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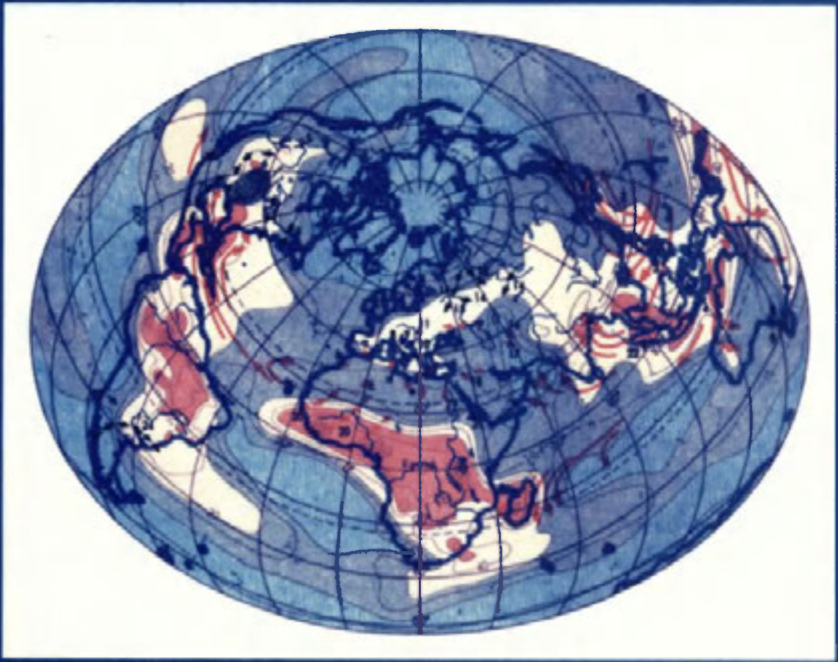

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GEOGRAPHIA POLONICA

PAPERS in GLOBAL CHANGE IGBP, No. 6

Guest Editors:
Lech Ryszkowski and Andrzej Kędziora
Polish National IGBP Committee

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STATE OF THE ART IN THE APPRAISAL OF GLOBAL CLIMATE CHANGE PHENOMENA

There is now a widespread conviction that global climatic changes are becoming one of the most important phenomena impacting upon the environment across the globe. An ever better understanding of the natural processes conditioning the climate combines with the gathering of observational data, as well as the increased calculational possibilities afforded by large computers, to allow for the recognition of global warming induced by the so-called "greenhouse effect". The organization of this research has been expressed through the establishment of the Intergovernmental Panel on Climate Change (IPCC) at the end of the 1980s, and through the consequent proposing of a UN Framework Convention on Climate Change (UNFCCC) for the "Earth Summit" Conference held in Rio de Janeiro in 1992. It was in this way that the problems of climatic change took on political significance – a phenomenon attested to *i.a.* by the Convention's ratification by 176 countries to date. The combatting of emissions of greenhouse gases has become one of the fundamental elements of environmental policy in these countries. Although not everyone is as yet convinced about the ongoing enhancement of the greenhouse effect, it has to be said that the majority of scientists, politicians and circles in society are treating the possibility of climate change in the approaching century seriously. If a policy to combat the negative consequences of climatic change is to be effective it should be based on a good knowledge of the more important factors determining such change. This is hard to achieve because the state of our knowledge regarding the processes that shape the climate is still advancing, and those politicians who do not wish to believe are unwilling to accept brand new scientific discoveries.

This fact may be illustrated by reference to what was established at the 1997 Kyoto Conference. Participants there included delegations from c. 160 countries which were interested in drawing up a policy by which to limit emissions of greenhouse gases (GHG) within the framework of UNFCCC implementation. In accordance with the so-called Kyoto Protocol, industrialized countries are to limit GHG emissions or increase net carbon sequestration in terrestrial carbon sinks. The possibility of applying two options in the control of GHG by relying on limitations on GHG emissions or carbon sequestration is a dynamic way of combatting the effects of GHG, which allows particular countries to be somewhat flexible in their policies. However, carbon sequestration was only defined in terms of the processes of afforestation, reafforestation and deforestation. In accordance with the Kyoto Protocol, afforestation means the act of establishing forests on previously non-forested land, while reafforestation is the establishment of forests on land previously covered by forests, and deforestation the removal of forest. In accordance with these definitions, the carbon sequestering processes are confined to those that bring about the storage of carbon in forests. However, terrestrial ecosystems have many other processes by which carbon can be sequestered, like storage in the soils of cultivated fields, grasslands and wetlands, and others. However, these are not taken into consideration under the Kyotot Protocol, despite the fact confirmed by scientific research that they may in some regions have much greater significance on carbon cycling than forests. The lack of such recognition may significantly distort the correctness of the actions set out in Kyoto with a view to limiting the concentrations of GHG in the atmosphere.

At this point, we would like to draw attention to a further difficulty in the relationship between science and policy. Kyoto provisions regarding CO_2 are not based on the carbon balance worldwide. A correct quantitative assessment of carbon cycling is very hard to achieve, and the methods used to do this will undoubtedly be much improved in the not-too-distant future. Leaving aside the existing difficulties, the assessments made so far have shown that carbon emissions from fossil fuels and industrial activity are currently running at c. 6.5 Gt a year. This is about 10% of total annual carbon emissions into the atmosphere (IGBP 1988)[1]. Carbon storage in the biomass of living plants (e.g. trees) represents only a temporary withdrawal from cycling. In the course of the decomposition or burning of plant biomass the carbon therein is re-released to the atmosphere. Of much greater significance in the sequestration of carbon is its storage in humus, whose decomposition time is very much longer. For this reason, an effective policy of carbon sequestration should make use of the processes by which humus is created and seek then to limit its mineralization if the action taken is to work over a longer time period.

The above remarks demonstrate the difficulties which have to be overcome in building a consensus between scientists and politicians. No less difficult, and perhaps more difficult, is to account for economic or legal aspects in devising methods by which to implement the UNFCCC. These issues have been discussed in more detail in the paper from **M. Sadowski** published in the presented conference materials.

Both the Kyoto Protocol and other proposals for using biological processes in carbon sequestration attach particular significance to forests, while other terrestrial ecosystems – most notably agroecosystems – are assigned a more minor

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[1] IGBP, 1988, *The terrestrial carbon cycle: implications for the Kyoto Protocol*, Science, 280, 1393–1394.

role. It would seem that this is an undeserved state of affairs, since the agricultural landscape is the dominant land-use form in many countries and since methods of cultivation may favour the accumulation of organic matter in soil, while improper cultivation may induce intensive processes of the mineralization of organic matter leading to the liberation of considerable amounts of CO_2. Thus, in relation to the method of soil cultivation, cultivated fields may be either major sources or sinks of carbon. The functions of forests are also looked at too one-sidedly, with the main role acknowledged being that of the accumulation of carbon in tree mass. With a view to discussing these issues further, the Polish National IGBP–Global Change Committee joined the Research Centre for the Agricultural and Forest Environment of the Polish Academy of Sciences in launching a Conference on **"The Effects of Global Climate Change in Forestry and Agriculture"**, which was held on December 10th 1998, in Warsaw.

The options for carbon sequestration in Polish forests are evaluated in a paper presented by **K. Rykowski**, who indicates that 6.1% of the total carbon emission from industry is offset by carbon assimilation by trees. Polish options for carbon sequestration would thus seem to be similar to the overall situation globally. The research discussed by **A. Breymeyer** and **R. Laskowski** confirms the results of research done previously in indicating that, as lower temperatures and rainfall levels occur, there is a decline in the rate of decomposition of forest litter. Climatic factors explain c. 40% of the variability in rates of decomposition of needles and mixed litter noted along the analyzed gradient of sites on a 1800 km transect. This result shows that the impact of changes in climate will not be reflected directly in litter decomposition in boreal forests, but will rather be modified by other factors.

Four Conference papers discussed the function of rural areas in generating the greenhouse effect. **B. Jakubiak** presented a general characterization of the numerical climate models used to predict the influence of the enhanced greenhouse effect on agriculture, while **E. Nalborczyk** and co-authors addressed the issue of assessing the emission and absorption of GHG on Poland's agricultural land. According to their assessments, agricultural land retains 3–6% of the annual carbon flux. If these assessments gain confirmation in further research, then cultivated fields would be seen to have considerable possibilities where carbon storage is concerned.

The influence of anticipated climatic change on Poland's agricultural output was the issue raised by **J. J. Lipa**, who pays particular attention to the impact of pests and pathogens on crops. It is probable that many new pests will emerge as the climate warms.

The modelling of atmospheric phenomena continues to develop apace, as does recognition of the causes of climatic warming and prediction of the many and varied changes it may bring. However, work now beginning to appear is also seeking to emphasize the major significance for the functioning of the atmosphere of changes in land use. Thus, for example, Pielke *et al.* (1991)[2] or Stohlgren *et al.* (1998)[3] have shown that changes in land use have a greater impact on regional climate and water resources than global climate change alone would have. As mentioned, this theme is only now beginning to be explored, but it was represented at the Conference by the paper from **A. Kędziora** and **L. Ryszkowski**, who indicate that land-use changes in the next few decades will have greater impacts on the convectional transport of energy into the atmosphere than would the assumed effects of climate change with no accompanying differences in land use. Equally, this shows that by increasing the structural diversity of the landscape, it is possible to mitigate the effects of global climate change to some extent.

In summary, the papers presented at the Conference can be said not only to have assessed the roles of forest and agricultural areas in Poland where global climate change is concerned, but also to have broadened and deepened our knowledge of the impacts ongoing between terrestrial ecosystems and the atmosphere. In consequence, they may find good application in policy seeking to combat global climate change.

Lech Ryszkowski, Andrzej Kędziora
Guest Editors

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A CRITICAL EVALUATION OF THE IMPLEMENTATION OF WORLD POLICY ON MITIGATION GLOBAL CLIMATE CHANGE

MACIEJ SADOWSKI
Climate Protection Center, Institute of Environmental Protection
Kolektorska 4, 01–692 Warszawa, Poland

ABSTRACT: This paper discusses problems concerning the negotiation process of the United Nations Framework Convention on Climate Change (UNFCCC), and the Kyoto Protocol, at international level. In spite of a strong lobby trying to delay the decisions obliging countries to limit their greenhouse gas emissions (mostly from fossil fuels), over 150 countries signed the UNFCCC in Rio de Janeiro in 1992, then ratified this Convention aiming at the stabilisation of greenhouse gas emissions at the 1990 level by 2000 and next negotiated the Kyoto Protocol with new commitments regarding the reduction of emissions of greenhouse gases in the period 2008–2012.

KEY WORDS: global climate change, greenhouse gas emissions, United Nations Framework Convention on Climate Change (UNFCCC), Kyoto Protocol, Intergovernmental Panel on Climate Change (IPCC).

INTRODUCTION

For almost 100 years, the problem of the influence of greenhouse gases on the climate was of interest to scientists only. It was only in the mid 1970s that there came the first signs of disquiet in world opinion regarding the continuing increase in atmospheric concentrations of these gases and their possible influence on human life and activities. It was at this time that the first measurement series of atmospheric carbon dioxide concentrations were published for the Mauna Loa station in Hawaii, in operation from 1958 onwards. The first serious discussions involving both scientists and politicians took place at the 1979 World Climate Conference. The result was the establishment of the World Climate Programme, of which the aim was to generate the scientific bases upon which real changes in climatic conditions and their influence on humankind could be assessed. Two subsequent conferences held in Villach (1985) and Bellagio (1987) saw further position statements issued by countries regarding possible global warming, as well as the proposed involvement of politicians in the issue. This appeal struck a real chord in political circles, with the result that a whole series of political and scientific and political conferences were convened, and the Intergovernmental Panel on Climate Change (IPCC) established in 1988. Further steps were the

1992 UN Framework Convention on Climate Change (hereinafter the Climate Convention) and most recently the Protocol to it adopted in Kyoto in 1997 and referred to below as the Kyoto Protocol. The IPCC, which comprises ca. 10,000 scientists, engineers, economists and politicians from around the world, has published reports assessing climatic change – the first in 1990 and the second in 1996. The general conclusion to be drawn from these is that anthropogenic emissions of greenhouse gases do have an influence in warming the climate, and that the consequences of this process will be negative where the impact on future human activity is concerned. However, both reports have stressed the considerable degree of uncertainty which must be ascribed to the results obtained. This reflects the inadequacy of our knowledge of climate-generating processes on the one hand, and the complexity of the climate system on the other. It was in fact the results of the first IPCC report that lay behind the Climate Convention.

Like all theories, this one has had its supporters and detractors from the very beginning, and in both scientific and political circles. Opponents have founded their arguments upon two premises: that the results derived from climate modelling are of limited reliability, and that the apparent warming trend has reflected the heating influence of urbanized areas on temperature measurements made at the meteorological stations whose data have been used to derive global temperature series. Some authors consider the observed increase in global temperature a result of natural processes, while still others cast doubt upon assessments made of temperature changes in past geological periods, questioning the methods of isotopic analysis used on ice cores. The majority of these accusations have been the result of either a lack of knowledge (for example as regards the methods of drawing up global temperature series or the warming influence of cities), substantive errors (the questioning of ice-core data) or perversity (the questioning of the results of models whose defects no authors seek to deny, but do instead work to improve).

BARRIERS IN NEGOTIATING THE CLIMATE CONVENTION AND KYOTO PROTOCOL

From the outset, the Climate Convention had a large number of opponents who sought to block the negotiating process by obstructing consensus-building, introducing numerous alternatives, proposing non-concrete solutions, etc.

The Convention's detractors have been (and are still) guided by narrowly-defined national interest or a defined lobby. To be included here first and foremost are the OPEC countries, which fear smaller exports of crude oil as a consequence of reduced CO_2 emissions, and many industrial, transport and power-supply lobbies, above all in the USA, Australia, China, Russia and Japan. These factors underpin the persistent blocking of the negotiating process by delegates from the countries in question. In this action they have many times based their cases on the aforementioned arguments apllied by scientific or pseudoscientific opponents of the warming theory. What is more, the lobby has financed its own scientific research with a view to disavowing the results set out in IPCC reports. The effects of these actions have however been mediocre.

The negotiation of more stringent obligations has also been opposed using such economic arguments as those relating to the costs associated with emission reductions (a 1% decline in national income), the resultant deceleration of economic development, especially in developing countries and those of Central Europe, etc. Use has also been made of political arguments, which hold that the Climate Convention increases poverty in developing countries.

Equally, however, an acceleration of the negotiating process and a stiffening of obligations have been demanded my numerous ecological organizations and movements, which were for example able to prevail upon President Bush to sign the Convention during the UNCED in 1992.

The adoption of more stringent obligations has also been pushed for by the Member States of the EU, and by the developing countries, albeit for different reasons. The EU wanted to force the United States to limit emissions in this way, while the developing countries sought to obtain the greatest possible amount of financial and technical assistance under the Convention.

This all came together to ensure the extremely slow progress of the negotiating process, and the emergence of approved fragments of the document that are characterized by a high degree of generality allowing for rather liberal interpretation. Thus, for example, the objective of the Convention was formulated in such a way that no quantitative assessment of progress in achieving it would be possible. Indeed, it does not even define whether attainment is possible at all ("The ultimate objective ... is to achieve ... stabilization of greenhause gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system"). In addition, the obligations imposed upon developed countries are open to a certain freedom of interpretation ("... developed countries ... return by the end of the present decade to earlier levels of anthropogenic emissions of carbon dioxide ...").

MEETING OBLIGATIONS UNDER THE CLIMATE CONVENTION

However, in spite of all these obstacles, the Convention has been adopted and ratified by nearly 170 countries, from among which the countries mentioned in Annex I to the Convention are obliged to stabilize emissions by the end of the century at the level in a given reference year (1990 for most countries). By the way, the idea of the end of the century has also aroused a certain amount of controversy among politicians. There are countries seeking to promote the view that 1999 marks the end of the century.

In the course of the negotiation process, a majority of the countries referred to in Annex I to the Climate Convention gave solemn assurances that there would

Table 1. Changes of total anthropogenic CO_2 emissions related to the reference year 1990 (100%) in 1990–1995 (excluding land-use change and forestry)

Country	1991	1992	1993	1994	1995
United States	99	100	103	104	105
Australia	101	102	103	105	109
Canada	98	101	101	104	108
Austria	107	97	96	96	100
France	106	106	99	99	102
Germany	96	91	91	89	88
Ireland	103	105	104	108	110
Japan	102	103	101	108	108
Netherlands	104	103	105	105	109
Norway	95	97	101	106	107
Sweden	100	101	101	106	105
United Kingdom	101	98	95	95	93
Bulgaria	68	62	64	61	64
Czech Republic	93	85	81	77	78
Estonia	98	73	58	60	55
Hungary	81	72	73	71	71
Latvia	78	66	58	48	49
Poland[#]	bd	78	bd	78	78*
Slovakia	88	81	77	72	81
Russian Federation	93	85	78	70	bd

[#] 1988 is the reference year for Poland,

* 1996,

bd – lack of data.

be no difficulty in their meeting the obligations adopted. However, as early as at the First Conference of the Parties (Berlin 1995), some of these countries (Norway, the United States and France) were not ashamed to admit that they were unable to meet obligations under the Convention. This problem was trumpeted by non-governmental organizations, which were very active during all the negotiating sessions of the First Conference of the Parties. It has recently emerged that the only parties meeting their obligations are the former socialist countries (on account of economic and systemic reforms and consequent recession), Germany (thanks to the modernization of the former East German economy) and the United Kingdom. 1990–1995 changes in emissions of CO_2 from anthropogenic sources were presented for selected countries in Annex I to the Convention (Tab. 1).

The Climate Convention also introduced a series of provisions concerned, *inter alia*, with the joint meeting of obligations by two or more countries, in the form of joint investments (the so-called joint implementation, mechanism-JI), the transfer of clean technologies to developing countries on preferential terms, or additional financial assistance to these countries.

Unfortunately, for a variety of reasons, none of these provisions are being implemented satisfactorily. The JI mechanism has been objected to by developing countries, which did not wish to agree to the party investing being allowed to count the emission reduction resulting from the development (the so-called credits) as a meeting of its own obligations. As a result, a pilot phase was instead put in place. Known as AIJ (Activities Implemented Jointly), this confers no credit – with the automatic result that few countries remain interested in this form of cooperation.

In turn, the preferential transfer of technologies is a utopian idea in the conditions of the market economy, where such technologies are traded in.

There is no great stream of additional funding either, for several very simple reasons. First, the developing countries do not have at their disposal the kind of large sums which could be assigned to donations. Second, the developing countries would like to obtain these resources with no donor control – something to which none of the donor countries will agree. Third, the obtainment of funding for precisely-defined undertakings requires very thorough justification and the drawing-up of proposals. Both are lengthy processes.

It can be seen from this review that, in the six years since the Rio Convention was signed, there has been only limited compliance with the obligations taken on. Sadly, there is no major indication that things will improve markedly in the period to the end of the present century.

NEGOTIATING THE KYOTO PROTOCOL

The First Conference of the Parties to the Convention decided to commence negotiations with a view to preparing a Protocol to it by the end of 1997. This was to set out a legal obligation to reduce emissions beyond the year 2000, with the time horizons accepted being 2010, 2015 and 2020. The two years of negotiations in practice confined themselves to exchanges of views and the continual announcement of new ideas. But each time that some standpoint seemed finally to have been agreed upon, opponents immediately appeared and the process had to begin from scratch once again. This was in fact the aim of the OPEC countries – especially Saudi Arabia and Kuwait – who made every effort to ensure that no Protocol emerged, whatever the price this might incur. The position of the United States – the world's number one emitter of greenhouse gases – was also ambiguous to say the least (as in fact was that of Russia). On the one hand the need for a Protocol was recognized by these countries, but on the other the adoption of obligations was avoided. In turn, Saudi Arabia responded to the agreed standpoint regarding the need to reduce emissions by demanding that developed countries who reduced their emissions should provide financial compensation for the limited importation of OPEC crude oil.

One extremely controversial issue was the demand from developed countries (including Poland) that the future commencement of a negotiating process should see certain "developing" countries take on an obligation to reduce emissions. The countries in question were the richest ones, such as those of OPEC and the so-called Asian tiger economies, in which national incomes were far in excess of those in many of the "developed" nations. This proposal evoked a large amount of dissatisfaction and indignation among the delegations of many developing countries, and most especially those of China, India and the Arab countries.

Thus, delegates arriving at the Kyoto Conference which was to adopt the Protocol did not bring a unified text with them, but rather a plethora of alternatives and proposals. It appeared that no adoption of a Protocol would be possible. It was only the arrival of high-ranking representatives of various countries at Kyoto (prime ministers, ministers and secretaries of state), and the holding of talks between the players behind closed doors, that led to the appearance of a new text of the Protocol, and then to its adoption in the course of plenary negotiations which continued uniterrupted for 28 hours. Unfortunately this element of haste and tiredness is reflected in the quality of the Protocol, which includes many imprecise formulations, undefined concepts and generalities.

The result of all the political games is that the obligations taken on have no linkage with the just division of burdens. This means, for example, that countries with the greatest potential for reductions – Russia and Ukraine – do not have to cut emissions at all, but merely to stabilize them, while Norway, Iceland, Portugal, Greece and Australia may even increase their emissions.

Thus the achievement of what is anyway an unclear objective of the Convention seems to be more and more distant. Many meetings and arduous negotiations will be needed if the formulations in the Protocol are to be given more precision. It is also unclear whether the required number of ratifications will be obtained. A fundamental question concerns the standpoint of the United States. Both Congress and the large industrial lobby are saying that they do not agree to the Protocol's being ratified. If it is not, then the whole process would become a fiasco. The Protocol only enters into force when it has been ratified by 55 of the countries mentioned in Table 1 whose combined emissions exceed 55% of the 1990 total emissions for all the countries listed. With this in mind, let us recall at the end that the emissions from the United States amount to more than 25% of this total.

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MAIN FEATURES OF GLOBAL CLIMATE MODELS AND THE IMPACT OF PREDICTED CLIMATE CHANGES FOR AGRICULTURE AND FORESTRY

BOGUMIŁ JAKUBIAK
Interdisciplinary Centre for Mathematical and Computational Modelling, Warsaw University
Pawińskiego 5a, 02–106 Warsaw, Poland

ABSTRACT: The atmosphere exchanges heat, moisture and momentum with other climate subsystems. All these interactions are modeled to a different degree of the accuracy, depending on the quality and resolution of data used. This paper describes some applications of climate models in agriculture and puts forward the argument, that recent climate models are very close to numerical weather prediction models. The physical parameterization approach implemented first in climate models, is now applied in a useful way to everyday agricultural management.

KEY WORDS: climate models, agriculture, interactions between climate system components.

INTRODUCTION

The components of the climate system such as the atmosphere, hydrosphere (oceans), cryosphere (snow and ice), lithosphere (land) and biosphere are open, nonisolated subsystems (Peixoto and Oort 1992). They are strongly coupled and characterized by intense interactions on various time and space scales. For climate modelling purposes the atmosphere is usually considered as the central system and the fluxes across the atmosphere-land surface boundary, the atmosphere-ocean boundary and the atmosphere-cryosphere boundary are taken into account. The interfaces constitute highly discontinuous boundaries for the various processes that occur in the atmosphere, and have a different influence on the atmosphere according to the nature of the underlying surface.

An important constraint for the surface flux is the conservation of total energy. The equation for the heat budget of an interfacial layer is fairly complex since many energy transfers and transformations from one to another have to be taken into account. These processes take place continuously both at and near the Earth's surface. Most of the transformations start with the absorption of solar radiation and end with the loss of infrared radiation to space. The incoming minus reflected solar radiation received at the Earth's surface is absorbed, leading to an increase in the heat content of the ocean's mixed layer or of the top layer of the soil.

Near the Earth's surface, the atmospheric circulation is strongly affected by friction causing marked modifications in the air flow. The tickness of the modified air grows in depth until a boundary layer 10's to 100's of meters tick is established. This planetary boundary layer is characterized by strong wind shear since the wind must vanish right at the surface. The strong wind shear combines with surface heating to lead to the development of a turbulent flow in the boundary layer, with eddies on various scales. The turbulent exchange of turbulent mixing constitutes a very efficient mechanism for the transfers of mass, momentum and heat both upward and downward through the boundary layer, thus linking the Earth's surface with the free atmosphere.

The exchange processes between the cryosphere and atmosphere have a profound influence in defining the cold polar and subpolar climates. The presence of ice and snow affects the structure of the planetary boundary layer leading to a local air temperature inversion, low air temperatures and certain feedback processes.

GLOBAL DATABASES

Investigation of climate changes and their impact on agriculture requires different types of data archives indispensable for both modelling purposes and statistical inference. The most useful are land cover data, climatic data and soil characteristization data.

To date, few comprehensive global land cover datasets have been created, documented and published. The most acceptable map is the global database compiled by Olson et al. (1985). It covers actual vegetation and has good documentation. Each item is clearly described by its vegetational structure, and the composition of its major species is listed. However, several agricultural land cover classes are combined with natural land cover classes and it is impossible to separate the two satisfactorily. An alternative approach to obtain a global database on land cover is to use remote-sensing techniques. Remote sensing can provide an adequate and timely description of global land-cover patterns with a coverage that is not obtainable with current ground-based surveys. Few years ago Townshend (1992) proposed classification of the remotely-sensed land cover database. The 51 classes from Olson et al. (1985) can be linked to the Townshend classification, and in this way it is easy to create an improved database when new information becomes available.

Another important dataset for running models concerns climate. Climatologists characterize a "normal" climate for each station or region by using a long-term average from weather records. Climatic normals are crucial for describing the interactions between climate and other components of the biosphere, such as vegetation. Climatic parameters needed to describe such interactions should be capable of representing monthly patterns of climate and include the most important aspects of air temperature (mean, minimum and maximum), precipitation (mean, range), radiation (cloudiness, sunshine duration) and humidity. For modelling purposes we need a high-resolution, gridded database which is interpolated separately for each monthly climatic normal. This database should be based on a large number of quality-checked stations, spread evenly throughout the world. Out of the few existing the best are from Leemans and Cramer (1991), who compiled their records mainly for the period 1931–1960 and have obtained reasonable global coverage. The dataset prepared by Bradley et. al. (1993) consists of a very long (1851–1980) time series of monthly precipitation totals and monthly air temperature means for stations from the Northern hemisphere.

The third set of data needed to develop and run a set of land cover models contains soil characteristics. Several digitized implementations of the FAO soil map of the world (FAO/UNESCO, 1974) have been created. Recently, the United Kingdom Meteorological Office has developed such a database for its mesoscale studies (Jones 1996). These data-sets all include soil, texture and slope classes and can be used in the derivation of such parameters as water holding capacity, soil fertility salinity and soil depth that are needed for modelling purposes.

DETERMINING THE POTENTIAL DISTRIBUTION OF VEGETATION, CROPS AND AGRICULTURAL PRODUCTIVITY

Climate-change models have been used with moderate success in such agriculture applications as the determination of potential land cover in different climate scenarios quite popular. Among these is the Terrestrial Vegetation Model (TVM), in which potential land cover is determined for both natural ecosystems and agrosystems. TVM consists of separate submodels for water-balance, global vegetation patterns, crop distribution and potential rain-fed crop yield. All these submodels are based on local climatic, hydrological and soil characteristics and appropriate global databases for these parameters are collected and compiled. The models give an adequate description of global vegetation and agricultural patterns.

The Authors of TVM define the potential distribution as that which exists under equilibrium conditions, i. e. those areas where a specific crop or ecosystem can occur. For ecosystems, the potential corresponds to a fully-developed and undegraded system. For crops, it is defined by those regions where conditions are adequate for the obtainment of an economically viable yield. The distribution here is only defined for completely rain-fed conditions. TVM plays the central role in the simulation of the terrestrial biosphere within the IMAGE 2.0 model (Alcamo et. al. 1994). It uses climate, if necessary, combined with climatic change (de Haan et al. 1994), providing a dynamic link between the impacts of global change and land cover. The main assumption within TVM is that there is strong linkage between climate, vegetation and crop distributions. TVM does not generate a specific climate classification, but uses limiting climate factors to determine the distribution of species. These factors should therefore describe plant responses more mechanistically and thus mimic important eco-physiological processes.

THE WATER BALANCE SUBMODEL

The water-balance model is based on the approach developed by Prentice et al. (1993). It is assumed that all water is transmitted to plants through the soil. Roots seize soil water, which is transported through stems to the leaves, where it transpires. Soil characteristics determine the extent to which moisture can be carried through into dry seasons. Water storage can be revealed locally, for each grid cell, by irrigation (or drainage); the excess of water disappears as runoff. The model is a simple bucket model that accounts for the hydrological budget of a single soil water store as driven by daily precipitation, drainage, air temperature and radiation. Output is actual and potential evapotranspiration. The main output of the soil moisture model is daily soil moisture availability (mm). This is a result of evaluating the daily difference between precipitation and actual evapotranspiration (P-AET) and soil water capacity (difference between field capacity and wilting point). If daily soil moisture availability is greater than soil water capacity, the excess is removed as runoff.

The water balance model can be used in combination with the temperature regime to define the characteristics of the growing season, which is defined as that period of the year in which warmth and soil moisture are adequate for growth. The growing period for crops is characterized by the annual pattern of daily evapotranspiration, precipitation and soil-moisture values. Growth only occurs at temperatures above 5°C.

The simulated vegetation patterns are difficult to validate. Leemans and Van den Born (1994) obtained a good correlation between the simulated patterns and the Olson et al. (1985) land cover database. However, such good pattern correlation was achieved without cell to cell comparisons. Inaccuracies between the initial data base and the simulated pattern will lead to major undesired shifts and unrealistic changes with major consequences for the carbon cycle. A partial solution to this problem could be achieved when better databases become available.

APPLICATION OF CLIMATE MODELLING RESULTS TO OPERATIONAL ACTIVITIES

From the practical point of view, climate models have a very positive impact on the implementation of physical parameterization of land-atmosphere processes for operational management in agricultural. The most useful tool for agricultural applications is the use of satellite data, coupled with state-of-the-art models of the land surface and atmosphere. In the TiSDat project developed at the University of Wisconsin (Diak et al. 1998), such tools are used for irrigation, frost protection of high-value crops and plant disease management.

IRRIGATION

Irrigation is important for crops grown on sandy soils, where the water in the substratum is insufficient to supply the demands of plants and the amount of rain is limited. Irrigated regions are about twice as productive as non-irrigated agricultural land. A knowledge of daily evapotranspiration is fundamental for irrigation management. Evapotranspiration estimates require an estimation of incident solar energy at the surface and satellite data can be used for this purpose. Many cultivated crops have a utilization of water close to the potential evapotranspiration rate when soil water is not limiting. One of the simple methods of estimating potential evapotranspiration (ET_p) is the Priestley-Taylor equation

$$ET_p = 1.26(R_n - G)S/(S + \gamma) \qquad (1)$$

In this equation ET_p – is potential evapotranspiration ($\mathrm{Wm^{-2}}$), R_n – net radiation at the land surface (net solar flux + net thermal infrared flux, $\mathrm{Wm^{-2}}$), G – soil heat flux ($\mathrm{Wm^{-2}}$), S – the slope of the saturation vapor pressure curve with respect to temperature at the temperature of the air ($\mathrm{hPaK^{-1}}$), and γ – the psychrometric constant ($\mathrm{hPaK^{-1}}$). A positive sign for the various fluxes indicates a flux toward the surface.

The term (R_n – G) denotes the available energy at the surface of the Earth, which is partitioned into heating the lower atmosphere, used in the transpiration of water from plants and used for the evaporation of water at the soil surface. In most daytime conditions $R_n - G$ is the dominating term in potential evapotranspiration. The $S/(S+\gamma)$ term modulates ET_p, taking account of the way the slope of the saturation vapor pressure curve influences evapotranspiration. The empirical constant 1.26 amalgamates the effects of atmospheric turbulent transfer coefficients and the atmospheric water vapor pressure deficit.

The net radiation term is expressed as

$$R_n = S_o(1 - A) - L_u + L_d \qquad (2)$$

In this equation S_o – is the incident solar flux ($\mathrm{Wm^{-2}}$), A – the surface albedo (dimensionless), L_u – the upwelling thermal infrared flux ($\mathrm{Wm^{-2}}$), and L_d – the downwelling thermal infrared flux ($\mathrm{Wm^{-2}}$). The largest contribution to net radiation and available energy (R_n – G) during daytime hours is usually the net solar energy at the surface. The incident solar flux is estimated from satellite data. A surface albedo of 0.25 is used to estimate net solar radiation.

The net thermal infrared flux term (L_n) for total net radiation consists of two directional terms, the first being the upward thermal radiation emitted by the surface (L_u) and the second the downwelling thermal radiation to the surface emitted by the atmosphere and clouds (L_d). Under clear conditions, the net effect is usually a loss of energy from the surface, with instananeous values ranging from approximately 50 to 150 Wm^{-2}. When clouds are present, this net loss from the surface is normally reduced from the clear-air value.

The upwelling thermal radiation from the land surface is estimated using the surface air temperature from synoptic weather service reports as the emitting temperature in the Stefan-Boltzmann relationship, that is,

$$L_u = \varepsilon\delta\, T^4 \tag{3}$$

In this equation ε – equals surface emmisivity (presumed = 0.98 for vegetated surfaces, dimensionless), σ – is the Stephan-Boltzmann constant (5.67∗10-8 K-4) and T – is the surface emitting air temperature (K). The daytime net long-wave radiation budget is estimated first by calculating clear-sky emissivity (εc, dimensionless) as a function of the air temperature and air vapor pressure of the lower atmosphere. The equation for net long-wave radiation at the surface under clear conditions is then

$$L_{nc} = L_u(1 - \varepsilon_c) \tag{4}$$

When clouds are present, the ratio C (dimensionless) is calculated by dividing the actual incident solar radiation by a theoretical value calculated for clear-air conditions. C is used to estimate the influence of clouds on clear net surface long radiation and the resultant cloudy net long-wave radiation is then calculated using the expression

$$L_n = L_{nc} * C \tag{5}$$

This has the desired effect of reducing the net long-wave flux from its clear-sky value when clouds are present. While the estimation of the L_n – term in the radiation budget may have large relative errors compared to the range of potential values, this net thermal radiation for daytime periods is usually small compared with the solar component of total net radiation. As a result, errors in the total net radiation budget caused by errors in estimating L_n – are relatively small. The ground flux term G – in formula (1) is often also a smaller term in the energy budget of the land surface, especially for vegetation-covered soil. On average, the daily conduction total is 0.10 times the daily net radiation.

FROST PROTECTION OF HIGH-VALUE CROPS

Successful prediction of air temperature near the freezing point of water depends on the skillful description of the temporal evolution of many subtle environmental factors that influence air temperature, such as humidity and wind speed in the lower atmosphere and cloud conditions, as well as on the possession of relatively good information on the structure of a particular soil and canopy. From non-advective situations, the net loss of thermal radiation from the surface is the forcing that drives the cooling of the lower atmosphere. Thus, one of the most important pieces of information in predicting whether there will be an overnight frost is whether a region is clear or cloudy. When clouds are present, more thermal energy is returned to the surface due to downward emission by clouds than when the atmosphere is clear. As a result, the surface as well as the air near the surface-stays warmer, and the chance of frost is reduced.

In the TiSDat project the minimum-temperature forecast system relies on a combination of satellite cloud information and synoptic upper-air and hourly surface measurements of air temperature, humidity and windspeed. Several computer forecast models based on the physics of the atmosphere and land surface are supplemented by a statistical adjustment procedure, in order to interpret data sources and predict if freezing temperatures will occur overnight.

PLANT DISEASE MANAGEMENT

A final aspect of crop management to which authors bring the tools of remote sensing, modeling and the Internet is the management of foliar diseases in the potato. The threat posed by these diseases depends significantly on temperature and humidity within the crop canopy and the presence of free water on leaves. Free water on leaves can be supplied by rain, irrigation or dew, while the residence time of the water is influenced by the ambient net radiation (supplying energy for evaporation during the daytime or influencing whether the night-time canopy air temperature falls to the dew point temperature at night), as well as the atmospheric humidity and temperature conditions.

OUR POSSIBILITIES

One of such models which could be used for agricultural purposes is the UMPL numerical weather prediction mesoscale model, tested operationally at Warsaw University over a few years (Niezgódka, Jakubiak 1998). The model, implemented from the United Kingdom Meteorological Office Unified Model, is capable of the prediction and diagnosis of the basic surface fluxes needed for agricultural applications. The potential evapotranspiration, usully estimated very approximately, could be replaced by actual evapotranspiration computed from simulated latent heat fluxes presented on Figure 1 and 2. Such fluxes are strongly dependent on actual weather conditions and differences between summer and winter situations for selected hour (15 UTC in our case) equal near 100 Wm^{-2}. Figure 3 and 4 present downward thermal infrared fluxes in Wm^{-2} for 15 UTC on 10 July and 24 November 1998 showing the spatial and temporal variability which should be taken into account.

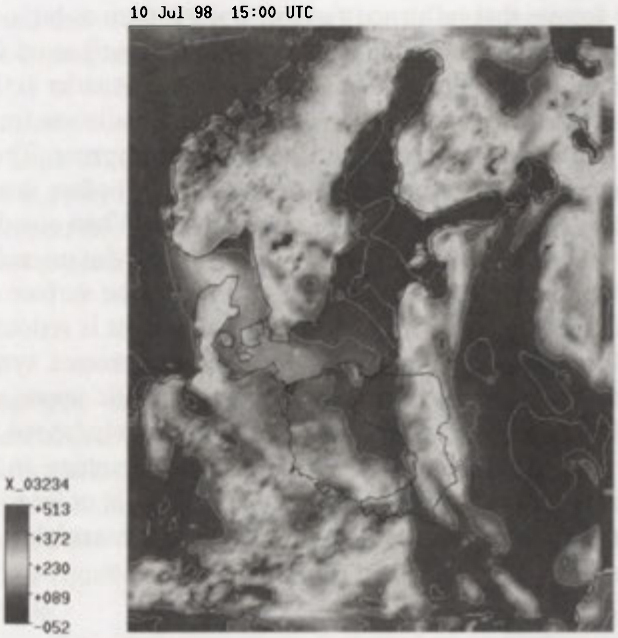

Fig. 1 Surface latent heat flux [Wm^{-2}] at 15 UTC, 10 July 1998 simulated by the UMPL model

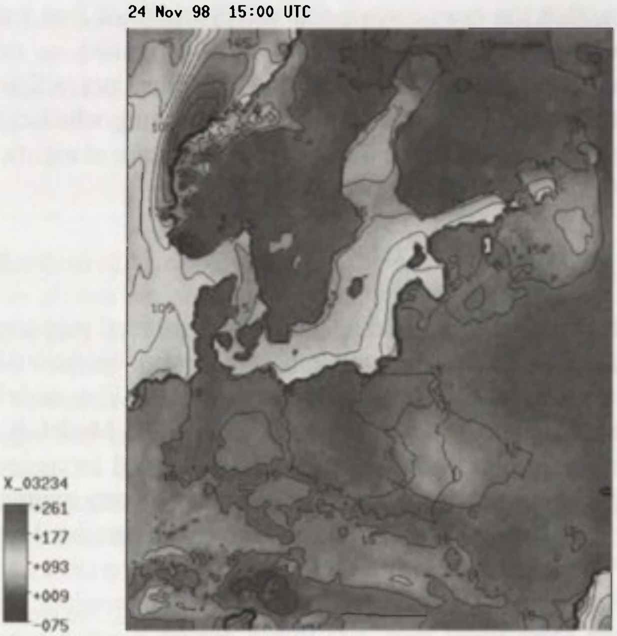

Fig. 2 Surface latent heat flux [Wm^{-2}] at 15 UTC, 24 November 1998, simulated by the UMPL model

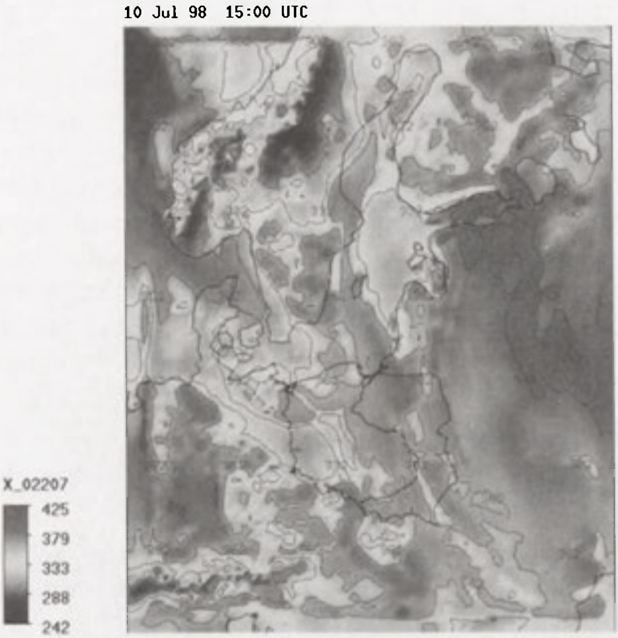

Fig. 3 Downward thermal radiation flux [Wm^{-2}] at 15 UTC, 10 July 1998 simulated by the UMPL model

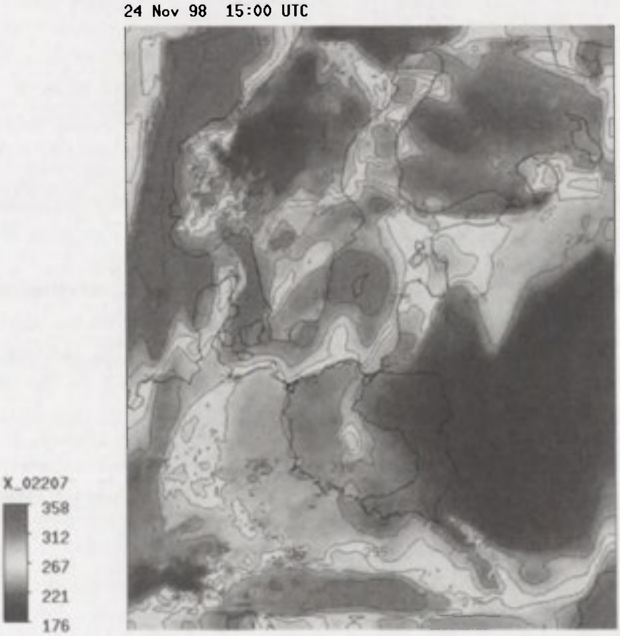

Fig. 4 Downward thermal radiation flux [Wm^{-2}] at 15 UTC, 24 November 1998, simulated by the UMPL model

CONCLUSIONS

As time passes, the distinction between weather-forecast and climate models becomes smaller due to the increased sophistication of parameterizations in weather forecast models and the increased resolution of climate models. It is now possible to reconfigure a global atmospheric circulation model for either weather forecasting or climate applications simply by fixing the resolution and making an appropriate choice from among available parameterizations. This is exemplified by the use of the UKMO Unified Model for both operational weather forecasting and climate simulations (Murphy and Mitchell 1995). At present, climate change models are capable of simulating the actual and predicted climate with errors dependent on the resolution and quality of the data used.

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ASSESSMENT OF THE IMPORTANCE OF FORESTS IN REDUCING GLOBAL CLIMATIC CHANGE (COUNTERACTING AND MITIGATING THE IMPACTS OF GREENHOUSE GASES)

KAZIMIERZ RYKOWSKI
Forest Research Institute, Department of Ecology and Environment Protection
Sękocin-Las, 09–090 Raszyn, Poland

ABSTRACT: Forests can contribute to increases in atmospheric levels of greenhouse gases (deforestation, bad harvest), are affected by changes in climate (change of natural range of forest tree species) and at the same time offer a unique opportunity to help mitigate future climate change. Forests contribute to the fight against the greenhouse effect in three ways: (1) carbon sequestering; (2) CO_2 avoidance through substitution by wood of energy-intensive materials such as plastics, aluminium, steal, cement and brick, (3) CO_2 avoidance by using timber instead of fossil fuels for generating energy. The effect of utilization of wood is even greater than that of fixation. Carbon storage would be optimized in plantation forests (reforestation and afforestation), harvested at the time of maximum mean annual increment, when the lifetime of the products exceeds the rotation period. The rate of carbon absorption by trees and forests is a function of growth and age – the rate is higher when they are fast-growing and young. There are some possibilities to increase the carbon accumulation ability of our forests: reconstruction of stands into ones of more adequate species composition; tending of the forest and to the creating of an opportunity to obtain so-called "thinning-induced increment"; the introduction of an understorey which could result in a increment in standing volume; the increase in the fraction of humus in forest soils which could be regulated by means of a preference for the forest regeneration model; resignation from clear-cutting and the afforestation of abandoned agricultural land. The role of Polish forests in reducing global change is not so important as far as the proportional contribution to world forest cover is concerned (0,002%) but from the domestic point of view and in the light of the obligation under the Kyoto Protocol, forest, forestry and wood utilization present a high interest for our environmental policy and an important element in the national development strategy into the 21st century.

KEY WORDS: carbon sequestration, wood utilization, forest management, climate change.

INTRODUCTION

Widespread recognition that changes in the Earth's climate system may potentially lead to a major threat to the global environment and economic development has been confirmed by the signing in Rio, by more than ISO Governments, of the UN Framework Convention on Climate Change (UNFCCC). The changes are attributable to human activities resulting in a substantial increase in the atmospheric concentration of greenhouse gases (GHG) perturbing the Earth's radiative balance.

The awareness of human responsibility led the countries to a conference held in Kyoto (December 1997). The parties to the UNFCCC agreed to sign a protocol to reduce greenhouse gas emissions by using the forces of the global marketplace to protect the environment. A central feature of the Kyoto Protocol is a set of binding emission targets for signatory countries. Forestry activities (such as afforestation) were agreed on as offsets against emission and forests were recognised as providing a chance to mitigate the greenhouse effect.

Poland has committed to reduce her GHG emissions to a level of 94% of the base emission from 1988 (before the period of transition).

Poland is a small (312.5×10^3 km^2) country with forest cover of ca. 28%, which constitutes very small portion (ca. 0.002%) of the world total. The potential for Polish forest ecosystems to mitigate the greenhouse effect on a global scale and in relation to a whole Earth threatened by CO_2 concentrations, is not significant and could from this point of view be neglected. But, from the domestic point of view, and in the light of the obligation under the Kyoto Protocol, forest and forestry present a major focus for our environmental policy and are an important element in the country's development strategy into the 21st century.

FORESTS AND CLIMATE CHANGE

According to the FAO definition "forests", are plant communities in which at least 10–20% of the surface area is covered by tree crowns. These account for roughly 3 459 million ha or about 27% of the Earth's land surface (FAO 1995).

"Other wooded areas" are defined as plant communities in which tree crowns account for less than 10–20% of the surface area and the vegetation consists mostly of shrubs, shrubby trees and thickets of woody plants between 0,5 and 7,0 meters in height. As these plant communities cover an additional 13% of the land area, more than 40% of the Earth's land surface supports of forests or other wooded areas. More than half of these areas are located in the tropics.

Green plants remove CO_2 from the atmosphere through photosynthesis. The carbon is stored in the foliage, stems, root systems and, most importantly, the woody tissues in the main stems of trees. Because of the long life span of most trees and their relatively large sizes, trees and forests are storehouses of carbon. Overall, forests store between 20 and 100 times more carbon per unit area than croplands, and play a critical role in regulating the level of atmospheric carbon.

The world's forests have been estimated to contain up to 80% of all above-ground terrestrial carbon and approximately 40% of all below-ground terrestrial carbon (soil, litter and roots). This amounts to roughly 1 146 Gt C (1 Gt = 10^9 t). Approximately 37% of this carbon is stored in low–latitude (tropical) forests, 14% in mid-latitude (temperate) forests and 49% in high–latitude (boreal) forests (Dixon et al. 1994).

There is much confusion and uncertainty associated with the climate change issue. The past decade has witnessed many studies designed to improve our capacity to predict future climatic trends and the ways in which human society might be affected. The results of these studies are often conflicting and unclear. The issues related to forestry are especially complex. The relation between climate change and the conservation and development of the world's forests is therefore an important issue to consider.

Forests and human uses of forests can contribute to increases in atmospheric levels of greenhouse gases and forests are also affected by changes in climate. In addition, trees and forests, because of their ability to absorb CO_2 and store carbon in woody tissues, offer a unique opportunity to help mitigate future climate change.

On the basis of the outputs of several global change models one can consider that: temperatures are expected to rise, precipitation will generally increase, the climate may become more variable and there could be an increase in the incidence of tropical storms. Warming could be much greater in the high latitudes and much more limited toward the tropics. The most extreme temperature increases are likely to occur in winter in the high latitudes of the northern hemisphere (boreal forests), where changes could be a much as 2,5 times greater than the global average.

Trees are expected to show both positive and negative effects of the changes in levels of GHGs in the Earth's atmosphere and expected changes in climate. One of the potential positive effects of increased levels of atmospheric CO_2 is known as the "CO_2 fertilization effect". It is known that CO_2 is a limiting factor in plant growth. Laboratory and field experiments indicate a ca. 30% increase in the photosynthesis process of plants which use the C_3 mechanism, with increasing root/shoot ratios implying more underground storage of carbon. (Plants possessing the C_3 pathway account for 85% of all plant species and include all trees and woody plants).

Related to the fertilizing effect is the fact that plants contract their stomatal openings at higher levels of atmospheric CO_2. As this results in more limited water vapour loss and an increase in water use efficiency, it implies possibility for increased plant growth in regions of the world with low precipitation. A study of the possible effects of higher water-use efficiency by plants, combined with the CO_2 fertilization effect, indicates that the area in which tropical rainforests could grow might increase by 75% with a doubling of atmospheric CO_2 while the area of deserts could shrink by 60% (Sombroek 1991).

When trees die or are harvested, the stored carbon is released. Some becomes part of the organic matter component of forest soils where, it can remain for long periods, depending on climatic conditions. The remainder is released into the atmosphere, largely as CO_2 but also as CH_4 or other GHG. The rate of release may be sow, as in the case of a single tree dying and being subject to years of breakdown and decay by fungi, insects, bacteria and other organisms. On the other hand, a sudden disturbance such as a wildfire or the clearing and burning of forests for agriculture and settlement by humans, can cause a rapid release of large volumes of GHG into the atmosphere.

Estimates for the year 1990 indicate that the low-latitude (tropical) forests (tropics) emitted 1.6±0.4 GtC per year into the atmosphere, primarily due to deforestation. This is equivalent to approximately 23% of total carbon emissions including from the burning of fossil fuels. This was offset by a sequestration of 0.7±0.2 GtC per year by forest expansion and growth in the mid (temperate) and high (boreal) latitudes (Tab. 2). Consequently, there is presently a net carbon contribution of 0.9±0.4 GtC per year to the atmosphere from the world's forest ecosystems (Dixon et al. 1994). This is undoubtedly due to increased rates of tropical deforestation during the 1980s.

DEFORESTATION

Deforestation – the felling and burning of forests to make land available for agriculture or livestock grazing, is the major forest-sector contributor to increases in the levels of GHG.

Human societies have been cutting forests for millennia. However, until the early part of this century, deforestation occurred mainly in temperate forests. More recently, it has been concentrated in the tropics. Deforestation, and associated burning, result in a massive and rapid release of carbon into the atmosphere, primarily as CO_2. Smaller amounts of CH_4 and CO are also emitted. Tropical forests play an important role in the global carbon cycle because they store about 50% of the world's living terrestrial carbon (Dixon et al. 1994).

Deforestation can also alter climate directly by increasing reflectivity (albedo) and decreasing evapo-transpiration. Experiments with climate models predict that the replacement of all of the forests of the Amazon Basin by grassland would reduce the rainfall over the basin by about 20% and increase the average regional temperature by several degrees (Maunder 1990).

The term "biomass burning" includes all intentional human activities associated with forest clearing, the burning of savanna vegetation to stimulate regeneration of grasses for livestock, the burning of fuel wood and charcoal and the consumption of agricultural residues. The area of savanna vegetation burned each year is an estimated 750 million ha, of which about half is in Africa. Shifting cultivation, a practice in which natural vegetation is cleared, an area used for agriculture for 2 to 5 years and then allowed to remain fallow and revegetate with natural vegetation for 7 to 12 years before being cleared again, is practised by 200 million people world wide on 300 to 500 million ha.

Estimates indicate that between 12 and 13 million ha of forests and other wooded lands are burned annually (Calabri and Ciesla 1992). With the exception of remote forest areas in North America and Siberia, most forests are burnt by human agency.

CARBON AND FORESTS

Carbon is the most important carrier of matter and energy – about half of the dry matter in forest biomass is carbon.

In contrast to fossil carbon, which moves in only one direction, from the reserves into the atmosphere, forest carbon is part of cyclical flux (Fig. 1). Forest carbon can be used repeatedly by sustainable management not only of forests – but also of wood as a forest product.

A unique characteristic of forest is the large pool of carbon in living biomass (Tab. 1, 2) and in forestry products. It was estimated that boreal forests contain a carbon pool of 64×10^{15} g of C in living biomass, 231×10^{15} g of C in soil and detritus and 419×10^{15} g of C in peatlands. Ca. 4×10^{15} g of C is estimated to be retained in wood products derived from the boreal region. By comparison, the atmospheric pool is about 700×10^{15} g of carbon. Temperate-zone forests are estimated to contain $20–40 \times 10^{15}$ g in above-ground biomass and $70–100 \times 10^{15}$ g of carbon in below-ground stock (Apps et al. 1993).

Hypothetically, if all the carbon from boreal forests were released into the atmosphere, the concentration of CO_2 in the air could double. The organic carbon currently found in the boreal zone has accumulated in the past 10 000 years after the last glaciation. The mean accumulation rate has been about 80×10^{12} g (million tonnes)/year. The current accumulation rate is estimated to be considerably higher: 700×10^{12} g/year in the boreal zone, and more than 200×10^{12} g/year in

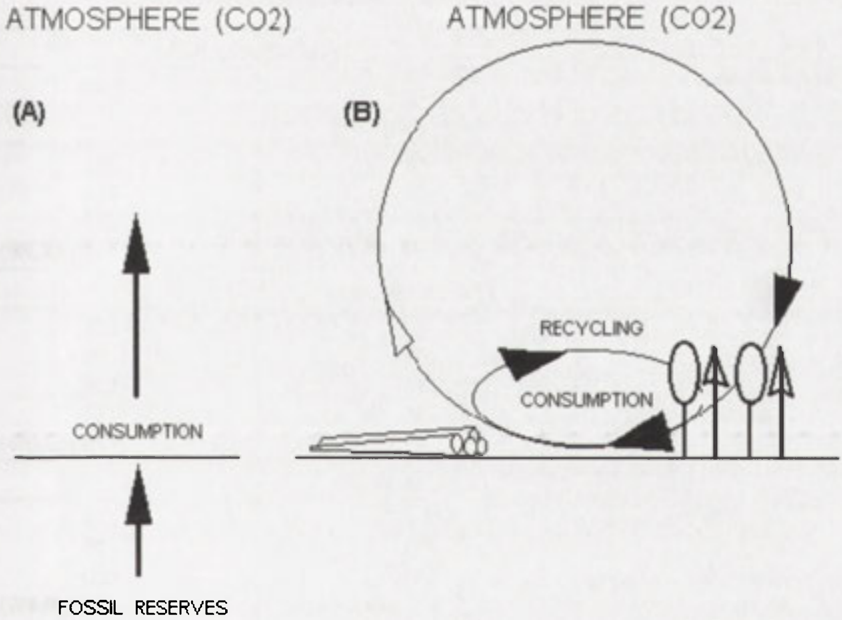

Fig. 1. Carbon flux associated with (A) fossil production and (B) forest sector

Table 1. Estimates of average above ground stored carbon/ha by various vegetation communities (Olsen et al. 1983)

Holdridge life zone	tC/ha
Forest	
Tropical wet	100
Tropical moist	70
Tropical dry	50
Subtropical wet	65
Subtropical moist	35
Warm temperate	50
Warm dry temperate	25
Cool temperate	50
Wet boreal	55
Moist boreal	40
Other plant canopy	
Temperate steppe	8
Cool temperate steppe	5
Tropical desert bush	2
Temperate desert bush	3
Boreal desert	5
Tundra	2.5

Table 2. Estimated carbon densities per unit of forest area in the vegetation and soils of the world's forests

Latitudinal belt (type of vegetation)	Carbon density tC/ha	
	Vegetation	Soils
High (boreal)		
Russia	83	281
Canada	28	484
Alaska	39	212
Mean	64 (15.7%)	343 (84.3%)
Mid (temperate)		
USA	62	108
Europe	32	90
China	114	136
Australia	45	83
Mean	57 (37.0%)	96 (63.0%)
Low (tropic)		
Asia–Pacific	132–174	139
Africa	99	120
Americas	130	120
Mean	121 (49.6%)	123 (50.4%)
World	34.1%	65.9%

the temperate zone (Apps et al. 1993). Biomass accumulation in temperate and boreal forests offsets at least 10% of the emissions of fossil carbon in the region.

By the early 20th century boreal and temperate forests had become a sink for carbon, while the tropical forests are still a source of CO_2 because of the deforestation.

The areas of forest plantation required to have a significant impact on the amount of carbon dioxide in the atmosphere are enormous. If we would like, for example, to sequester the annual net increase in atmospheric carbon (approximately 3 000 million tonnes) we have to establish approximately 465 million hectares of plantation forests for about 30 years (Sedjo and Solomon 1989). This corresponds to an increase of more than 10% in the current area of all forests on the Earth's surface or an increase of more than four times the present plantation area in the world to sequester only the current net annual increase in atmospheric carbon. Even this enormous estimate is based on the assumption of an average annual growth of 15 m^3 per hectare per year, which is unlikely to be achieved in temperate regions. In Poland we have an average annual growth of timber of 3.54 m^3/ha.

Reafforestation and afforestation are considered means of countering the increase in CO_2 in the atmosphere. Carbon uptake is greatest in the period of the greatest rate of tree growth (Fig. 2).

The portion of carbon released to the atmosphere after the cutting of trees varies with the product made from the wood. If the tree is burned as fuelwood then a high proportion of the fixed carbon is released, but if it is transformed into

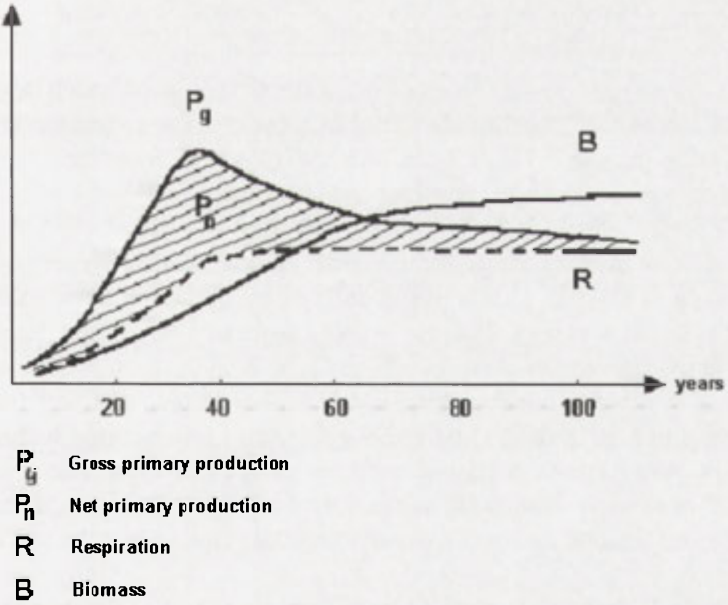

Fig. 2. Energy use during forest successional stages (Odum 1989)

a durable product with a long-term use, such as furniture, wooden houses or panels, then the carbon will remain fixed for a long time.

Forests vary considerably in their capacity to absorb and store carbon. Factors which influence carbon absorption rates include temperature, precipitation, stocking, soil, slope, elevation, site conditions, growth rates and age. Generally speaking, closed forests have a greater capacity to store carbon than open forests and woodlands. Undisturbed forests store more carbon than degraded forests. Wet or moist forests store more carbon than dry or semi-arid forests and mature forests store greater quantities than do young forests (but the rate of storage is greater in the case of young forests – mature forests are in the balance of assimilation/releasing).

Many studies have been conducted to estimate the biomass of forest ecosystems. These can be used to estimate carbon storage. The ratio of dry total biomass to carbon is roughly 2:1. The carbon content of an undisturbed tropical moist forest can range as high as 250 tC/ha of standing, above-ground biomass. On the other hand, the carbon content of dry tropical forests with open, discontinuous canopies generally averages less than 40 tC/ha (Brown and Lugo 1984).

Forest soil also stores carbon. A study indicates that 84.3% of the total carbon content of high-latitude (boreal) forests is stored in the soil. In temperate (mid-latitude) forests, 63% is stored in the soil and in tropical (low-latitude) forests the proportion is 50.4% (Dixon et al. 1994) (Tab. 2).

CARBON AND WOOD

Until now studies on the greenhouse effect have paid much attention to carbon fixation by forests, while the entire CO_2 cycle of forest and forest products remained underexposed. Forests and the use of wood contribute to the fight against the enhanced greenhouse effect in three ways:

(1) by carbon sequestering (converting CO_2 into wood);

(2) by CO_2 avoidance through the substitution of wood by energy-intensive materials such as plastics, aluminium, steel, cement and brick. Processing timber uses relatively little energy and the wood can easily be reused later, e.g. as particle board;

(3) by CO_2 avoidance through the use of timber instead of fossil fuels in the generation of energy. When the recycling of wood has become technically or economically impractical, it may be used for energy purposes. The same is true for timber from special energy plantations. Only the previously sequestered CO_2 will be released when burning the woody material. This makes the use of timber 'CO_2 neutral'.

The potential contribution to CO_2 reduction (in tons CO_2/ha) is presented in Table 3. The greatest contribution to CO_2 reduction results from substituting coal

Table 3. Potential contribution to CO_2 reduction (in tons CO_2/ha) of several forest types (species) (Sikkema and Nabuurs 1995)

Contribution	Oak Beech	Spruce	Poplar 15 years
1. CO_2 fixation in biomass, soil and products	432	394	104
2. CO_2 avoidance through replacement of non-timber materials	182	784	653
3. CO_2 avoidance through replacement of fossil fuels	966	1289	1560
Total CO_2 reduction in 300 years	1580	2467	2317

by wood in energy production. This is especially true of energy-wood plantations.

The effects of both product and fuel substitution are repeatable, while the squestration has a once-only effect, because in time the CO_2 is released again, either through decay or through combustion. The effect of the utilization of wood is greater than that of fixation.

To illustrate the importance of wood utilization and some environmental advantages of wood as a building material in relation to steel a simple comparative simulation has been made (Meil 1995). The application for comparison was the typical exterior infill wall assembly used in light commercial structures. Usually a building of this type of assembly would be built using steel as the post and beam supporting structure. For the purpose of material comparison, use has been made of steel studs (C cross-section, about 1 mm thick) as one example, and 2 × 4 in. (38 × 89 mm) wooden studs as the second alternative. The height of the wall was arbitrarily set at 3 meter and its length at 30 meters.

In terms of embodied energy (Fig. 3) the steel wall is 3.5 times more energy intensive than the comparable wooden wall. Minimizing energy use is a key sustainable development objective as energy, especially energy from fossil fuels, represents a major environmental impact.

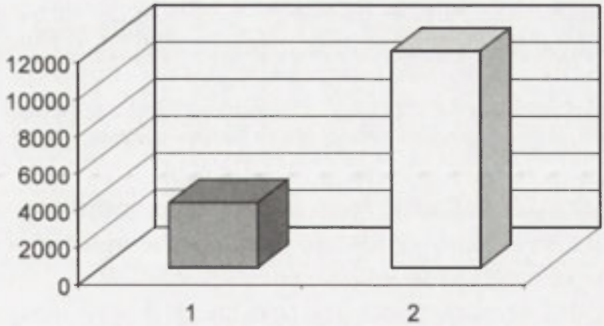

Fig. 3. Energy use (Mj) to build 3 × 30 m wall example (Meil 1995)
1 – wood, 2 – steel

Carbon dioxide emissions for the steel wall are three times that of the wooden wall (Fig. 4).

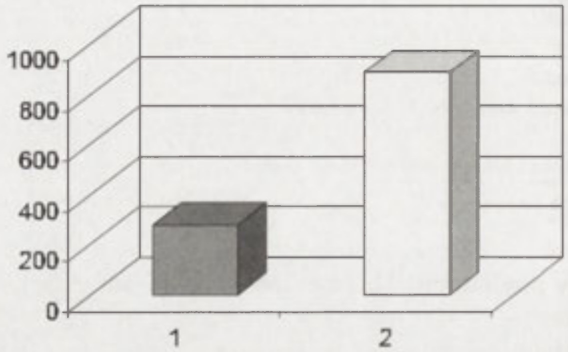

Fig. 4. Carbon dioxide (CO_2) emmission (in kg) (Meil 1995)
1 – wood, 2 – steel

Wood also proves advantageous when we compare the other air pollutants: carbon monoxide, sulphur dioxide, nitrous oxides, methane, particulates and volatile organic compounds (Fig. 5).

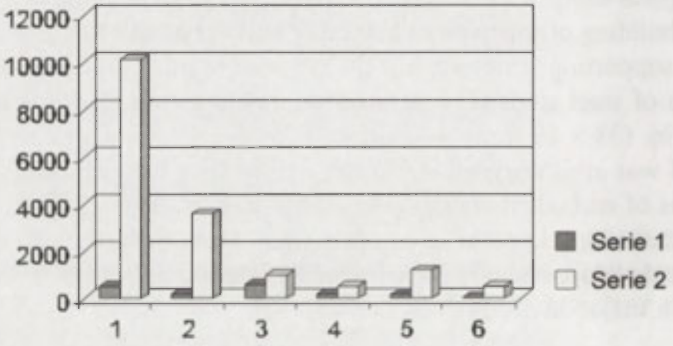

Fig. 5. Air emmissions (g) associated with the wood (Serie 1) and steel (Serie 2) 3 × 30 m wall design (Meil 1995)
1 – CO, 2 – SO_x, 3 – NO_x, 4 – part, 5 – VOC, 6 – CH_4

In terms of the greenhouse effect (Fig. 6) the wooden wall generates only a third of the effect of the steel wall.

The calculated Air Pollution Impact (Fig. 7) indicates that, relative to the wooden wall, the steel wall requires seven times the volume of ambient air to dissipate its air pollutants to acceptable levels.

The largest difference between the two material wall designs lies in their comparative water-use during product manufacturing, with the steel assembly demanding over 20 times more water input than the wood design (Fig. 8).

Figure 9 shows the calculated Water Pollution Impact index for the two walls.

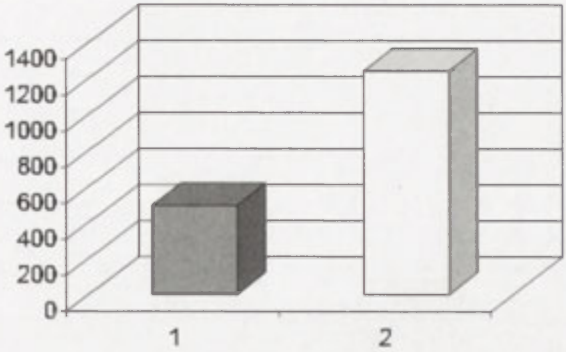

Fig. 6. Greenhouse gases impact (in equivalent CO_2 kg) (Meil 1995)
1 – wood, 2 – steel

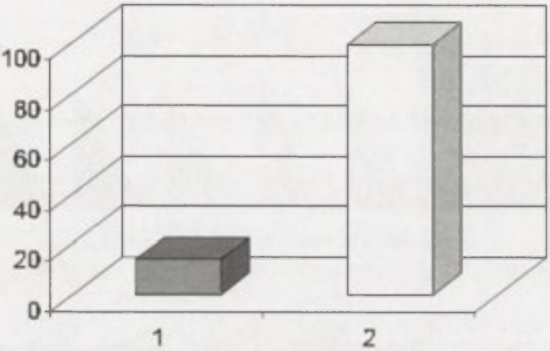

Fig. 7. Air pollution impact. Impact measure is the volume of ambient air to dissipate air pollutants to the same acceptable levels (Meil 1995)
1 – wood, 2 – steel

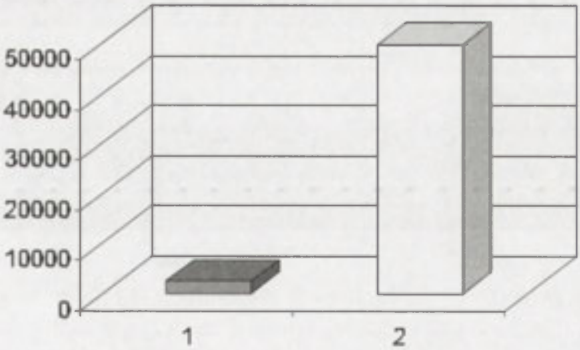

Fig. 8. Water demand (litre) (Meil 1995)
1 – wood, 2 – steel

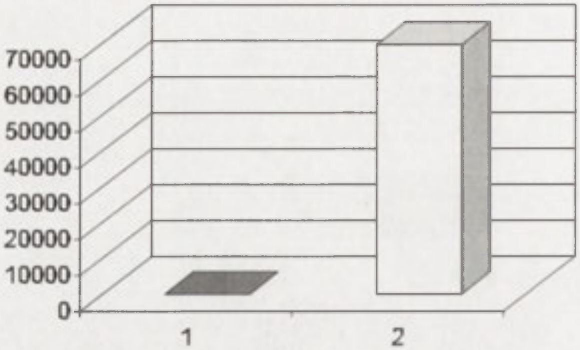

Fig. 9. Water pollution impact. Impact measure is the amount of water necessary to dilute the effluent stream from the technology process to produce wood (1) and steel (2) (Meil 1995)

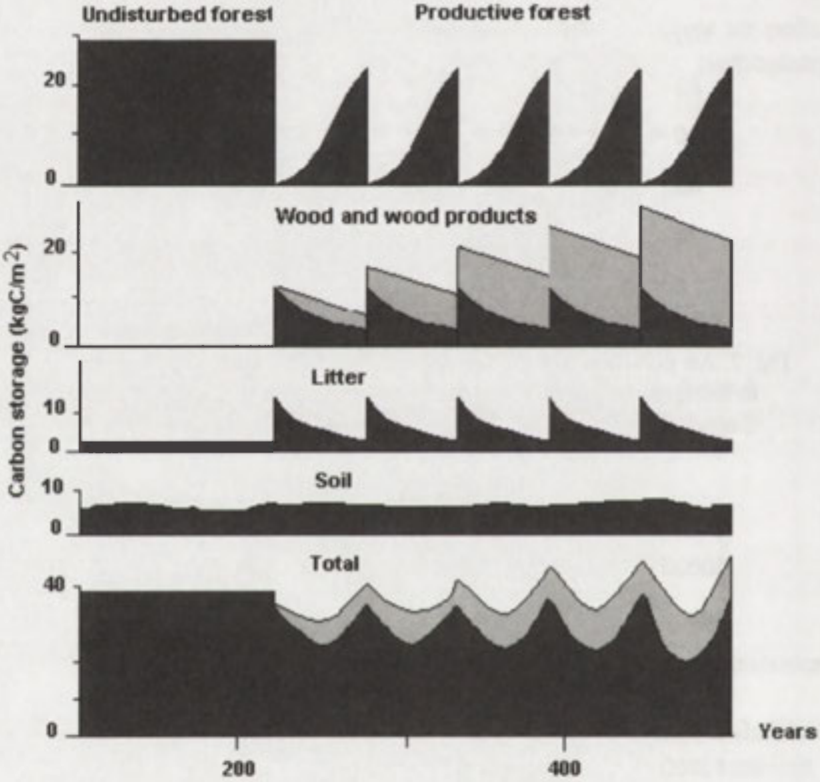

Fig. 10. Simulated carbon storage in the trees of undisturbed and productive forest, wood and wood products, litter and soil (when undisturbed European broadleaved species are replaced by a plantation with similar growth characteristics. The light green colour means difference between wood and wood product lifetimes of 420 (upper line) and 72 (lower line) years respectively (Cannell 1994)

As is evident, the amount of water necessary to dilute the effluent stream from the steel wall is considerably greater than for the wooden wall.

In general, carbon storage would be optimized in plantation forests, harvested at the time of maximum mean annual increment, when the lifetime of the products exceeds the rotation period (Fig. 10). In the light of the above, the most effective improvement of the environment through the forest sector and real contribution of forests to the mitigation of global change is the production of wood and the use of this material and its products in a sustainable way, especially as substitutes for other harmful industrial products.

The rate of carbon absorption by trees and forests is a function of growth and age. Generally speaking, trees and forests remove atmospheric carbon at high rates when they are fast-growing and young. As stands approach maturity and growth rates are reduced, the net carbon absorbtion is also reduced. In theory, mature (climax) forests reach a stage of equilibrium with respect to carbon absorption. Roughly an equal amount of carbon is released through the decay of dead and diseased trees as is absorbed. However this is rarely achieved in natural forests. Mature forests, if left undisturbed, as is the case in reserved or protected forests, are carbon reservoirs but not necessarily net carbon sinks.

Studies of carbon absorption rates in tropical forest plantations indicate that maximum growth and carbon uptake occurs during age classes 0–5 and 6–10 years (62%). Carbon uptake decreases by about 50% during the next 5 years and decreases even further after age 16 (Brown et al. 1986).

SUSTAINABLE FORESTRY AND CARBON MANAGEMENT

The objective of sustainable forest management in the UNCED statement of Forest Principles is expressed as follows: "*Forest resources and forest lands should be sustainably managed to meet the social, economic, ecological, cultural and spiritual human needs of present and future generations*".

In June 1993, in Helsinki, the Ministerial Conference on the Protection of Forests in Europe defined sustainable forest management as "*the stewardship and use of forests and forest lands in a way, and at the rate, that maintains their biodiversity, productivity, regeneration capacity, vitality, and their potential to fulfill, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems*".

If the forest sector is asked to control the CO_2 concentration of the atmosphere, this new forestry objective is not exempt from the requirement for sustainable management. A specific statement can be derived from the above definitions: "*Carbon can be sequestered from the atmosphere in a way, and at a rate, that neither reduce the possibility of future generations to control atmospheric* CO_2 *concentration, nor adversely affect other relevant ecological, economic, and* *social functions*". This is the proposal for the definition of sustainable carbon management for the forest sector (Kauppi 1994).

If the proposal is acceptable, the forest sector has to discuss the ways of sequestering carbon in forest ecosystems. It is questionable as a policy option to build up the biomass pool per hectare of forested land. An increase in biomass will lead to a reduction in net annual increment in the long term, reducing the potential for using biomass as raw material or energy, increasing the risk of economic waste and ecological damages. It also reduces the potential for sequestering CO_2 in the long term (more than 50 years).

The observed trend to increased growing stock per hectare of forest land in temperate forests is not a sustainable way of carbon sequestration. The potential will be exhausted within less than 100 years. Nor is afforestation a sustainable method, if the aim is to generate new carbon pools. However, afforestation is sustainable carbon management, if the objective is to create a continuous product flux and to use the products as a substitute for fossil-based production.

A sustainable policy is recycling, especially in the sense that it expands the total potential of renewable material to substitute for non-renewable goods. Storage of used products in landfills is sustainable, if suitable sites are available in the long term. Assuming a 5–30% increase in forest area, improvement of the present average yield, and the full use of sustainable yield, the upper limit in Europe is 100–200 million t/year of sequestered carbon. This is 10–20% of current fossil emissions.

The methods of forest management applied to sequester CO_2 have to be cautious – they should neither reduce the possibility of future generations to control atmospheric CO_2 concentration nor adversely affect other forestry objectives.

POLAND

There are few studies on carbon sequestration in Polish forest ecosystems and on the possibility to mitigate the greenhouse effect. Some publications have concerned other related issues, mostly the impact of climate change on the forest ecosystem than the role of forests to mitigate global change: the changes in species composition as related to climate change (Kowalski 1991, 1993), modelling the potential impact of global climate change on forest ecosystems (Brzeziecki 1993), changes in the borderline of the boreal forest and threats to the forest posed by insects and fungi (Sadowski 1993), forest management versus climate change (Bernadzki 1993) or the annual carbon balances of Polish forest ecosystems (Galiński 1993).

The country's total emission of CO_2 in 1990 was of 360 million t This will reach, it is predicted (Bojarski et al. 1993), levels of: 412–510 mln t/yr in the year 2010 (depends on the scenario). The authors emphasized that carbon dioxide emission in Poland in the year 1989 was about equal to 400 tons (carbon mass) per km^2 and was one half of that in Germany (824 tC/km^2) and Belgium (871 tC/km^2), one third of that in The Netherlands (1285 tC/km^2) and below the mean value for the European OECD countries. In this context the authors said that "Poland should not pay much attention to any pressure referring to the reduction of CO_2 emission, much more important for us is the reduction of dusts and sulphur oxides".

As we now know, Poland has committed itself under the Kyoto Protocol (1997) to reduce her GHG emission to a level of 94% of that in the base year 1988.

The forest formation store huge amounts of carbon in both living and non-living organic matter. Calculating after Burschel's (1993) results and taking under consideration Polish conditions of forest growth and management, Bernadzki (1993) assessed the total amount of carbon in Polish forest dendromass (with standing volume lower by about 30% than in Germany) to be 45–50 tons C/ha.

There are some possibilities to increase the carbon-accumulation ability of our forests (Bernadzki 1993):

(1) reconstruction of stands into ones of more adequate species composition; there by increasing tree volume by about 100–125 m^3/ha, or ca. 20–25 tons C/ha;

(2) tending forests and creating an opportunity to obtain the so-called "thinning-induced increment"; a tending measure can only indirectly result in an increase in CO_2 accumulation and the effects can be expected in the distant future;

(3) introduction of an understorey which could result in an increment of standing volume (1.1 m^3/ha/year for instance) as well as through the fixing of CO_2 directly by understorey trees (beech stands fix 0.4 t C/ha/year for instance);

(4) an increase in the fraction of humus in forest soils which could be regulated by means of the giving preference to the forest regeneration model. The clear cutting method of forest management results, for instance, in high losses of organic matter and a consequent release of ca. 24 tones C/ha on average sites and 15 tC/ha on poor sites (Heinsdorf et al. 1986); resignation from clear-cutting in Germany, for example, could result in additional fixation of 0.4 million tC a year);

(5) afforestation of abandoned agricultural land could contribute to the fixation of about 80 tC/ha in the dendromass of a 60-year old new forest stand.

Finally, if the accepted assumptions prove true the measures presented above could provide as:

- a result of the reconstruction of stands 200–215 × 10^6 tC;
- an effect of the creation of an understorey 16–20 × 10^6 tC;
- an effect of afforestation 80–240 × 10^6 tC.

The figures do not include that carbon being fixed in the forest soil, which exceeds 150 tC/ha (at least in Germany conditions) (Bernadzki 1993).

Another estimation (Galiński and Küppers (1993) has been presented in the context of the political changes and economic crisis in Poland and referred to the period 1988–1990. The retention of CO_2 in Polish forest ecosystems equaled

2 057 × 10^6 Mg CO_2 for 1988 and 2 421×10^6 Mg CO_2 for 1990 (or per ha, 237.2 Mg CO_2/ha and 278.5 Mg CO_2/ha for the two respective years).

The carbon sequestration equals ca. 6.1% of the total carbon emission (Galiński and Küppers 1993) and forest carbon pools exceed annual carbon emission by ca. 20 times (Galiński and Küppers 1993a).

However, the range of error for this evaluation is not precisely known. It has to be underlined that all the figures mentioned above are based, unfortunately, on very risky calculations/assessements with a high degree of uncertainty.

The reduction of GHG emissions, committed to by Poland (94% of the emission occurring in 1988), should be counted using a method taking into account uncertainties, transparency in reporting, verifiability and the methodological work of the Intergovernmental Panel on Climate Change (IPCC). This means that Poland will apply IPCC guidelines to national greenhouse gas inventories (IPCC 1995, 1997).

The first approach to the prognosis of carbon sequetration in Polish forest ecosystems (Galiński 1998) indicates that the Polish forestry and land-use sector possesses a substantial potential to offset the GHG emission from industrial sources. The potential results mainly from past and projected afforestations and is almost independent of harvest, if the requirements of sustainable forestry management are adhered to.

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ECOSYSTEM PROCESS STUDIES ALONG A CLIMATIC TRANSECT AT 52–53°N (12–32°E): PINE LITTER DECOMPOSITION

ALICJA BREYMEYER
Department of Geoecology, Institute of Geography and Spatial Organisation,
Polish Academy of Sciences, Twarda 51/55, 00–818 Warsaw, Poland

RYSZARD LASKOWSKI
Department of Ecosystem Ecology, Institute of Environmental Biology, Jagiellonian University,
Ingardena 6, 30–060 Krakow, Poland.

ABSTRACT: The response of litter decomposition to changing climate was studied on a transect set in Central Europe along parallel 52°N. Rates of decomposition of pine forest litter were measured for one year in 15 stands of Scots pine (*Pinus sylvestris*) along the 1500 km (20°) W–E transect. The stands were carefully selected on the basis of existing maps and data banks, and were similar as regards topography, soil type, tree-stand age and composition of the herb-layer. Long-term climatic data were assigned to each stand from surrounding climate stations and indexes of climate continentality – an important characteristic for a latitudinal transect – were determined.

Litter-bags with Scots pine needles, wood material, cones or mixed litter were used. Of the different litters tested, needles and natural mixed litter displayed the best correlation between decomposition rate and climatic indices. No effect of climate on wood decay was found.

Along the gradient of oceanic and continental climates, with only minor differences in average annual temperature or AET (Actual Evapotranspiration) between sites, almost 40% of the variability in rates of needle and mixed-litter decomposition was explained by the degree of continentality, expressed as annual temperature amplitude, temperatures of the coldest and warmest months (January and July) and annual amplitude of precipitation. The relationship with precipitation amplitude is especially interesting as this index is not usually used in studies on litter decomposition.

The relationship between decomposition rate and the aforementioned climatic indices, was augmented by significant differences between sites classified in three categories according to diversity of plant cover. Decay was slowest on pure stands of Scots pine, significantly faster on mixed pine stands and fastest on anthropogenically-modified pine stands.

KEY WORDS: decomposition, pine forest litter, transects, pine needles, cones.

INTRODUCTION

Although the relationship between the rate of decomposition of forest litter and climate is generally documented or predicted by modelling efforts, the geographical patterns of relationships to climatic elements are not defined clearly.

Two characteristics, actual evapotranspiration (AET) and average annual temperature, are treated as the most important factors determining the rate of degradation of organic matter whose chemical composition is held constant (Meentemeyer and Berg 1986). Meentemeyer (1984), and Dyer (1986) formulated an empirical regression model allowing forest litter decomposition rates to be predicted using only two parameters: AET and lignin concentration in a substrate.

Studies on litter decomposition performed under the FERN (Forest European Research Network) programme over an extensive network of 39 sites between northern Finland and Madrid or Istanbul along the N–S axis, and between Budapest, Belgrade and Portugal along the W–E axis, showed a strong correlation between rates of litter decay and such climatic factors as AET, average July temperature and average annual temperature. Approximately 70% of the geographical variability in litter decomposition rates was explained by a combination of these three factors. However, when subsets of sites belonging to the North European, Central European, Atlantic or Mediterranean climatic zones were analysed separately, the strength of the correlation appeared to differ and was negligible for Central Europe (Berg et al. 1993). On the other hand, Berg et al. (1984) obtained exceptionally high correlations (explaining approximately 90% of variability) between decomposition rate and AET alone for 14 forest stands on a transect stretching from 66°N 13°E to 56°N 20°E. In that case the authors used so-called ‘unified litter’ (pure needles of Scots pine originating from one reference site), and all stands were located in forests with Scots pine (pure or with admixtures of European spruce [*Abies picea*] or birch [*Betula verrucosa*]). An even more strict approach was adopted by Breymeyer (1991a, b), who minimised the effects of all factors driving decomposition rate other than climate by selecting only pure Scots pine forests growing on similar sediments and of similar age and position in phytosociological classification. As a result, it was possible to demonstrate regular increases in annual rates of litter decomposition along a transect running north (61°14’) to south (50°30’): the calculated increase in decomposition rate was between ca. 1% (woody parts) and 3% (needles) for every 1°C increase in average annual air temperature.

Little is known about the effects on rates of decomposition of other, otherwise known, climatic patterns. In particular, to our knowledge, there are no published studies on the relationship between litter decomposition and continentality of climate, i. e. continental characteristics versus maritime ones. Transects running longitudinally across a continent are characterised by relatively small differences in average annual air temperatures but well-pronounced gradients in air temperatures amplitudes and minimum winter air temperatures (Fig. 1 and 2). These gradients are reflected clearly in plant species composition (Solon 1997) and the occurrence of plant communities (Kornas and Medwecka-Kornas 1986). Ellenberg (1974) and other authors have ranked plant species according to their dependence on climate features and some are known and used as “indicators” of continentality (Roo-Zielinska 1997). These findings have led us to hypothesise

Fig. 1. Study sites along the continental W-E transect at 52°N. Positions of 16 stands located by GPS GeoExplorer, Trimble Navigation, Model 17319

that the litter decomposition rate is also related to the degree of climate continentality.

The important characteristic of the continental climate is the large difference in air temperature between the coldest month (January or February) and the warmest (July). In the studied transect that amplitude ranges between 18.5°C in the west and 26°C in the east (Figs. 2b, c, d).

The presented W–E transect crosses the North European plain and features a particularly well-pronounced continentality gradient (Fig. 1). This leads to the formation of transitional climates with an increasing prevalence of oceanic or continental characteristics to the west and east respectively. At the same time, the western end of the transect is warmer than the eastern with the largest difference in average annual temperatures being 3.7°C (Fig. 2a). Due to slightly worse water supply conditions in Poland than in surrounding areas, the transect can be divided into western and eastern parts with annual precipitation in the ranges 520–550 and 600–670 mm respectively. Thus, from the point of view of the rates of production and decomposition of organic matter, the western end has better thermic conditions, while the eastern end has better humidity. It should be mentioned at this point that the western end of our transect is more contaminated by

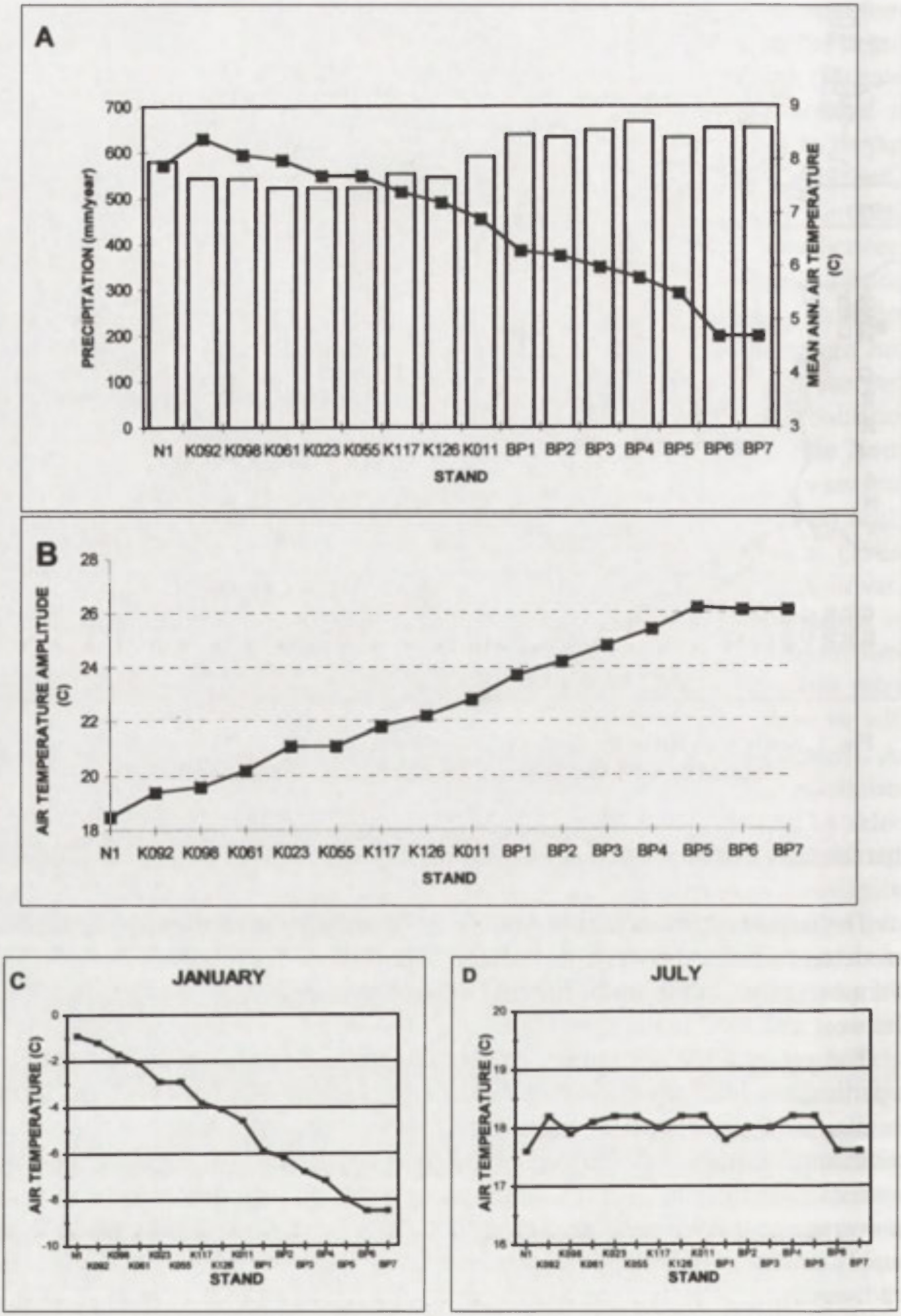

Fig. 2. Climatic characteristics of the pine forest sites studied: A – Long-term mean annual air temperatures and precipitation totals, B – Yearly amplitude of air temperature – difference between warmest (July) and coldest month (January), C – Long-term mean January air temperatures, D – Long-term mean July air temperatures (after Śmialkowski unpubl.)

industrial emissions coming through Poland's western border or produced in the country (Breymeyer 1997); however this factor is not analysed in this paper.

Romer (1946), Degorski (1984) and Wos (1995) all suggest that the continentality gradient across Poland is uneven, and that a borderline of oceanic-continental climate can be traced along isoamplitudes of 21°C and 23°C, approximating to Poland's eastern border. A 50% isocontinentala (continentality isoline) based on annual temperature amplitude can be traced in the same region (Ewert 1973; Wos 1995).

METHODS

SITE SELECTION AND CHARACTERISTICS

The studies were carried out in forests of Scots pine on a transect across Central-Eastern Europe (from eastern Germany through Poland to eastern Belarus) at 52°N – 53°N. The Polish stands involved are among the extensive network of sites monitored by the Forest Service. All are classified as Scots pine forests and are on similar acidic sandy soils (Breymeyer 1997). If any impact of agricultural origin was found in a soil profile, the stand in question was tagged as "anthropogenic".

According to the Braun-Blanquet system of phytosociological classification, all sites belong to the *Dicrano-Pinion* alliance, and to either the *Peucedano-Pinetum* or *Leucobryo-Pinetum* associations (sub-continental and sub-maritime pine forest), or to the mixed forest association *Querco-Pinetum.* These forest types occupy the same place along the scale of humidity, but differ in degree of continentality (Matuszkiewicz and Matuszkiewicz 1973). The communities of the sub-maritime *Leucobryo-Pinetum* association cover a large area and are amongst the most common types of forest in Central Europe. They are replaced by the sub-continental *Peucedano-Pinetum* to the east of a line formed by the Bug and lower Vistula rivers. The sub-continental forest is much richer floristically, being characterised by the presence of continental species, mainly perennials of a somewhat xerothermic nature, as well as by limited regional variation. The classification of some of the sites as mixed pine forest was justified by the presence of a sufficiently significant deciduous component of the *Querco-Pinetum* type (Matuszkiewicz 1987). More details on site characteristics can be found elsewhere (Degórski 1998a, b; Roo-Zielińska and Solon 1998; Solon and Roo--Zielińska 1998).

FIELD AND LABORATORY WORK

After initial screening of a few dozen plots in the databanks of Warsaw's Forest Research Institute, Eberswalde Forstliche Forschunganstalt and the Minsk Institute of Botany, sixteen sites were selected for in-depth study. Litter fall and

Table 1. Characteristics of sites used in the analysis of litter decomposition along a continental transect; symbols described in the text

Site	Type	Climatic variables									Ellenberg's*		Soil
		TAVG	TAMP	TJAN	TJUL	PANN	PAMP	PVEG	PANE	PVEE	CONT	NITR	pH
N1	bad**	7.9	18.5	–0.9	17.6	581	41	444	1.29	0.98	3.6	3.0	3.5
K092	pine	8.4	19.4	–1.2	18.2	542	48	413	1.16	0.89	2.6	3.1	3.9
K098	bad**	8.1	19.6	–1.7	17.9	523	64	409	1.15	0.90	2.8	2.8	3.2
K061	pine	8.1	20.2	–2.1	18.1	553	66	401	1.21	0.88	3.7	1.7	3.3
K023	pine	7.7	21.1	–2.9	18.2	546	55	409	1.23	0.92	3.9	2.4	3.9
K055	mix	7.7	21.1	–2.9	18.2	639	49	409	1.44	0.92	4.8	3.0	3.9
K117	mix	7.4	21.8	–3.8	18.0	655	53	426	1.50	0.98	3.3	1.9	4.0
K126	mix	7.2	22.2	–4.1	18.2	652	56	430	1.51	1.00	3.9	2.7	3.7
K011	pine	6.9	22.8	–4.6	18.2	543	50	457	1.29	1.09	4.3	2.7	4.5
B1	mix	6.3	23.7	–5.9	17.8	523	49	493	1.29	1.22	4.0	2.4	4.0
B2	pine	6.2	24.2	–6.2	18.0	523	64	491	1.30	1.22	4.5	3.2	4.1
B3	pine	6.0	24.8	–6.8	18.0	590	53	502	1.50	1.27	4.2	2.8	4.2
B4	mix	5.8	25.4	–7.2	18.2	633	56	497	1.62	1.27	4.4	3.3	3.9
B6	mix	4.7	26.1	–8.5	17.6	632	51	499	1.76	1.39	4.3	4.5	4.0
B7	pine	4.7	26.1	–8.5	17.6	652	56	499	1.82	1.39	3.6	3.6	4.1

* – according to Ellenberg's phytosociological indices,

** – classified as anthropogenic forests grown on inappropriate stand.

decomposition was ultimately studied on 15 plots (Fig. 1) selected on the basis of their similarity in terms of soil and plant species composition with a view to excluding, as far as possible, the effects of non-climatic factors. While all plots represented stands of Scots pine, 7 were classified as pure pine, 6 as mixed and 2 as pure but anthropogenic ("bad" forests on atypical soils) (Tab. 1). A detailed description of the procedure used in site selection is given by Breymeyer (1997).

Litter decomposition was studied using a standard litterbag technique (Berg et al. 1993). Litterbags were always made of the same site litter which had fallen to the forest floor in the course of the previous year. Litter samples were taken from 0.1 m^2 circles on special demarcated areas cleaned at every sampling time to ensure that the litter collected was always "of the same age". Weighed portions of litter dried to constant weight were enclosed in bags made from 1 mm nylon netting (10 × 10 cm surface). Bags were then incubated at the sites; the surfaces on which the bags were placed were cleaned of moss and small shrubs to ensure that the exposed litter made contact with the upper layer of the soil. Placed simultaneously at each site were 60 litter bags: 20 with 1 g each of mixed litter (the same composition as was collected at the same site during the previous year), 20 with 1 g of pine needles each, 10 with a single cone in each and 10 with 1 g of small twigs. The exposure of litter bags always began in autumn (October), with samples being collected after two time periods: half after winter (in March or April – winter decomposition) and the remaining half during the following autumn (October – annual decomposition), when samples for the next year were being laid out. After collection from the forest, the litter bags were transferred to the laboratory and cleaned of soil and plants overgrowing the netting to leave litter, which was then dried (60°C) to constant weight and weighed. The so-called decomposition coefficient (k) was calculated by applying the formula: In (final mass/initial mass) = –k.

STATISTICAL ANALYSIS

The decomposition rate was expressed as the annual mass loss (% initial mass). After checking for normality of distribution (chi^2 test) and appropriate transformation if necessary, Principal Components Analysis (PCA) was used to describe total variability in the dataset. The purpose of the PCA is to obtain a small number of linear combinations of the variables which account for most of the variability in the data. This was followed by Factor Analysis (FA) with VARIMAX rotation to separate effects of variables co-varying with decomposition rate from those non-related to decomposition. Rotation is performed in order to simplify the explanation of principal components calculated with the PCA and to classify variables (detect structure in the relationships between variables). A few different methods can be used for rotation of the correlation matrix; the VARIMAX rotation used here simplifies the columns of the factor matrix. In this case, two principal components were selected for rotation, following the initial general hypothesis about the distribution of total variability between two sets of factors: correlated or non-correlated with litter decomposition rate.

Variables used in analysis were: rate of decomposition of pine needle litter (DECNEED), decomposition rate of wood (DECWOOD), decomposition rate of cones (DECCONE), mixed-litter decomposition rate (DECMIX), average annual air temperature (TAVG), average July and January air temperatures (TJUL and TJAN), yearly amplitude of air temperature (TAMP), total annual precipitation (PANN), precipitation during the growing season (PVEG), amplitude of precipitation (PAMP), ratio of PANN to potential evaporation (PANE) and ratio of PVEG to potential evaporation (PVEE), soil pH (pH), and two indexes based on the Ellenberg (1964) theory on the "bioindicative value" of plant species [Ellenberg's continentality index (CONT) and Ellenberg's index of nitrogen availability (NITR)].

Stepwise regression was used to select factors having a significant effect on decomposition rate. Considered first were the climatic factors TAVG, TJUL, TJAN, TAMP, PANN, PVEG, PAMP, PANE and PVEE, with soil pH and the Ellenberg indices of continentality (CONT) and nitrogen status (NITR) being added in a second step. In the regression analysis, the proportion of total variability explained by particular models was expressed as R^2 adjusted for degrees of freedom (R^2_{adj}). This made R^2s comparable where regressions had different numbers of independent variables in the model.

In looking for unexplained between-site variability, Analysis of Variance (ANOVA) was used to check for possible differences between sites assigned to different phytosociological types. Means were separated by Tukey-Kramer test (95% HSD intervals).

All calculations were done with the aid of the Statgraphics package.

RESULTS

All 15 studied sites are described in Table 1, listed from the most western German stand (N1) to the most eastern Belarussian (B7), situated a few kilometres from Belarussian-Russian border. The geographical positions of all stands are shown on the map (Fig. 1). Following the description of soils and vegetation, 7 stands were classified as pure pine forest and 6 as mixed pine forest, while 2 were called "bad" in Table 1 – signs of agricultural activity were found in their soils. These 2 stands cannot be classified as pine forests according to the Braun-Blanquet system accepted in our studies and they were excluded from some analyses. All climatic indices reported in Table 1 were calculated using long-term measurements provided by the regular meteorological networks in Germany, Poland and Belarus; the 2 to 3 nearest meteo stations were selected and the climatic conditions for a given site interpolated (selected climatic indices are shown in Fig. 2). The annual mean air temperature was always above 7°C in the

Table 2. Average annual decomposition rates of different litters

	Site	Type	Annual decomposition (%)			
			Needles	Wood	Cones	Mixed litter
W	**N1**	bad**	44.6	12.5	11.0	32.6
	K092	pine	32.5	14.8	15.6	22.4
	K098	bad**	33.2	10.8	8.9	21.0
	K061	pine	25.1	11.9	22.4	17.3
	K023	pine	32.5	13.9	11.8	22.5
	K055	mix	39.5	13.1	9.7	–
	K117	mix	34.3	18.0	18.4	24.9
	K126	mix	37.1	15.3	13.2	24.9
	K011	pine	30.0	17.4	18.1	20.9
	B1	mix	29.7	15.2	6.8	23.0
	B2	pine	33.4	12.8	22.8	25.2
	B3	pine	28.1	20.3	7.4	14.1
	B4	mix	35.1	9.4	13.8	15.7
	B6	mix	34.2	17.2	11.0	23.6
E	**B7**	pine	28.6	12.5	6.5	15.1

western half of the transect (from 7.2°C to 8.4°C) and always below 6.9°C in the eastern part (from 4.7°C to 6.9°C). Thermic amplitudes are greater further east, rising from 18.5°C in Germany to 26.1°C in Belarus. All the investigated forests grow on acidic soils: pH ranges from 4.4 to as low as 2.6 and does not show any regular geographical pattern. Of the two Ellenberg indices, only continentality shows a distinct trend, being lower in the group of 5 western sites (2.6–3.9) and higher (above 4.0) in the group of 6 eastern sites (the groups are shaded in Tab. 1).

Annual decomposition rates for all stands and all incubated litters are shown in Table 2. As was to be expected, needles and mixed litter decomposed faster, woody twigs and cones distinctly more slowly. Among the 4 different litter types studied on our transect only needles and mixed litter demonstrate a response of decomposition rate to the geographical position of a stand of pine forest (Fig. 3). Their rate of decay decreases further east, in cooler and more continental climatic conditions. Decomposition in pine forests is slower than in mixed forest stands (Fig. 4).

Distributions of the rates of decomposition of needles, wood and mixed litter did not deviate significantly from the normal (p = 0.2 in all cases). Only for cones was there a significant deviation from the normal distribution (p = 0.0024), and this was easily normalised by log transformation (p = 0.597).

The two first principal components (PC) explained over 62% of the total variability (Tab. 3). The estimated communalities (the amount of variance an original variable shares with all other variables in the analysis) indicate that, among the decomposing materials, mixed litter and needle litter share the greatest amount of variability with other variables. As expected, most of the common

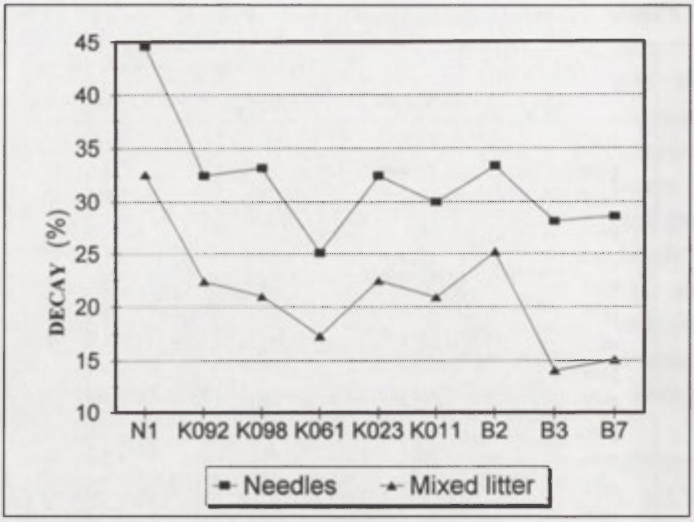

Fig. 3. Annual decomposition of needles and mixed litter in pine forests along continental transect

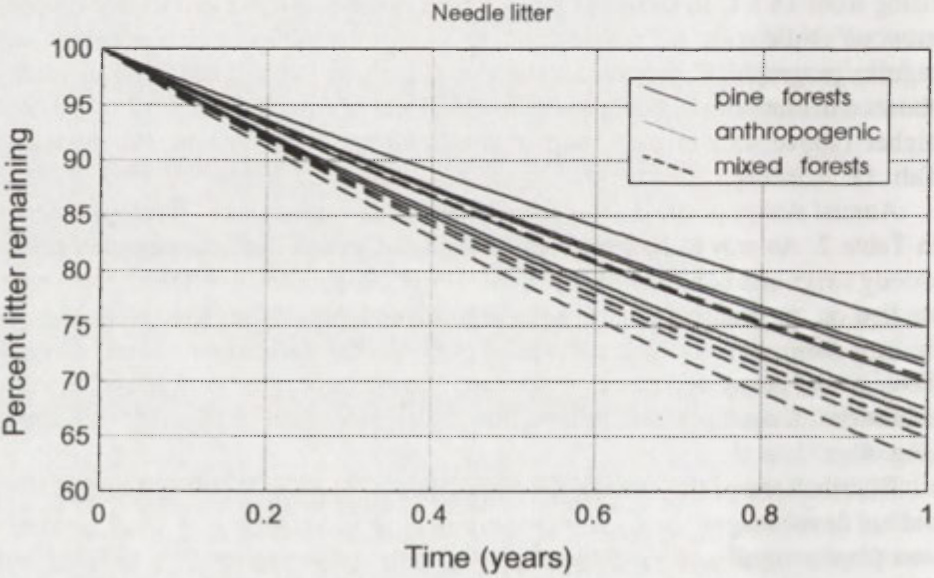

Fig. 4. Decomposition of needle litter in 3 types of forest; plotted are one-year decomposition curves expressed by the formula $W_t = W_0e^{-kt}$, where W_t and W_0 stand for the litter mass at time *t* and at the start of incubation respectively, and *k* is the decomposition coefficient. The difference between stands of pure Scots pine ("pine forest") and "mixed forest" is statistically significant ($p = 0.016$)

Table 3. First two factors of the VARIMAX-rotated factor matrix of total variability in the data set; dominant loadings in each factor (0.4) are typed boldface. Also given are estimated communalities for each variable and the percentage variability explained by each factor (% VAR)

Variable	Estimated communality	Rotated factor I	Rotated factor II
DECNEED	0.21	–0.03	**–0.46**
DECWOOD	0.07	0.06	0.25
DECCONE	0.16	–0.31	0.25
DECMIX	0.34	–0.15	**–0.57**
TAVG	0.98	**–0.95**	–0.28
TJUL	0.74	**–0.65**	**0.57**
TJAN	0.97	**–0.89**	**–0.43**
TAMP	0.97	**0.85**	**0.49**
PANN	0.89	**0.94**	0.11
PVEG	0.90	**0.93**	0.17
PAMP	0.56	–0.06	**0.74**
PANE	0.65	**0.77**	0.24
PVEE	0.99	**0.97**	0.21
pH	0.59	**0.44**	**0.63**
CONT	0.40	0.38	**0.50**
NITR	0.58	**0.74**	–0.17
% VAR		48.2	14.2

variability was shared between purely climatic characteristics of the sites studied. After VARIMAX rotation of the two first PCs (see Methods), the variability was split between an almost purely climatic factor – Rotated Factor I with low loadings of all decomposition variables (‘factor loading’ is a correlation between a variable and the extracted factor), and a second factor with relatively high loadings for decomposition rates of needle and mixed litter (Tab. 3, Fig. 5). From our point of view, the second factor is of more major interest, as it accounts for that part of total variability which is related to decomposition rate. In that factor, the variables gaining relatively high loadings (>0.4) were, besides DECNEED and DECMIX, the four purely climatic characteristics: TJUL, TJAN, TAMP and PAMP, the Ellenberg continentality index (CONT) and soil pH (Tab. 3, Fig. 5). The loading of average annual air temperature was notably low. Thus, the variables selected for the second factor indicate that, if decomposition rate is related to climate along the latitudinal transect across Europe, the indices involved are those connected with continentality (extreme air temperatures and amplitudes of air temperature and precipitation), rather than average yearly conditions.

Significant regressions for decomposition rate on climate characteristics (see Methods) were found for needle litter ($p < 0.0001$), cones ($p = 0.0165$) and mixed litter ($p < 0.0001$). However, as the highest proportion of total variance explained by climatic factors was 0.37 (R^2_{adj} for needle litter), it has to be stressed that, although the effect of climatic factors on decay rate was highly significant, as

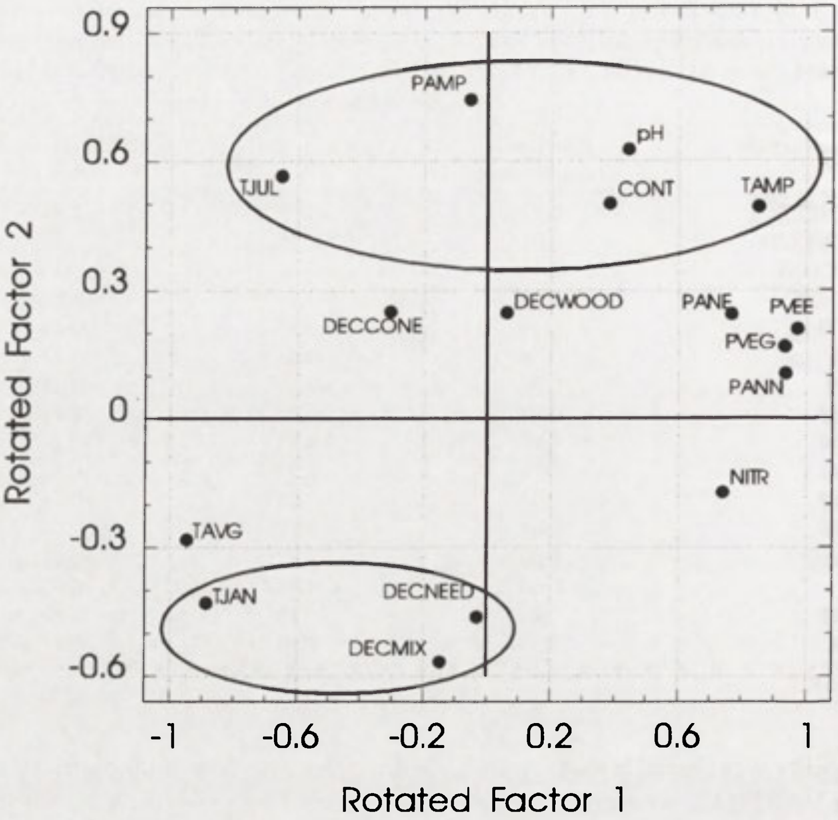

Fig. 5. The VARIMAX-rotated first two factors of the Principal Components Analysis; variables associated with decomposition (loadings > 0.4) are encircled. Communalities and loadings of the variables are given in Tab. 1

much as 63% of the variability remained unexplained in that way. That high residual variability may be caused by other factors, such as soil-specific characteristics or differences in substrate chemistry, which may mask the effect of the climatic gradient. Furthermore, high intra-site variability in decomposition rates (Figs 6–8) made it more difficult to detect climate-driven trends, especially since there was in fact no simple and strong high-low temperature or high-low AET gradient, but one in which the effects of different climate characteristics were more subtle. Additionally, latitudinal gradients in some factors were probably driving the decomposition rate in opposite directions: for example, towards the western end of the transect there is an increase in average annual temperature with decreasing precipitation.

The stepwise variable procedure (F-to-enter = 4.0) allowed for the identification of four variables having a significant effect on the decomposition rate of needles and explaining 36% of its total variability. These were TJAN

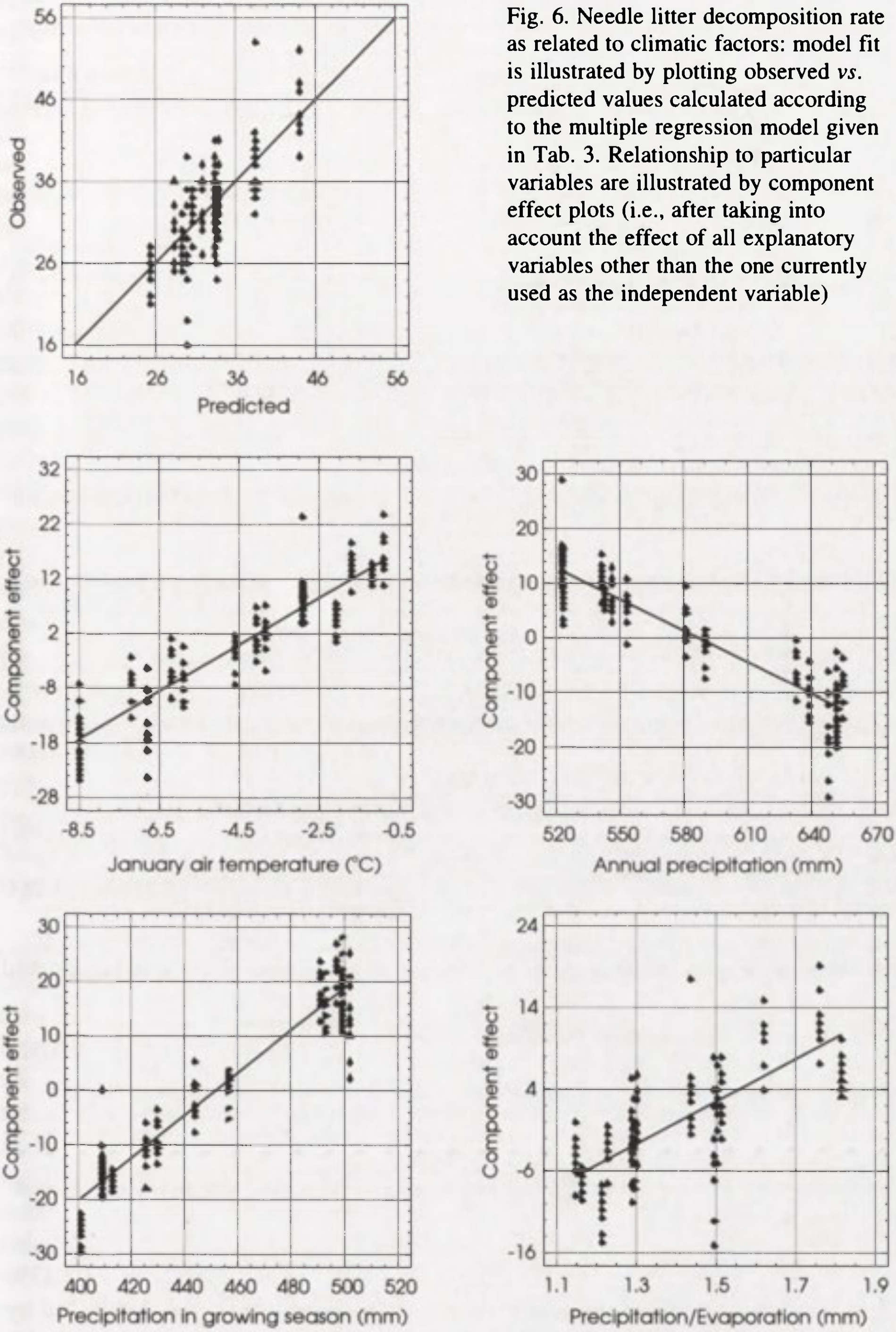

Fig. 6. Needle litter decomposition rate as related to climatic factors: model fit is illustrated by plotting observed *vs.* predicted values calculated according to the multiple regression model given in Tab. 3. Relationship to particular variables are illustrated by component effect plots (i.e., after taking into account the effect of all explanatory variables other than the one currently used as the independent variable)

Table 4. Results of stepwise variable selection procedure relating decomposition rates of needles, wood, cones and mixed litter to climatic factors (for description of variables see text)

Variable	Needles	Cones	Mixed litter*	Mixed litter**
Constant	–48.48 ($p < 0.0001$)	–160.2 ($p = 0.0263$)	192.4 ($p < 0.0001$)	–34.11 ($p = 0.006$)
TAVG	n.s.	n.s.	n.s.	–
TJUL	n.s.	9.64 ($p = 0.0165$)	n.s.	–
TJAN	4.31 ($p < 0.0001$)	n.s.	–8.09 ($p = 0.0001$)	3.37 ($p < 0.0001$)
TAMP	n.s.	n.s.	–9.21 ($p < 0.0001$)	–
PANN	–0.19 ($p = 0.0024$)	n.s.	n.s.	–0.26 ($p = 0.018$)
PVEG	0.39 ($p < 0.0001$)	n.s.	n.s.	0.46 ($p = 0.0004$)
PAMP	n.s.	n.s.	n.s.	–
PANE	25.98 ($p < 0.0001$)	n.s.	n.s.	12.10 ($p = 0.002$)
PVEE	n.s.	n.s.	n.s.	–
Model	$R^2_{adj} = 0.36$ $p < 0.0001$	$R^2_{adj} = 0.064$ $p = 0.0165$	$R^2_{adj} = 0.24$ $p < 0.0001$	$R^2_{adj} = 0.27$ $p < 0.0001$

* raw results of stepwise variable selection procedure,

** results of multiple regression with variables forced into the model confined to those selected for needle decomposition.

Table 5. Results of the stepwise variable selection procedure relating decomposition rates of needles, wood, cones and mixed litter to climatic factors, pH and Ellenberg indices (for description of variables see text)

Variable	Needles	Cones	Mixed litter*	Mixed litter**
Constant	267.8 ($p < 0.0001$)	–160.2 ($p = 0.0263$)	354.8 ($p < 0.0001$)	456.7 ($p < 0.0001$)
TAVG	–28.81 ($p < 0.0001$)	n.s.	35.83 ($p < 0.0001$)	–40.90 ($p < 0.0001$)
TJUL	n.s.	9.64 ($p = 0.0165$)	n.s	–
TJAN	n.s.	n.s.	–50.76 ($p < 0.0001$)	–
TAMP	–3.27 ($p < 0.0001$)	n.s.	–40.58 ($p < 0.0001$)	–5.09 ($p < 0.0001$)
PANN	n.s.	n.s.	n.s.	–
PVEG	0.81 ($p < 0.0001$)	n.s.	n.s.	0.79 ($p = 0.062$)
PAMP	n.s.	n.s.	n.s.	–
PANE	19.86 ($p < 0.0001$)	n.s.	15.93 ($p < 0.0001$)	–0.04 ($p = 0.51$)
PVEE	–3436 ($p < 0.0001$)	n.s.	n.s.	–376.5 ($p < 0.0001$)
PH	n.s.	n.s.	7.35 ($p < 0.0001$)	–
CONT	n.s.	n.s.	8.81 ($p < 0.0001$)	–
NITR	6.32 ($p < 0.0001$)	n.s.	7.18 ($p < 0.0001$)	3.98 ($p = 0.0001$)
Model	$R^2_{adj} = 0.57$ $p < 0.0001$	$R^2_{adj} = 0.064$ $p = 0.0165$	$R^2_{adj} = 0.52$ $p < 0.0001$	$R^2_{adj} = 0.45$ $p < 0.0001$

* raw results of stepwise variable selection procedure,

** results of multiple regression with variables forced into the model confined to those selected for needle decomposition.

($p = 0.0001$), PANE ($p < 0.0001$), PVEG ($p = 0.0141$) and PANN ($p = 0.0179$) (Tab. 4). Thus, the effect of climate on needle decomposition was dominated by that of air temperature during the coldest month of the year, and by three different measures related to precipitation. Again notable is the lack of any significant effect of TAVG on decomposition. On the other hand, after the additional inclusion of pH, CONT and NITR, the stepwise procedure generated a model with selection of the variables: TAVG, TAMP, PVEG, PANE, PVEE, and NITR (Tab. 5). This regression explained as much as 57% of the variability in rates of decomposition of needle litter. Thus, the impact of particular climatic variables on decomposition rate should be treated with caution. A high intercorrelation between most climatic characteristics (Fig. 2) might have a confounding effect on the results of the stepwise regression procedure. In general, we believe that even if the regression equations obtained do not have much predictive power, they do indicate how large a proportion of the variability in decomposition rate of a particular litter fraction (needles, wood or cones) can be explained by reference to climate, and how much can be assigned to soil-specific factors such as pH and nitrogen status. In the case of needles, approximately 36% of the variability is explained by reference to the former factors, and the next 21% by reference to differences in soil pH and N status between sites. The remaining 43% of the variability needs explanation, and as pointed out above, the two possible sources of this variability are: (1) the high intra-site variance and (2) differences in decomposition rates between different forest types. The second source is certainly important, as can be seen on Figure 4, but the experimental design applied did not allow for any indication of the reasons for this variability. On the other hand, ANOVA did indicate highly significant differences ($p < 0.0001$) in needle decomposition rates between forest types. Needle decomposition was slowest in pure pine stands, significantly faster in mixed stands, and fastest in stands described as anthropogenic ("bad", *cf.* Tab. 1). The stand types differed significantly from each other (Tukey 95% HSD intervals). This confirmed our assumption that, with subtle specific variability in climate along longitudinal transects such as ours, differences in vegetation of the same forest type contribute significantly to the total variability in litter decomposition rate.

The decay of materials more resistant to decomposition, such as wood and cones, was less affected by climatic factors, at least during the first year of decomposition. Wood and cone materials generally decomposed more slowly thus in order to detect any climatic effects it might be necessary to make much longer studies. After one year of decay, no significant regression was found for the rate of decomposition of wood, while the rate for cones, although positively related to TJUL ($p = 0.0165$), was explained only marginally by this climatic factor. The adjusted coefficient of determination (R^2_{adj}) was as low as 0.064, indicating that almost 94% of the variability remained unexplained (Fig. 7). With a large number of independent variables used, this regression should be considered non significant in practice. No differences in rates of decomposition of wood or cones were detected between forest types either (ANOVA $p > 0.1$).

The mixed litter, a natural mixture of pine needles, cones and woody materials, took an intermediate position where the relation between decomposition rate and climatic factors was concerned. In this case, approximately 24% of total

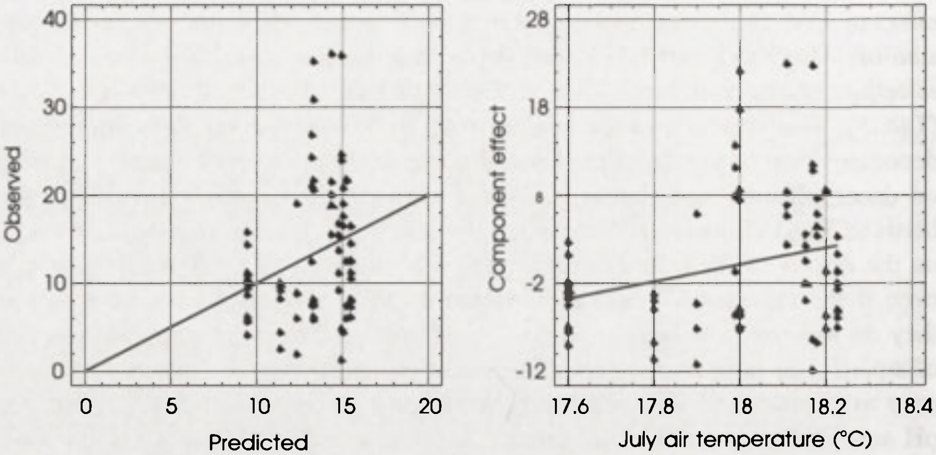

Fig. 7. Decomposition rate of cones as related to climatic factors: model fit is illustrated by plotting observed *vs.* predicted values calculated according to the multiple regression model given in Tab. 3. Relationship to particular variables are illustrated by component effect plots (see fig. 6 for explanation)

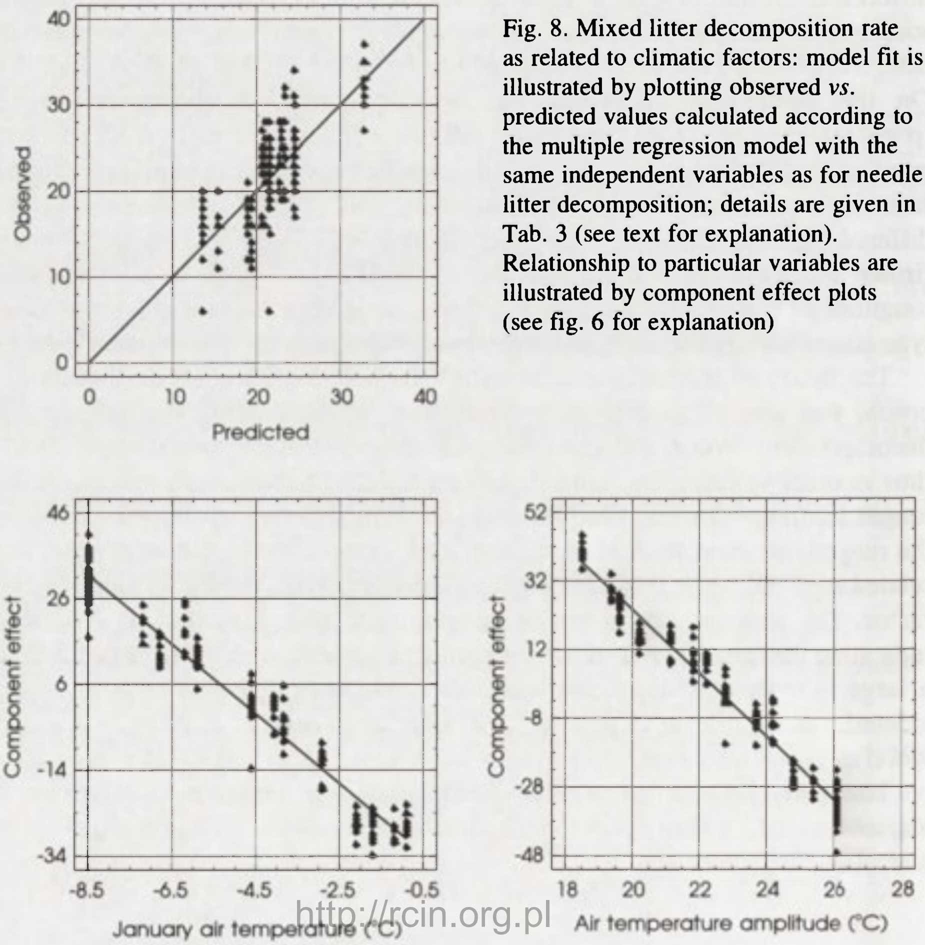

Fig. 8. Mixed litter decomposition rate as related to climatic factors: model fit is illustrated by plotting observed *vs.* predicted values calculated according to the multiple regression model with the same independent variables as for needle litter decomposition; details are given in Tab. 3 (see text for explanation). Relationship to particular variables are illustrated by component effect plots (see fig. 6 for explanation)

variability was explained by TAMP ($p < 0.0001$) and TJAN ($p < 0.0001$) (Tab. 4). Average January temperature appeared significant in both regressions of decomposition rate on climatic factors established with the aid of the stepwise regression procedure. However, surprisingly the signs were opposite: positive for needles and negative for mixed litter (Tab. 4). When these results were checked with simple linear regression, the results were consistent: in both cases decomposition rate correlated significantly and positively with January temperature. Knowing that the stepwise procedure may sometimes lead to erroneous solutions (Sokal and Rohlf 1981), we tested the multiple regression again, this time forcing into the model for mixed litter decomposition those variables accepted as good predictors of the decomposition of needle litter (positive correlation with January temperature). The regression calculated in this way gave results similar to those for needles and, at 27%, the explained portion of total variability was even higher than in the model selected initially (Tab. 4, Fig. 8). It can thus be concluded that the decomposition rates of needle and mixed litter were related to the climatic factors in a very similar manner (*cf.* Figs. 6 and 8). The addition of pH, CONT and NITR to the model for mixed litter raised R^2_{adj} to 0.52. The new variables entering the model were TAVG, PANE, pH, CONT and NITR (Tab. 5). ANOVA results were the same as for needles alone ($p < 0.0001$), with the slowest decay rate in pure pine, a faster one in mixed forest, and the fastest rate in anthropogenic ("bad") forests. Thus, at least part of the variability unexplained by climatic or soil-specific differences between sites could be assigned to differences in forest type. As in the case of needles, some of the remaining unexplained variability has to be assigned to intra-site variance in decomposition rates (Fig. 8).

CONCLUSIONS AND DISCUSSION

– Rates of decomposition of forest litters were measured for one year in 15 stands of Scots pine along a 1800 km (20° W–E) transect at 52°N. Litter-bags (10 × 10 cm, 1 mm diameter nylon net) with Scots pine needles, wood material, cones or mixed litter were used. The values obtained are similar to those cited by Breymeyer (1993), obtained 10 years earlier in the area close to the central part of the transect.

– Along the W–E gradient of climate continentality (Germany, Poland, Belarus), with only minor differences in average annual temperature or AET between sites, above 40% of the variability in rates of needle and mixed litter decomposition was explained by climatic factors. No climate effect on wood decay was found.

– Decomposition rates of needles and mixed litter decreased in pine forests futher to the east, in cooler and more continental climatic conditions.

– Of the different litter fractions tested, needles displayed the best correlation between decomposition rate and climatic indices. The mixed litter, i.e. the natural composition of litter falling down, responds well to climate differences. No climate effect on wood decay was found.

– Decomposition rate along the transect was mostly correlated with climatic indices describing the degree of continentality, such as annual amplitude in air temperature, air temperatures of the coldest and warmest months (January and July) and annual amplitude of precipitation. The relationship with precipitation amplitude is especially interesting as this index is not usually used in studies on litter decomposition; however, it is rather obvious that litter decay may be affected by periodic drying or overwatering.

– Besides the relationship between decomposition rate and the aforementioned climatic indices, there were significant differences in decomposition rates between sites belonging to three different categories according to biological diversity evaluated for forest floor vegetation. The rate of decay was slowest on pure, most-sandy stands of Scots pine, significantly faster in mixed stands (pine forest with significant admixtures) and fastest on anthropogenically – modified stands (pine forest with visible signs of human treatment).

– The conclusions presented above are based on first-year decomposition rates. It is known that plant remnants decay fastest during the first year of incubation; during this year easily decomposable fractions of organic matter disappear. The course of decay of other organic matter components is described from some long-term experiments; e.g., Berg and Ekbohm (1991) followed decomposition dynamics for 4 years and found that rates of decay of different litters change: the fast, more nutrient-rich litters had considerably lower mass-loss rates in the later stages. These authors extrapolated the measured litter decay values and estimated the maximum, "asymptotic" value of mass loss for different litters. For Scots pine litter the predicted asymptotic mass loss was 68% for green needles and 89% for brown needles (the authors used needles collected directly from a pine tree on one, "standard" stand – the so called "standard litter"). These authors did not estimate distinctly the time needed to reach the asymptote; from analysis of the printed curves, it seems that some litters arrive at the asymptotic level in less than 1 year, while others need over 3 500 days. A significant linear relationship was found between the asymptote level of mass loss and the initial decomposition rate. In the light of these findings we assumed that we can use the first year decomposition rate as an index of litter decay characteristic for a given stand and climate.

– The conditioning of litter decay by climatic indices of continentality described in our paper suggests oversimplification in the equations used by Global Change models to predict the response of ecosystems on the basis of temperature increase/decrease alone. Our transect covers only a short distance across the Euroasiatic continent; we can only imagine how strong the influence of continentality characteristics can be on the scale of the continent as a whole.

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DOES PLANT COVER STRUCTURE IN RURAL AREAS MODIFY CLIMATE CHANGE EFFECTS?

ANDRZEJ KĘDZIORA, LECH RYSZKOWSKI
Agricultural University of Poznań
Research Centre for the Agricultural and Forest Environment,
Polish Academy of Sciences, Bukowska 19, 60–809 Poznań, Poland

ABSTRACT: Estimates were made of the effects on sensible and latent heat fluxes of a change in real land-use patterns to simulated simplified and mosaic agricultural landscapes. Climate change in Poland due to the enhanced greenhouse effect was assumed after Jager (1988). Land-use changes have stronger impacts on the transport of energy into the atmosphere by convection and evapotranspiration than climate change to 2050 or 2075. These results were assessed by analyses carried out at than landscape level as well as at the scale of the predicted region and the whole of Poland. The effects of global climate change can be mitigated to some extent by manipulation of the land-use pattern.

KEY WORDS: agricultural landscape, land-use, plant cover, heat fluxes, evapotranspiration.

INTRODUCTION

The influences of climate change on world ecosystems and the socio-economic development of humanity have evoked widespread concern not only among scientists but also among politicians and decisionmakers, to say nothing of the wider public. Many scientific papers have provided information on our understanding of global climatic changes and the still-existing uncertainties. The core of our knowledge was described along with response strategies, in the publications of the Intergovernmental Panel on Climate Change (Houghton et al. 1992; Watson et al. 1996 and 1998). The main stream of analyses deal with the impacts of presumed climate changes on various ecosystems and on economic development, while the feedbacks of land-use changes on climate are studied less frequently. The biological feedbacks on climate could be large but it is difficult to estimate their magnitude by relying on models considering physiological principles alone (Hurtt et al. 1988). There is a need for aggregated characterizations of the heat and water balances of plant stands and a knowledge of the trends to land-use change.

Studies carried out by Kędziora et al. (1989), Olejnik and Kędziora (1991), and Kędziora and Olejnik (1996) have led to the devising of a model estimating the heat balance for a whole plant stand on the basis of meteorological characteristics and the parametrization of plant cover structures. Use of the model has made it possible to estimate the influence of various kinds of plant-cover structure (cultivated plants, grasslands, forests, shelterbelts and others) on evapotranspiration and the air and soil heating fluxes for particular landscapes. Plant-cover structure has been shown to have important impacts on evapotranspiration rates and air heating (Ryszkowski and Kędziora 1987, 1993). Additionally, plant-cover structure has also been found to exert important mitigating effects on the presumed effects of global climate change in terrestrial ecosystems (Ryszkowski and Kędziora 1995).

The effects of land cover on microclimatic conditions, air temperature, moisture, wind speed and so on are well known. The feedback of those modifications on mesoscale air circulations, cloud formation and precipitation are less well-recognised, but such information is crucial if microscale modifications are to be linked with global circulation models. Data from Stohlgren et al. (1998) indicate that land-use practices influence regional climate in the plains of Colorado and so have an indirect influence on the vegetation in adjacent areas of the Rocky Mountains.

The aim of this paper is to show that:

1. modification of the plant cover in an agricultural landscape influences the vertical flux of sensible heat;
2. the changes in land-use pattern influence the vertical fluxes of sensible and latent heat at the scale of the Wielkopolska region;
3. the last studied problem concerns the mutual effects of climate and land-use changes on the intensity of sensible and latent heat fluxes in Poland.

FIELD INVESTIGATION METHODS

The results presented in this paper referring to field investigations were obtained using the system of automatic measurement of heat-balance components (Olejnik, Kędziora 1991). Radiation air temperatures of the active surface were measured using an infra-red thermometer, while thermodynamic temperatures of field surfaces were obtained with a thermocouple thermometer. Measurements were made using two independent systems installed in the fields. Those concerning air temperature, vapour pressure and wind speed were carried out at 5 levels above ground each hour for a few days. Soil heat flux was measured directly using soil heat plates, and all radiation fluxes were measured through the use of a Kipp-Zonnen pyrgeometer and a CRN balansometer.

CALCULATING METHODS

Heat balance components and evapotranspiration were calculated for the vegetation period according to the method elaborated by Kędziora and Olejnik (1997) and Olejnik and Kędziora (1991). The brief description of this method is as follows:

The heat balance equation is usually written in the form:

$$Rn + G + LE + S = 0 \tag{1}$$

where: Rn – is net radiation, G – the energy flux exchanged between the active surface and the soil, S – the turbulent flux of sensible heat and LE – the turbulent flux of latent heat of evapotranspiration. All fluxes are expressed in Watts per square metre and the sign is positive when the flux is oriented towards the active surface, and negative when it is oriented off it.

Components of the heat balance are dependent on meteorological conditions as well as on plant phenological stage. The influence of these factors is expressed through the so-called agrometeorological index W, which is given by:

$$W = \frac{(d \cdot \sqrt{v})^{\mathrm{artn}(\frac{\pi}{2} \cdot \mathrm{f})}}{t \cdot (u + 0.4)} \tag{2}$$

where: d – is the saturation water vapour pressure deficit [hPa], v – the wind speed [$\mathrm{m} \cdot \mathrm{s}^{-1}$], f – the plant development stage (0 to 1), t – air temperature [$^{\mathrm{o}}\mathrm{C}$] and u – the relative sunshine (0 to 1).

The empirically-found relationship between the Bowen ratio $\beta = S/LE$ and the index W enables the impact of meteorological conditions on the Bowen ratio to be approximated. It is expressed by the equation:

$$\beta = \frac{12.75}{W + 3.9} - 0.02 \tag{3}$$

The latent heat of evaporation was given by:

$$LE = -(Rn + G)/(1 + \beta) \tag{4}$$

Net radiation (Rn) and soil heat flux (G) can be measured directly, or calculated according to the method given in Olejnik and Kędziora (1991), using the equations:

$$Rn = (1 - \alpha) \cdot R_o \cdot (0.54 + 0.22 \cdot u) - \sigma\,(t + 273)^4 \cdot (0.56 + 0.08 \cdot e^{-0.5}) \cdot (0.1 + 0.9 \cdot u) \tag{5}$$

where: α – is the albedo, R_0 – the extra-terrestrial solar radiation, σ – the Stephan-Boltzman constant equal to $5.67 \cdot 10^{-8}$[$\mathrm{W} \cdot \mathrm{m}^{-2} \cdot \mathrm{K}^{-4}$], e – the water vapour pressure [hPa], u – the relative sunshine [dimensionless], and t – the air temperature [$^{\mathrm{o}}\mathrm{C}$].

The albedo depends on features of the active surface, and was calculated for the main ecosystems according to the equations:

$$\alpha = 0.18 + 0.05 \cdot f \quad \text{for crop fields and meadows} \tag{6}$$

$$\alpha = 0.15 + 0.05 \cdot f \quad \text{for deciduous forests} \tag{7}$$

$$\alpha = 0.15 \quad \text{for coniferous forests} \tag{8}$$

$$\alpha = 0.18 \quad \text{for bare soils,} \tag{9}$$

where f is the phenological stage of plant development (from 0 to 1).

Soil heat flux was calculated according to the relation:

$$G = -0.2 \cdot Rn \cdot (1-0.75 \cdot f) \cdot \sin[\pi/6(i-2)] \tag{10}$$

where i is cardinal number of month.

Finally evapotranspiration for the given period was calculated according to the equation:

$$ETR = LE/28.34 \cdot n \tag{11}$$

where: LE – is the average value for latent heat flux density in the given period [$\mathrm{Wm^{-2}}$], n – the number of days in the period (month or ten-days).

The following assumptions were taken into consideration when the scenario for climate and land use changes were selected.

1. According to IIASA (Jager 1988) the air temperature increase in the future will be equal to 2 degrees in summer and 6 degrees in winter, with annual air temperature changes being expressed by the equation:

$$T_f = T_a + 2 \cdot (\cos[\pi/6 \cdot (i-1)] + 2) \tag{12}$$

where: T_f – is air temperature in the future,
T_a – present air temperature,
i – number of month beginning from January.

2. The water vapour pressure (e) in the future was calculated according to the empirically-obtained function (Kędziora 1995):

$$e = 5.5 \cdot \exp(0.05662 \cdot t) \tag{13}$$

and saturation water vapour pressure deficit (d)

$$e_s = \exp\left[\frac{17.2696\, t}{t + 237.45} + 1.810418\right] \tag{14}$$

$$d = e_S - e. \tag{15}$$

3. Two scenario of land-use changes were taken into consideration:

a – a simplified landscape that is 80% cereals and 20 % row crops,

b – a mosaic landscape that is 50% forest, 20% of meadow, 20% cereals and 10% row crops.

THE IMPACT OF PLANT COVER ON THE VERTICAL FLUX OF SENSIBLE HEAT

The influence of the plant-cover structure on the flux of sensible heat will be illustrated by reference the results obtained in studies on the heat balance in a sugar beet field and a nearby field of stubble, following the harvesting of wheat.

The active surface of an intensively-transpiring sugar beet field uses much more solar energy for water evapotranspiration than a stubble field does. This causes big differences in the surface temperature of these ecosystems. The difference in surface temperature between the stubble field and the sugar beet was of as much as 6.4 degrees on a sunny day (Tab. 1), while the difference in air temperature over these fields at a level 2 m above the ground was of only 0.13 degree. On a cloudy day the differences were much smaller, reaching only 1.1 degree on the active surface and disappearing 2 m above the ground.

The large vertical gradient in the air temperature of near-surface strata indicates that a lot of sensible heat is transmitted from the earth's surface to the atmosphere on a sunny day, with ensuing air turbulence. This process intensifies the exchange of mass in the boundary layer, e.g. by evapotranspiration. Such a situation is characteristic for anticyclonal circulation. In the studied landscape cases of such circulation account for about 40 % of the total time span in the summer.

The vertical gradient of air temperature on a sunny day is nearly 9 times greater over the stubble field than over sugar beet. On a cloudy day the vertical gradient over the stubble field is negative, though 14 times smaller than on a sunny day. At the same time the vertical gradient over the sugar beet field is positive. This is of course the result of plant transpiration, which uses more energy than is available from the sun. The transpiring sugar beet plants gain the lacking energy from the air, thereby causing a air temperature inversion. Thus bare soils or dried surfaces resulting from human activity are areas on which convection is generated, thereby influencing the energy and mass exchange on both the local and a regional scales. The vertical gradient of wind speed was higher over the sugar beet field than over stubble field because of a greater roughness of the former which to some extent compensates for the effects described above.

Table 1. Meteorological condtitions and heat balance structure of sugar beet field and stubble field on a sunny day (19.08.98 – relative sunshine equals 0.746) and a cloudy day (22.08.98 – relative sunshine equals 0.146) near Cessieres, France. Daily values are taken as averages from 7 am to 8 pm. Sugar beets were 45 cm high, stubble 15 cm

Parameter	19.08.98		22.08.98	
	Stubble	Sugar beet	Stubble	Sugar beet
Meteorological conditions				
Radiation temperature of active surface [^oC]	26.36	19.99	15.37	14.27
Air temperature 2 m above ground [^oC]	19.49	19.36	14.87	14.87
Windspeed 0.5 m above ground [ms^{-1}]	1.63	2.42	0.63	2.42
Windspeed 2.0 m above ground [ms^{-1}]	1.97	2.92	0.76	2.92
Vertical gradient of air temperature [$^oCm^{-1}$]	–3.43	–0.42	–0.25	0.4
Vertical gradient of wind speed [s^{-1}]	0.53	1.20	0.63	1.44
Aerodynamic resistance [sm^{-1}]	93.0	47.0	46.0	23.0
Heat balance				
Net radiation, Rn, [Wm^{-2}]	184.2	269.6	48.9	70.1
Sensible heat flux density, S, [Wm^{-2}]	–108.3	–46	–10.9	18.1
Soil heat flux density, G, [Wm^{-2}]	–18.4	–22.5	–5.1	–5.2
Latent heat flux density, LE, [Wm^{-2}]	–57.5	–201.1	–32.9	–83
Bowen ratio, S/LE	1.88	0.23	0.33	–0.22
Alpha ratio, LE/Rn	0.31	0.75	0.67	1.18

At 184 W · m^{-2}, the net radiation of the stubble field was much lower than that of the sugar beet (270 W · m^{-2}) a situation mainly due to the much higher reflection of solar radiation shoved by albedo. This difference was much lower on a cloudy day (Tab. 1). The active surface of the sugar beet used nearly 4 times more energy for evapotranspiration on a sunny day and 3 times more on a cloudy day than did the stubble field. But the stubble field used 2.5 times as much energy for air heating as the sugar beet field on a sunny day (Tab. 1, Fig. 1). On a cloudy

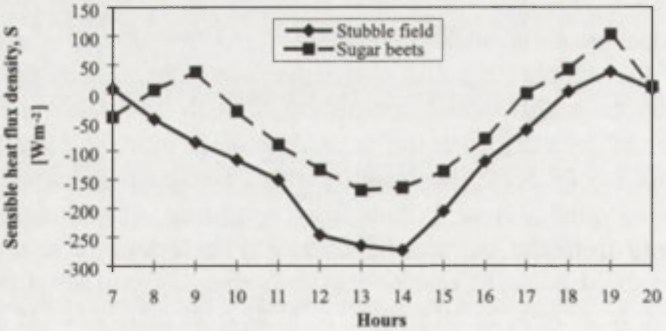

Fig. 1. Daily course of sensible heat flux above sugar beet and stubble fields on a sunny day. Cessieres, 19.08.98
(The sign of the Values are according to the direction of flux: positive for inward amd negative for outward direction of the active surface)

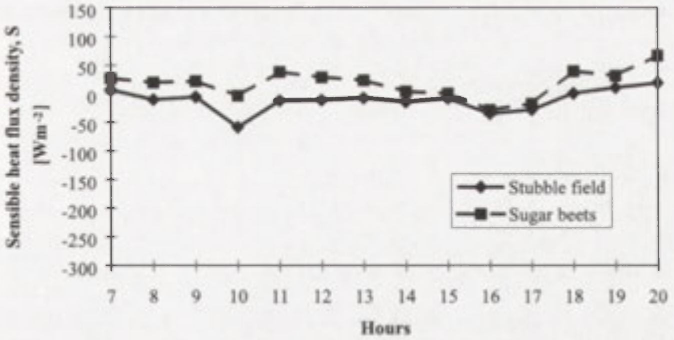

Fig. 2. Daily course of sensible heat flux above sugar beet and stubble fields on a cloudy day. Cessieres, 22.08.98 (Signs of the fluxes as on Fig. 1)

day, the stubble field warmed up the air while the sugar beet field was cooling it (Tab. 1, Fig. 2).

In general, biologically-active ecosystems are seen to damp down the vertical exchange of sensible energy between earth and atmosphere, while the biologically inactive ecosystems (bare soil and the stubble field) are factors intensifying these processes.

CHANGES IN THE VERTICAL FLUXES OF SENSIBLE (S) AND LATENT (LE) HEAT AS A RESULT OF CLIMATIC AND LAND USE CHANGES IN THE WIELKOPOLSKA LANDSCAPE

Three different types of landscape structure were analysed in order to evaluate the impact of land-use patterns on sensible and latent heat fluxes at the landscape level. The area of the first landscape (K1) is near Turew in the Wielkopolska region. It is 30% forest, 15% meadow, 10% row crops and 45% cereals. All components of the heat balance were calculated for this landscape on basis of standard meteorological data taken from field measurements for the period 1994–1996. Average values for the period of plant growth (21.03. to 31.10) were used (Tab. 2).

In addition, two other landscape patterns were assumed. The second (K2) was 80% cereals and 20% row crops thereby exemplifying the simplified agricultural landscape, while the third (K3), which was 50% forest, 20% meadow, 20% cereals and 10% row crops was an example of a mosaic landscape.

The simplification of landscape structure under present climatic conditions will cause a 3.73 $W \cdot m^{-2}$ decrease in the seasonal average value of latent heat flux density and an increase in sensible heat by 1.94 $W \cdot m^{-2}$ (Tab. 3, K2–K1). But changing the landscape structure from a simple one (K2) to a mosaic (K3) will cause a 6.2 $W \cdot m^{-2}$ increase in latent heat flux density and a decrease in sensible heat flux density of 3.31 $W \cdot m^{-2}$ (Tab. 3, K3–K2).

Under future climatic conditions (Jager 1988), the impact of changes in land-

Table 2. Meteorological characteristics of the vegetation period in the Turew countryside. Average from 1994–1996

Month and ten-day period		Air temp. °C	Water vapour pressure hPa	Sat. water vapour pressure deficit hPa	Wind speed $m \cdot s^{-1}$	Relative sunshine [1]	Relative humidity [1]
March	I	7.1	8.5	1.7	2.7	0.645	0.84
	II	3.7	7.3	1.0	4.3	0.233	0.88
	III	3.5	6.5	1.7	4.4	0.378	0.82
April	I	6.4	7.5	2.4	5.1	0.481	0.77
	II	3.9	6.9	1.2	5.4	0.223	0.86
	III	9.2	10.3	2.3	3.3	0.692	0.83
May	I	13.5	12.9	3.0	4.4	0.687	0.84
	II	19.1	18.6	3.7	3.3	1.113	0.85
	III	11.0	11.9	1.5	3.4	0.441	0.90
June	I	17.6	17.0	3.8	2.5	1.539	0.83
	II	18.7	17.7	4.2	2.8	1.522	0.82
	III	17.4	20.4	3.5	3.5	1.023	0.88
July	I	19.5	20.3	2.7	3.8	0.700	0.89
	II	18.9	19.2	3.1	2.4	1.305	0.88
	III	20.9	20.5	4.5	2.0	2.282	0.84
August	I	20.7	20.2	4.5	2.0	2.233	0.84
	II	22.9	21.0	7.3	2.3	3.259	0.77
	III	21.8	18.8	7.9	3.3	2.405	0.74
September	I	18.2	17.2	4.3	3.5	1.207	0.81
	II	13.9	13.6	2.9	2.8	1.060	0.85
	III	10.8	12.9	1.2	2.9	0.421	0.92
October	I	13.6	14.9	1.1	2.8	0.384	0.94
	II	7.9	10.1	0.8	2.9	0.310	0.93
	III	2.1	6.7	0.7	2.9	0.236	0.91

[1] – dimensionless.

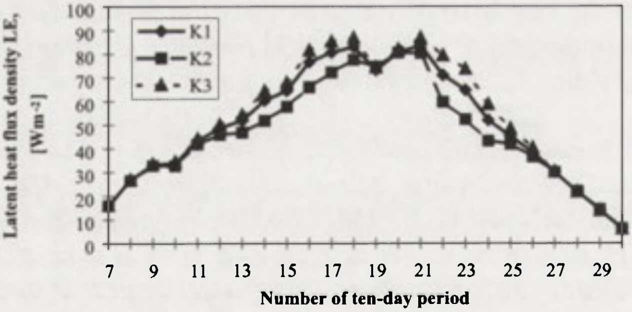

Fig. 3. Seasonal course of latent heat *LE*, in different landscapes under present climatic conditions*

K1 – landscape consists of 30% forests, 15% meadows, 10% row crops, 45% cereals,
K2 – landscape consists of 20% row crops, 80% cereals,
K3 – landscape consists of 50% forests, 20% meadows, 10% row crops, 20% cereals+

* On this picture as well as on Fig. 4, 5 and 6 the absolute Values of latent and sensible heat flux were shown

Table 3. Seasonal average values for heat balance components (Wm^{-2}) under present and future climatic conditions and different landscape structure

Parameter	Landscape		
	K1	K2	K3
Latent heat flux density LE under present clim. conditions	49.93	46.2	52.4
Latent heat flux density LE under future clim. conditions	55.44	50.68	58.53
Sensible heat flux density S under present clim. conditions	17.85	19.79	16.48
Sensible heat flux density S under future clim. conditions	15.89	17.94	12.97
Change of latent heat flux, LE, as a result of landscape structure changes under present climatic conditions			
	K2–K1	K3–K1	K3–K2
	–3.73	2.47	6.20
Change of sensible heat flux, S, as a result of landscape structure changes under present climatic conditions			
	K2–K1	K3–K1	K3–K2
	1.94	–1.37	–3.31
Change of latent heat flux, LE, as a result of landscape structure changes under future climatic conditions			
	K2–K1	K3–K1	K3–K2
	–4.76	3.09	7.85
Change of sensible heat flux, S, as a result of landscape structure changes under future climatic conditions			
	K2–K1	K3–K1	K3–K2
	2.05	–2.92	–4.97
Change of latent heat flux, LE, as a result of landscape structure and climatic condition changes			
	K1p–K1o	K2p–K1p	K3p–K1o
	5.51	–4.76	8.60
Change of sensible heat flux, S, as a result of landscape structure and climatic condition changes			
	K1p–K1o	K2p–K1p	K3p–K1o
	–1.96	2.05	–4.88

Landscape structure: K1 – 30% forests, 15% meadows, 10% row crops, 45% cereals, K2 – 20% row crops, 80% cereals, K3 – 50% forests, 20% meadows, 10% row crops, 20% cereals, o – present, p – future climatic conditions.

scape structure will work in the same direction as in the present situation, only absolute values for these changes will be a little higher (Tab. 3). Thus, such marked changes in meteorological parameters as assumed by IIASA – Jager (1988), (e. g. an increase in summer air temperature of 2 degrees and a 4 degree increase in spring and autumn result in only a small increase in heat flux densities, thereby indicating a greater role for plant cover than climate changes in modifying heat balance structure.

In the seasonal course of latent heat under present (Fig. 3) and future (Fig. 4) climatic conditions, the biggest differences between the landscapes occur in May, June, August and September. In July the differences are small because

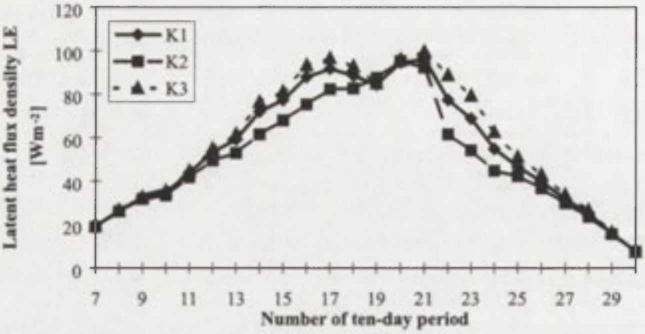

Fig. 4. Seasonal course of latent heat *LE*, in different landscapes under future climatic conditions

K1 – landscape consists of 30% forests, 15% meadows, 10% row crops, 45% cereals,
K2 – landscape consists of 20% row crops, 80% cereals,
K3 – landscape consists of 50% forests, 20% meadows, 10% row crops, 20% cereals

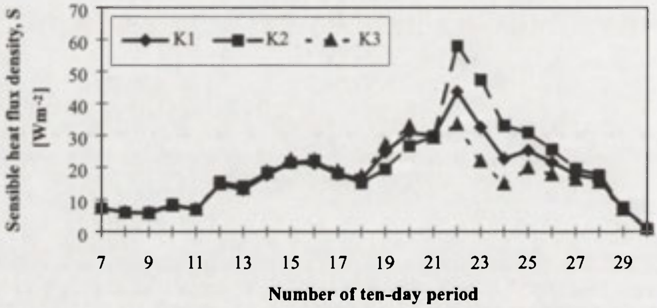

Fig. 5. Seasonal course of sensible heat *S*, in different landscapes under present climatic conditions

K1 – landscape consists of 30% forests, 15% meadows, 10% row crops, 45% cereals,
K2 – landscape consists of 20% row crops, 80% cereals,
K3 – landscape consists of 50% forests, 20% meadows, 10% row crops, 20% cereals

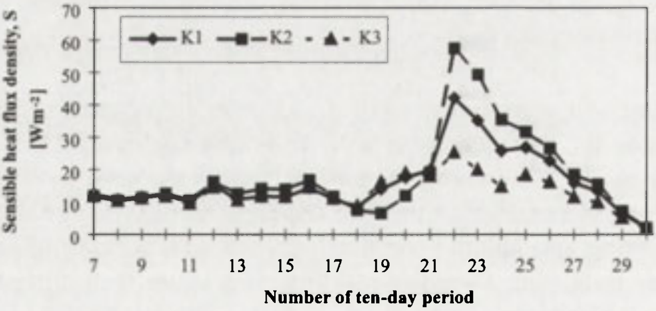

Fig. 6. Seasonal course of sensible heat *S*, in different landscapes under future climatic conditions

K1 – landscape consists of 30% forests, 15% meadows, 10% row crops, 45% cereals,
K2 – landscape consists of 20% row crops, 80% cereals,
K3 – landscape consists of 50% forests, 20% meadows, 10% row crops, 20% cereals

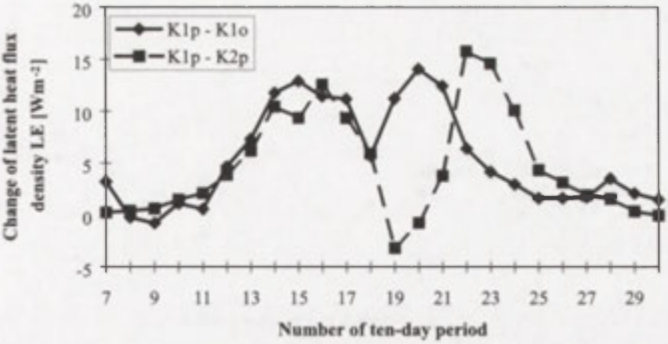

Fig. 7. Change of latent heat LE as a result of climatic and landscape structure changes
K1 – landscape consists of 30% forests, 15% meadows, 10% row crops, 45% cereals,
K2 – landscape consists of 20% row crops, 80% cereals,
K3 – landscape consists of 50% forests, 20% meadows, 10% row crops, 20% cereals,
o – present climatic conditions, p – future climatic conditions

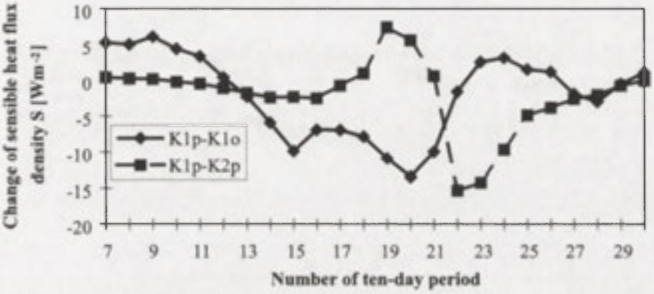

Fig. 8. Change of sensible heat as a result of climatic and landscape structure changes
K1 – landscape consists of 30% forests, 15% meadows, 10% row crops, 45% cereals,
K2 – landscape consists of 20% row crops, 80% cereals,
K3 – landscape consists of 50% forests, 20% meadows, 10% row crops, 20% cereals,
o – present climatic conditions, p – future climatic conditions

cereal fields still evaporate more while row-crop fields are growing. In May and June only cereals are well-developed, while row crop fields are rather bare, while the opposite situation exists in August and September, when cereals have been harvested, and fields are bare, while only row crops evaporate.

A similar situation applies to sensible heat (Fig. 5 and 6); the biggest differences between landscapes are detected in summertime. The modification effects of plant-cover structure on sensible and latent heat appear in the summertime, when the moisture content of the habitat is much lower than during the spring months. This is the result of evapotranspiration, which is intensive even from bare soil during spring, as opposed to summer when only growing plants evapotranspire intensively.

A change in climatic conditions can bring about a 5.50 W · m^{-2} increase in

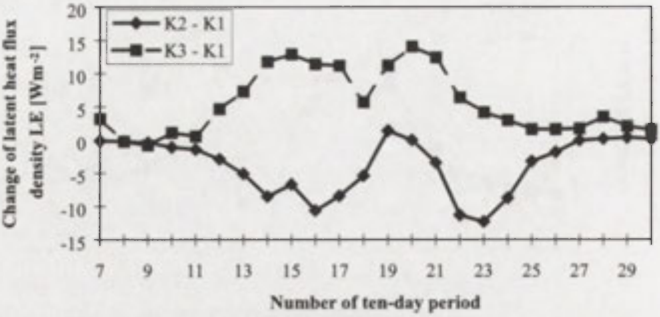

Fig. 9. Change of latent heat *LE* as a result of landscape changes under present climatic conditions

K1 – landscape consists of 30% forests, 15% meadows, 10% row crops, 45% cereals,
K2 – landscape consists of 20% row crops, 80% cereals,
K3 – landscape consists of 50% forests, 20% meadows, 10% row crops, 20% cereals

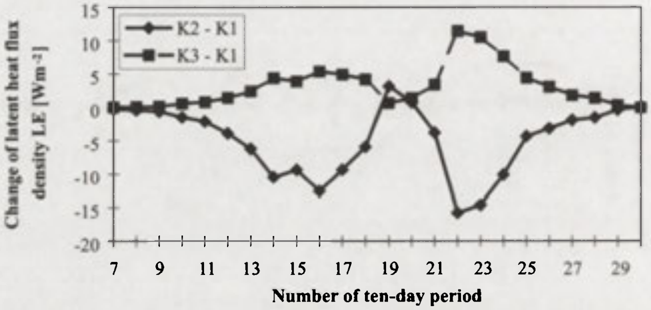

Fig. 10. Change of latent heat *LE* as a result of landscape structures changes under future climatic conditions

K1 – landscape consists of 30% forests, 15% meadows, 10% row crops, 45% cereals,
K2 – landscape consists of 20% row crops, 80% cereals,
K3 – landscape consists of 50% forests, 20% meadows, 10% row crops, 20% cereals

the latent heat flux density (*LE*) of the present landscape, and decrease sensible heat flux density (*S*) by nearly 2 W · m^{-2} (Tab. 3, K1p–K1o). But a change in landscape structure from the simplified (K2) to the mosaic (K3) can increase latent heat flux density by 6.2 W · m^{-2} under present climatic conditions and by 7.85 W · m^{-2} under future climatic conditions (Tab. 3, K3–K2). So, changes in the latent heat flux density caused by land-use changes can be greater than those caused by climatic changes. The seasonal course of the latent and sensible heat flux densities caused by land use changes show greater amplitude (Fig. 7 and 8 K1p–K2p) than the changes caused by climatic change (Fig. 7 and 8, K1p–K1o).

There is a comparable range of variation to the seasonal course of changes in latent and sensible heat density of fluxes present as well as future climatic

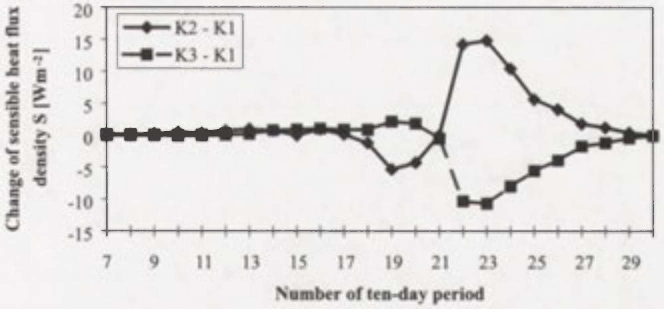

Fig. 11. Change of sensible heat *S* as a result of landscape structures changes under present climatic conditions

K1 – landscape consists of 30% forests, 15% meadows, 10% row crops, 45% cereals,
K2 – landscape consists of 20% row crops, 80% cereals,
K3 – landscape consists of 50% forests, 20% meadows, 10% row crops, 20% cereals

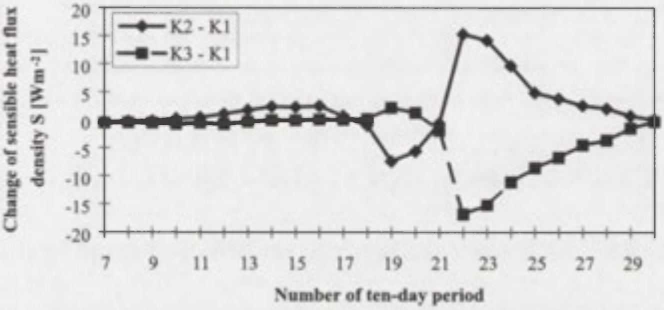

Fig. 12. Change of sensible heat *S* as a result of landscape structures changes under future climatic conditions

K1 – landscape consists of 30% forests, 15% meadows, 10% row crops, 45% cereals,
K2 – landscape consists of 20% row crops, 80% cereals,
K3 – landscape consists of 50% forests, 20% meadows, 10% row crops, 20% cereals

conditions (Fig. 9, 10, 11 and 12). The greatest variation in sensible heat flux density caused by land use changes occurs in the summertime (Fig. 11 and 12) as a result of the depletion of habitat moisture and the removal of plant cover after harvest. This means that, during the summer period, bigger changes in the intensity of energy and mass exchange between earth and atmosphere can be expected.

The increasing diversity of landscape structure can combine with changes in climatic conditions to force latent heat flux density (*LE*) and decrease sensible heat flux density (*S*) during the summer – by as much as 18 $W \cdot m^{-2}$ for both fluxes, which amplifies the exerted effects (Fig. 13).

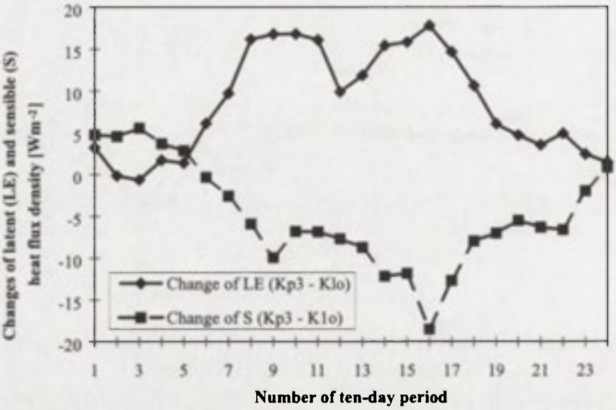

Fig. 13. Change of latent (*LE*) and sensible (*S*) heat as a result of climatic and landscape structures changes

K1 – landscape consists of 30% forests, 15% meadows, 10% row crops, 45% cereals,
K2 – landscape consists of 20% row crops, 80% cereals,
K3 – landscape consists of 50% forests, 20% meadows, 10% row crops, 20% cereals,
o – present climatic conditions, p – future climatic conditions

CHANGES IN BOWEN-RATIO VALUES IN POLAND AS A RESULT OF CLIMATIC AND LAND-USE CHANGES

The Bowen ratio (that is ratio between sensible and latent heat flux density) can be interpreted as a measure of atmospheric convectivity. The higher the value of the Bowen ratio the greater the possibility of convection appearing.

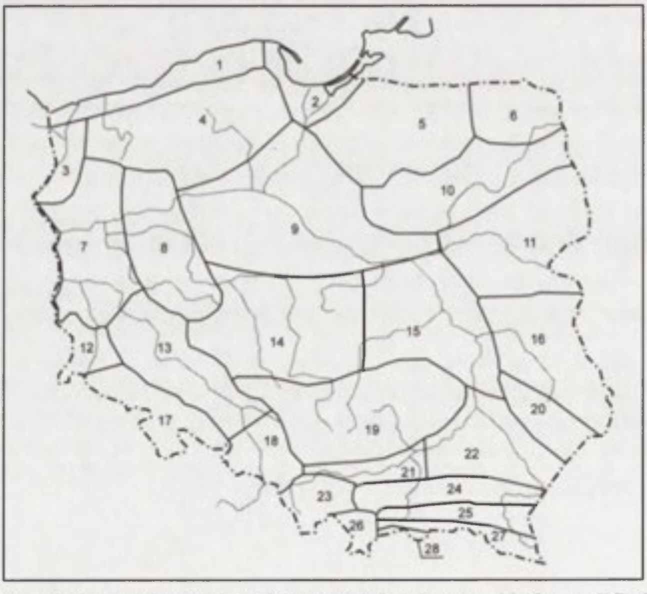

Fig. 14. Climatic regions of Poland (after Romer 1949, modified)

Table 4. Bowen ratio of different landscapes under present and future climatic conditions

Region number	Bowen ratio					
	Present climatic conditions			Future climatic conditions		
	Present landscape structure	Simplified: 80% cereals 20% row crops	Mosaic: 50% forests 20% meadows 20% cereals 10% row crops	Present landscape structure	Simplified: 80% cereals 20% row crops	Mosaic: 50% forests 20% meadows 20% cereals 10% row crops
1	0.38	0.47	0.30	0.33	0.49	0.27
2	0.38	0.44	0.29	0.34	0.47	0.27
3	0.38	0.45	0.28	0.35	0.49	0.28
4	0.37	0.46	0.31	0.35	0.49	0.30
5	0.37	0.45	0.30	0.36	0.49	0.30
6	0.36	0.44	0.28	0.34	0.48	0.29
7	0.31	0.45	0.28	0.31	0.48	0.28
8	0.32	0.42	0.25	0.33	0.46	0.26
9	0.37	0.44	0.28	0.38	0.49	0.30
10	0.38	0.47	0.32	0.37	0.50	0.31
11	0.36	0.46	0.29	0.36	0.48	0.28
12	0.33	0.45	0.29	0.32	0.49	0.28
13	0.34	0.44	0.26	0.35	0.47	0.27
14	0.34	0.42	0.24	0.36	0.47	0.26
15	0.39	0.46	0.30	0.38	0.49	0.28
16	0.38	0.46	0.30	0.38	0.50	0.29
17	0.37	0.48	0.33	0.36	0.51	0.32
18	0.39	0.47	0.31	0.37	0.49	0.30
19	0.36	0.46	0.30	0.36	0.50	0.30
20	0.41	0.49	0.33	0.39	0.50	0.29
21	0.39	0.47	0.31	0.39	0.50	0.39
22	0.36	0.46	0.30	0.33	0.48	0.33
23	0.33	0.45	0.29	0.29	0.50	0.34
24	0.40	0.48	0.33	0.33	0.50	0.38
25	0.44	0.52	0.40	0.40	0.51	0.37
26	0.40	0.48	0.38	0.38	0.48	0.35
27	0.40	0.49	0.40	0.40	0.49	0.32
28	0.37	0.47	0.34	0.34	0.49	0.33
Average	0.37	0.46	0.31	0.36	0.49	0.31

For location of regions see Fig.14.

Bowen ratios were estimated from heat balance components calculated independently for real climatic conditions and land-use patterns in 28 regions of Poland (Fig. 14). The division into regions is based on climatic characteristics from Romer (1949), with the exception of the central regions where differences in land-use pattern (low contribution of afforested areas) were also taken into consideration (Ryszkowski at al. 1991). All information on the prevailing climatic conditions for each region was taken from the Climatic Atlas of Poland

Table 5. Changes of Bowen ratio caused by changes in climatic conditions and landscape structure

Region number	Changes of Bowen ratio				
	K2o–K1o	K3o–K1o	K2p–K1p	K3p–K1p	K1p–K1o
1	0.09	–0.08	0.16	–0.06	–0.05
2	0.06	–0.09	0.13	–0.07	–0.04
3	0.07	–0.10	0.14	–0.07	–0.03
4	0.09	–0.06	0.14	–0.05	–0.02
5	0.08	–0.07	0.13	–0.06	–0.01
6	0.08	–0.08	0.14	–0.05	–0.02
7	0.14	–0.03	0.17	–0.03	0.00
8	0.10	–0.07	0.13	–0.07	0.01
9	0.07	–0.09	0.11	–0.08	0.01
10	0.09	–0.06	0.13	–0.06	–0.01
11	0.10	–0.07	0.12	–0.08	0.01
12	0.12	–0.04	0.17	–0.04	–0.01
13	0.10	–0.08	0.12	–0.08	0.00
14	0.08	–0.10	0.11	–0.10	0.02
15	0.07	–0.09	0.11	–0.10	–0.01
16	0.08	–0.08	0.12	–0.09	0.00
17	0.11	–0.04	0.15	–0.04	–0.01
18	0.08	–0.08	0.12	–0.07	–0.02
19	0.10	–0.06	0.14	–0.06	0.00
20	0.08	–0.08	0.11	–0.10	–0.02
21	0.08	–0.08	0.11	0.00	0.00
22	0.10	–0.06	0.15	0.00	–0.03
23	0.12	–0.04	0.21	0.05	–0.04
24	0.08	–0.07	0.17	0.05	–0.07
25	0.08	–0.04	0.11	–0.03	–0.04
26	0.08	–0.02	0.10	–0.03	–0.02
27	0.09	0.00	0.09	–0.08	0.00
28	0.10	–0.03	0.15	–0.01	–0.03
Average	0.09	–0.06	0.13	–0.05	–0.02

K1 – landscape of present structure, K2 – landscape consists of 80% cereals and 20% row crops, K3 – landscape consists of 50% forests, 20% meadows, 20% cereals and 10% row crops, o – present climatic conditions, p – future climatic conditions.

(1973). The effects of land-use changes were assessed by assuming that the real landscapes of a region will be converted to the simplified and mosaic patterns described in the previous chapter (K_2 and K_3; Tab. 4).

The smaller the values of the Bowen ratio the greater the part of solar energy that is used for evapotranspiration and the smaller the amount going to air heating. Under present climatic conditions, the simplification of landscape structure to cultivated fields only will increase the average value of the Bowen ratio for the whole country by 0.09 (Tab. 5, K2o–K1o), while increasing landscape diversity will reduce the Bowen ratio by 0.06 (Tab. 5, K3o–K1o). These changes in Bowen ratio are relatively large. For example, in the vegetation season, when

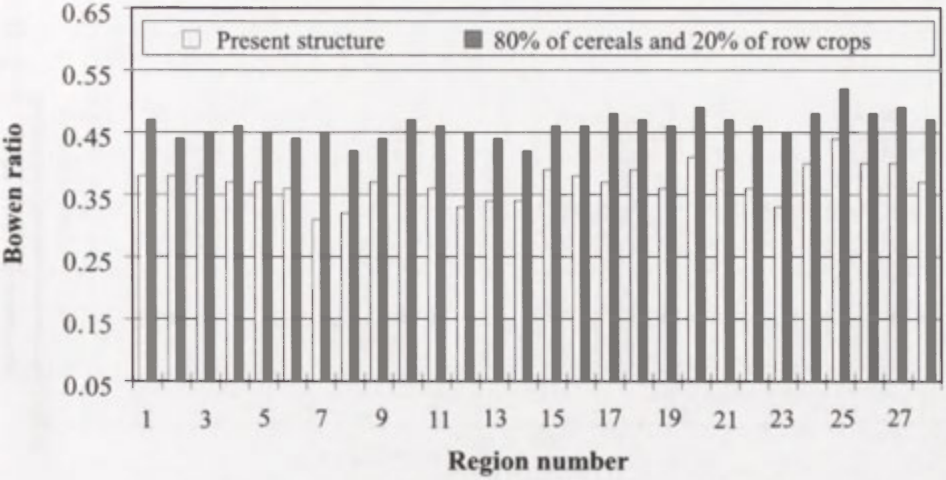

Fig. 15. Increase of Bowen ratio as a result of simplification of landscape structures under present climatic conditions

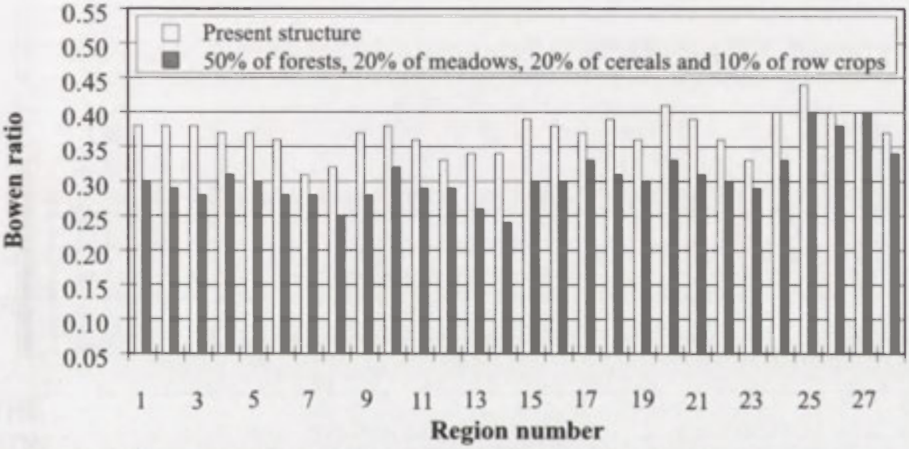

Fig. 16. Decrease of Bowen ratio as a result of developing of landscape structures under present climatic conditions

net radiation is equal to 80 W $\cdot$ m^{-2}, a 0.09 increase in the Bowen ratio (from 0.37 to 0.46) causes a 30 mm increase in total evapotranspiration.

Under future climatic conditions, the changes in the Bowen ratio will be of 0.13 (Tab. 5, K2p–K1p) and –0.05 (Tab. 5, K3p–K1p) respectively (Tab. 4). The changes will occur in all regions (Fig. 15 and 16) and these caused by climatic changes only will range from 0 (landscape K3) to 0.03 (landscape K2), and will thus be smaller in all regions (Fig. 17) that those caused by land-use pattern changes (Fig. 18). So, the effects of land-use changes are much greater than those of climatic changes (Fig. 17 and 18).

Simplification of the landscape structure will cause the biggest changes in

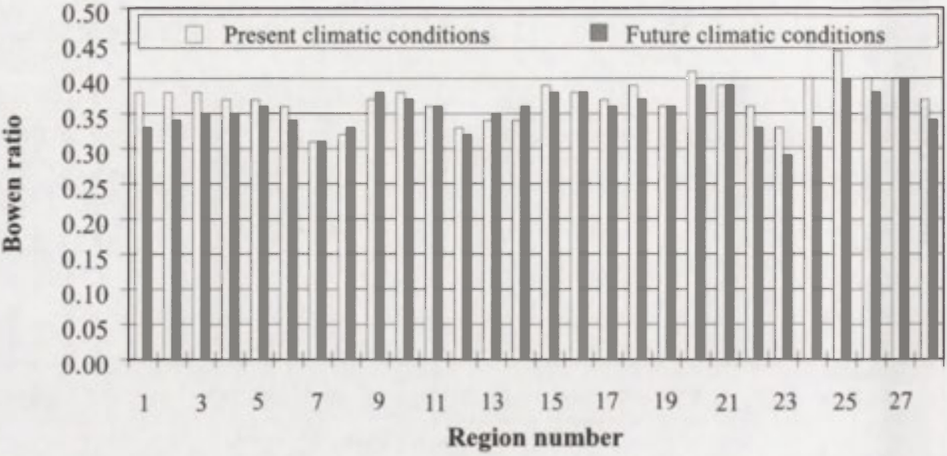

Fig. 17. Bowen ratio of 28 regions of Poland under present and future climatic conditions and present landscape structure

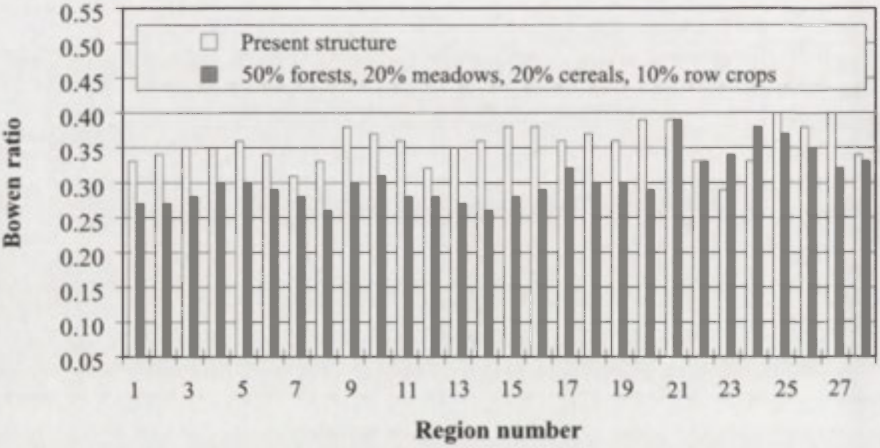

Fig. 18. Bowen ratio of 28 regions of Poland under present and future climatic conditions for present landscape structure and after change of landscape structure

regions that are well afforested (Fig. 19, K2o–K1o) in the west and north-eastern part of Poland, as well as in the region of the Swiętokrzyskie Mountains. Consequently, an increasing diversity of landscape structure will cause smallest changes of the Bowen ratio in those regions which are well afforested under present climatic conditions (Fig. 20, K3o–K1o) as well as in the future (Fig. 21, K3p–K1p).

The Bowen-ratio changes caused by climatic change only are very small over the country as a whole, varying from 0.01 to –0.02 (Fig. 22, K1p–K1o).

So, on the scale of the whole country, the changes in the Bowen ratio caused by plant-cover changes can be bigger than those caused by climatic changes only.

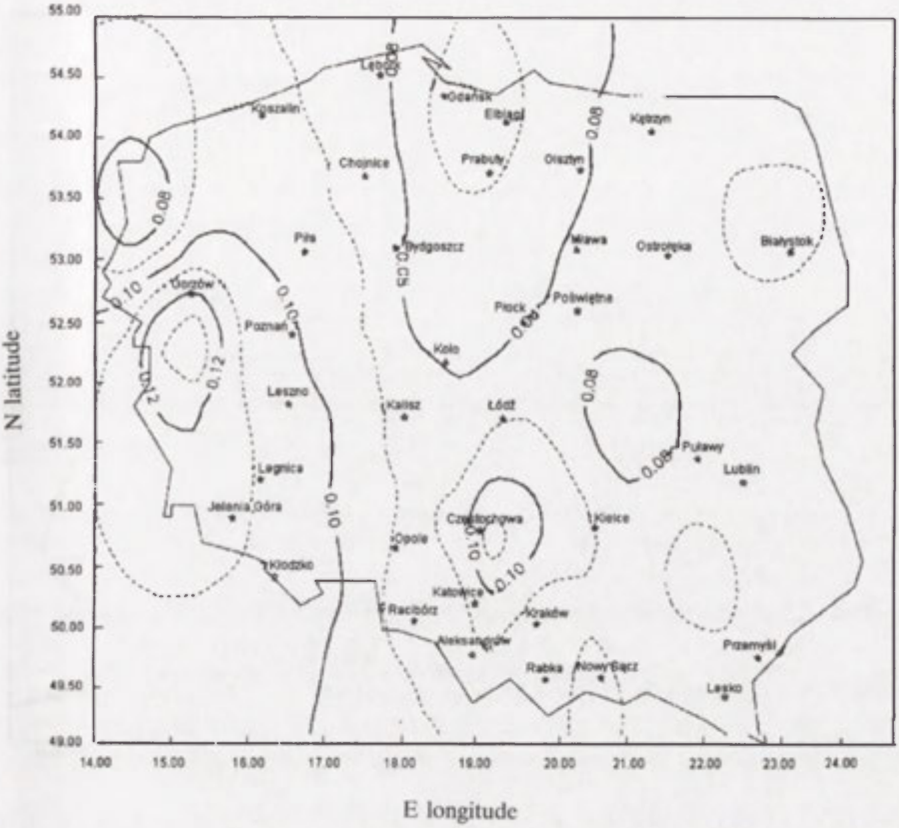

Fig. 19. Change of Bowen ratio due to conversion of present land use pattern to simplified landscape (K2o–K1o)

THE IMPACT OF MIDFIELD SHELTERBELTS ON HEAT-BALANCE STRUCTURE UNDER NORMAL METEOROLOGICAL CONDITIONS AND UNDER DRY AND HOT AIR MASS ADVECTION

To illustrate the possible options for mitigating the heat and water-balance structure of the landscape through human activity under different weather conditions, the effect of the introduction of shelterbelts into an agricultural landscape was evaluated (Ryszkowski and Kędziora 1987, 1995). The introduction of shelterbelts into a simplified landscape is one of the best tools by which to manage heat balance in the landscape. Shelterbelts reducing wind speed conserve the water supply of a field located between shelterbelts, but increase sensible heat flux a little (Tab. 6). However, during the strong advection of dry and warm air, irrigated fields can conserve as much as 10% of water during evapotranspiration in comparison with a landscape without shelterbelts (Ryszkowski and Kędziora 1995).

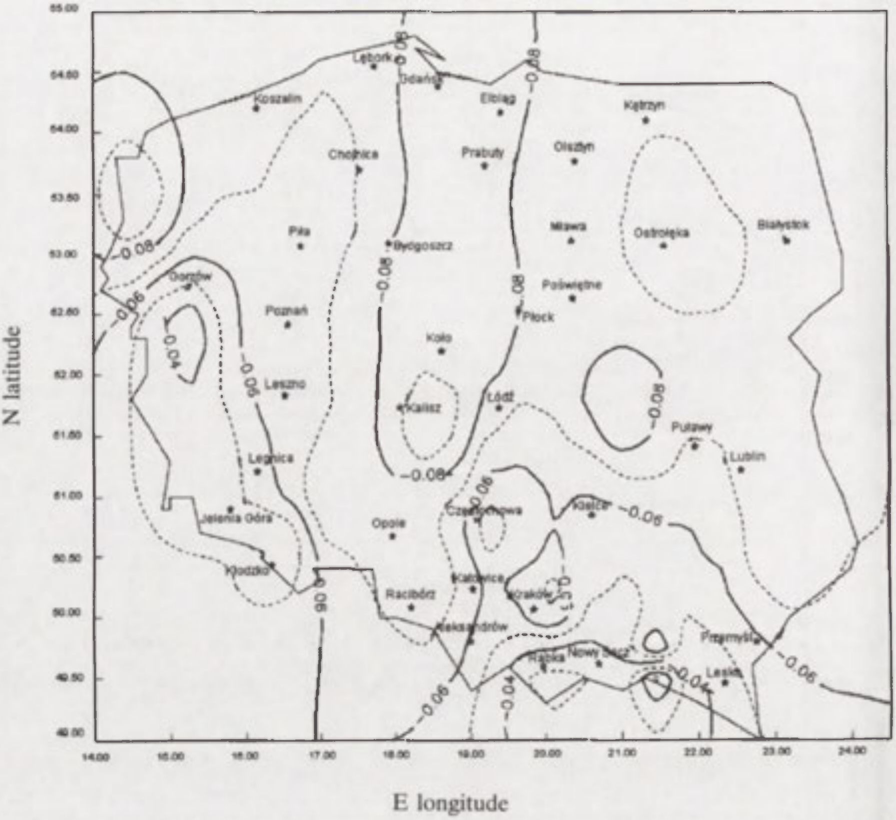

Fig. 20. Increase of forest area to 50% and grassland area to 20% will bring major changes in Bowen ratio in areas with low percentage of permanent vegetation (K3o–K1o)

Table 6. Heat and water balance components of different agricultural landscapes in the vicinity of Turew in the vegetation season (21.03 – 31.10)
Heat balance components are expressed in $\mathrm{MJ \cdot m^{-2}}$, and water balance in mm

Landscape	*Rn*	*LE*	*S*	*ETP*	*ETR*	*ETR/ /ETP*	ETR/Prc
Cereal monocultures	1542	1035	495	650	414	0.64	1.10
Cereal monocultures with a network of shelterbelts	1586	1078	496	586	431	0.76	1.15
Cereal monocultures with windbreaks	1567	1010	546	581	404	0.76	1.08
Cereal monocultures without shelterbelts under advection	1586	1258	315	898	503	0.56	1.34
Cereal monocultures with shelterbelts under advection	1586	1181	412	592	464	0.78	1.24

Rn – net radiation, *LE* – latent heat of evapotranspiration, *S* – sensible heat, *ETP* – potential evapotranspiration, *ETR* – real evapotranspiration, *Prc* – precipitation.

According to equation 1 the absolute value of *LE* and *S* are shown.

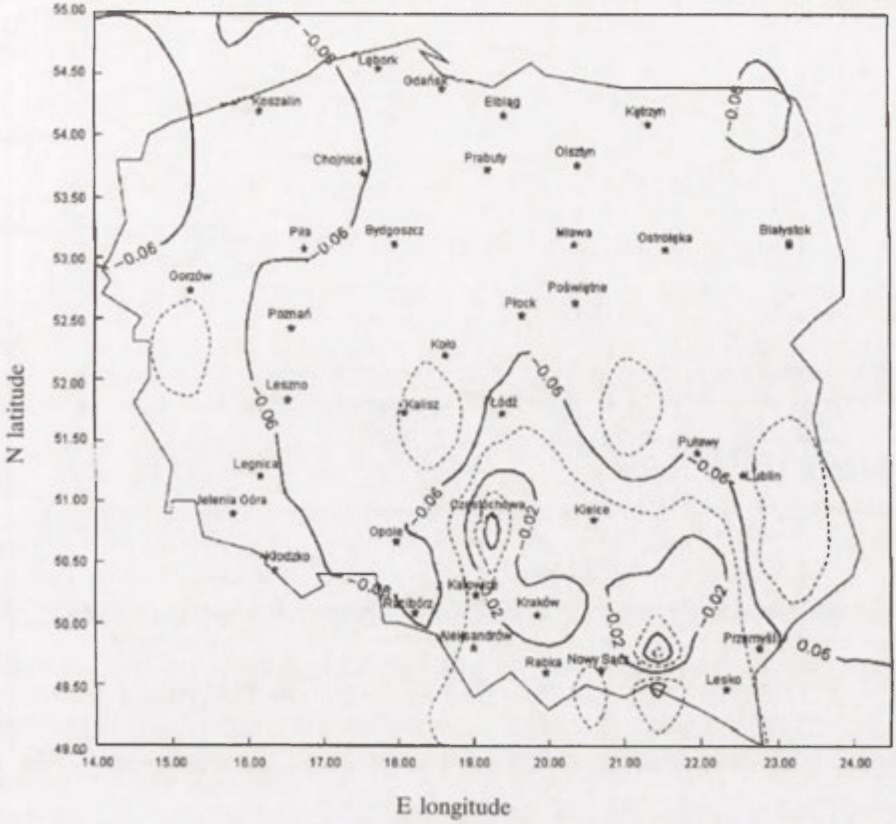

Fig. 21. Change of Bowen ratio due to increase of area with permanent vegetation under presumed temperature conditions (K3p–K1p)

CONCLUSIONS

Actively-growing plants (like cereals in spring or sugar beet in summer) modify the structure of the heat balance to damping convection and enhancing the flux of latent heat. Simulated effects of land-use changes show that feedbacks due to plant cover concerning the heat balance are greater under predicted climate conditions than the changes evoked by enhancement of greenhouse effect alone.

An increase in landscape structural diversity can compensate for the effect of climate changes in latent and sensible heat flux changes. On the scale of the whole of Poland conversion of forest into cultivated fields will increase the sensible heat flux and decrease the latent heat in proportion to the percentage of forest in the region. The changes will be greater, for example, in the south–westen part of Poland (Fig. 19).

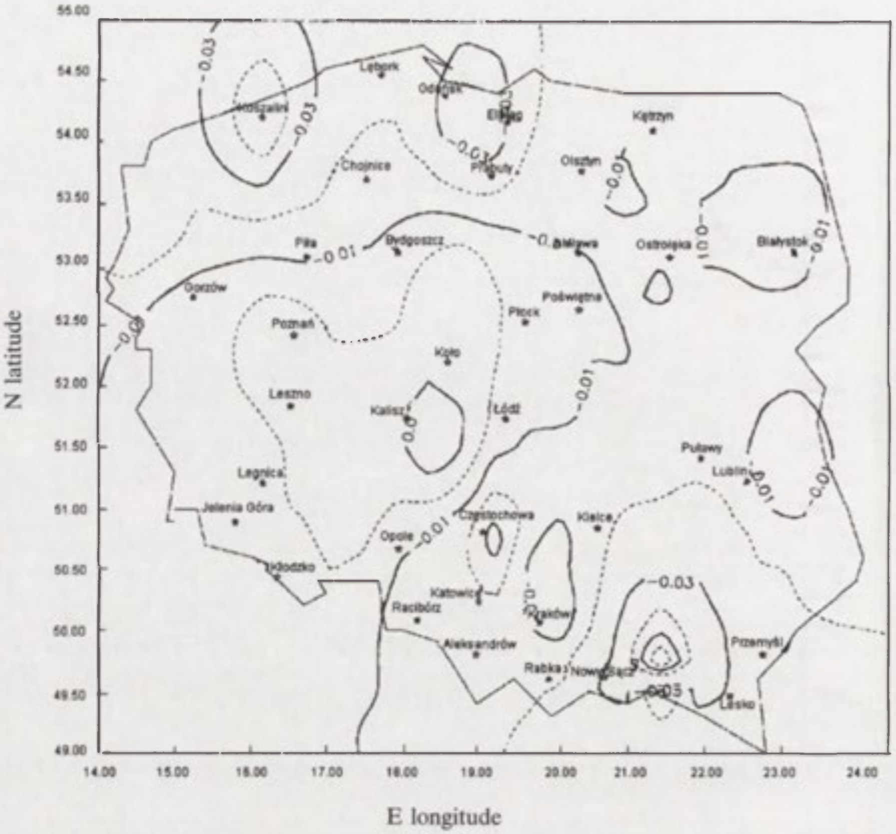

Fig. 22. Change of Bowen ratio due to alternations of air temperature only (K1p–K1o)

Our simulated results of the effects of land-use change are supported by field evidence of regional climate changes evoked by alternations in the agriculture practices shown by Stohlgren at al. (1998).

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THE EMISSION, ABSORPTION AND RETENTION OF GREENHOUSE GASES (GHG) IN POLISH AGRICULTURE

EMIL NALBORCZYK, STEFAN PIETKIEWICZ, TADEUSZ LOBODA
Plant Physiology Department, Warsaw Agricultural University, Rakowiecka 26/30,
02-528 Warsaw, Poland

LESZEK SIECZKO
Department of Statistics and Experimental Design, Warsaw Agricultural University,
Rakowiecka 26/30, 02-528 Warsaw, Poland

ABSTRACT: Principal findings concerning the balance of GHG emissions, absorption and retention in Polish agriculture are discussed in relation to the anticipated enhancement of the greenhouse effect. Balances for GHGs on Polish farms oriented towards crop and animal production are presented, along with strategies for the reduction of GHG emissions in Polish agriculture based firstly on better organization of agricultural production, e.g. increased effectiveness of milk production, better use of agricultural land, the introduction of biological progress into plant and animal production and the introduction of a new generation of agricultural machines. Strategies are also based on the introduction of plants for the production of renewable energy sources and other industrial uses.

KEY WORDS: greenhouse effect, agriculture, GHG, emission, absorption, retention, farms, Poland, mitigation.

INTRODUCTION

As a party to the United Nations Framework Convention on Climate Change Poland is obliged to work out and implement a strategy for the stabilization and in future the reduction, of GHG emissions and far the adaptation of those sectors of the economy most dependent on climatic conditions to the expected climate changes, while simultaneously realizing that activities undertaken by Poland with a view to reducing GHG emissions do not, by and large, affect global climate change (Sadowski 1996).

Although agriculture is the branch of the economy most vulnerable to climate-change effects (Rozenzweig and Hiller 1993; Mott 1990), the study of both its adaptation and mitigation under the forthcoming enhanced greenhouse effect have only been started quite recently. A valid assessment of possible C pools and fluxes in agriculture is needed to decide whether C inputs and outputs are nearly balanced there, i.e. it is neither a major source nor sink of atmospheric C (Cole et al. 1993). Contemporary world crop production includes the cultivation of many thousands of cultivars of several main crop species cultivated. In Poland alone are more than 100 cultivars of cereals, 30 cultivars of potatoes and so on (Nalborczyk and Czembor 1992). A large amount of various energetic inputs (e.g. mineral fertilizers, pesticides, electricity and fuels) are needed to successfully cultivate aforementioned plethora crops.

The steadily-increasing consumption of energy originating from burned fossil sources such as petrol, coal and natural gas is causing a continuous increase in the atmospheric CO_2 concentration thereby leading to the enhancement of the greenhouse effect (Rozema et al. 1993). Consequent global worming (elevation of mean annual air temperature all over the Earth) can have many negative aspects for world climate, agriculture and people if the industrial activity of humankind does not cease to enhance the magnitude of the effect. Thus, there should be a well-grounded belief that this artificial increased effect is one of the worst expected phenomena on the global scale (Benarde 1992; Bazzaz et al. 1985). The atmospheric carbon dioxide concentration has increased from about 280 $\mu mol \cdot mol^{-1}$ of air at the beginning of the Industrial Revolution to 350 at the present, and is currently increasing at between 1.4 and 2.33 $\mu mol \cdot mol^{-1} \cdot a^{-1}$ (Goudriaan and Ketner 1984). If this increase continues, a doubling of the present CO_2 concentration (to almost 700 $\mu mol \cdot mol^{-1}$) can be expected by the middle of the next century (Sadowski 1996).

It is usual for the role of forests as big surfaces absorbing and sequestering GHGs to be underlined (Rozema et al. 1993), while there is not full appreciation of the role of agricultural crops. These crops do not only absorb CO_2 from the atmosphere temporarily during vegetation period; they can also sequester it in underground parts (roots, bulbs, tubers). Agriculture is thus a branch of the economy capable of fixing and sequestering carbon from the atmosphere. The balance of GHG in agriculture involves their emission, absorption and retention. Plants of terrestrial ecosystems are the main absorbers of atmospheric CO_2 due to their ability to fix it during photosynthesis. An increasing of the CO_2 concentration increases photosynthesis, dry matter production and yield, and greatly improves the efficiency of water use in photosynthesis (Woodward et al. 1991), so the ability of plants in agrosystems to photosynthesize under increasing concentrations of it will determine both the rate of increase of the greenhouse effect and the magnitude of plant production. A doubling of atmospheric CO_2 from 330 to 650 $\mu mol \cdot mol^{-1}$ increases the productivity of a large number of C_3 crop plants on average by 35%, and in the case of C_4 crop plants by 10% (Kimball 1983; Cure and Acock 1986).

The paper reports the principal findings concerning the carbon economy in Polish agriculture.

METHODOLOGY

Included here is an evaluation of the absorption, emission and retention of CO_2, CO, N_2O and CH_4 in Polish agriculture during the last 27 years (1970–1996). The obtained results may be helpful in finding possible ways to increase the absorption and retention of greenhouse gases and to limit their emission in animal and plant production in Poland.

The following specific assumptions have been adopted:

– the amount of organic matter produced in the previous year and used in the analyzed one was the same as that produced in the studied year and used in the next;

– all the carbon fixed in the biological yield (total plant biomass) was emitted, excluding that relatively firmly fixed in the soil;

– the absorption of CO_2 by weeds was not included owing to the lack of reliable data. Their absorption was probably no more than 5% of the total;

– the main producers of methane in agriculture are animals (especially ruminants) and manure fermentation;

– methane from the above sources is emitted to the atmosphere;

– the efficiency of manure fermentation is close to that occurring in animals.

Many other assumptions were common to this and previous works (Nalborczyk et al. 1991).

Data concerning plant yields (fresh or air-dry matter), crop area and the number of animals originated from Yearbooks of the Polish Central Statistical Office (Anonymous 1971–1990, 1997). Calculated on this basis were plant dry matter production using various percentage of water content and harvest index (Donald 1962) as well as recalculations for total methane and N_2O production.

BALANCE OF GHG IN POLISH AGRICULTURE IN THE YEARS 1970–1996

Data presented in Table 1 cover the 1970–1989 period within the centrally-steered economy and the year 1996 from the period of economy in transition (1990–1996). Polish agriculture in the 20-year period 1970–1989 was already showing a high level of CO_2 absorption, which rise substantially in the years 1985–1989. Cereals were revealed as the main absorber of CO_2 and their share was increased from 39 to 50% by the end of that period (data not shown). It is worth underlining the significant role of triticale (the first manmade species) in the absorption of CO_2 which seems to replace the contribution of rye. Simultaneously, a decreasing contribution of root and tuber crops from 20 to 13% was noted, mainly due to a decrease after 1980 of approx. 1/3 in potato acreage and a resulting proportional decrease in biomass. The nearly constant absorption of CO equal to 23–25,000 Mg was converted into the CO_2 equivalent and added to

Table 1. Absorption, retention and emission of CO_2 (10^6 Mg CO_2) in Polish agriculture during the period 1970–1996

	Absorption of CO_2	Retention of CO_2	Emission of CO_2
1970–1974	201,98	11,75	187,34
1975–1979	200,95	13,81	183,96
1980–1984	200,89	11,87	186,14
1985–1989	227,48	11,13	213,71
1996	162,90	4,40	158,50

total CO_2 absorption (Nalborczyk et al. 1991). The CO_2 emission also tended to increase substantially during the period 1985–1989. The years of greatest herd size and manure production were characterized by proportionally less emission of CO_2. A lower CO_2 emission was also found for years in which there were increased shares of pulses i.e., crops capable of retaining organic matter in the soil. The main factor in the emission of CH_4 was the size of the cattle herd. On average its share was constant and was equal to 78% of the total CH_4 emission. The second-ranked source of emission of methane (due to manure fermentation) accounted for only the 15% of total. This emission was also converted to the CO_2 equivalent and added.

Total CO_2 retention was dependent on the organic matter input in manure, with the highest level being during 1975–1979, the period in which the number of head of livestock, especially of cattle, was also at a maximum. The contribution of pastures, meadows and perennial pulses was maintained at a constant level.

The years of transformation in Polish agriculture following the departure from central steering were characterized by lower production of both crops and animals, something which substantially affected the balance of GHG. Only in 1996 was there a marked drop in the absorption, emission and retention of these gases (in term of CO_2 equivalent). It will depend on the agricultural policy of the government as to whether this drop will continue or bottom out.

THE EMISSION OF GHG IN POLISH AGRICULTURE IN 1996

A balance of GHG in Polish agriculture devoted to the specification of possible energy sources used was drown up for the individual year 1996. Detailed analysis of the emission caused by the various energy sources used in Polish agriculture was possible thanks to data available from the1996 National Agricultural Inventory.

The total CO_2-equivalent emission of GHG due to the use of various energy sources was 47 mln Mg CO_2, with about 35 mln of this being emitted directly from farms, while ca. 12 mln originated from external “real” emissions of CO_2 (production of fertilizers and pesticides) which should in spite of this be analyzed

Table 2. Emission of GHG from agriculture and from non-agricultural sources (for 1996)

Emission source	Gas	10^6 Mg of a given gas	10^6 Mg CO_2 (equiv. CO_2)
Emission from agriculture			
Solid fuels	CO_2	7.23	7.23
Liquid fuels	CO_2	5.73	5.73
Gas	CO_2	0.047	0.047
Total		13.00	13.00
Cattle	CH_4	0.43	10.53
Pigs	CH_4	0.21	5.14
Other animals	CH_4	0.015	0.37
Manure and other organic fertilizers	CH_4	0.015	0.37
Total		0.66	16.41
Manure and other organic fertilizers	N_2O	0.0061	1.95
Nitrogen fertilizers	N_2O	0.0108	3.46
Legumes	N_2O	0.0005	0.16
Total		0.0174	5.57
Total emission from agriculture only			34.99
Emission from non-agricultural sources			
Electricity	CO_2	6.5	6.5
Mineral fertilizers	CO_2	5.3	5.3
Pesticides	CO_2	0.1	0.1
Total		11.9	11.9
Total emission			46.89

as a significant (approx. 30%) component of emissions from Polish agriculture (Tab. 2). This amount of CO_2 emitted can be fully absorbed if the yearly increment of crop yield is only 7%, a finding which points to the special role of production processes in agriculture, which may be some kind of self-regulation factor in the case of an unfavorable balance for GHG. Among the 35 mln Mg CO_2 emission directly from farms there was only 13 mln of "fair" emissions of carbon dioxide, the remaining part being emissions of CH_4, N_2O and CO, converted into the CO_2 equivalent. About 25 mln Mg CO_2 was emitted directly or indirectly from Polish agriculture and was mainly due to: a 7.2 mln Mg emission from solid fossil fuels (29.01%), and a 6.5 mln Mg emission from the use of electricity (26.09%). Thus together some 13.7 mln Mg CO_2 resulted from the use of coal, 5.7 mln Mg from liquid fossil fuels (23.01%) and 5.3 mln Mg from the use of mineral fertilizers (21.28%). The GHG emission caused by pesticide and gas use was marginal, at 0.43 and 0,19%, respectively. A significant feature of the GHG emission from Polish agriculture alone (34.99×10^6 Mg CO_2) seems to be the high contribution of methane emissions related to animal production, as well as the N_2O emission related to fertilizer use in soil (together 22×10^6 Mg

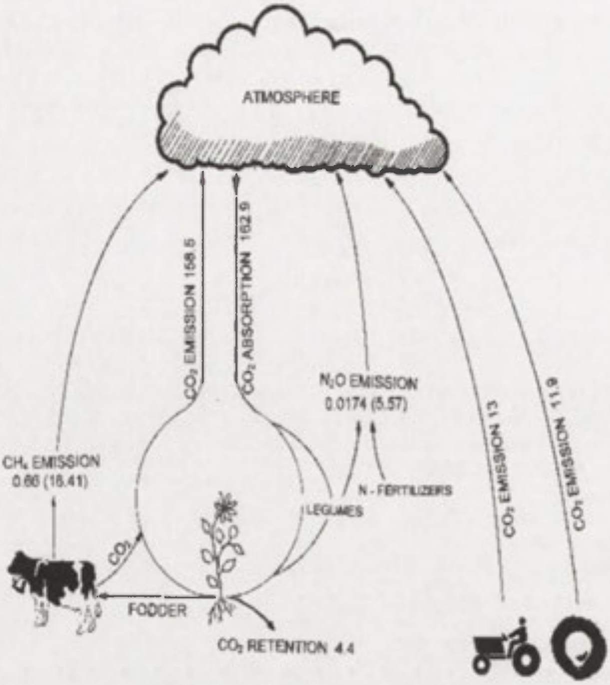

Fig. 1. Overall balance for GHG absorption, emission and retention in Polish agriculture (10^6 Mg) – equivalent of CO_2 in brackets

CO_2). In the global balance of GHG in Polish agriculture for 1996, emission was equal to 21 % of the total amount of CO_2 absorbed by crops, while its retention in soil was only 2.7 %. Nevertheless, 158.5×10^6 Mg of the gas was involved in the biological turnover of cycling CO_2 by then (Fig. 1).

BALANCES FOR GHGs IN DIFFERENT TYPES OF FARMS ORIENTED TOWARDS CROP PRODUCTION

The principal greenhouse gases in a crop-oriented profile of production are CO_2, N_2O and CH_4. Their emissions result from the farm use of oil, gas, coal, electricity, the processes accompanying the production of mineral fertilizers and pesticides and processes of the fermentation of organic matter. The higher the acreage of the farm, the higher its total emission, increasing according to farm size from 20 to 140 Mg CO_2. The lowest unit emission of 1.65 Mg CO_2 ha^{-1} occurs in the group of biggest farms, while the maximum of 5.7 Mg CO_2 ha^{-1} was found for the smallest (Fig. 2).

Crops are the main absorbers of atmospheric CO_2 in this profile of farms. Total absorption ranged from 74 Mg CO_2 for farms of less than 5 ha to 861 Mg CO_2 for farms of more than 50 ha. Unit absorption varied less, ranging from 9.4 Mg CO_2 ha^{-1} (on 5–10 ha farms) to 13.7 Mg CO_2 ha^{-1} (on 20–50 ha farms).

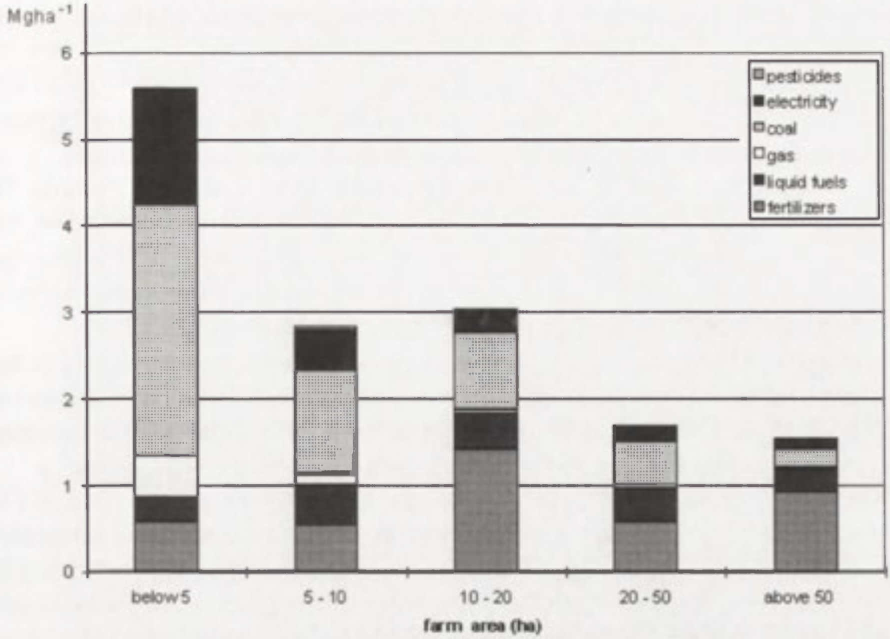

Fig. 2. CO_2 emission from various sized farms and sources (in Mg ha^{-1})

Distinct differences between the analyzed farms were found in the case of atmospheric CO_2 retention. This ranges from the negative for extensive small farms (–0.6 Mg CO_2 $ha^{-1} \cdot a^{-1}$) to a relatively high positive value (0.3 Mg CO_2 $ha^{-1} \cdot a^{-1}$) for large farms.

The factors chiefly affecting the magnitude of the emission, absorption and retention of GHGs on farms of a crop-oriented profile are: the size of the farm, its regional location, the kind of production (field crops, orchards, vegetables), the degree of mechanization, the inputs of mineral and organic fertilizer, the intensity of chemical plant protection and processes of the fermentation and humification of organic matter.

BALANCES OF GHG IN DIFFERENT TYPES OF FARMS ORIENTED TOWARDS ANIMAL PRODUCTION

All size groups of the analyzed farms oriented towards animal production were characterized by nearly the same unit absorption of CO_2 (9.3 Mg CO_2 ha^{-1} on 10–20 ha farm to 10.7 Mg CO_2 ha^{-1} on 20–40 ha ones). Cereals (50–60%) and pastures and meadows (25–30%) were revealed as the principal absorbers. Maximum total unit CO_2 absorption was attributed to farms having more than 50 big animals (13.4 Mg CO_2 ha^{-1}), whereas the lowest values were for ones of less than 5 such animals (8.9 Mg CO_2 ha^{-1}). The farms dealing with pig production and common use type prevailed in respect to unit absorption as compared with sheep-oriented ones (11.2 and 8.3 Mg CO_2 ha^{-1}, respectively).

All of the analyzed farms displayed a rather small unit retention (from 0.51 Mg CO_2 ha^{-1} in the case of 5–10 ha farms to 1.03 Mg CO_2 ha^{-1}). More retention occurred on farms with an increased share of grass higher use of manure.

The size of the retention was dependent on the number of large animals. The lower this number, the lower the retention, with the range from 0.5 Mg CO_2 ha^{-1} (1–10 animals) to 1.52 Mg CO_2 ha^{-1} (more than 50 animals). The latter are characterized by abundant manure usage. Farms with a high contribution of cereals and root and tuber crops showed negative retention of CO_2.

Retention of CO_2 depends on the character of animal production and is highest on farms where common cattle use prevails (1.2 Mg CO_2 ha^{-1} a^{-1}), and lowest where pig production is dominant (0.44 Mg CO_2 ha^{-1} a^{-1}). Other animal uses have intermediate values for CO_2 retention, i.e. from 0.73 to 0.91 Mg CO_2 ha^{-1} a^{-1}.

On all the studied farms with large animal production, the absorption of CO_2 was (from 20 to 120%) higher than CO_2, CH_4 and N_2O emission presented in CO_2 equivalent per farm. Taking into account the fact that CO_2 absorbed by plants is later emitted again into the atmosphere, its emission from the fuels used in agriculture, and especially that of CH_4 and N_2O, is of great importance.

EMISSION OF GHG FROM VARIOUS KINDS OF FARMS UNDER DIFFERENT CLIMATIC SCENARIOS

Expected climate warming implies a 20–30% increase in GHG emissions from Polish agriculture by 2030. In the case of farms of a crop-oriented profile this will be due to the emission of “fair” CO_2 caused by an increased intensity of production and decomposition of humus in soils. This is especially the case for small farms (of less than 10 ha). Big farms (above 10 ha) are expected to increase total N_2O emissions to the level of 50% of total CO_2 equivalent emission. In the case of the farms specializing in animal production a 20% increase in methane production is predicted, while there will be a decrease in the direct emission of CO_2 from fuels used to warm livestock buildings. A many-fold decrease in the direct emission of CO_2 to the atmosphere is expected for all farms that produce vegetables as well as flowers in greenhouse and glasshouse conditions. There is also an awareness that warm and dry climatic conditions will favour a decrease in CO_2 sequestration in humus compounds of soils and hence diminish soil fertility. On the other hand, under warm and humid climatic conditions soil fertility should increase through enhanced biological activity.

STRATEGIES FOR THE REDUCTION OF GHG EMISSIONS IN POLISH AGRICULTURE

There are many ways to reduce GHG emissions in agriculture on both the global scale and under the specific conditions Poland.

The most important are:

- restructuring of agriculture to decrease the number of small farms and increase the number of large farms;
- increased use of biological progress in plant and animal production;
- development of sustainable agriculture promoting enhanced carbon retention in soil;
- the introduction of new generations of tractors and agricultural machines of greater fuel efficiency;
- the afforestation of barren agricultural land;
- the introduction of plants for energetic use e.g. the production of biological fuel and other industrial uses, especially on contaminated soils and areas flooded frequently;
- an increase in the production and consumption of plant rather than animal proteins.
- an increase in the effectiveness of milk production at lower CH_4 emission.

Realization of the above ways of reducing GHG emissions makes agriculture the main human activity capable of diminishing possible forthcoming enhancement of the greenhouse effect and to mitigating its global-scale influences.

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DO CLIMATE CHANGES INCREASE THE THREAT TO CROPS BY PATHOGENS, WEEDS AND PESTS?

JERZY J. LIPA
Institute of Plant Protection, Miczurina 20, 60–318 Poznań, Poland,

ABSTRACT: Several countries including Poland are evaluating possible scenarios of climate change and their effect on agriculture, which include aspects of plant protection. Two appraisals of the consequences of climate change for Polish agriculture consider four possible scenarios based on GISS and GFDL models. The National Study of Climate Change considers that changes will affect about 60% of the country and that their consequences will be relatively great due to changes of the water balance in soils.
Possible impacts of global climate change on the occurrence, distribution and economic significance of the pests, pathogens and weeds on various continents and in Poland are discussed.

KEY WORDS: Climate change, global warming, plant protection, greenhouse effect, pests, weeds, pathogens.

INTRODUCTION

There are two appraisals of consequences of climate change for Polish agriculture. First – prepared by Bis et al. (1993) and based on GISS-GCM model gives a preliminary prognosis of changes in plant crop production in Poland in a macroscale, in relation to crop and animal production level estimated by Main State Statistical Bureau in 1989. In several tables and diagrams changes in crop areas, crop yields and percentage participation of various crops in a general area of arable land as a result of presumed climate warming in Poland were presented.

Second appraisal entitled "National Study on Climate Change" (Anonymous 1996) accepted four possible scenarios of climate change that may affect the development of Polish agriculture towards 2030, which are presented in Table 1. These scenarios are based on GISS and GFDL Models.

According to the GISS model, mean temperature will increase by 3.5°C (4.5°C in winter and 2°C in summer). The annual mean rainfall may be of 700 mm under the situation of a doubled concentration of CO_2 in the atmosphere.

According to the GFDL model, mean temperature will increase by 5.0°C and rainfall will be at the present level or slightly lower (about 450 mm).

The National Study emphasizes that... "Climatic changes in Poland will affect about 60% of the country (18.8 million ha used agriculturally), and the scale of the consequences will be greater than in present EU member states due to the lower quality of soil types in our country, which are more vulnerable to changes in water content".

Table 1. Four scenarios of climate change in Poland in year 2030 (Anonymous 1996)

1. Climate humid and warm – rainfall greater by 20% (up to 700 mm) – air temperature higher by 2°C – CO_2 concentration 450 ppm
2. Climate humid and very warm – rainfall greater by 20% (up to 700 mm) – air temperature higher by 4°C – CO_2 concentration 600 ppm
3. Climate dry and warm – rainfall lower by 20% (up to 450 mm) – air temperature higher by 2°C – CO_2 concentration 450 ppm
4. Climate dry and very warm – rainfall lower by 20% (up to 450 mm) – air temperature higher by 4°C – CO_2 concentration 600 ppm

Details of climate-change consequences for agriculture and forestry in Poland can be found in several publications (Ryszkowski and Kędziora 1993; Ryszkowski et al. 1995; Kędziora 1996; Lipa 1997a). Ryszkowski et al. (1995) estimates that the increase in temperature by 2°C in summer and 4–6°C in winter will cause elongation of the vegetation period by over 2 months in north-eastern Poland, and by 3–4 months in the remaining regions. Therefore the farming season (daily temperature above 2.5°C) will increase by 76–90 days in eastern Poland, and by 121–135 days in the north-west part of Poland, providing an opportunity for work in the field year round.

According to Bis et al. (1993), the above change of the climate in Poland will affect crop production in many ways. In general, there will be a 15% increase in the production of nearly all current crops, as well as an acreage increase for maize, sunflowers, soybeans and other warm-climate fruits and vegetables. An exception will be potatoes, whose production will decline due to a smaller planted area and lower yields.

All the above authors also foresee also negative consequences, such as a less-favourable water balance and an increase in yield losses due to plant pathogens, pests and weeds. However, they do not provide specific data.

CONSEQUENCES OF CLIMATE CHANGE FOR PLANT PROTECTION WORLDWIDE

There is a significant interest in the possible consequences of climate change for plant protection, and abundant literature on the subject (Atkinson 1993a; Bell et al. 1993; Cammell and Knight 1991; Friedrich 1994; Harrington and Woiwod 1995; Lipa 1997b; Porter et al. 1991; Tinker 1993; Watson et al. 1995). Several international programs have been initiated, among which special mention should be made of: the International Geosphere-Biosphere Program (IGBP) with its subproblem: Global Change in Terrestrial Ecosystems (GCTE) and group 3.2 Global Change Impacts on Pests, Diseases and Weeds (GCTE 1995).

Several international meetings and conferences have been organized to identify characterize, and quantify the consequences, for the distribution and density of agrophages and losses caused. Of special interest is the conference that took place in Brighton and was specifically oriented to crop protection (Atkinson 1993b). The international workshop in Brisbane titled "Impacts of Climate Change on Pest, Diseases and Weeds in Australia" discussed not only the aspects concerning the Australian continent, but also world-wide topics (Sutherst 1995). Various aspects, including also plant protection problems, were discussed in 1995 in Helsinki at the conference entitled "Global Climate Change and Agriculture in the North" (Kaukoranta 1996).

GENERAL EFFECT OF GLOBAL WARMING ON PLANT HEALTH

Pregitzer (1993) discussed the direct and indirect effects of climate change on plants, e.g. through changes in soil processes. A temperature increase of soil by 2–3°C will increase soil microbiological activity by 15–23% and will affect the occurrence of phytopathogenic microorganisms.

Sanders et al. (1993) reviewed the literature concerning the effect of ozone on the action of herbicides. The authors emphasized that ozone increases the tolerance of sugar beet to phemediphan and chlorsulfuron herbicides but decreases its tolerance to EPTC, as well as that of tobacco to pebutate.

Wong (1990) emphasized that higher temperature and CO_2 concentration will intensify photosynthesis processes in plants, resulting in the production of softer tissues more susceptible to pathogen or pest attacks.

EFFECT ON INSECTS AND MITES

As reviewed by Cammell and Knight (1991), climate warming will increase the migration, reproduction, feeding activity and population dynamics of insects and mites, resulting in higher crop losses.

Porter et al. (1991) considers that the corn borer (*Ostrinia nubilalis*) will extend its range northwards and eastwards by 1200 km, if the temperature rises by 3–6°C in the period 2025–2070, and will thus occur around Saint Petersburg.

Kozar (1991), Kozar et al. (1995) and Kozar and David (1986) emphasize that many noxious insects have migrated into Hungary, widened their distribution or increased their economic significance during the last fifty years as a result of climate warming. Example are *Pseudalacaspis pentagona* and *Corythuca ciliata*.

Worner (1988) pointed out that, due to climate warming, several quarantine pests will broaden their geographical distribution, finding new host plants and favorable conditions in northern regions.

A good analysis has been made in Australia, to define the possible consequences of global warming for a variety of categories of plant and animal pests exemplified by: *Diuraphis noxia* (Aphididae), *Chorteicetes terminifera* (Orthoptera), *Mythimna convecta* (Lepidoptera) and *Boophilus microplus* (Acarina) (Sutherst 1990, 1991; Sutherst et al. 1995, 1996).

However, in referring to the fauna of northern Europe Solbreck (1993) comes to the conclusion that it is difficult to differentiate population changes caused by long-term climatic trends from those brought about by other factors. The northern European insect fauna consists of species which are recent immigrants that colonized this region at the last glaciation and may be less sensitive to future climatic changes than faunas in other geographical regions.

EFFECT ON NEMATODES

Boag et al. (1991) stress that, due to global warming, the noxiousness of Xiphinema spp. and Longidorus spp. in Europe will increase. Tiilikkala et al. (1995) made a pest risk analysis and demonstrated that a nematode Meloidogyne chitwoodi, which at present occurs in Western Europe, will present a threat for Northern Europe including Finland, when the climate warms up. Evans et al. (1996) presented an analysis of the risk to Europe from a possible introduction of *Bursaphelenchus xylophilus* and its vectors of the genus Monochamus, which considered climatic, biological and other information.

EFFECT ON PLANT PATHOGENS

Climatic conditions greatly affect the survival, growth and distribution of fungal and bacterial pathogens, as well as the resistance or susceptibility of their host plants.

Coakley (1988, 1995) and Friedrich (1994) discussed the relationship between climatic conditions and the most important plant pathogens. It is generally believed that higher concentrations of CO_2 and ozone, as well as an increased level of ultraviolet radiation, will negatively affect the state of plant health. Manning and Tiedeman (1995) reviewed the expected effect of the above factors on various groups of plant pathogens.

Good simulation studies were made on the effect of CO_2 concentration on sporulation of a fungus *Alternaria tagetica* (Cotty 1987) and on the occurrence of a barley mildew (*Erysiphe graminis* f. sp. *hordei*) (Hibbard et al. 1994).

Global warming will favor epidemics of rice blight (*Pyricularia grisea*) in Asia due to a lowering of the resistance of rice plants (Finckh et al. 1995; Lu et al. 1995). Similar consequences are expected by Brasier and Scott (1994) in relation to the occurrence and economic significance of *Phytophthora cinnamom*, which causes dieback of various oak species (e.g. *Quercus robur*, *Quercus suber*, *Quercus ilex*) in Europe.

Kaukoranta (1996) presented a detailed analysis of the effect of climate warming and elevated CO_2 on potato yield and possible losses caused by potato blight (*Phytophthora infestans*) in Finland.

EFFECT ON WEEDS

When evaluating the possible effects of climate warming due to increased CO_2 concentrations account must be taken of the differences among plants as to assimilation processes. Prescott-Allen and Prescott-Allen (1990) emphasize that, while among the 86 plant species which provide 90% of world food, 80 belong to the C_3 plant group, 14 of the word's 18 most important weeds belong to the C_4 group. The experimental studies of Patterson et al. (1984) showed that, at a doubling of the concentration of carbon dioxide, C_3 plants grew better by 35%, C_4 plants by 25%. The problem of the similarities and differences between weeds and cultivated crops in the efficient use of elevated concentrations of CO_2 are presented in a book edited by Kropff and van Laar (1993).

However, Henderson (1993) concludes that, at higher air temperature, plants of the C_4 (most weeds) are more efficient competition with C_3 plants, including a majority of crop plants. The same author emphasizes that, under elevated temperature, the phenology of plants can change either positively or negatively from the agronomic standpoint.

It is known that the persistence of the wild oat (*Avena fatua*) in agricultural fields is due to the fact that seeds drops before the cereals are cut and harvested. If the phenology of wild oat changes to the benefit of cultivated plants this will contribute to the elimination of wild oat or lower its significance.

However, many of the previous considerations must be reevaluated in the light of findings from Grime (1996) on uncertainties with respect not only to the consequences of global change for more' and less' intensively managed ecosystems but also due to the fact that plants with low-DNA and high-DNA amounts are differentially sensitive to yearly variation in climate. The results of experiments showed that the yields of plants with small genomes are more responsive to temperature.

CONSEQUENCES FOR PLANT PROTECTION IN POLAND

To date, no specific studies or analyses have been carried out concerning the impact of global warming on plant protection problems in Poland. However, Bis et al. (1993) made a general statement that, due to climate change... "New species or strains of plant pathogens or pest may occur. The majority of the present noxious phytopathogens may intensify their role" and further that... "Higher rainfalls and elevated air temperature will favor the development of weeds, diseases (e.g. potato blight) and plant pests. Therefore the significance of plant protection measures will grow, and the costs involved". Similarly, the National Study report (Anonymous 1996) emphasizes that, as a consequence of climate change,... "Yields decrease due to enlargement of overwintering pests and increased intensity by 15% of fungus, bacterial and viral diseases".

INCREASED THREAT DUE TO PESTS

The expected climate warming in Poland will be favorable to all pests, and their distribution and density will increase. The economic importance of the Colorado beetle (*Leptinotarsa decemlineata*) will definitely increase in Poland. While this pest has one full generation at present, under future climate conditions it may have 2–3.

A larger area under maize and elevated temperature will greatly increase of the economic status of the corn borer (*Pyrausta nubilalis*), a pest which may can have 2–3 generations annually. Invasion of the western corn borer (*Diabrotica virgifera*) into Poland can be expected with great certainty, as it quickly dispersed from Serbia into Central Europe (Lipa 1995).

Such quarantine pests as *Hyphantria cunea* (Lepidoptera) and *Quadraspidiotus perniciosus* (Diaspidae) will enter the territory of Poland from neighboring Slovakia.

As mentioned above, a warmer climate will greatly increase the plant growing season and aphids (*Aphididae*), psyllids (*Psyllidae*) and leafhoppers (*Jassidae*) will build much greater populations than at present. The damage induced by the above plant pests will therefore greatly increase, not only due to the direct feeding effect but also due to the transmission of virus diseases among plants.

A longer growing season will also favor the development of plant pathogenic nematodes such as *Globodera* spp. and *Meloidogyne* spp.

INCREASED THREAT OF DISEASE

Milder winters and warmer and more humid springs and summers will greatly favor the epidemic occurrence and spread of diseases as well as the losses they cause: on cereals – powdery mildew (*Erysiphe graminis*), barley rust (*Puccinia hordeum*), yellow rust (*Puccinia striiformis*), leaf blotch (*Rynchosporium secalis*), glum blotch (*Septoria tritici*) and blotch (*S. nodorum*), on sugar beet – leaf spot (*Cercospora beticola*), mildew (*Erysiphe betae*) and rhizomania, on clover – root rot (*Sclerotinia trifolii*).

As mentioned above, there will be a significant increase in the occurrence of the viral diseases which are transmitted by aphids, psyllids and leafhoppers.

INCREASED SIGNIFICANCE OF WEEDS

Climate warming will provide several advantages for weeds, as they will grow faster and produce more seeds due to intensified phytosynthesis. Although the same advantage will be available to cultivated plants, we know that weeds are more aggressive than other species.

A climate warming by 2–5°C also means that many Mediterranean or thermophilic weeds will widen their geographic distribution and enter the territory of Poland. Many species which at present occur sporadically will also be more numerous, e.g. the quarantine weeds *Ambrosia spp.*

On the other hand, climate warming will create better opportunities for the biological control of weeds using herbivores or pathogens e.g. against *Euphorbia spp.*, *Amaranthus retroflexus*, *Convolvulus arvensis.*

Warm climate and higher rainfall may the affect effectiveness of herbicides by greater intake rate and translocation within tissues (Treherne 1989). On the other hand definitely there will be better growth of rhizomes and roots in C_3 plant group and this phenomenon may lower effectiveness of some herbicides.

NEED FOR MODEL STUDIES IN POLAND

On the basis of the scenarios for climate change in Poland seen in Table 1, several analyses or experimental studies must be carried out as to the possible impact on pests, diseases and weeds. Of the greatest value are climate chamber studies in which host plant and pest/pathogen interactions under various scales of temperature increase, CO_2 or O_3 concentration, UV-irradiation and rainfall/humidity levels should be tested.

Where such chamber facilities are not available mathematical models may provide valuable data or a realistic answer to the question “What will happen due to global warming?”

Ways of proceeding with such problems can be found in the following papers: GCTE (1995), Busby (1991), Kaukoranta (1996), Lu et al. (1995) and Kropf and van Laar (1993).

CONCLUSION

As recently printed by Lipa (1998) the Committee on Plant Protection of the Polish Academy of Sciences and the Polish Entomological Society took under consideration the necessity of starting broad evaluation of the impact of climate change on plant protection problems.

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A REPORT ON DISCUSSIONS AT THE CONFERENCE "THE EFFECTS OF GLOBAL CLIMATE CHANGE IN FORESTRY AND AGRICULTURE"

Opening the Conference, **L. Starkel**, chairman of the Polish National IGBP–Global Change Committee of the Polish Academy of Sciences (PAS), emphasized the need for our knowledge of global climate change to be assessed and evaluated. In his view, the considerable progress with understanding the functioning of the global climatic system was to be set against regional predictions taking account of the specifics of relief and land use. The choice of a Conference devoted to the "Effects of global climate change in agriculture and forestry" had, he said, been dictated by such considerations; and – in a country like Poland, where agricultural land is 60% of the total – a knowledge of the way in which global change influences agriculture and forestry had to be of great significance in the devising of a strategy to adapt the economy to the predicted global changes. **L. Starkel** then passed the chairmanship of the sessions to **L. Ryszkowski** and **A. Kędziora** of the Research Centre for the Agricultural and Forest Environment PAS – the organizers of the Conference as far as its content was concerned.

Before commencing with papers, **L. Ryszkowski** sought to underline certain aspects of the present state of knowledge on global climate change. There was, he said, no doubt that recent decades had witnessed an increase in concentrations of greenhouse gases, as well as an increase in surface temperatures globally. However, after certain critical comments, this had been explained recently by taking into consideration the activity of volcanoes in limiting influxes of solar energy to the Earth's surface, by linking El Ninio phenomena with climate change, etc. As recent articles in "Science" had shown, the warming of the Earth's surface was finding its reflection in rising temperatures in the lower layers of the stratosphere and subsurface layers of the Earth. Nevertheless, **L. Ryszkowski** said, it was necessary also to recall the continuing suggestions that the next Ice Age was approaching. However, the results put before the Second Intergovernmental Panel on Climate Change (IPCC, 1995) were unambiguous in showing intensification of the greenhouse effect, even if the causes of the changes remained debatable. While a majority of researchers linked enhancement of the greenhouse effect to human activities, others were inclined to make connections with natural processes operating within the climatic system. According to **L. Ryszkowski**, the resolution of these controversies was hindered *i.a.* by a lack of complete information on the cycling of matter, including, for example, major gaps in our knowledge of the balance to the Earth's carbon cycle. Of the $7,1 \times 10^{-15}$ g C released by humankind annually the fate of some 15–29% remained unknown. Similar, perhaps even greater, problems were encountered with the balancing of the nitrogen and sulphur cycles, etc., while predictions of atmospheric circulations and ocean currents were also very problemmatical.

L. Ryszkowski noted that the many publications and syntheses presented by the IPCC or others had greatly advanced the state of knowledge on the anticipated effects of climate change on plants, animals, different sectors of the economy, etc. There was wide discussion of the different actions limiting the production or liberation of greenhouse gases, and this was finding reflection in, amongst other things, conferences devoted to the implementation of the Convention on Climate Change from 1992. However, much less consideration had been given to the feedbacks between changes in land use and the enhancement or otherwise of the greenhouse effect.

According to **L. Ryszkowski**, the call for papers for the Conference had assumed the taking of a critical approach to knowledge on global change on the one hand, as well as confinement of the selection to issues concerning the linkage between global change and the agricultural and forestry sectors.

The paper from **M. Sadowski**, entitled "Critical evaluation of the implementation of world policy on mitigating global climate change", provided an insight into the ever more clearly-defined conflict between those standing for industrial development and those working to protect the environment. Attention was drawn to the diametrical opposition of the positions taken by the developing and developed countries, a difference of view that had its origin in the disproportionate burdening of countries of the poor South when it came to reducing emissions of GHGs, albeit in return for financial assistance. This has led to economic discrimination against developing countries and was all hindering the introduction of effective means by which to limit emissions. Emphasis was also put on the lack of more significant linkage between policymaking and the scientific justification for it.

B. Jakubiak's paper on "The main features of global climate numerical models and the impact of predicted climate changes for ariculture and forestry" was followed by a discussion that concentrated on the need for models to take account of the way in which specific features of land-use forms impacted upon the climate. There were a number of reservations expressed in relation to the application of numerical models of climate change, and it was stressed that predictions of climatic changes should be based on physical models to an ever greater extent. However, the discussion also brought forward a standpoint that the present state of knowledge in describing change on larger temporal and spatial scales made numerical models essential, though this did not mean ignoring the achievements of statistical and physical analyses. In short, systematic physical analysis of climate change was still regarded as impossible at the current stage of progress. **B. Jakubiak's** attempt to apply numerical modelling of climatic conditions at the local level, and to create applied databases, was considered noteworthy, because it provided for an assessment of the influence of irrigation in agriculture on the local climate, as well as for prediction of the occurrence of frosts and the emergence of crop pests.

K. Rykowski's paper entitled "Assessment of the importance of forests in reducing global climate change" provoked a wide-ranging discussion, in which stress was placed on the indirect impacts exerted by forests as they modified water cycling, for example by intensifying evapotranspiration processes. The effect of storage in forest biomass in removing carbon from the cycle is generally regarded as an important regulatory factor, but the annual primary production of forests is similar to that of meadows or agroecosystems when these are used with forecrops and aftercrops. For this reason, some participants in the discussion sought to emphasize that it was not the mere size of biomass production that was of significance in assessing the influence of different ecosystems on carbon storage, but rather the factors impacting upon the decomposition of biomass and consequent re-release of CO_2. Also stressed was the lack of knowledge on carbon storage by the vegetation of Poland's marshlands. However, treeplanting in agricultural areas was considered significant when it came to compensating for emissions of carbon dioxide from industry. In summary, participants in the discussion attached great importance to a more precise evaluation of the role of Poland's forests, in order that means of limiting GHG emissions might be better understood. There was, for example, a lack of assessments regarding releases of N_2O from forests.

The paper from **A. Breymeyer** and **R. Laskowski** was not given as the authors were absent.

It was with an assessment of the role of Polish agriculture in the processes of the emission and absorption of greenhouse gases that **E. Nalborczyk** and co-workers **S. Pietkiewicz**, **T. Łoboda** and **L. Sieczko** concerned themselves in a paper entitled "The emission, absorption and retention of greenhouse gases in Polish agriculture". A lively subsequent discussion drew attention to the use of alternative methods of cultivation such as non-ploughing, with a view to limiting mineralization and thus the emission of CO_2 from soil. A similar role is played by the introduction of forecrops and aftercrops into crop rotations. There has been little success with the introduction to Poland of multi-year wheat, which could reduce emissions of CO_2 from cultivated fields. The discussion stressed that the release of CO_2 by decomposition in cultivated fields was very intensive compared with that in other ecosystems, and then moved on to consider the emission of N_2O from such soils. Wide discrepancies in these evaluations were noted, and it was thus considered essential for further research to be done on the release of this gas from field soils in different habitat and weather conditions, and for knowledge of the influence of various cultivational techniques on this to be improved. Also discussed were the problems of using biomass to produce fuel so that use of fossil fuels might be limited and emissions of greenhouse gases reduced markedly in consequence. In Poland, the technologies involved are still underdeveloped.

Overall, the paper presented was considered a very interesting attempt at defining the contribution and role of Poland's agriculture where the balance for greenhouse gases was concerned.

A. Kędziora and **L. Ryszkowski** gave the paper "Does plant cover structure in rural areas modify climate change effects?". This was followed by a discussion concentrating on modifications to the water cycle and to local air circulation. Cultivated fields were considered to intensify fluxes of sensible heat and thus to increase the exchange of heat energy via convection and modify mesoscale atmospheric circulation. The significance of the presence and structure of vegetation cover was emphasized in regard to the intensity of evapotranspiration processes. Consideration was also given to the feedbacks between local, regional and global climatic phenomena. Much interest was aroused by the authors' conclusion, which held that changes in forms of land use were currently of much greater significance to climate change than effects induced by greenhouse gases. These results suggest that global feedback models should pay more attention to the modifying effects of vegetational structure on the atmosphere. The different mechanisms by which vegetational structures impact upon the exchange of heat energy and water were also discussed. For example, it was emphasised that, since stomata were further from the ground in trees than in crop plants, the former were exposed to greater air turbulence and hence to more intensive evapotranspiration.

In a paper entitled "Do climate changes increase the threat to crops posed by pathogens, weeds and pests?", **J. Lipa** reviewed the literature data on this subject. The subsequent discussion touched upon the issue of the population explosion in the allergy-promoting *Heracleum sosnowskyi*, whose presently-observed spread in Poland may be linked with climatic change. Several further examples of observed range expansions in different pest species were given, and changes in the species composition of the plant and animal communities of some Polish ecosystems were also discussed, with a view to assessing the degree to which they might have been induced by global climate change. In many situations, a clear indication of the causes of change is very difficult, because of overlap between the processes of climate change, the acidification of the environment and other transformations brought about by human activities or else the natural processes by which ecosystems evolve.

The detailed discussion of particular papers was followed by an intervention from **A. Kowalkowski**, who stressed the major significance of soil processes in the mineralization of organic matter. Thus, for example, changes in habitat conditions have been found to induce much greater changes in the concentrations of calcium and magnesium in pine needles, than in the concentration of nitrogen. This is regarded as a sign of pine's adaptation to a soil environment modified by industrial emissions. Thus changes in the species composition of plant communities were considered to proceed from systematic changes in entire ecological systems.

In closing the Conference, **L. Starkel** noted that the papers given had been of a high scientific standard and had brought many interesting results from within Poland. In his view, there was a need for strong action to convey the results of the Conference to political and economic decisionmaking circles. Efforts should also be made to gain increased funding for research into the effects of global climate change in various sectors of the economy.

In assessing the value and purpose of the editorial preparation of Conference materials, **B. Obrębska-Starklowa** noted that the papers presented were of "a high degree of professionalism when it came to recognizing the mechanisms by which the climate functions, and the ways in which geographical and anthropogenic factors influence processes of matter cycling and changes in the structure of the heat balance influence the nature of climatic relationships". The subject matter of the Conference had served in presenting the feedbacks between economic activity and the climatic system. Among the new conclusions emphasized by **B. Obrębska-Starklowa** was the fact that, while "appropriate steering of landscape structures might lead to a levelling-out of the influences of global warming, the dimensions of the changes in climate obtained in such a way might equally surpass those induced by the enhanced greenhouse effect itself".

Lech Ryszkowski and Andrzej Kędziora
(Guest Editors)

INFORMATION FOR AUTHORS

The editors of GEOGRAPHIA POLONICA invite theoretical and empirical contributions to human as well as physical geography, in broad terms. Articles are expected to be original and not yet published elsewhere unless in languages other than English.

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As all manuscripts will be reviewed, therefore, authors are kindly requested to provide two hard copies of the complete text (main text, abstract, references, tables, illustrations (one set of illustrations may be in xeroxed form) and one 3.5" diskette in MS Word.

The manuscripts should be arranged in the following order. First sheet: title, full name of author(s), affiliation, full postal address, e-mail address (if possessed). Second sheet: abstract of no more (no less) than 100 words, key words (3–10) at the end of the abstract. Subsequent sheets: the main text of about 20–25 pages double-spaced (in A4 format). Then on separate sheets: acknowledgements (if desired), notes, references, tables, illustrations, captions to illustrations.

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REFERENCES should be printed in alphabetical sequence at the end of the text. Examples:

Articles from journals: Berry B. J. L., 1960, *The impact of the Expanding Metropolitan Communities upon the Central Place Hierarchy*, Annals of Association of American Geographers, 50, 112–116.

Books: Stren R., White R., Whitney J., 1992, *Sustainable Cities*, London, Jessica Kingsley Publishers.

Chapters from books: Dematteis G., 1996, *Toward a Unified Metropolitan System in Europe*: *Core Centrality Versus Network Distributed Centrality*, [in:] Pumain D., Saint-Julien T. (eds), *Urban Networks in Europe*, INED, John Libbey, Paris, 19–28.

Theses: Elfring T., 1987, *Service employment in advanced economies*, Unpublished Ph. D. Thesis, Rotterdam, Erasmus University, School of Management.

References should be indicated in the text by listing, in parenthesis, the author's name followed by the data of publication, eg. (Kowalski 1995) or (Kowalski et al. 1996) if there are more than two authors (Note: all the authors should be listed in the references).

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ILLUSTRATIONS (photographs and figures) must be in a camera-ready form suitable for reproduction or scanning. Lines and symbols should allow for size reduction, if required. Figures (maps, graphs, diagrams and drawings) should be in black and white, laser printed or as clear drawings. Illustrations should be sequentially numbered with Arabic numerals (eg. Figure 1) and prepared on separate sheets. Their position in the text should be indicated.

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MEASUREMENTS should be given in metric units.

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