WORKING PAPER

Determination of broad scale land use changes by climate and soils

Floor Brouwer

January 1988

WP-88-007

IIASA
International Institute
for Applied Systems Analysis

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Foreword

One of the objective of IIASA's Study *The Future Environments for Europe: Some Implications of Alternative Development Paths* is to characterize the large-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 environmental components being considered include climate, hydrology, air and water quality, toxic substances, major nutrients and land use, all of which have an influence on the soils of Europe. The present Working Paper contributes to the discussion of plausible scenarios of changes that could take place in the next century in the European soils.

R.E. Munn

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Summary

Soil quality and climatic conditions are vital environmental determinants of land use patterns. This paper addresses some major environmental determinants for broad-scale land use changes in the context of the European continent. The land can be degraded, owing to anthropogenic and environmental changes, rendering it unfit for agricultural (and possible other human) use. Major land degradation factors include (i) compaction, (ii) erosion, (iii) toxification, (iv) reduction of nutrients and organic matter, and (v) salinization. A possible future change in global climate will have profound effects on all kinds of land use, including both natural and managed vegetation. A qualitative assessment is presented of possible changes in these land degradation factors due to a "not-impossible" scenario for a future transformation in European climate.

Key words:

Soil quality, climatic change, land use changes, land degradation.

Determination of broad scale land use changes by climate and soils

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1. Introduction

Many research efforts have been made over the last few decades to model the complex interactions between socio-economic activities and ecological processes (a state-of-the-art-survey of environmental-economic models pertaining to the classical environmental compartments air, water, and land is presented in Brouwer (1987)). Most of these studies have focussed on the economic-ecological interactions with a ten to twenty year time horizon, and a spatial coverage of regions or nations. The models developed were elaborated for a wide range of political decision-making processes such as national or regional physical planning, and also for sectors such as agriculture, fisheries, outdoor recreation and housing (the application of economic-ecological models for resource policy and management is evaluated by Braat and Van Lierop, 1987).

However, it is becoming increasingly clear that many environmental processes require a broad geographical scale and a long-term frame of reference. An example is climate and its possible interactions with ecosystems (e.g., forests) and society (e.g., agriculture). This broad-scale and long-term focus on environmental processes becomes increasingly clear in the case of environmental transformations that may span several decades to a century and cross national boundaries or even wider areas. For example, climate is expected to change on a global scale over the next century due to increased concentrations of carbon dioxide and other 'greenhouse' gases (mainly chlorofluorocarbons, nitrous oxide, methane, and ozone). Such a long-term environmental transformation as climatic change may cause various kinds of responses in ecosystems, and the human activities related to them (such as agriculture), at the regional and continental scale.

Various international collaborative efforts were therefore initiated in recent years, and they emphasized the need for studying the long-term and large-scale environmental effects of socio-economic activities. The World Commission on Environment and Development (1987) for example, recently described the need to consider ecological sustainability for long-range planning. An extensive conceptual document of results on recent research efforts related to long-term and broad-scale transformations in human development (such as energy and agriculture) and the environment (like climate and terrestrial ecosystems) is provided by Clark and Munn (1986). A regional case study on possible future environments in Europe is in progress at IIASA. Its purpose is to examine linkages of human development with the long-term and large-scale possible transformations in the environment. The environmental transformations that result from socio-economic development (e.g., agriculture, energy use and industrial development) include changes in, among other factors, climate, hydrology, acidity, toxic material loads, plant nutrient availability and land use patterns.

This paper examines a set of critical environmental factors related to land use. The use of land is the result of a complex set of interactions between (a) socio-economic and historical changes over time, (b) political decisions, and (c) environmental conditions. Land can be used for a wide variety of activities such as, among others, agriculture, forestry, recreation, industry, settlements, transportation and communication. This wide range of possible purposes illustrates that land is a primary resource for most kinds of socio-economic activities, and a vital component of natural ecosystems.

A substantial part of the total land area in Europe is devoted to agriculture and forestry (the total proportion in arable land, permanent grassland and wooded areas in Europe during the 1980's is about 80%). Biophysical characteristics as related to climatic conditions and soil quality are extremely important for the productivity of the land, and they will be further explored in this paper.

The major environmental factors that are related to the use of land will be presented in Section 2. This investigation will emphasize some major characteristics of climatic conditions as well as of soil quality as the critical environmental determinants concerning land productivity. However, the land can also be degraded by various factors, including environmental factors (such as extreme climatic conditions or changes in soil nutrient content), as well as anthropogenic factors (such as compaction of the soils from use of heavy machinery, or irrigation and drainage practices in agriculture). The major land degradation factors in Europe will be described in Section 3 within the context of changing land use patterns.

Climatic factors are important for land productivity. A "not-impossible" scenario for a change in European climate will be described in Section 4. Land use may therefore have to respond over the next 100 years to accommodate such transformation in the environment. A qualitative assessment of the possible response to a change of climate and hydrology of various land degradation factors is presented in this section.

2. Soil quality and climatic conditions: environmental determinants of land use

The patterns of land use that have evolved over centuries in Europe are the outcome of interactions between natural features of the environment and socio-economic responses. Initially, humankind was almost entirely bounded by natural factors such as climate, geology, soil and vegetation. Increasingly, however, it became possible for people to obtain more freedom from constraints of the natural environment by using their developed skills. However, we still operate largely within the constraints of natural environmental features, particularly climate and soils, and they determine our social responses and degrees of freedom of action.

This paper will primarily focus on the vulnerability to environmental factors of biologically productive land (e.g., land that is used primarily for agriculture, forestry and horticulture). However, other kinds of land use that are not included here (such as land for settlements, transportation or communication), might also be vulnerable to possible transformations in the environment. Consider for example the potential vulnerability of urban areas to environmental transformations. Weinberg (1985) noted that because urban centers and infrastructure were developed under past and present climatic conditions and because they are less adaptive than biologically productive land, they may be highly vulnerable to rapid climatic shifts (e.g., possible required response of infrastructure, transportation and communication networks due to a sea level rise, and its protection against increasing risks of flooding).

The potential productivity or suitability of land for either agriculture or forestry is determined by physical as well as by chemical factors. Maximum potential productivity of crops can be determined by a theoretical photosynthesis model. De Wit et al. (1987) described the present production potential for Europe, based on a photosynthesis analysis. Europe was characterized in terms of 27 climatic and soils regimes, the major purpose of the analysis being to find out to what extent agricultural production may still increase in Europe. The conclusion was that the potential production in Europe still exceeds considerably the actual production level, even in countries like The Netherlands, with high production levels and large input requirements such as chemical fertilizers. However, this analysis did not focus on possible degradation factors in soils.

Land productivity can be evaluated from climatic phenomena and soil quality conditions, in an approach developed by FAO (1976), to evaluate the suitability of land for, among other things, agriculture, forestry and nature conservation, using a land-evaluation concept. That report also formulates a set of land qualities that are relevant for growing crops, including nutrient availability, salinity and alkalinity of the soils, soil toxicity, resistance to soil erosion, and temperature and precipitation. Land productivity can therefore be based on soil quality characteristics and climatic conditions, and Sanchez et al. (1982) developed a system of classifying soils according to their fertility constraints. The fertility of the soils is based on soil characteristics like cation exchange capacity, organic-matter content, acidification or salinization, soil moisture regime, and slope. Sanchez et al. applied this system of soil fertility capability to South America, transforming the soil units of the FAO-UNESCO soil map of the world into fertility categories.

Land suitability not only depends on soils and climate, but also on the type of crops grown, since each variety has its own requirements for soil quality and climatic conditions. The growth of a cereal crop such as winter wheat needs a growing period (i.e., the number of days with an average temperature over 5^oC) of about 180 to 250 days, and an effective water consumption over this period of about 450 to 600 mm. The growth of winter wheat is limited when the moisture levels are smaller, with only slight limitations in the range between 350 and 450 mm, and moderate limitations in the range between 250 and 350 mm (Verheye, 1986).

The land-use potential depends on an evaluation of socio-economic factors as well as of physical factors (climate, soils and physiography). The land evaluation for a specific use involves a comparison between the input requirements of a specific kind of land use and the qualities of the land. Crop growing, grass production or wood production each has different input requirements, while the land itself has a certain potential based on its soil quality and climatic characteristics.

The different productivity levels of agricultural land can be evaluated in broad terms by means of a distinction between core and marginal agricultural land. Marginality of land refers to land used for agricultural production that has achieved both relative and absolute limits with present technological conditions. The occurrence of marginality may be the result of physical, chemical, economic or social conditions (Beattie et al., 1981). Marginality with respect to physical conditions includes climatic considerations (e.g., water consumption and availability, which are based on precipitation and (potential) evapotranspiration) and soil quality characteristics (such as susceptibility to water erosion, or low water-retention capacity). The chemical conditions of land for crop growing concern primarily nutrient conditions of the soils, mainly nitrogen, phosphorus and potassium. The economic focus in marginality is primarily based on low levels of return on investments, which might be related to factors such as location, profit and capitalization. Finally, marginality may also be defined from social conditions, such as the availability of educational and transport facilities, or social characteristics of the farming population such as age structure, educational level and managerial skills.

The marginality of agricultural land in the European Communities (EC) as based on socio-economic and physical conditions is described for different crops in Meester and Strijker (1985). The regional distribution of wheat growth during the seventies indicates that 90% of the wheat production is produced on only 60% of the agricultural land used for growing that crop. This distribution is even more uneven for rye, where 90% of the production is produced on around 40% of its land coverage. This distribution indicates that the marginal land, which is here based on a mixture of socio-economic and biophysical conditions in the EC, already covers large areas.

The productivity of biologically productive land may be diminished owing to soil degradation. A subdivision will be made here into 5 major types of soil degradation, which render them unfit for agricultural (and possible other human) use, viz. (i) compaction, (ii) erosion (either by wind or water), (iii) toxification (e.g., from the accumulation of heavy metals, organics and pesticides), (iv) reduction of nutrients and organic matter, and (v) salinization. These soil degradation factors in Europe will be described in the following section within the context of changing land-use patterns.

3. Degradation of the soils

3.1. *Introduction*

The use of agricultural land on the European Continent changed drastically over the past few decades, with respect to both the productivity of land, and the required inputs for growing crops. The post-war period of agricultural development in Europe has been characterized by steadily increasing yields, increasing use of technological inputs (e.g., chemical fertilizers and pesticides), improved crop varieties, larger farms, mechanization, and capital that replaced labor. The intensification of the use of land for agriculture as well as increase in labor productivity of agriculture over the last decades are reflected by the fact that the production of 1 ton of wheat in The Netherlands required about 300 man hours around the beginning of this century, whereas this has been reduced to about 1.5 man hours in present intensive modern agriculture (De Wit et al., 1987). Table 1 below shows a summary on the major transformations of outputs and inputs in European agricultural development during the last three decades (excluding the USSR).

Table 1. Main output and input characteristics of European agriculture between 1950 and 1980 (source: various FAO production yearbooks).

type	unit	1950	1960	1970	1980
arable land	1,000 ha	147,000	154,000	146,700	140,900
cereals	area: 1,000 ha yield: 1,000 MT yield: ton/ha	72,390 108,260 1.50	72,540 146,080 2.01	71,496 186,520 2.61	70,591 258,111 3.66
sugarbeet	area: 1,000 ha yield: 1,000 MT yield: ton/ha	2,295 55,870 24.34	2,970 100,870 33.96	2,993 110,131 36.80	3,616 138,241 38.23
potatoes	area: 1,000 ha yield: 1,000 MT yield: ton/ha	9,390 130,000 13.84	9,180 143,640 15.65	7,354 136,311 18.54	5,677 93,204 16.42
irrigation	1,000 ha	n.a.	6,000	10,794	14,452
machinery	1,000 tractors	1,050	3,764	6,169	8,465
fertilizer(NPK)	1,000 MT	8,000	13,000	24,900	32,800

Arable land includes the land which is cultivated and used for growing annual crops (such as cereals, potatoes and sugarbeet), and perennial crops. The total coverage of arable land decreased in Europe by about 6 million ha in a period of about 30 years. The production of arable crops increased both in absolute and relative terms. The increases in agricultural production during the post-war period were mainly achieved by intensification of production per unit area. This is reflected by the changing input levels in agriculture. An increasing use of chemical fertilizers, and also machinery and capital that replaced labor, contributed to a large extent to the rapid increase in agricultural yields. The use of chemical fertilizers in Europe increased rapidly over the last few decades, mainly due to:

(i) changing cropping patterns, such that large areas are not used over the winter period, which resulted in a reduction of the supply of nutrients from one crop to another;

(ii) intensified use of sandy soils for crop growing, soils having relatively large nutrients requirements; and

(iii) a less optimal utilization of animal manure.

The relative production increases were large for all kinds of crops over the last 30 years; e.g. it has been about 70 kg/ha/year for wheat in the original nine countries of the EC, and this was larger than in any period before (De Wit et al., 1987). A sudden transition occurred a few years after the Second World War from an annual growth of only a few kg/ha to the level of about 70 kg/ha. This tendency of relative growth in agricultural production is also reflected in Table 1 for cereals, sugarbeet and potatoes (which in total cover the major part of arable land in Europe).

While the productivity of agricultural land increased, the use of chemical fertilizers increased even more over this period. This shift can be shown by the change in the relative productivity of using chemical fertilizers, as defined by the ratio of the cereals production per ha to the amount of fertilizer application per ha. This ratio decreased from 0.028 in 1950 to 0.016 in 1980, which means that the increase in cereals production was only achieved through an even larger increase in the application of chemical fertilizers. The increase in fertilizer use for growing cereals was around 40% larger than the increase in productivity of growing that crop.

Various kinds of land degradation that are related to the quality of the soils became more apparent over this period due to anthropogenic and environmental changes, and five major types of soil degradation will be described below. Soil degradation is a process where the short-term or long-term productive capacity of the soil to grow crops as well as its role in ecosystems is deteriorated (OECD, 1985). Important consequences of soil degradation include deterioration with respect to (i) structure, (ii) water retention capacity, and (iii) soil quality characteristics. Soil quality relates to the fertility of the soils, and maintaining the long-term multifunctionality is an important characteristic of soil fertility. The five major types of soil degradation in Europe that will be described here include

(1) compaction;

(2) erosion, either by wind or water;

(3) toxification (e.g., heavy metals, organics and pesticides);

(4) depletion of nutrients and organic matter; and

(5) salinization.

These processes of soil degradation may result from environmental as well as from anthropogenic changes.

3.2. *Soil compaction*

Physical soil degradation can be defined as a change in soil physical properties which have a negative influence on crop production. A main type of physical soil degradation is soil compaction, which increases the bulk density of the soils, and is caused by the use of heavier tractors and machinery. This kind of degradation may also induce a lower soil uptake of nutrients and water (see also Boels et al., 1982 for a description of various case studies on physical soil degradation). Clay soils in humid areas are most susceptible to compaction, particularly when they are planted with cereal crops.

3.3. *Soil erosion*

Soil erosion, a major type of soil degradation that occurs everywhere, is a degradation process where insufficiently protected soil particles are detached and transported either by wind or by water. Various factors may be related to the vulnerability of soils to erosion, including physical, climatic and chemical factors as well as agricultural management factors (see also Hodges and Arden-Clarke, 1986 for a study on soil erosion in Britain and its relationships to farming practice).

Erosion by wind is often a local problem that tends to damage field crops, while erosion by water may result into a long-term degradation process with respect to soil quality. However, large-scale desertification occurs in many semi-arid regions due to sustained drought and/or over-grazing. Water erosion occurs when the supply of moisture from precipitation or runoff exceeds the capacity of the soils to absorb it. The principal factors that characterize the susceptibility of soils to erosion are soil structure and capacity to absorb and retain water. Low water retention and infiltration levels indicate that less water is available for plant growth, and more water is available for runoff in slopes (Imeson, 1986). Soils with low levels of clay materials, nutrients and organic matter are in general rather more prone to erosion because they compact more easily when heavy mechanization is used.

The farm-management factors that are relevant to the vulnerability of soils to erosion can be characterized as (i) continuous cropping, (ii) conversion of meadows and pastures to arable land because of the smaller nutrient levels for arable land, and (iii) compaction and damage of the soils from the use of heavy machinery. The organic-matter content of meadow and pasture soils is in the range of 5 to 10%, while it may be as low as 1 or 2% for coarse-textured crop land. Since a proper soil structure depends on levels of organic matter, this difference in nutrient levels of soils already suggests the larger vulnerability of arable land to erosion when compared with permanent grassland.

The areas in Europe most affected by erosion can be subdivided into roughly two parts, viz., the erosion that occurs on the loamy soils north of the Alps in the Northwestern part of Europe (especially in the United Kingdom, Belgium, The Netherlands, Germany and France), and the erosion that is occurring in the Mediterranean area (such as in parts of Greece, Spain and Italy). The productive loamy soils erode largely because of compaction. In the Mediterranean area, soil erosion is mainly the result of low levels of nutrients and organic matter. The Mediterranean area has long shown a high vulnerability to environmental factors such as climate, and large areas are already degraded and the original top soil is absent. Rainfall is a critical factor with respect to the potential erodibility of the soils, since areas with a maximum annual rainfall of around

400 to 600 mm tend to have an increased potential for erosion.

Erosion is not only causing problems for agricultural productivity, but also for leaching of nitrogen and phosphorus. In addition to that, erosion may also cause problems for settlements in lowlands, which may be damaged by flooding through the transport of water and mud.

3.4. *Toxification of soils*

Toxics in soils include heavy metals, organics and pesticides. Toxification of soils may result from mining of land, waste dumping, former industrial sites, and changes in agricultural activities. Metals such as zinc, copper and lead are toxic to plants. The toxification of soils from current industrial activities (mainly chemical industry and metallurgy) in Poland is discussed by Carter (1986). There, toxic industrial dust and gases affect soil productivity seriously, especially in the Upper Silesian Area, which is a highly industrial region with steel production and thermal power stations that rely heavily on brown coal and lignite.

Chemicals have been used for a long time in agriculture, primarily to control pests and diseases. A major point of concern of potential soil toxification is the ongoing accumulation of heavy metals in topsoils (e.g., the top 20-25 cm of soils), since a positive balance exists for almost all materials and buffer capacity can be exceeded, although that may take decades to centuries. Until the buffer capacity is used up, the cumulating heavy metals do not have direct effects on, for example, plant growth, but at some point plants cannot sustain additional levels, without highly negative growth effects. Fauna have very slow adaptation rates, and cannot withstand the processes that are now taking place. Toxification is an irreversible process, such that land recovery is very complicated when the buffer capacity is used up and the soils become toxic.

3.5. *Depletion of nutrients and organic matter*

Organic matter in the soils is an important source of soil nitrogen and micronutrients, it may improve the water retention capacity of the soils, and it provides a proper soil structure. The depletion of organic matter and nutrient content of soils is a fourth type of soil degradation that is determined to a large extent by the kind as well as the way of crop growth. This kind of degradation occurs when more nutrients are removed from the soils than are replaced. It is complicated by the fact that chemical fertilizers are so greatly used, making it difficult to determine whether soils are in fact losing fertility.

Acidification of soils is an important source of toxification and depletion of nutrients (see Kauppi et al., 1986). This kind of land degradation is mainly occurring on forest soils, and will not be further explored here, since the major focus is on degradation of agricultural land. Depletion of nutrients and organic matter in soils is often interpreted as a problem that results in a loss of soil fertility. However, the depletion of soil nutrients is primarily related to problems of groundwater and surface water. Nitrate especially is causing problems for the supply of drinking water, and the EC has established a regulation for drinking water with a maximum allowable concentration of 50 mg/liter. Phosphate may cause problems for surface water due to eutrophication. Much recent research has focused on the leaching of nitrate to groundwater and surface water from high levels of fertilizer use in modern agriculture. The leaching of nitrate from a clay soil under grass and cereal crops was estimated for Finland by Jaakkola (1984). That study showed lower levels of leaching than in Denmark, explained partly by the smaller fraction of clay material and the longer frost-free period in the Danish situation. This indicates a potential link between this kind of soil degradation and a possible change in climate. An increase in winter temperature and a related longer frost-free period may make the soils more vulnerable to nitrogen leaching. A link between depletion of organic matter levels in the soils and climatic factors was also mentioned by Imeson and Dumont (1987) who indicate that the depletion of organic matter might increase in the Mediterranean area, due to an increasing water deficit in this part of Europe.

3.6. *Salinization of the soils*

Salinization is a kind of soil degradation that occurs mainly as a result of salt accumulation from surface evaporation of groundwater or irrigation water. "The rate of soil salinization is proportional to the volume of evaporated ground water and to the concentration of salts dissolved in it" (Kovda, 1983, p. 92). On seacoasts, marsh lowlands and deltas, the emergence of salinized soils is accelerated by the fact that sea water easily transports soluble salts to the land. Large quantities of salt are accumulated in groundwater and in soil as a result of evaporation.

Soils and plants that are affected by salts (such as by sodium chloride and sodium carbonate) will produce less biomass. Salinization occurs when plants absorb the irrigation water and leave the concentrated salts behind. The humus soil fraction is then oxidized and soil fertility is reduced (Kovda, 1979; Pearce, 1987). The soils are then unfit for agricultural use, and groundwater as well as drinking water may be contaminated.

The accumulation of salt in soils is a slow process. Szabolcs (1986) noted the long-term effects of salinization from irrigation in the valleys of the rivers Tigres and Euphrates in the Mesopotamia area. This area had very fertile soils and produced food for large populations some two thousand years ago, while the area is now mainly desert. The world's irrigated agricultural land increased rapidly over the last two hundred years, especially to enable an increase in the yields. In 1800, about 8 million ha were irrigated, increasing to 50 million ha by the turn of the century, and then steadily increasing to 200 million ha in 1980 (Szabolcs, 1986). Irrigated agricultural land in Europe (excluding the USSR) increased over the last decades from 6 million ha in 1960 to over 14 million ha in 1980 (Table 1). Table 2 shows the main trends in irrigated land of some European countries.

Table 2. Main trends in irrigated land of some European countries (in million ha). (Source: FAO production yearbooks).

year	Bulgaria	France	Italy	Romania	Spain	Europe
1960	0.40	0.10	2.44	0.20	1.83	6.00
1970	1.00	0.54	2.60	0.73	2.38	10.79
1980	1.20	1.09	2.87	2.30	3.03	14.45
1983	1.20	1.14	2.95	2.50	3.13	15.31

The rain water used for crop growing normally has only 10 to 30 mg/l of salts, while irrigation water from large rivers may contain between 200 and 500 mg/l of salts. This means that when 10,000 m^3 of water are applied to 1 ha of land during an irrigation season, in total 2 to 5 tons/ha of salts are deposited on the soil surface. The result of this salt accumulation is a destabilization of aggregated soil particles, rendering them more vulnerable to erosion.

The salt-affected soils in Europe have been mapped by Szabolcs (1974), who shows that about 12 European countries currently suffer salinization of irrigated soils, namely Austria, Bulgaria, Czechoslovakia, France, Greece, Hungary, Italy, Portugal, Romania, Spain, USSR and Yugoslavia. Nowadays about 47 million ha of land is affected by salinization in the USSR while in the rest of Europe about 3.5 million ha of land is salinized. Salinity occurs particularly in arid and semiarid regions, although the present extent of salinized soils in Europe indicates that this type of soil degradation is not limited to arid regions.

The potential for salinization may change drastically due to changes in the environment. A major potential source for future soil salinization (as well as groundwater) in Europe may be rising sea level. This process of salinization would then be a source of soil erosion. The present model results and empirical studies indicate a sea level rise around the European continent of between 20 and 140 cm in the next 50 years. This kind of soil degradation, which may become apparent over the next decades, may therefore cause serious problems for groundwater and soils in the lowland coastal areas of Western Europe (France, Belgium and The Netherlands).

4. Climatic change and changing land use patterns

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

A shift of climate is expected to occur on a global scale due to increased atmospheric concentrations of carbon dioxide and other 'greenhouse gases', and may result in global warming. Recent estimates, based on simulation experiments and empirical studies on increases in atmospheric CO_2, suggest an annual global warming of between 1.5 and 4.5^oC due to a doubling of atmospheric CO_2 concentration (see for example, Smagorinski, 1983). The present levels of atmospheric CO_2 are around 340 ppm, and are expected to double by the middle of the next century compared to the level of some 300 ppm from about 1850 when humankind began to burn fossil fuels extensively. This scenario of increasing CO_2 is partly based on (uncertain) long-term projections of fossil fuel consumption.

This kind of broad-scale and long-term climatic change would have profound effects on all kinds of land use, including both natural and managed vegetation. A primary effect of increasing carbon dioxide is that production will be stimulated, owing to increasing photosynthesis rates. The production of cereal crops may increase due to such an increase in atmospheric carbon dioxide concentrations, although Crosson (1986) also emphasizes that the supply of nutrients other than carbon dioxide might be more important for crop growth. However, he emphasizes that 'some regions now marginal for crop production because of climate may become even more so' (Crosson, 1986, p. 109).

The order and magnitude of effects on land use due to a change in temperature and precipitation depend on which of them is critical to growing crops. The major critical climatic factors for growing crops in the boreal and sub-arctic part in Northern Europe include temperature, the length of growing season, and the rainfall distribution. An increase in crop production is expected to be a major positive effect of a shift in climate in this part of Europe. However, in the Mediterranean area, a temperature increase is likely to have serious implications for (i) water supply (quality and quantity), (ii) soil and water conservation (e.g., water and nutrients retention capacity, sedimentation, flooding, and erosion).

Various climate models have been developed during the past decade to simulate the global effects of changes in atmospheric carbon dioxide concentrations, such as the model from the Goddard Institute for Space Studies (the GISS-model) and the model from the British Meteorological Office (hereinafter referred to as the BMO model). The global warming in the twenty-first century may vary in spatial and seasonal pattern. An increase in temperature in Europe is found in all simulation experiments of the climatic effects of increased carbon dioxide levels (Bradley et al., 1987). The annual temperature increase in Europe over the next 100 years may range between 0 and 4^oC. The temperature change in winter may vary from -0.5^oC to $+4^oC$ for the Mediterranean area, between +4 and $+6^oC$ in Central Europe, and even between +5 and $+10^oC$ in Northern Europe. The average summer temperature increase may be in the range of 2 and 6^oC for the Mediterranean area, and around 2^oC for the rest of Europe.

A "not-impossible" pattern of annual precipitation and temperature in Europe for the twenty-first century results from use of a General Circulation Model (GCM), namely in this case the BMO model, with a scenario of doubling of atmospheric carbon dioxide concentrations. This scenario has been selected here for a further investigation on the possible effects of climate change to changes in land use and land degradation factors, mainly because the simulation results of precipitation change include a wide variation over Europe. The simulation model shows an increasing trend in annual temperature of about 3 to 4^oC all over Europe. However, the possible change in precipitation might be even more important than the change in temperature, because of the changes in the hydrological cycles (precipitation and (potential) evapotranspiration).

Figure 1 and 2 show the present and "not-impossible" future situation of precipitation in Europe. The present situation of annual precipitation (which is based on averages of a thirty years period from 1931-1960) is presented in Figure 1 (see Müller, 1982). The annual precipitation levels for Europe, that result from the BMO simulation are given in Figure 2. Comparing these two figures shows that annual precipitation roughly would increase north of around 50^o latitude, and decrease south of it. The annual increase in Northern Europe might be as large as 150 mm. A considerable decrease in annual precipitation levels might occur in the Mediterranean area, being as large as some 300 mm in parts of Southeastern Europe.

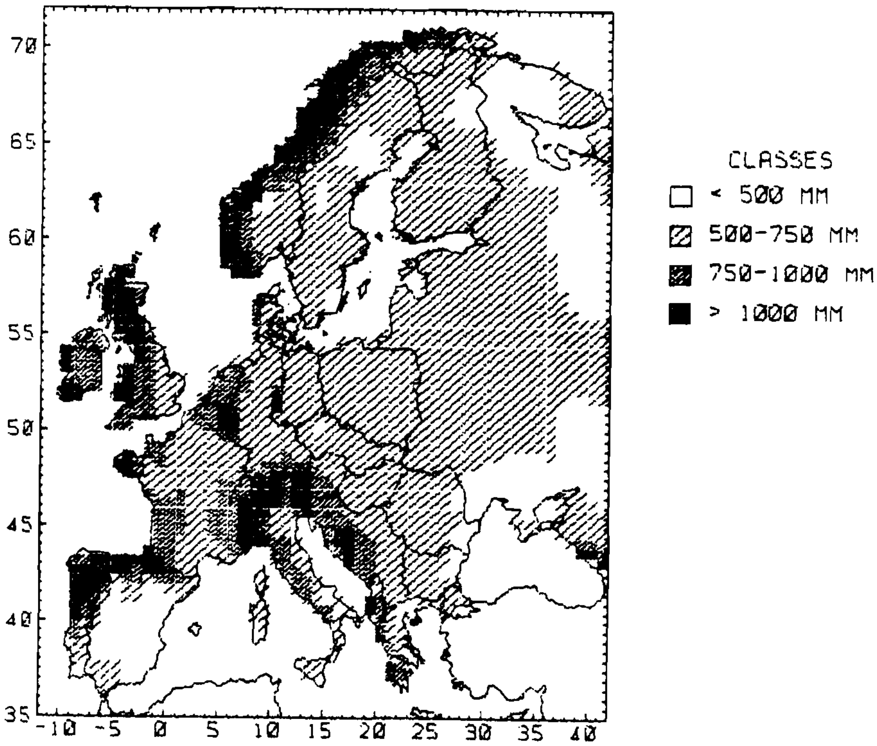

Figure 1. Annual precipitation levels in Europe (source: Müller, 1982).

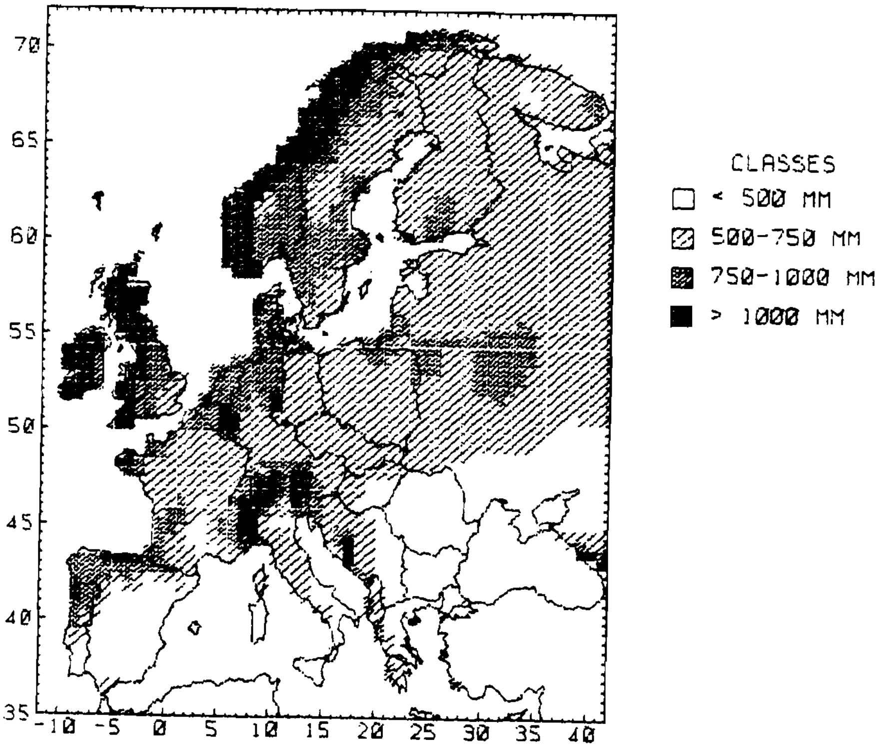

Figure 2. Future annual precipitation levels in Europe (source: BMO scenario).

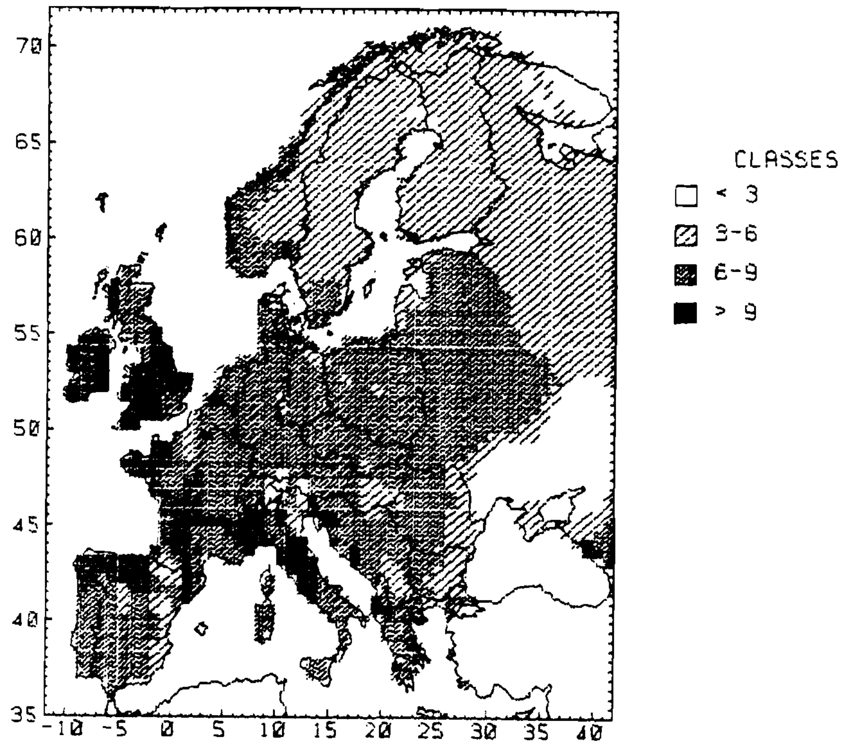

Figure 3. Growing period in Europe (in months).

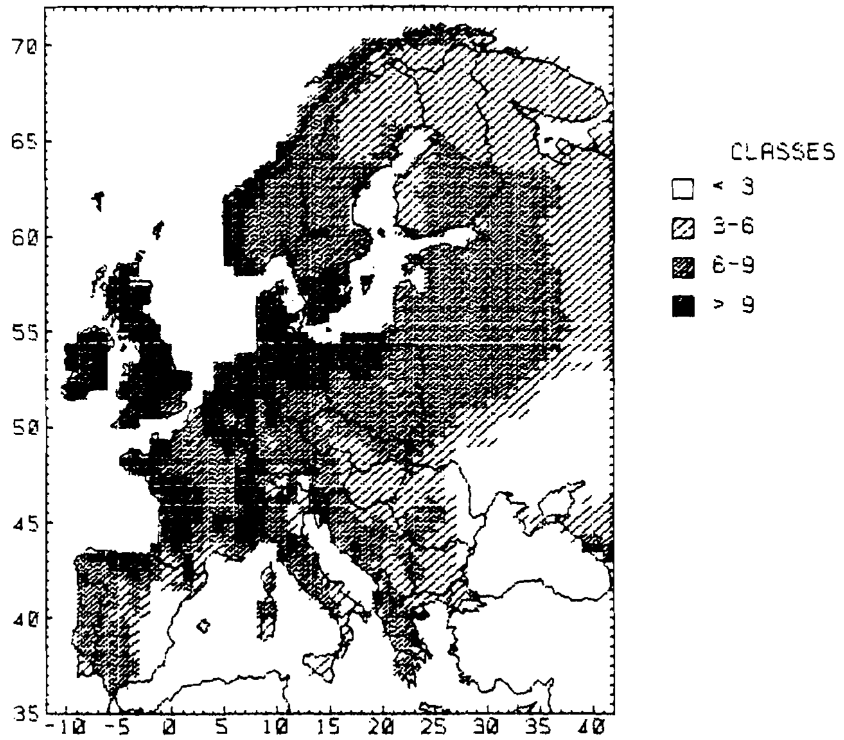

Figure 4. Future growing period in Europe (in months) for the BMO scenario.

The period for growing crops is based on temperature and moisture criteria. The moisture criterion is based on a comparison of precipitation with potential evapotranspiration. Potential evapotranspiration is defined here as the evapotranspiration from a moist surface which is so small that it does not affect the vapor content of the air. The critical temperature for plant growth is chosen to be $5^{o}C$. The growing period is then defined as the period during the year (in months) that the monthly precipitation exceeds half of the potential evapotranspiration, and that the monthly temperature is at least $5^{o}C$. Figure 3 and 4 show the growing period for Europe, successively under present climatic conditions and under the BMO scenario for an equilibrium greenhouse warmed earth, i.e., about 100 years into the future.

By comparison of the present climatic conditions with the BMO scenario, the growing period will increase in the Nordic countries (Norway, Sweden and Finland), and in the Northwestern part of Europe. This increase is due to the rise in temperature during the growing season, while soil moisture is not a limiting factor in that part of Europe for growing crops. The growing period will decrease in the whole Mediterranean part of Europe, where it becomes less than three months in the Southeastern part of Spain, and around the Black Sea region of the U.S.S.R. Soil moisture deficit will increase in this part of Europe, since on the one hand seasonal precipitation will decrease, while on the other hand potential evapotranspiration will increase due to a rise in temperature. The reduction in summer soil wetness in various parts of Europe due an increase in atmospheric carbon dioxide was also described by Manabe and Wetherald (1986).

Some possible changes in soil degradation processes owing to a climatic change by the BMO scenario are described in qualitative terms in Table 3.

Table 3. The occurrence of soil degradation in some parts of Europe.

Degradation	Mediterranean	Northwestern Europe
Soil erosion	Increasing soil moisture deficit.	Increasing runoff causing an increase in water erosion on the loamy soils. Coastal erosion and shift of sediments due to a sea level rise.
Salinization	Increasing requirement for irrigation in growing crops.	Increasing due to saltwater intrusion in groundwater of the coastal lowlands.
Depletion of organic matter and nutrients	Increasing soil moisture deficit.	Intrusion of salts in groundwater due to sea level rise.

An increase in soil moisture deficit would accelerate various soil degradation processes in the Mediterranean area from wind erosion and depletion of nutrients and organic matter. An increasing water availability in the Northwestern part of Europe would also lead to soil degradation from increased water erosion. Furthermore, salinization might increase in both parts of Europe; in the Mediterranean area from increasing use of irrigation for agricultural purposes, and in Northwestern Europe in the coastal areas of the lowlands from sea level rise and salt water intrusion in groundwater.

5. Conclusion

The post-war period in Europe was characterized by many unforeseen land use transformations. For example, the total coverage of arable land decreased by about 10% over the past 30 years. Such unforeseen land-use changes were mainly responses to socio-economic and technological changes (Table 1). The use of land also depends on environmental processes, climate and soils being the major ones. Such environmental processes may change over long periods.

Land use in Europe will have to respond over the next 100 years to accommodate broad scale environmental transformations such as global climatic change. Various types of soil degradation are major critical long-term soil factors for land productivity. Such degradation factors may be apparent at a local scale (such as depletion of organic matters and nutrients), a regional scale (such as water erosion on the loamy soils in Europe north of the Alps), or at a continental scale (such as salinization of soils which may become a serious problem in the next century in the coastal areas of Western Europe due to a sea level rise).

Acknowledgement

The author is indebted to P. Duinker and A. Solomon for their comments and suggestions on a draft version of this paper.

The Study is supported by the Dutch Ministry of Housing, Physical Planning and Environment, and the French Ministry of the Environment.

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