land Use Changes in Europe: Processes of Change, Environmental Transformations and Future Patterns*, to be held in Warsaw, September 5-9, 1988.

R.E. Munn
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ABSTRACT

The objective of the paper is to focus on a set of 'not-impossible' but still plausible land use patterns in Europe until the middle of the next century. Changes in technologies and environmental transformations are vital determinants for future land use patterns that are taken into account. The paper therefore makes an assessment of the following:

- a Conventional Wisdom scenario for agriculture covering the period 1980-2030. This scenario is based on the consideration that present trends of increasing yields in European agriculture are extrapolated.
- a scenario for changing land use patterns for the period 1980-2030, considering various trends in the application of new technologies (i.e., a scenario that is based on a rapid increase in land productivity, and a scenario to improve the marginal land, and which is based on the adaptation to poor local environmental conditions).
- a scenario for changing land use patterns that is based on a change in climate. Two scenarios of climate change are included here: (i) for the year 2030 that is based on an analysis of historical analogues, and (ii) for the year 2050 that is based on a general circulation model.

ACKNOWLEDGEMENT

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This paper is a contribution to IIASA's Study on the *Future Environments for Europe: some Implications of Alternative Development Paths*, which is supported by the Netherlands' Ministry of Housing, Physical Planning and Environment, and the French Ministry of the Environment.

Future land use patterns in Europe

F.M. Brouwer and M.J. Chadwick

1. *INTRODUCTION*

Land is a key resource for most socio-economic activities (agriculture, wood production, industry, recreation) and infrastructure (settlements, transportation and communication networks), and a vital component of natural ecosystems (such as forests). The use of land is characterized by large transformations over time (see for example Wolman and Fournier, 1987 for a state-of-the-art view on the availability of land for agriculture, as well as the quality of the land that is required to produce food and fiber, and including the major kinds of land transformations in agriculture). The transformation of European land results from a complex set of interactions. The most important include:

(a) *socio-economic and historical changes*, such as in land ownership and tenure, population growth, urbanization, industrialization, development of technology, the establishment of transportation and communication networks. Grigg (1987) describes the constant modification of the environment by human interference to facilitate the production of crops and livestock;

(b) *political decisions*, such as subsidies and taxes for using the land. In addition, decisions like the Corn Laws of Britain in 1846 also determined land use patterns, since they made it easier for overseas producers to sell wheat in that country. A more recent example of policy decisions being important for land use patterns is the Common Agricultural Policy (CAP) in the European Economic Communities (EEC), which was established in 1957 to achieve among others, an increasing level of self-sufficiency in food consumption, and an equilibrium in the markets of agricultural products (see EC Commission, 1985), and

(c) *environmental conditions*, particularly climatic factors and soil quality.

Large areas of European agricultural land have been transformed over the past few decades to land that is being used for non-agricultural purposes, mainly for development of infrastructure and communication, urban areas, industries and recreation (arable land has decreased over the past 30 years by about 6 million ha). The land transformed over this period was larger than at any previous time, and it has been commented that "at the prevailing rates of land conversion, the whole of Britain would be covered by bricks, mortar and asphalt by the twenty-first century" (Hill, 1986, p. 30). While the changes in European infrastructure and land-use were greater than in any previous century, society has also shown a flexibility in adapting to and incorporating such transformations. This flexibility is reflected by the fact that the total European population living in urban areas increased both in absolute and relative terms, while agricultural production also rose. However, human development now requires an alternative view of land management. In the past Man was able to cultivate rural areas, establish new settlements and industries, and move to other places when these areas became degraded (from mining, waste disposal, or by over-exploitation of agricultural land). But land is now becoming a critical factor in the establishment of new activities, as a more closed and interdependent system of socio-economic activities and environmental constraints has developed. A long-term and broad-scale perspective on the interface between socio-economic and technological changes, environmental transformations and land-use patterns is therefore required. An integrated approach to long-term land-use planning is also increasingly becoming evident as conflicts arise due to the constraints imposed by natural environmental features, and these act to limit our social responses and degrees of freedom of action.

A long-term and broad-scale view of land use changes is essential when environmental transformations (such as global climatic changes) and the impacts of new technologies become evident. Clark and Munn (1986) have recently outlined the extent to which long-term and extensive societal transformations may predicate significant changes in many environmental spheres. An investigation of future land use patterns, notably one that examines possible strategies for future sustainable development, involves the following considerations:

- *time perspective* - this should be long enough to foresee interactions between environmental transformations and socio-economic development;
- *spatial scale* - this should (i) be sufficiently broad to incorporate large scale transformations in the environment, and (ii) enable a linkage between causes, consequences and management of human development at the local, regional and global scale;

- *flexibility and resilience* - such that options should be kept open for long-term alternative development and for adaptation to environmental transformations;
- *significant change* - this should be incorporated since the use of land cannot be sustained under static conditions, but is ".. rather a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are made consistent with future as well as present needs .. " (WCED, 1987);
- *technological innovation* - this should be characterized with a focus on how it would modify the environmental consequences of socio-economic development;
- *allocation and renewability* of resources.

This paper focuses on 'not-impossible' future land use patterns in Europe. They are associated with a few plausible long-term and large-scale transformations in technological innovations and in the environment over the next century. The time horizon includes the period until the middle of the next century to allow the incorporation of the concept of sustainability.

The present land use patterns in Europe and the changing role of anthropogenic and environmental factors which determine changes in such patterns, will first be discussed in Section 2. A so-called Conventional Wisdom scenario for agricultural and land-use development from 1980 to 2030 will also be discussed. The Conventional Wisdom scenario considers extrapolation of present trends in agricultural productivity, but impacts on agriculture and land use from the application of new technologies are not incorporated. Development in technology and transformations in the environment are vital determinants of future land use patterns. The role of new technologies in future land use patterns, notably information technology and biotechnology, will be discussed in Section 3, and some scenarios for agricultural and land use development are presented. Some 'not-impossible' future changes in climate and soils, and how these might influence future land use patterns, is discussed in Section 4.

Such 'not-impossible' environmental transformations and technological trends might have a low-probability of occurrence, although they would certainly have a large impact on society. This will be further explored in Section 5 in the framework of future land use changes in Europe.

2. *LAND USE PATTERNS IN EUROPE: PRESENT SITUATION AND A CONVENTIONAL WISDOM SCENARIO*

The current land use distribution in Europe is summarized in Table 1. Europe has been subdivided into five regions. The table has four main land use categories: (i) arable land for growing annual crops and land under permanent crops, (ii) permanent meadows and pastures for growing forage crops, (iii) forests and woodland, which is land under natural or planted stands of trees, and (iv) 'other' land. The last category includes land that is being used for settlements, transportation and communication networks, recreation, industry, as well as unproductive land (from contamination in former times by open-cast mining, waste disposal, or intensive agricultural use).

Table 1. Land use distribution in Europe during the 1980's in million ha (source: FAO production yearbook, 1984; data for the European part of the U.S.S.R. are from Alayev et al., 1987).

region	arable	pasture	forest	other	total
Nordic (1)	6.2	0.9	58.1	37.3	102.5
EEC-9 (2)	50.7	40.9	32.3	26.6	150.5
Central (3)	1.9	3.6	4.3	2.5	12.3
South (4)	36.5	23.4	32.5	8.1	100.5
East (5)	237.0	117.0	168.0	39.0	561.0
Europe	332.3	185.5	295.3	113.6	926.7

(1) Finland, Norway and Sweden;

(2) Belgium/Luxembourg, Denmark, France, Germany, F.R., Ireland, Italy, The Netherlands and United Kingdom;

(3) Austria and Switzerland;

(4) Albania, Greece, Portugal, Spain and Yugoslavia;

(5) Bulgaria, Czechoslovakia, G.D.R., Hungary, Poland, Romania and the European part of the USSR.

The percentage distribution of the four land use categories is depicted in Figure 1.

The Nordic countries cover about 10% of the European land area, and have large wooded areas, such that they include about 20% of European forests. About 60% of the EEC-9 are covered with cultivated land that is used for agricultural purposes. The central part of Europe includes much of the mountain areas, which are largely covered with pastures and forests. Eastern Europe includes the centrally planned economies, with arable land for growing crops covering about 40% of the total land area.

A substantial part of the total land area in Europe is devoted to agriculture and forestry. The total coverage of arable land, pasture land and forests is around 90% (Figure 1). A wide variation exists over Europe and there are many factors contributing to

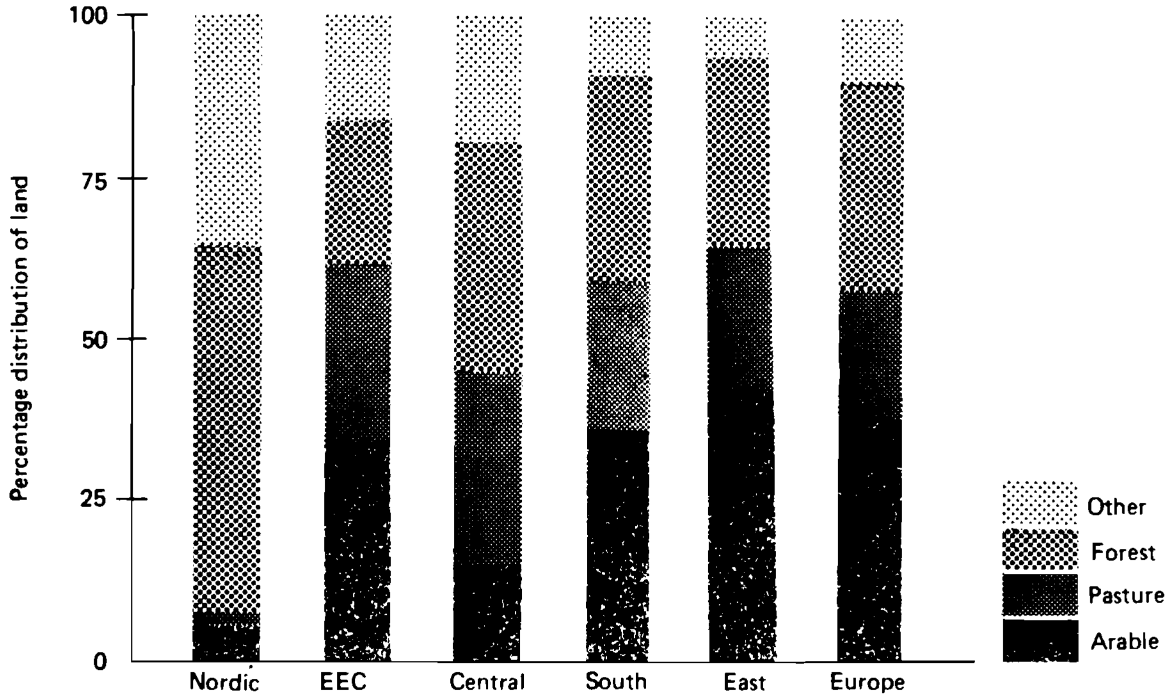

Figure 1. Percentage distribution of land use categories in Europe.

this. Environmental factors such as climatic and soil conditions are one set of determinants; another set of factors are the combination of socio-economic, political, historical and technological factors (and these might change in a relatively short period of time). These factors not only determine the way in which the land is used but also the productivity of cultivated and forest land.

The post-war period of agricultural development in Europe is mainly characterized by steadily increasing yields (productivity per unit area) (both in absolute and relative terms), improved crop varieties, a better understanding of crop physiology, larger farms, an increasing use of chemical fertilizers and pesticides, and also by the replacement of labor by machinery and capital. The relative increases in agricultural production were large in Europe during this period amounting to about 70 kg/ha/year for wheat in the original nine countries of the EEC (De Wit et al., 1987), and about 50 kg/ha/year for wheat in the Eastern part of Europe (Wong, 1986).

Some of the major changes since 1950 of inputs of machinery, chemical fertilizers and irrigation in Europe are summarized in Table 2.

Table 2. Some major input characteristics of European agriculture between 1950 and 1980 (not including the European part of the USSR) (source: various FAO production yearbooks).

type	unit	1950	1960	1970	1980
machinery	1,000 tractors	1,050	3,764	6,169	8,465
fertilizer(NPK)	1,000 tonne	8,000	13,000	24,900	32,800
irrigation	1,000 ha	n.a.	6,000	10,794	14,452

Machinery increased largely to replace labor. The application of chemical fertilizers (mainly nitrogen, phosphorus and potassium) contributed to a large extent to the increasing productivity of arable land (Olson, 1987). The total extent of irrigated agricultural land more than doubled, to improve productivity (especially in countries like Bulgaria, France, Italy, Romania and Spain). Irrigation may transform the land through the construction of canal networks and through the change in the water and salt balance of the cultivated land (Shannon, 1987).

The present situation of agricultural productivity in Europe can be characterized by (i) overproduction in relation to markets, (ii) considerable difference in productivity over the continent, and (iii) different potentials for increases in productivity under present technological conditions:

(i) One of the original purposes of the Common Agricultural Policy (CAP), namely to increase the level of self-sufficiency in the EEC, was a driving force for various transformations in European agriculture (larger farms, improvements in efficiency), which have resulted since 1980 in an overproduction in many products (cereal crops, milk). An example may be found in the total domestic consumption of cereals around 1965, which was about 20 million tonnes larger than the total production levels. This trend has changed such that after 1980 the domestic consumption has increasingly exceeded by production of arable crops (Porceddu, 1986).

(ii) While there is an overproduction of various cereal crops, agricultural land productivity also shows a wide variation in Europe. In the EEC for example, about 50% of the total wheat production is produced on about 25% of the total wheat acreage (Strijker and De Veer, 1986). The average wheat yields during the early 1980's were about 3 tonne/ha in Greece, Italy and Spain, while it was over 7 tonne/ha in Denmark, The Netherlands and United Kingdom.

(iii) The productivity of agricultural land could further grow, since the present levels of agricultural production in Europe are still below potential. The potential land productivity, based on climatic and soil conditions of the area and including water and soil constraints, was still above the attained value, even for a country like The Netherlands (De Wit et al., 1987). The production potential can be constrained by biophysical factors (climate and soils), but also by socio-economic factors (location, transportation facilities, level of return on investments), or social conditions (availability of educational facilities, age structure and managerial skills of the farming population). The different productivity levels of agricultural land can be evaluated by distinguishing between core and marginal land, such that marginality of land is based on land that has achieved absolute and relative limits with present technologies (Beattie et al., 1981).

Large areas of European agricultural land are likely to be taken out of production over the next decades for the reasons described, the more so when technological improvements in society and environmental transformations are also taken into account. In a country like Britain, 6 million ha of agricultural land could be taken out of production, when all currently available techniques to improve yields are implemented (Milne, 1987). The present agricultural surpluses in the EEC corresponds to an area of some 9 million ha (Lewis, 1987). The landscape of Europe could therefore change drastically in a period between the 1980's and the middle of the next century.

The key questions to be considered with respect to such land-use policies are among others, what land will be set-aside from agriculture (which is important for the socio-economic structure and living conditions of a region, because agriculture is the major activity of most of the rural areas) and to what alternative use will this land be put (such as use for recreation, nature conservation, forests to grow biomass energy, wood production and cottage industry).

It was already mentioned that an investigation of future land use patterns involves the consideration of significant changes over a long time period, and covering a broad-scale. The changes will be described here in terms of scenarios for future land use patterns. A Conventional Wisdom scenario for agricultural development from 1980 to 2030 is presented in Table 3, being an extrapolation of present trends. The scenario up to 2000 considers an annual increase in productivity of 1% for cereal crops. The scenario also considers an annual increase in productivity of 0.5% for the period 2000-2030. These cereal crops cover the major arable crops. Table 3 shows the actual and projected land (in million ha), total production (in million tonnes), and yield (in tonne/ha) for various regions for such a Conventional Wisdom scenario.

Table 3. Conventional Wisdom scenario for agriculture for the period 1980-2030.

	1980			2000			2030		
region	land	prod.	yield	land	prod.	yield	land	prod.	yield
Nordic	3	10	3.3	2	9	4.5	2	10	5.0
EEC-9	27	120	4.5	18	98	5.4	13	82	6.3
Central	1	5	4.5	1	6	5.5	1	6	5.8
South	15	42	2.8	14	46	3.3	11	44	4.0
East	84	189	2.3	68	200	3.0	60	216	3.6
Europe	130	366	2.8	103	359	3.5	87	378	4.2

In total some 40 million ha of arable land might be taken out of production as the present trends of increasing land productivity continue. This corresponds to about 35% of the present land used for growing cereal crops. The largest decrease in land used for agriculture is for the EEC, such that about 50% of the land might be set-aside for non-agricultural purposes.

In the following, we shall describe a 'not-impossible' transformation in technology, and how this might affect the use of land, and also assess the possible linkages between environmental transformations and land use changes - notably a change in climate and soils.

3. *NEW TECHNOLOGIES AND CHANGING LAND USE PATTERNS*

It has been pointed out that it is not only environmental changes, but also social, economic and technological factors that result in the transformation of land use patterns. The present land use distribution is the result of structural changes in the European agricultural industry, changing technologies and the demographic transitions resulting from urbanization. Rapid advances in new technologies, notably biotechnology and information technology, may particularly lead to further unexpected transformations in European land use within the next decades. A recent report (OTA, 1985) gives projections for production growth for the period until the year 2000, both under present technological conditions and under a wide application of new technologies for American agriculture. The annual growth rate of wheat, now about 1%, might grow to over 2% when further new technologies are applied in agriculture. Although this report summarizes the agricultural position of the USA, the future trends for technology described may also be applied to European agricultural development in the next 10 to 20 years. Such developments may, for example, result in a conservation of land because of land being set-aside from agriculture owing to increased productivity.

Biotechnology will lead to the emergence of new products (i) to control disease by breeding crops resistant to pests and diseases, (ii) to produce cultivars for harsh environments (e.g., salty soils and poor climatic conditions), and (iii) to produce cultivars with altered nutritional requirements. The breeding of plants that are resistant to diseases or certain pests could result in a considerable reduction in the use of insecticides and herbicides. In addition, the improvements in biotechnology may result in growing crops that are able to use atmospheric nitrogen and therefore require less chemical fertilizers (Arntzen, 1984; Nielsen, 1986). This would provide opportunities to diminish the nitrate pollution of water and air. However, when pest-resistant crops are applied on a large scale, and cheap herbicides are available, these may transform the cultivated land in such a way that it is not possible to grow anything else (Von Weizsäcker, 1986).

The role of biotechnology producing biomass for energy purposes and the alteration of land use patterns in Western Europe is assessed by Lewis (1986). By the year 2000, a maximum of 1.2 Exajoule net biomass energy could be produced each year in the EEC-9, requiring about 7 million ha of land previously used for agriculture or forests. The total production of biomass energy in Europe might double by the year 2000 when methanol fuel will be produced from cultivated crop land in Norway, Sweden, Portugal, Spain and Greece.

Information technology is the application and integration of computers and electronics into farm management. A wide application of available information technology (microcomputers and software) at the farm level may improve the management of pests. The application of information technology may decentralize production, and also conserve energy and material through an efficiency improvement in the way of using agricultural inputs (Von Weizsäcker, 1986).

The potential impacts of the application of new technologies for future land use patterns may be summarized as:

(a) *an increase in productivity*, which can be as large as some 50%. The wheat production in countries such as The Netherlands, France and United Kingdom is presently between 6 and 8 tonne/ha, which might increase to some 12 tonne/ha. Such an increase in productivity may result in a further reduction of agricultural land when compared to the Conventional Wisdom scenario;

(b) *adaptation to poor local conditions*, such as soils, water and climate. The productivity of marginal land can be improved through the possibility of growing crops on harsh environments (e.g., land affected by salts or drought). This can be incorporated in a land-use policy to improve the marginal land and to maintain the socio-economic structure of rural areas, but it would further aggravate the current problem of agricultural surpluses;

(c) *improvement of the environment*, through the application of among others, nitrogen fixation, integrated pest management or recycling of agricultural waste. The application of integrated farming to control pests and diseases by the development of biological control methods and the reduction of pesticide use may result in a decrease of physical productivity, although the economic yields may still increase owing to a decrease in input of fertilizers and pesticides (Bal and Van Lenteren, 1987). This approach can be promising in the highly productive agricultural land of Europe. About 90% of the present total use of pesticides is obsolete, and its abandonment would require a transformation of chemical farming to a more biological-oriented farming practice;

(d) *unexpected risks of biotechnology*, which may transform the cultivated land so it becomes impossible to grow anything else than those man-made, high-technology, crops;

(e) *increasing monoculture*, through a wide application of clones. This will affect the diversity of landscape in rural areas.

Figures 2 and 3 successively show some trends for land use and yield of cereal crops, considering different developments in the application of new technologies in agriculture. Two scenarios of technological development are presented, one that is based on an *increase in productivity*, and another one being based on the *adaptation to poor local conditions*. The results of the Conventional Wisdom scenario, as described in Section 2, are also given to show the order and magnitude of changes.

The scenario which is based on an increase in productivity owing to the application of new technologies shows an increase in yield, which reaches a level of about 50% above the Conventional Wisdom scenario. In addition, it will result in a decreasing use of agricultural land when compared to the Conventional Wisdom scenario. On the other hand, the scenario which is based on an adaptation to poor local environmental conditions, shows an increase in yields which however remains less than the increasing trend in the Conventional Wisdom scenario, while the total land cover that is set-aside from agriculture could be less than in the other scenarios.

To summarize, the application of new technologies could result in different trends of European land use patterns, when compared to the Conventional Wisdom scenario for the period 1980-2030. A further increase in productivity will result into a further increase in the amount of land set-aside from agriculture, but a land use policy focussing on an adap-

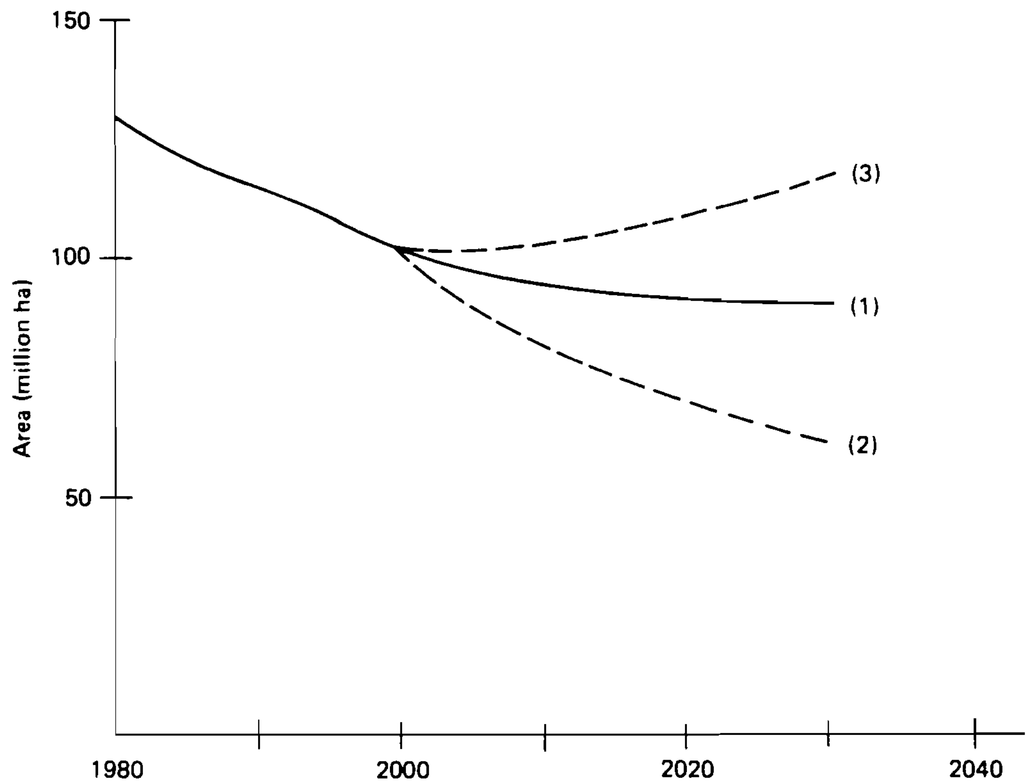

Figure 2. Agricultural scenarios for Europe to the year 2030: land utilized for agriculture (1 = Conventional Wisdom; 2 = increase in productivity; 3 = adaptation to poor local conditions).

tation to poor local environmental conditions could result in an increase in the land coverage for agriculture compared to the Conventional Wisdom scenario. In the following section, we will assess the possible linkages between environmental transformations over the next decades and land use changes.

4. *CLIMATE CHANGE AND SOIL DEGRADATION IN RELATION TO CHANGING LAND USE PATTERNS*

4.1. *Introduction*

Temperature and precipitation are important factors determining natural as well as managed vegetation. Water availability, for example, is a major limiting factor for crop growth and forest production, and about 80% of the consumed fresh water on the globe is now being used agriculturally (Pimentel, 1986). Where rainfall is inadequate, water can be supplied to crops by irrigation.

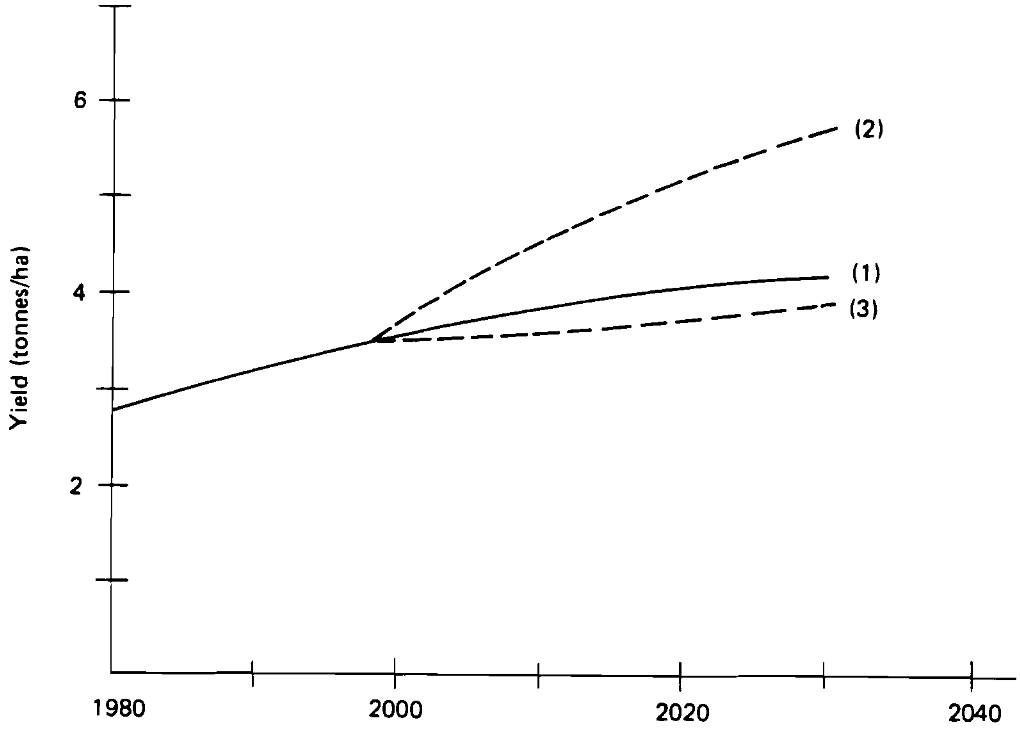

Figure 3. Agricultural scenarios for Europe to the year 2030: yields of cereal crops (1 = Conventional Wisdom; 2 = increase in productivity; 3 = adaptation to poor local conditions).

The present climatic conditions in Europe are summarized in Table 4. It shows mean annual precipitation (in mm), the seasons of the year with maximum and minimum precipitation, mean annual temperature (in °C) as well as the averages for January and July temperature.

Large parts of Europe (including Western Europe, Nordic countries and the central part of Europe) are characterized by relatively large amounts of rainfall during Summer or Autumn, and minimum rainfall during Spring and Winter period. On the other hand, Mediterranean climate is mainly characterized by maximum rainfall in Autumn or Winter period, with minimum amounts during the Summer period. The average January temperature in this part of Europe is over $5^o C$ with only occasional occurrence of frost, while the monthly average July temperature is over $20^o C$. Figures 4 and 5 show the distribution of mean annual temperature and precipitation over Europe.

Table 4. Climatic conditions in Europe (data from weather stations are based on averages for a thirty years period from 1931-1960, and are from Müller, 1982).

country	precipitation (mm)			temperature (°C)		
	mean annual	maximum	minimum	mean annual	January	July
Albania	1050	winter	summer	15	5	25
Austria	1150	summer	winter	7	-4	16
Belgium/Luxembourg	925	summer	spring	9	1	16
Bulgaria	625	summer	winter	12	-1	23
Czechoslovakia	675	summer	winter	9	-2	19
Denmark	675	summer	spring	8	0	17
Finland	550	summer	spring	2	-10	16
France	775	autumn	spring	11	3	19
Germany, F.R.	750	summer	winter	8	0	17
German, D.R.	625	summer	winter	8	-1	18
Greece	625	winter	summer	16	6	26
Hungary	675	summer	winter	11	-2	22
Ireland	1000	autumn	spring	10	5	15
Italy	825	autumn	summer	14	5	24
Netherlands	750	summer	spring	9	1	17
Norway	1000	autumn	spring	4	-5	14
Poland	600	summer	winter	8	-3	19
Portugal	800	winter	summer	15	9	22
Romania	725	summer	winter	10	-3	21
Spain	650	winter	summer	14	7	23
Sweden	700	summer	spring	4	-7	16
Switzerland	1275	summer	winter	8	-1	17
United Kingdom	1050	autumn	spring	9	4	15
USSR	550	summer	winter	5	-8	18
Yugoslavia	950	autumn	winter	12	0	22

A shift of climate is expected to occur on a global scale due to increased atmospheric concentrations of carbon dioxide and other 'greenhouse gases' (chlorofluorocarbons, nitrous oxide, methane and ozone). Pre-industrial concentrations of CO_2 were about 280 ppmv (ppmv = parts per million volume), and present concentrations are around 340 ppmv. The pre-industrial amounts of carbon dioxide may be doubled by the year 2030 (Lough et al., 1983). Such a scenario of increasing atmospheric CO_2 largely depends on (uncertain) projections for fossil fuel consumption. The last hundred years has already seen an increase in global mean temperature of between 0.3 and 0.7^oC. This increase is consistent with the observed increasing concentrations of carbon dioxide and other greenhouse gases. Recent estimates from simulation experiments with General Circulation Models and empirical studies on a doubling of atmospheric CO_2 suggest a global mean temperature increase of between 1.5 and 4.5^oC. However, the magnitude and order of variation as well as change over the seasons will vary with latitude.

A change in climate will here be considered to occur in two phases. The first phase, to be discussed in Section 4.2, covers the period around 2030 with a climate scenario for Europe in a warmer world that is based on historical analogues. The historical approach

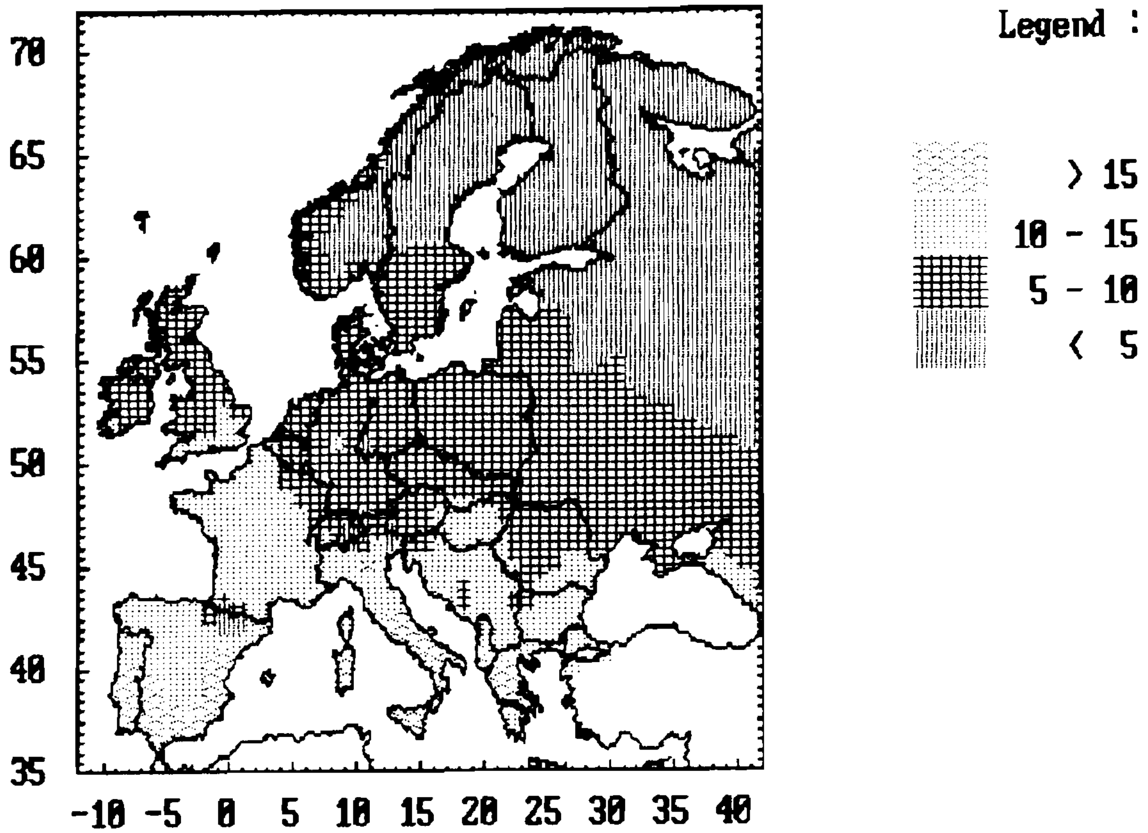

Figure 4. Mean annual temperature in Europe (in °C) (source: Müller, 1982).

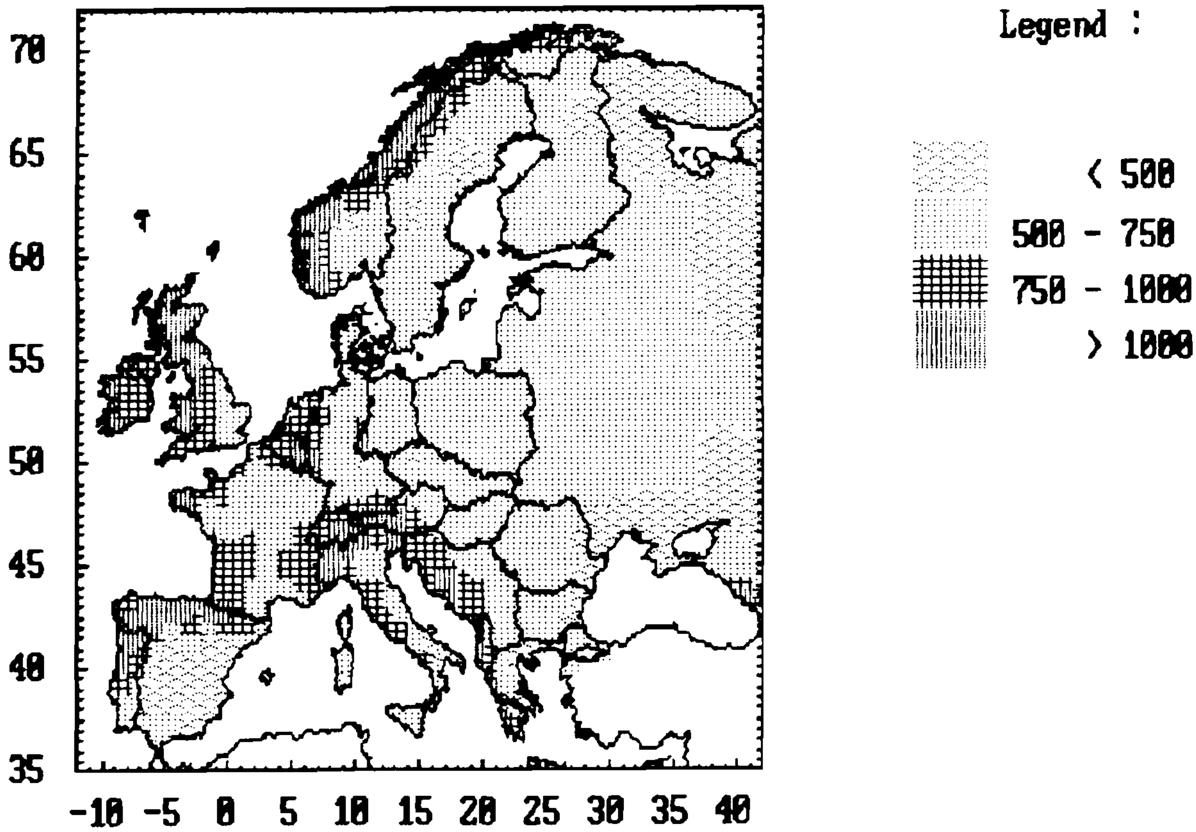

Figure 5. Mean annual precipitation in Europe (in mm) (source: Müller, 1982).

is based on a comparison of warm and cold periods between 1880 and 1980, where warm periods are considered to be analogues of a future, warm world with increased atmospheric carbon dioxide (see also Lough et al., 1983). This is considered to be the climate for the year 2030. The future climate based on the historical analogues may however not be appropriate for the climatic conditions in a later period (with increasing frequency of extreme climatic events) because of the expected increase in atmospheric carbon dioxide. The second phase, to be discussed in Section 4.3, and which might occur around 2050, is therefore based on a doubling of greenhouse gases, and an equilibrium climate response that results from a general circulation model, notably the model from the United Kingdom Meteorological Office (hereinafter referred to as the BMO model) (Mitchell, 1983). Both scenarios show the seasonal variation of changes in temperature and precipitation for Europe. Such seasonal characteristics and the order of variation in time are important for the suitability of using the land for agriculture and other purposes, since they affect the water availability for agricultural crops or forests, and the length of growing season.

4.2. *European climate around the year 2030*

The climatic conditions of the first period - based on the analysis of historical analogues from Lough et al. (1983) - can then be characterized as follows. Figure 6 shows the mean annual changes in temperature and precipitation. Such changes are considered to be the climatic changes to occur around the year 2030.

Mean annual temperature shows an increase over all of Europe, with largest increases in the Northern part (over 1 °C) and the South-eastern part of the continent (over 0.5 °C). *Mean annual precipitation* decreases in large areas of Europe, with the exception of Norway, Sweden, Finland, parts of the United Kingdom, France, Spain, Central and Eastern Europe.

Figure 7 shows the changes of temperature in Summer and Winter. The main features of the temperature scenarios shown are the slight to moderate warming over much of Europe in Summer but slight cooling in Winter. The largest increase in temperature (with an increase over 1 °C) is found in the Summer period, with the exception of the south-eastern part of Spain which shows a slight cooling. The major part of Europe shows a slight cooling in Winter (of less than 0.5 °C), with an exception for the major part of the Nordic countries, United Kingdom, Ireland and southern Spain which would experience a slight temperature increase. Spring and Autumn patterns (not shown) are similar to those in Summer.

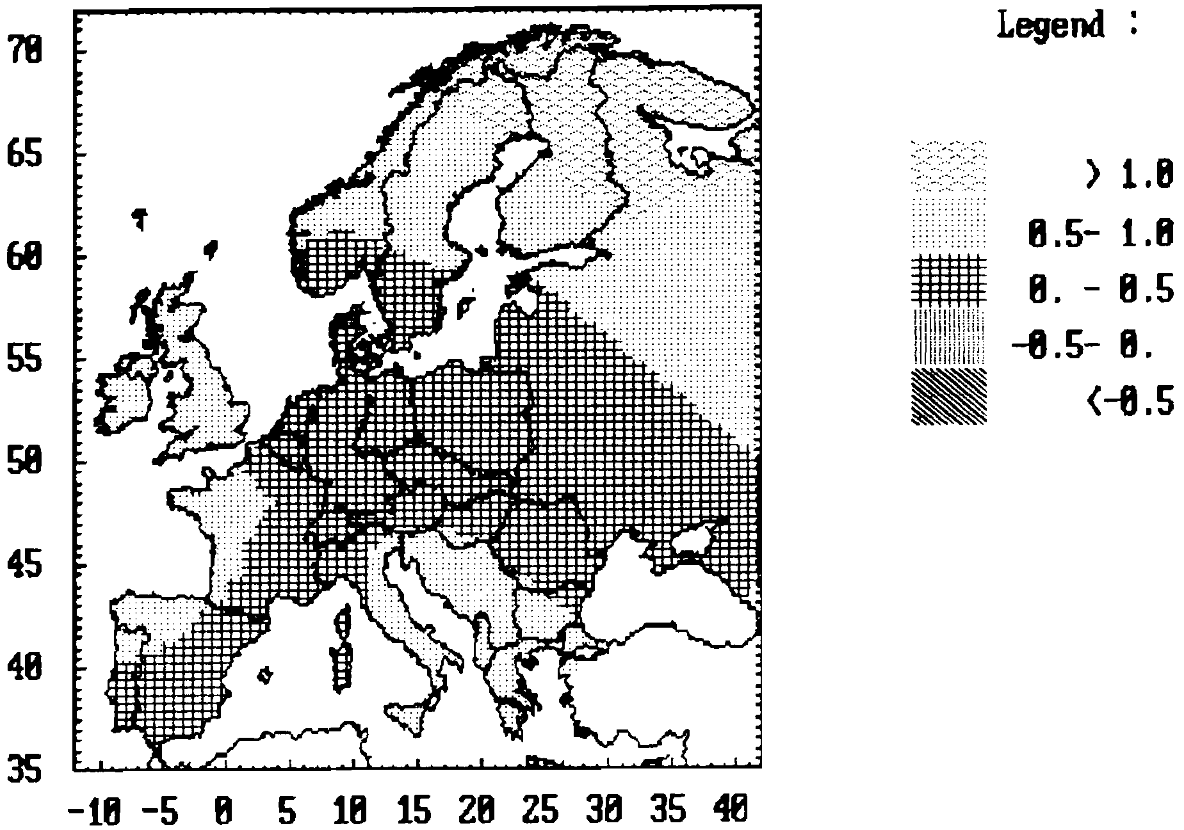

Figure 6a. Changes in mean annual temperature (in °C).

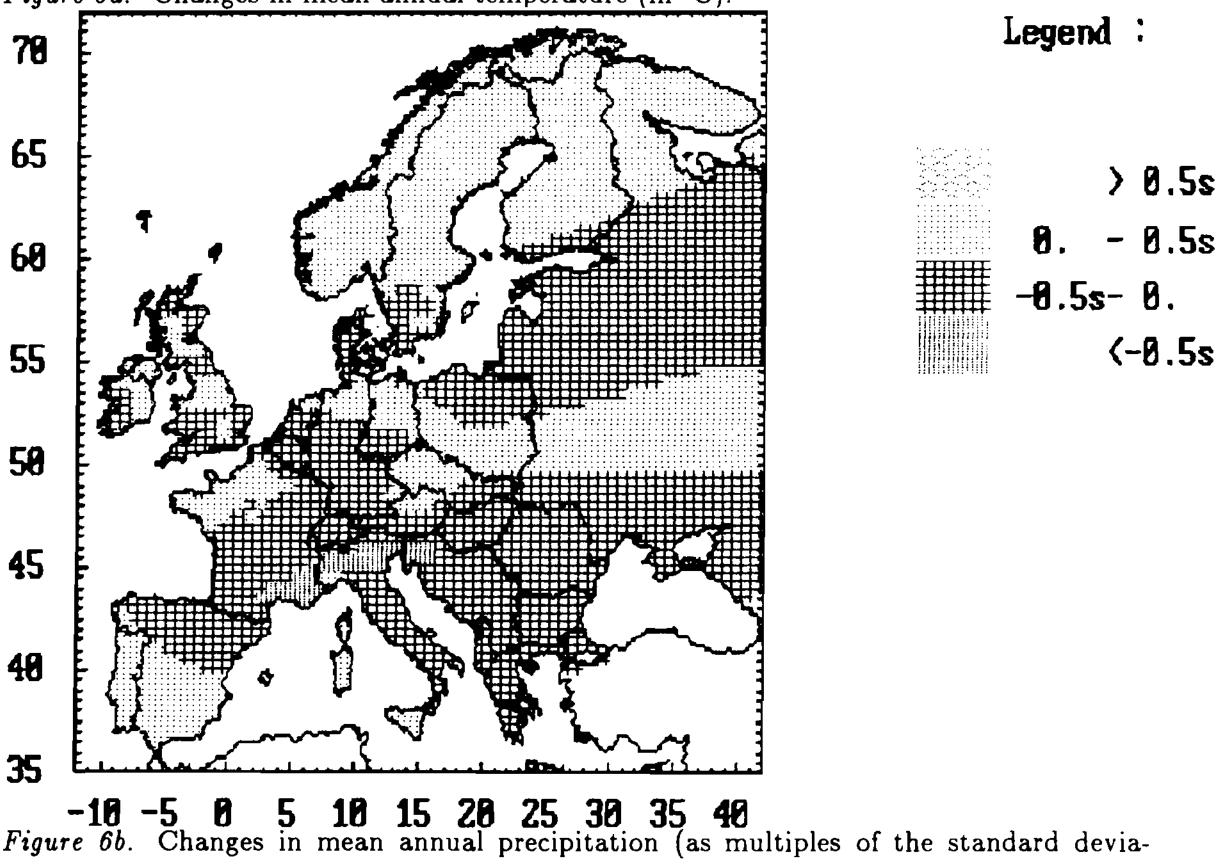

Figure 6b. Changes in mean annual precipitation (as multiples of the standard deviation).

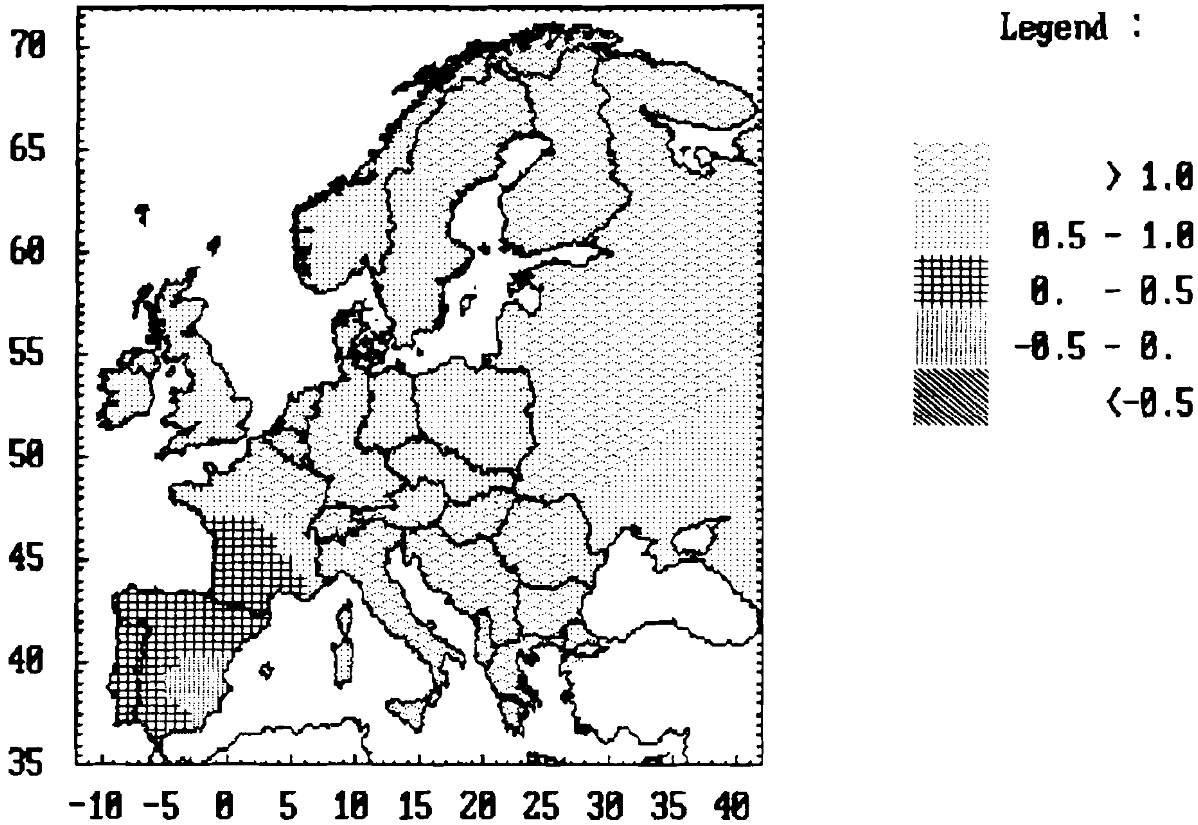

Figure 7a. Changes of temperature in Summer (in °C).

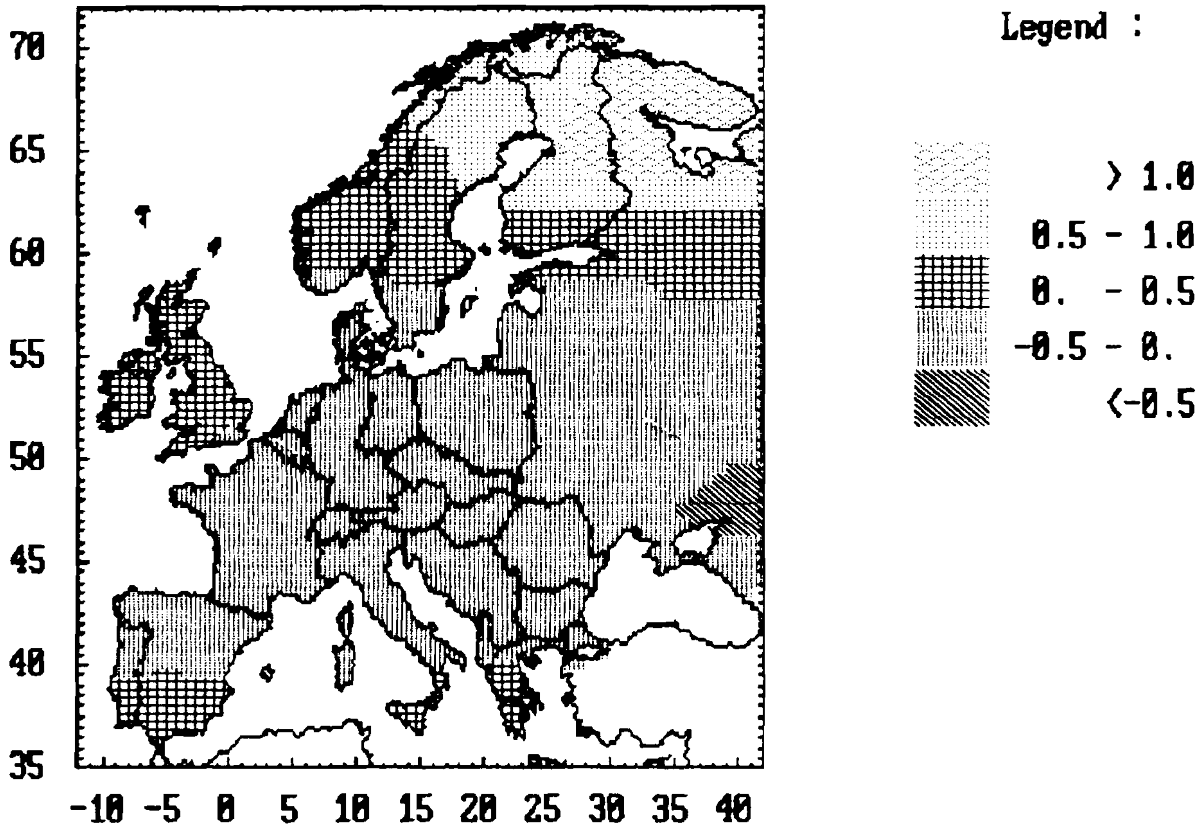

Figure 7b. Changes of temperature in Winter (in °C).

Figure 8 shows the changes of precipitation in Summer and Winter. There is a general tendency for drier Summers and wetter Winters. Major decreases during the Summer period are found in areas which now already have their minimum amounts during that season (Italy, Portugal, Spain and south-eastern part of Europe).

4.3. *European climate around the year 2050*

The climatic conditions in the first period, which includes the period around 2030, were based on an analysis of historical data. However, the climatic conditions are considered to be changed by 2030 owing to the large increase in atmospheric greenhouse gases, which may be doubled before the middle of the next century. The climatic conditions of the second period - which is considered to occur around the middle of the next century - is based on a doubling of atmospheric carbon dioxide globally, and an equilibrium response in climate. The results originate from the general circulation model of the BMO, and shows the seasonal variation of climate in a warmer Europe. The increase in mean annual temperature in Europe is around 3 to 4 °C. The mean annual precipitation pattern roughly shows an increase north of around the 50° latitude and a decrease south. The annual increase in Northern Europe might be as large as 150 mm, while the decrease in the Mediterranean area might be some 300 mm. Figure 9 shows the changes in mean annual temperature in Europe for this scenario, compared to present climatic conditions.

The scenario considers an increase in temperature during all seasons in Europe. The regional distribution of the seasonal variation in temperature shows the largest increase during the winter season, which might be as large as 7 °C in Northern Europe, and around 2 °C in the Mediterranean part. Figure 10 shows the changes in mean annual precipitation in Europe for this scenario, relative to the present climatic conditions.

The climate change scenario also considers a resulting sea level rise over the next 70 years of between 40 and 160 cm (UNEP/WMO/ICSU, 1988). This is especially important for the coastal lowlands of Western Europe (France, Belgium and The Netherlands), and the Mediterranean coastal areas (Italy).

4.4. *Soil degradation factors and the change in climate*

The kind of broad-scale transformation in climate discussed in the previous subsections would have profound effects on all kinds of land use. Cultivated land and wooded land are vulnerable to a change in climate. It has been emphasized that 'some regions now marginal for crop production because of climate may become even more so' (Crosson, 1986). This is illustrated by the Mediterranean area, which is characterized by high soil

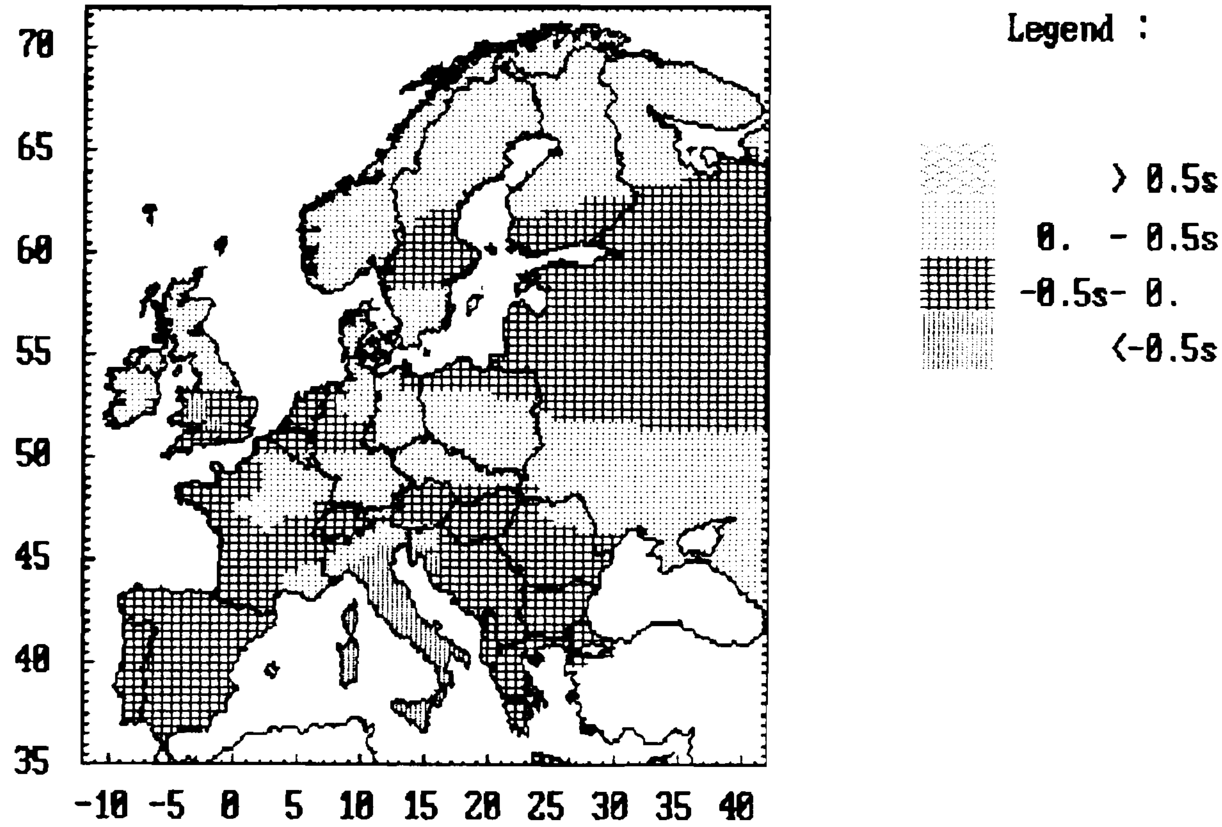

Figure 8a. Changes in precipitation in Summer (as multiples of the standard deviation).

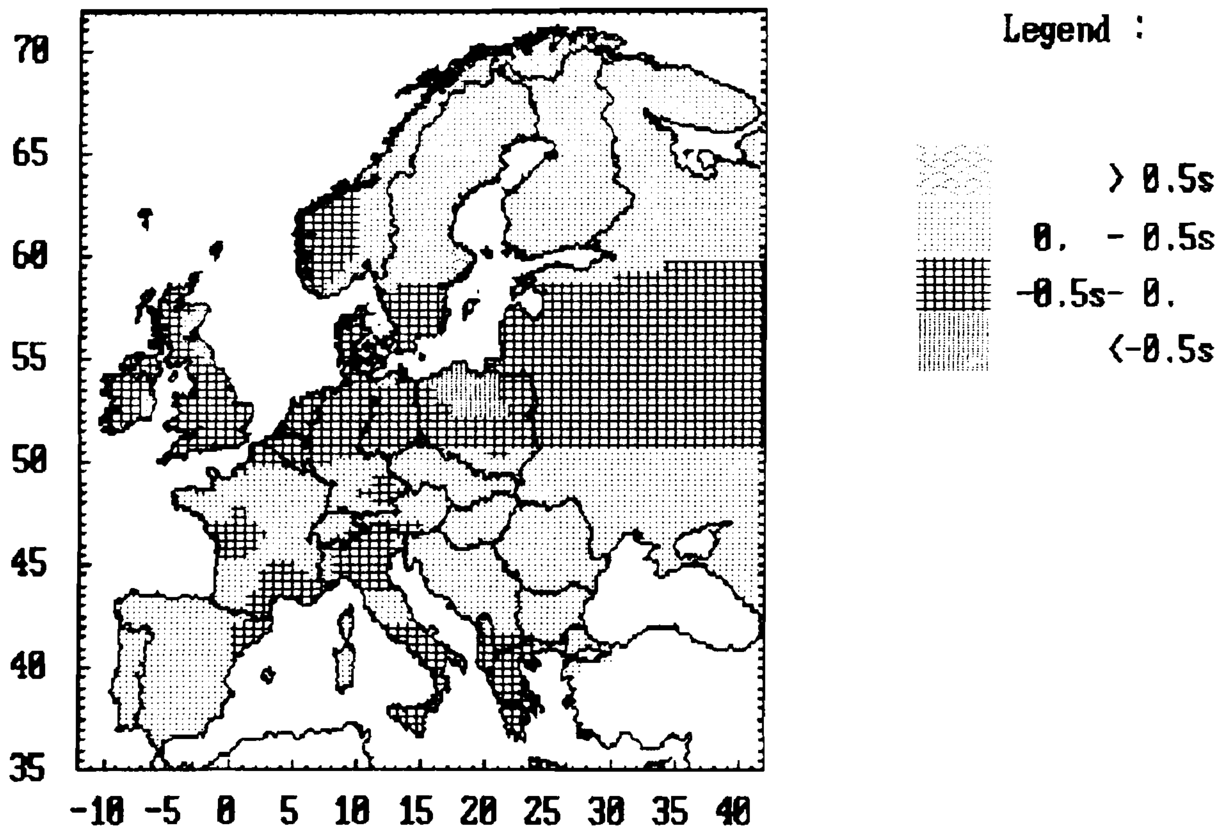

Figure 8b. Changes in precipitation in Winter (as multiples of the standard deviation).

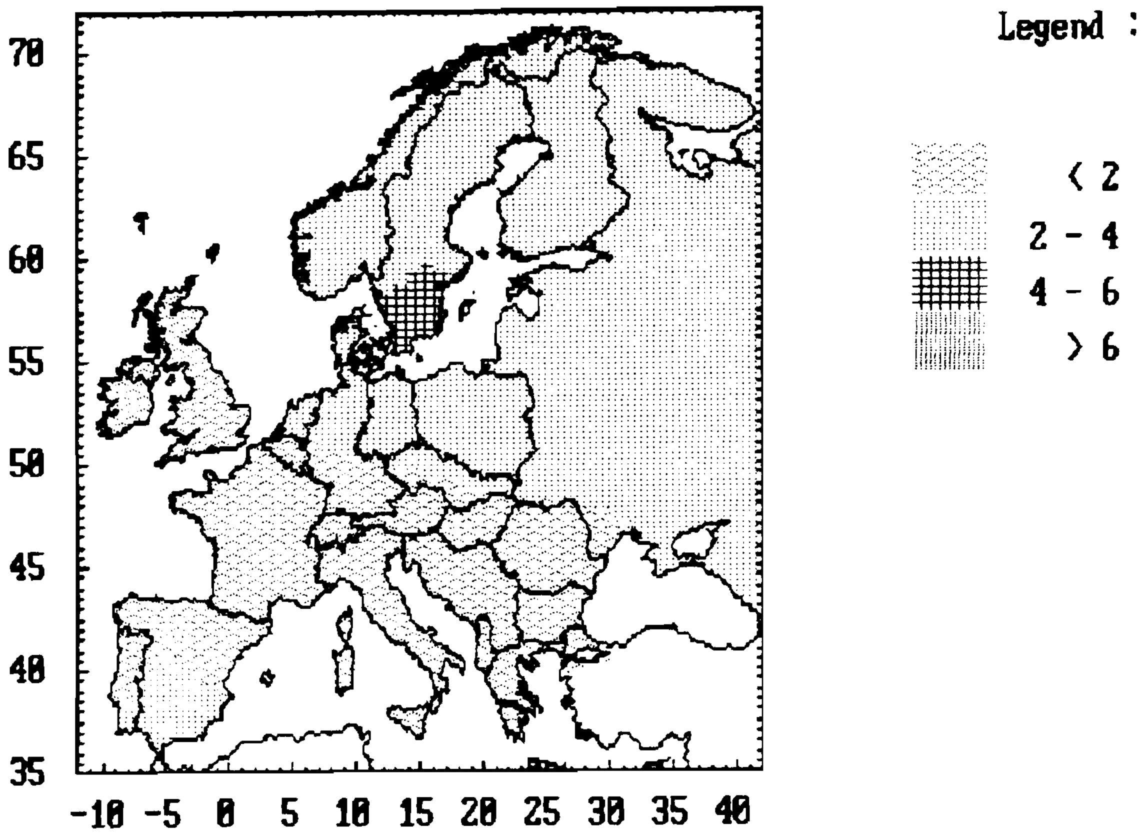

Figure 9. Changes in mean annual temperature (in °C) (BMO scenario).

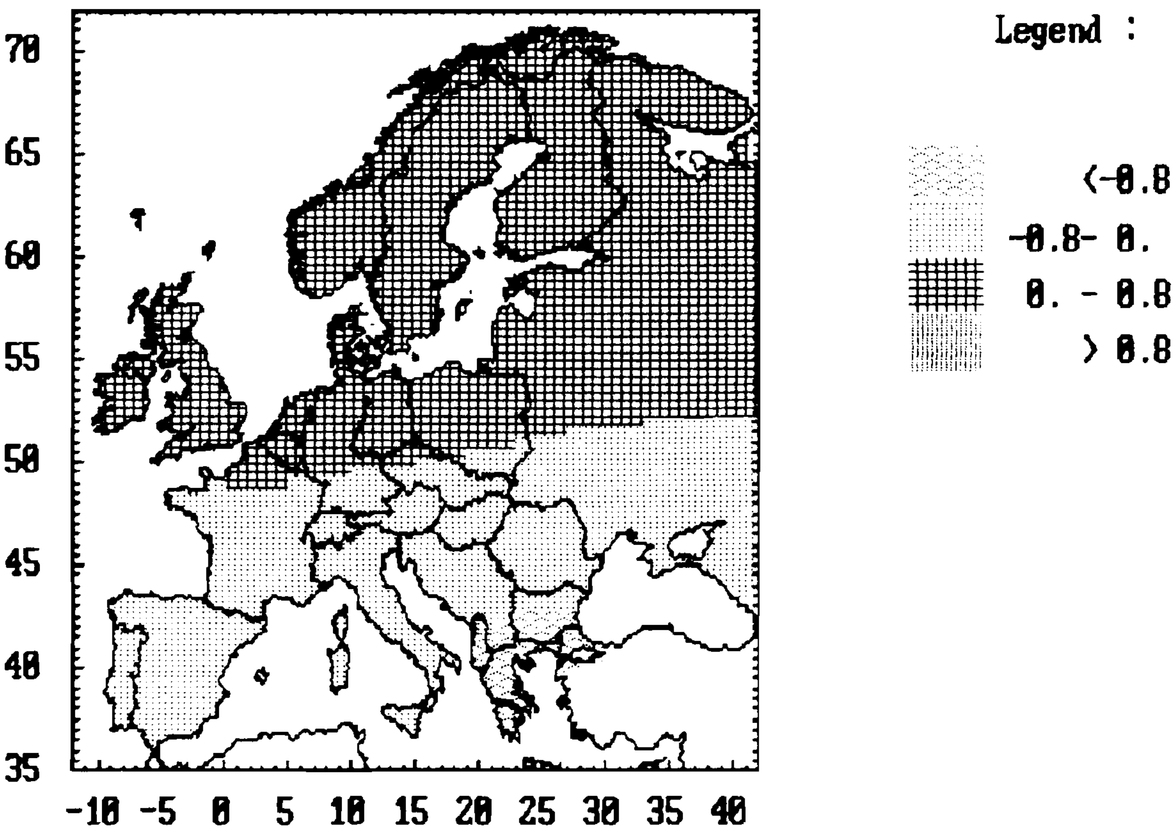

Figure 10. Changes in mean annual precipitation (in mm/day) (BMO scenario).

moisture deficit in the Summer period. However, other kinds of land use might also be highly vulnerable to rapid climatic shifts. Weinberg (1985) considers the adaptation or land use change that might be required for urban centres and infrastructure due to a climate change (e.g., change in transportation and communication networks due to a sea level rise, and the protection of land against increasing risk of flooding). We will first focus on the kind of soil degradation factors that are related to changes in climate and which would result into a decrease in land productivity. A 'not-impossible' scenario for land use changes for the period until the middle of the next century will be discussed in Section 5. Important degradation factors that relate to changes in using cultivated land and climatic factors are:

- erosion, either by wind or water;
- depletion of nutrients and organic matter; and
- salinization.

Soil erosion is a degradation process where soil particles are detached and transported either by wind or water. Erosion causes problems for agriculture not only through the transport of the fertile soil, but it may also cause problems for settlements in lowlands, which can be damaged by flooding through the transport of water and mud.

Depletion of nutrients and organic matter occurs when more nutrients are regularly removed from the soils than are replaced during the year. This kind of land degradation may accelerate over the next decades in areas of increased mean annual precipitation due to leaching, or where increased mean annual temperature result in increased oxidation of soil organic matter. A change in climate might result in an increasing soil moisture deficit in the Mediterranean area, especially important during the growing season for crops. This increasing soil moisture deficit might result into changing fertilization patterns (an increase in the application of fertilizers to remain productivity of that land), which again may result into an increase of leaching problems.

Salinization may occur as a result of salt accumulation from surface evaporation of ground water or irrigation water in the Mediterranean area, and where the intrusion of salts in groundwater occurs due to a sea level rise in the Northwestern part of Europe. A change in salt accumulation in the future may result from:

(i) increasing use of irrigation for agriculture;

(ii) increasing soil moisture deficit owing to a change in climate;

(iii) sea level rise, mainly in the coastal lowlands of Western Europe.

The land degradation factors that are described here in relation to a change in climate during the period until the middle of the next century will be further elaborated in the next Section in terms of future land use changes.

5. *FUTURE LAND USE CHANGES IN EUROPE*

The Conventional Wisdom scenario, to which we have referred, considers that, over an approximate 100-year period, global population will stabilize (at about 10 billion), energy use will increase by about a factor of 6 and that a steady growth in the scale of agricultural production (an increase of a factor of 4) will occur. It is essentially a 'continuing trend' scenario although means whereby the trends are perpetuated are not taken to be necessarily those at present prevailing. It is possible to conceive of 'surprise rich' scenarios in place of this relatively 'surprise free' one. The value of doing this is emphasized by those who point out that "if we know anything about the future, it is that projections will not hold for ever" (Svedin and Aniansson, 1987). Surprises are sure to occur. Therefore, the argument goes, let there be an attempt to build an element of surprise in to certain scenarios. This has been attempted in some studies (Svedin and Aniansson, 1987) so that changes occur in population density (away from Europe to south and east Asia, for example) or so population stabilization does not occur. These scenarios, known as the Big Shift and the Big Load respectively, are described along with other scenarios in Svedin and Aniansson (1987). Such changes would imply changes in various aspects of the agricultural system and some details are summarized in Table 5.

Table 5. Changes associated with increases in agricultural production in Europe for three scenarios described in Svedin and Aniansson (1987) - 1975=100.

	Conventional Wisdom	Big Shift	Big Load
Fertilizer applied	200	250	100
Irrigation	125	100	145
Land acreage	95	130	70
Yield	250	200	290

It can be inferred from this information that a number of other changes are occurring only peripherally related to agriculture (such as use of land for biomass production for energy purposes in the Big Shift scenario and the advent of food shortages in Europe under the Big Load scenario).

It is important to distinguish between end points predicted by these scenarios and the means by which these may be attained. For example, a Conventional Wisdom scenario, that considers population, energy use and agricultural production changes with time, does not expose the possible land use changes in Europe or allow these to be assessed realistically as it does not explicitly explore the impact of technological, socio-economic and physico-environmental (particularly climatic) factors that are likely to change over the next 50 - 100 years. Cropping and other land use boundaries are determined by the interplay of all these factors. Andreae (1981) distinguishes a number of boundaries to land use including those based on profitability (where returns tend to zero), technological boundaries (the boundary up to which a particular land use could be undertaken at a certain stage of technology if economic considerations are waived) and effective boundaries that represent the actual limit of a certain form of land use.

Some technological boundaries are well-documented for Europe: grain corn (Zea mays) has shifted its northern boundary in Europe by approximately 5° latitude in the last 25 years due to selection by plant breeders, yielding varieties that can produce economic yields under shorter growing seasons and mature at lower mean Summer temperatures. Other technological advances, especially those associated with genetic engineering activities, are likely to result in the potential for large shifts in the critical limits for a whole range of crops currently used in European agriculture and horticulture, and to a lesser extent for forest crops as well, over the next hundred years. This could lead to the clearance of large areas of land, not at present devoted to agriculture, to enable these new varieties to be exploited. In addition, land use changes will undoubtedly result from intervention policies that evolve from the mis-match of production and demand. The set-aside policies at present under implementation in the EEC may result in considerable changes in land use although it is not clear at present whether these changes will involve taking out of production large areas of 'marginal' farm land or the application of 'production quotas' to the more productive land, in order to reduce the more extensive effects of such a policy and allow the implementation of more conservation-oriented farming systems on land hitherto farmed extremely intensively. It is also necessary to consider limitations on productivity resulting from soil degradation (due to erosion, salinization and loss of fertility) and adverse pollution loads.

In the light of this it might be envisaged, in evolving a 'not impossible' scenario applicable to Europe, that production surpluses will limit crop extension marginally; that new crop varieties will allow yields to continue to increase; that major pollution sources will be, on the whole, abated as it is seen that such measures represent cost-effective responses to pollution damage in the longer term. However, interacting with these factors, ecological land use boundaries are likely to shift in response to an overall climatic change that imposes new geographical limits on plant growth and land use systems.

Land use boundaries are imposed by a range of ecological limitations: altitudinal, temperature, moisture availability (aridity and waterlogging) and even slope and exposure. In view of the climatic changes postulated by general circulation models that explore the effects of increased concentration of greenhouse gases, it seems necessary to consider, as a minimum activity, limitations related to changes in moisture availability and mean annual temperature, and the closely related feature of length of growing season, as a 'back cloth' to the other factors stimulating change.

Length of growing season (or growing period) is defined by the period over which mean daily temperatures above 5 °C prevail (and are frost-free) in northern Europe as, here, the limitation to plant growth is not affected by lack of soil moisture in a major way, although this is not to say that areas do not exist where crop yields would not be enhanced in some years, particularly in May - August. Soil moisture deficits, however, are much more frequent limitations to growth in southern Europe, particularly in Mediterranean regions. Although soil moisture deficits are recharged during Winter and soil moisture storage can meet moisture demand during short periods when evapotranspiration exceeds precipitation, soil moisture deficits soon restrict transpiration and gas exchange and the rate of dry weight increment is reduced.

Figures 11 and 12 indicate the length of the growing period. This is defined here by the period of the year, in months, that the mean temperature is above 5 °C and the period during which precipitation exceeds 0.5 of the potential evapotranspiration (Verheye, 1986). When the growing season in Europe under present climatic conditions (Figure 11) are compared with the period based on the BMO scenario of climatic conditions, it can be seen that the greatest increases are in northern Europe (due to an overall rise in mean annual temperature) and the largest decreases are in the Mediterranean area where increasing soil moisture deficit limits crop production.

The result of the changes in length of growing season outlined above is the background against which other interacting factors must be placed (such as technological, pollution and socio-economic changes) to arrive at an indication of land use changes. In general, there is a potential for the northern crop boundaries to shift 5 - 7° in a northerly direction and an associated limitation on crop growth in parts of the Mediterranean with the southerly boundary shifting 3 - 5° N. Figure 13 gives some indication of this for selected crops.

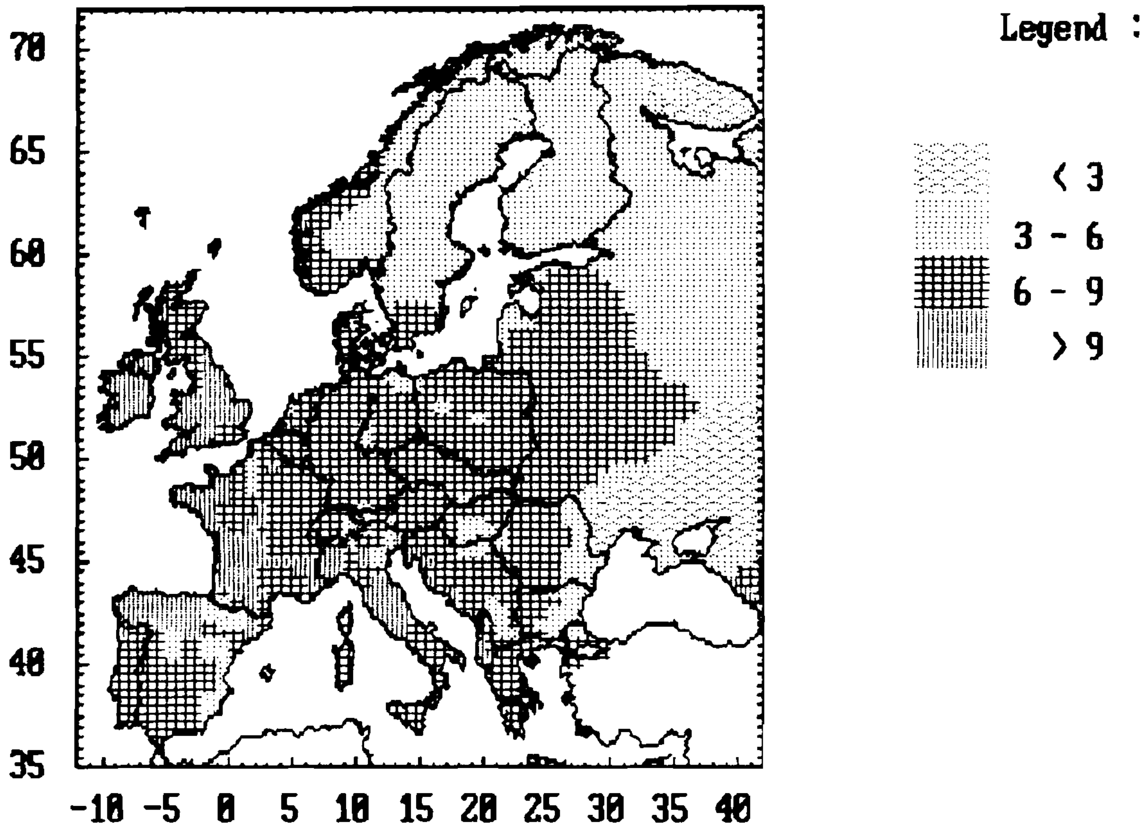

Figure 11. Growing period in Europe (in months) (present climatic conditions).

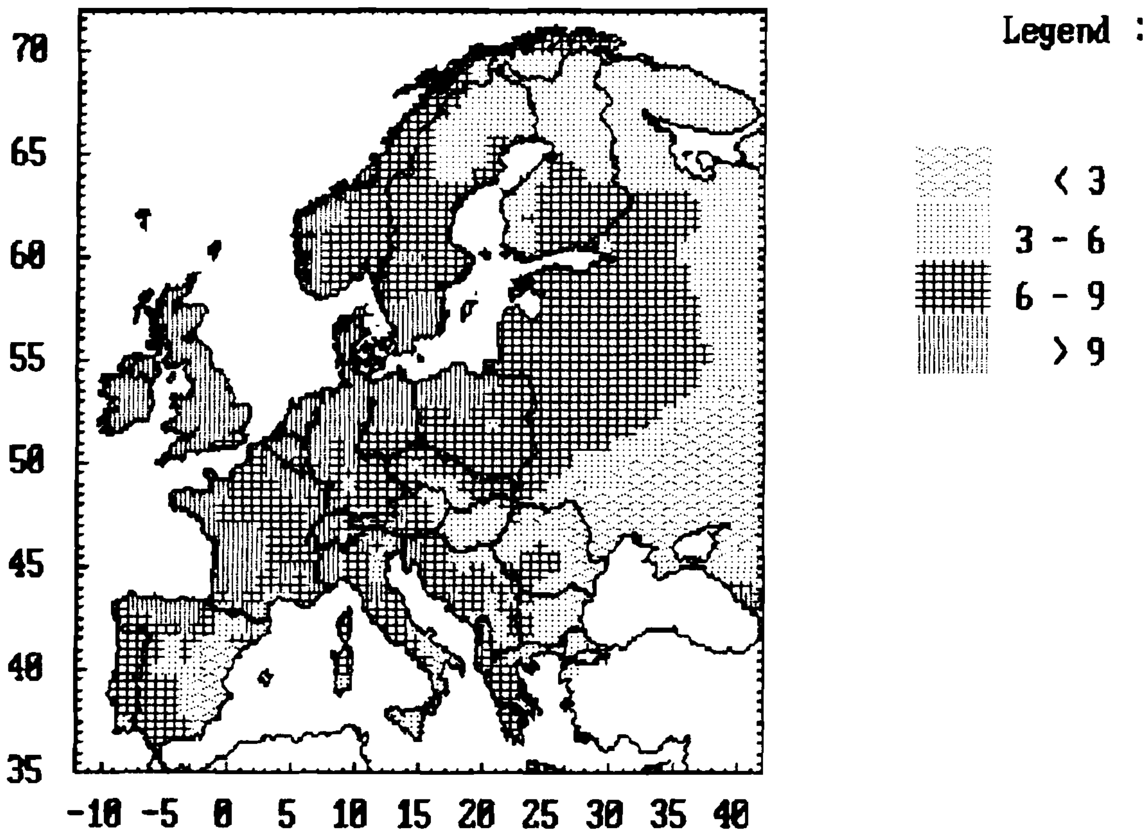

Figure 12. Growing period in Europe (in months) (BMO scenario).

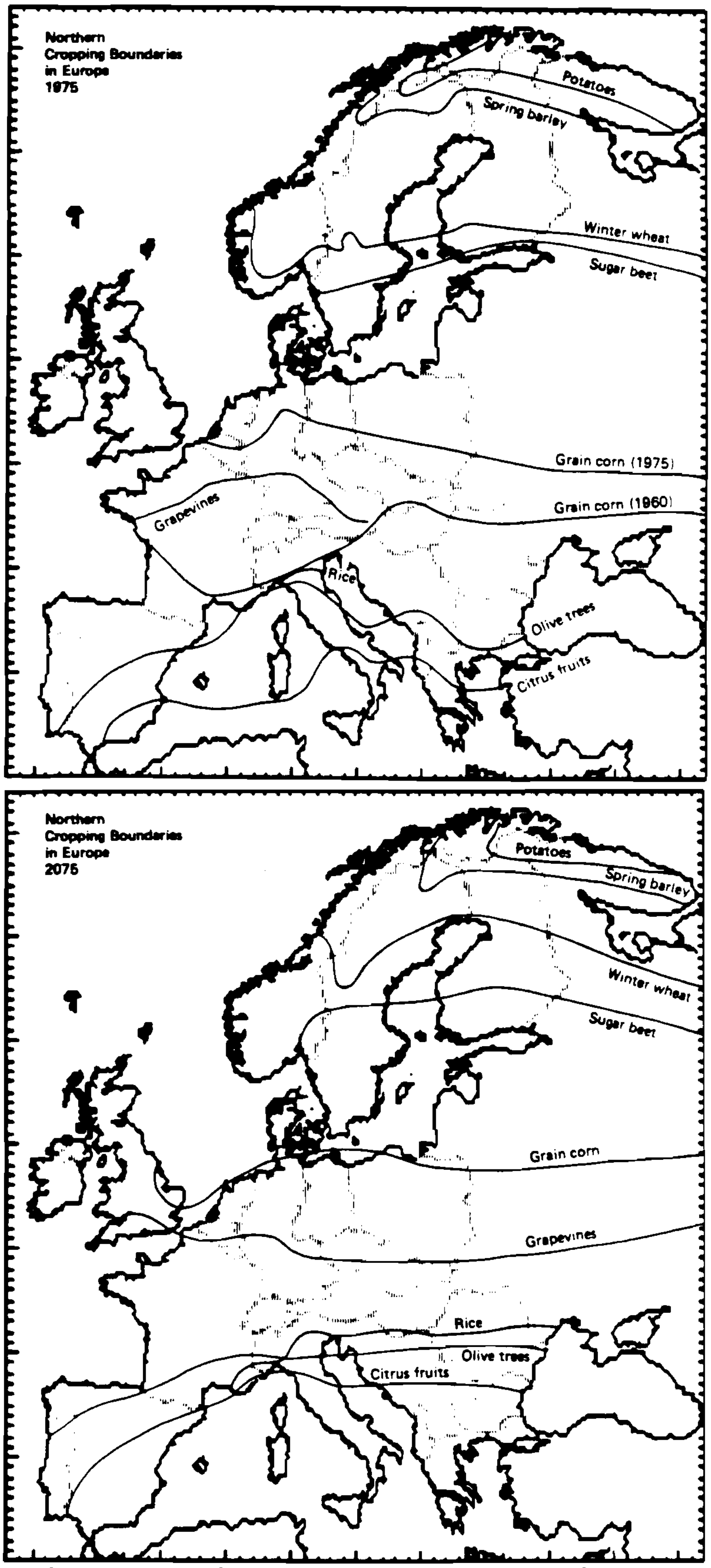

Figure 13. Northern cropping boundaries in Europe for 1975 (Andreae, 1981) and 2075.

The potential northern shift of the boundary for Sugar Beet, Winter Wheat, Spring Barley and Potatoes could mean that large areas of land hitherto devoted to forestry (the northern boreal forest) would be able to be cleared for the growth of some of these crops. Even some soil constraints could be overcome by some of the well-tried farming method practised previously on areas of difficult soils. Approximately 18-20 million ha of present-day forest land in northern Europe would be potentially exploitable in this way. In southern Europe (Mediterranean and bordering the Black Sea) it would most probably no longer be feasible to grow perennial tree crop products (Citrus fruits and Olives) successfully and the potential would switch to such crops as cotton (and possibly rice) under irrigation. In between these two extremes significant shifts in cropping regimes would be possible.

6. *CONCLUDING REMARKS*

We have stressed that changes in technology and socio-economic conditions will combine with any environmental transformations to determine future patterns of land use in Europe by the middle of the next century. That large potentials for the shift of present land use boundaries exist does not mean that such changes will extensively occur. But, equally, it is inconceivable that no change in land use patterns will take place in response to trends in climatic modification and associated soil features, catchment characteristics and other ecological conditions. The factors we have discussed serve to focus on the considerations that need to be weighed in reaching an assessment of the plausible land use patterns that will develop into the middle of the next century.

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