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CONTENTS

1. ADAPTATION OF AGRICULTURE IN EUROPEAN REGIONS AT ENVIRONMENTAL RISK UNDER CLIMATE CHANGE – PROJECT IMPLEMENTATION

Josef Eitzinger[1], *Jacek Leśny*[2], *Tomasz Serba*[2], *Radosław Juszczak*[2], *Janusz Olejnik*[2]

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INTRODUCTION

Present and new policies of the European Union must be adopted under climate change conditions. Policies must consider all potential and realistic adaptation measures, especially on the regional and farm level, to secure sustainability of agricultural crop production. According to the above statement, program ADAGIO (Scientific Support Action – SSA) analysed and evaluated potential and actual adaptation measures in agriculture for different climatic and agroecosystem regions in Europe. The SSA will consider not only future scenarios and results based on modelling tools, but also already visible (or known) ongoing changes and adaptation measures for a better and realistic assessment of potential future adaptation measures at the regional level. Furthermore, probably changes in the European policies, as the Common Agricultural Policy (CAP) or the *Water Framework Directive (*WFD), will be taken into account as well, since final decisions of farmers would be based on several issues additionally to climate risks. Results of ADAGIO program showed that establishing a continuous interacting information and discussion network, connecting science with decision makers and support a holistic approach to solve the related problems are presently the most important activities undertaken.

OBJECTIVES OF THE PROJECT

Project is carried out within the 6th Framework Program of European Union, priority 8 (Scientific Support to Policies, Area 1.1, Task 18), type Specific Support Action (SSA). The main objective of the FP6 is to contribute to the creation of the European Research Area (ERA) by improving integration and co-ordination of research in Europe which is so far largely fragmented.

The overall objective of ADAGIO is development and dissemination of recommendations on how to better adapt agriculture to climate change in three European regions considered to be significantly affected by climatic change (representing also different climatic conditions and agricultural systems over Europe). The present project is to promote a regional-based European network that utilizes, disseminates, evaluates and adapts the results of European past researches about climate-change impacts on agriculture, and potential adaptations for securing sustainability of agricultural production and resources (effective use of resources, reducing risk of production, optimising management, etc.) for decision makers and for agricultural policy decision-making within vulnerable regions of Europe.

The main specific objectives of the ADAGIO were:

- To identify significant vulnerability issues in each partner country and the related potential problems due to climate change:
  - Selection of most vulnerable regional issues (e.g.identifying climatic risks) through climate change (defined e.g. by various agroecosystems) by each partner and identifying related potential problems.
  - To describe the related agroecosystems regarding their main limitations, observed trends, socio-economic conditions.
- To identify feasible potential adaptation measures for the selected regional agricultural systems, based on the identified problems:
  - Evaluation and description of feasible potential adaptation measures for the selected regional agroecosystems, based on the identified problems..
  - Identify ongoing trends or adaptations in order to evaluate potential future adaptation measures.
  - Identify and describe uncertainties, cost/benefits, risks, opportunities for co-benefits etc. of potential adaptation measures.
- To identify and demonstrate dissemination strategies of adaptation measures to decision-makers:
  - Identify, recommend and disseminate strategies of adaptation measures to decision-makers.
  - Demonstrate dissemination strategies of adaptation measures at the national, regional and international level.

ORGANISATION AND DECISION-MAKING STRUCTURE OF THE PROJECT

Coordinator of the project is Prof. Dr. Dipl. Ing. Josef EITZINGER: Agrometeorologist, Researcher and teacher at the Institute of Meteorology (BOKU-Met) at BOKU (Universitaet fuer Bodenkultur, University of Natural Resources and Applied Life Sciences) is a part of the Department of Water, Atmosphere and Environment. Beside others, he is a member of the WMO RA VI Commission for Agrometeorology (CAgM) Expert Team on “Impact of Climate Change Variability on Medium- to Long-Range Predictions for Agriculture”; Founding member of International Society of Agrometeorology (INSAM). Prof. Eitzinger is involved in projects and other activities focusing on establishing drought-monitoring system for agriculture. He is involved in many public relation activities for decision makers and end-users in the field of agrometeorology and climate change impacts in Austria (articles, lectures).

The list of ADAGIO participants is presented at Table 1.

Table 1. Participants list of ADAGIO project

Participant name	Short name	Country
Coordinator		
Institute of Meteorology, University of Natural Resources and Applied Life Sciences	BOKU	Austria
Contractors		
Agrarian Technological Institute of Castilla and Leon	ITACyL	Spain
National Institute of Meteorology and Hydrology	NIMH-BAS	Bulgaria
Center for Meteorology and Environmental Predictions, Faculty of Science, University of Novi Sad	CMEP- FSUNS	Serbia
Mendel University of Agriculture and Forestry Brno	MZLU	Czech Republic
Instituto Sperimentale Agronomico	CRA-ISA	Italy
Institute of Environmental Research and Sustainable Development	IERSD	Greece
Central Laboratory for Agricultural Climate	CLAC	Egypt
Poznan University of Life Sciences, Agrometeorology Department	PULS	Poland
State Hydrological Institute	SHI	Russia
Fundatia pentru Tehnologia Informatiei Aplicata in Mediu, Agricultura si Schimbari Globale	TIAMASG	Romania

As defined in the objectives, three main regions of Europe, identified as significant vulnerable to climate change (Mediterranean area, Central and Eastern Europe) were covered by this project and by the SSA partners from that regions (Fig.1).

As a „bottom up“ approach is used to develop and evaluate adaptation strategies, for each of this regions a regional group were formed, consisting of the national partners. Each group is lead by a group leader out of that region, coordinating the regional activities. The group leader for Central Europe is the Austrian partner (BOKU, also coordinator), the group leader for Eastern Europe is the Bulgarian partner (NIMH) and the group leader from the Mediterranean area is Spain (ITACyL). These 3 partners already lead some regional issues from the above mentioned AGRIDEMA SSA, and are already an established and good working team.

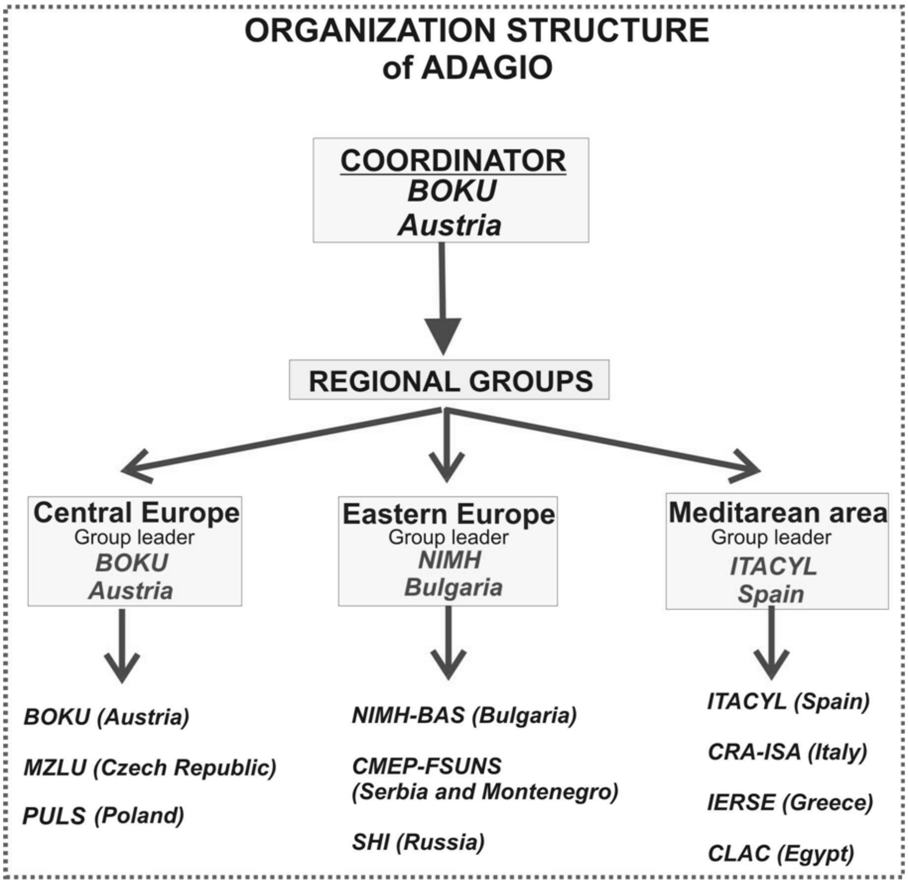

Fig. 1. Organization structure of ADAGIO

The coordinator (BOKU, Austria) is responsible for general management of the project (including general meetings between all partners) and directly control the financial issues of all partners. Regional group leaders are established in order to coordinate and control the project implementation (as defined by the work-packages) by region. This includes activities such as organisation of cooperation between countries (using synergies, exchanging methods, organisation of meetings etc.) Each of the partners are/were responsible for project implementation in their own country (on the national and regional basis). This includes activities such as the organization of regional meetings (e.g. with decision makers), creating national contacts and expert networks, local dissemination of results to applicants, regional assessments, national reports etc.

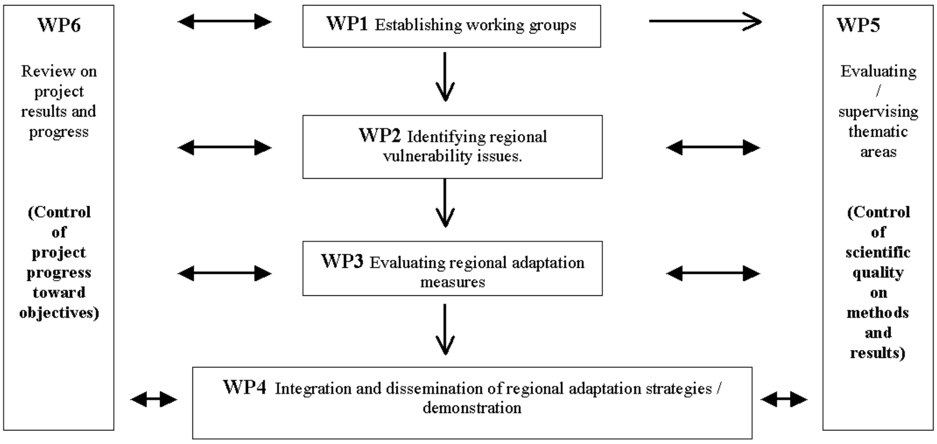

Fig. 2. Graphical representation of the work packages (WP)

The project is carried out in 5 stages (work packages, Fig. 2):

1. On the national basis, the participants of each country were established useful contacts to local "experts" (e.g. agricultural research institutes as well as specialists in plant protection and crop production and management) and "applicants" such as decision-makers, agricultural instituional services and schools, associations of producers, farm organisations and farmers in order to gather information on ongoing adaptation measures and gather feedback for potential adaptation measures. Further these contacts were used in order to create selected national based assessments on adaptation measures for each specific problem identified. All the national activities were communicated by the national partner in the national language in order to reach as much people as possible. The national activities can comprise personal meetings, communication by media, workshops and excursions.
2. The work in this part was carried out mainly on the national and regional basis (using the established in WP1 working groups). Especially results from previous simulation studies (e.g. from literature, from previous AGRIDEMA project), expert knowledge and feedback from applicants were used in that context. For these, especially relevant farming organizations were involved as much as possible. National meetings in each partner country with the established network members (and all other applicants interested in this subject) were carried out with main goal to exchange information and data related to climate change most vulnerable issues. The indicated regional (national) pilot assessments were carried out as supplement to specific national problems (e.g. collecting data and interpreting results from previous studies related to: crop damag-

es during the past years by weather extremes such as drought, phenology dynamic and yield variability during the last years, intensity and frequency of climatologically induced diseases and pest attack, appearance of spring frost after high-temperatures period, etc.). The specific problems (vulnerabilities) within each region were clearly stated, as well as their similarities and differences with other problems identified in the region. The goal is to identify critical climate-change agricultural risks to evaluate/develop the corresponding mitigation-adaptation strategies (WP3) which could be used all over similar regions.

3. This work packages especially considered regional specifications, limitations and conditions in all relevant problem fields (production technique, ecological and economical aspects) including uncertainties and costs/benefits analysis, multicriteria assessment of adaptation measures. The adaptation options that are technically feasible and economically viable were identified from previous results and with the relevant contribution of the involved "experts".

   This were done by assessments (including also WP2 tasks) by the regional groups, by using expert knowledge, feedbacks from meetings etc. Also relevant farming organizations were involved as much as possible in order to define adaptation options in form of procedures to provide their permanent character. It means that they should be carried out after end of project. One possible solution is that institutions with strong agrometeorological background become responsible for operational use of defined adaptation measures and procedures (part of dissemination strategies of WP5).

   The assessments were conducted using the experience of previous research results, based on the assessments of WP2, contact with experts and the existing data in the involved institutions. The assessments were also identified ongoing trends or adaptations in order to evaluate potential future adaptation measures, taking into account other possible issues that might interact with climate risks as CAP, FMD, etc.

4. Using the regional results of the project, each country was identifying possible ways of dissemination and integration in decision-making and demonstrates it by reliable examples. The results of each assessment are (will be) presented to the local authorities, farmer' associations and all the relevant stakeholders that might be involved. The dissemination comprises publications (e.g. this publication), brochures, presentations, use of local and regional media; as well as Internet.

5. Beyond the regional groups (geographical aspect), the thematic groups ensured the complementarity of applied methods, state of art, exchange of related Know-How and problems between the partners and other international experts and organisations out of the project. Methods on estimation of technical fea-

sibility, economic and environmental impacts of mitigation options were considered as well.

Each tasks were lead by one partner. The leaders of WP 5 were responsible for cooperation between thematic groups (e.g. identifying feedbacks, co-benefits etc.).

6. Organisation and chairing of General meetings. Technical coordination of workpackages: elaborating guidelines, and decision making. Overall co-ordination and supervision work (coherence/integration of workpackages, internal communication, organisation of meetings and of further eventual bilateral meetings). Overall legal, contractual, ethical, financial and administrative management. Evaluation and assessment of work progress. Reporting to Commission. Each of the partners contributed to management aspects of the meetings at national level. All the partners were responsible for financial management and scientific reporting to the coordinator for the activities they are in charge.

Thematic groups

In order to ensure the state of art and the exchange of Know-How at the European level, thematic groups were created to be a forum of discussion, exchange of Know-How and results, and methods. Further, thematic groups focused on main problems, related to adaptation strategies. The thematic groups were lead (coordinated) by selected partners according to their experience in the relevant field. Each partner is a contributor (member) of each thematic group as it was a function as a feedback system between all partners. The thematic group leaders were responsible for organisation of the interaction activities between the partners. For each thematic group, for example, an electronically discussion forum or "market place" were created such as e-mail list or web page, within the main ADAGIO web page.

The four thematic groups, in specific, are (were):

1. Adaptation of farm production practices (lead by the Czech partner),
2. Adaptation to climate-related pest and disease risks (lead by the Serbian partner),
3. Adaptation strategies by changing land-use and crop selection (lead by the Italian partner),
4. Implementation of adaptation into management strategies and into agricultural policy (lead by the Spanish partner).

All these groups focused especially on assessment of uncertainties and cost/benefit analysis of specific adaptation measures as well as regional conditions and limitations.

POLISH PARTNER OF ADAGIO

Poznań University of Life Sciences (PULS) is one of the most highly ranked institutions of higher agricultural education in Poland. It has 8 faculties (Agronomy, Forestry, Horticulture, Animal Breading and Biology, Land Reclamation and Environmental Engineering, Food Science and Nutrition, Wood Technology, Economic and Social Sciences) on which 19 major branches of studies are realized. The university employs about 780 scientific workers and academic teachers, from among them about 170 are employed on the position of a professor. Agrometeorology Department is a branch of the Faculty of Land Reclamation and Environmental Engineering and is one of the leading didactical-scientific units of Faculty. The Department developed research of the energy flow and the matter circulation in the agricultural landscape. Wide spread methodological works led to creation of the unique apparatus for micrometeorological measurements of energy fluxes. Presently, Agrometeorology Department is more focused on measurements of greenhouse gases exchange between surface area of wetland and forest ecosystems and the atmosphere as well as estimation of their balances. The results of the research resulted in numerous scientific publications. Thanks to the wide international cooperation and own research works, the Agrometeorology Department is today an equivalent partner of leading research institutions all over the world, developing research in exchange of energy and matter (mainly CO_2, CH_4 and H_2O) between ecosystems and the atmosphere.

IDENTIFYING OF MOST VULNERABLE REGIONAL ISSUES THROUGH CLIMATE CHANGE

According to WP1 tasks, working groups of experts and end-users were established in Poland. Potential national experts (in a field of climate change and its impact onto agriculture), as well as potential end-users (farmers, agricultural services, farmer associations, clerks, decision-makers, and schools) were selected. Next, the detailed lists of contacts of national experts, who agreed to cooperate within ADAGIO, were created (Tab. 2). At the end,, the ADAGIO information brochures, which were distributed between experts and end-users by post and the Internet as well as between PULS staff and students during the conferences organized within WP2, were worked out. Additionally, Polish ADAGIO website http://www.agrometeo.pl/adagio/ was created. This Website is available only in Polish and is dedicated mainly to ADAGIO experts and applicants involved in the Project, but it is open also to any other visitors, who would like to know details about the ADAGIO project (its goals, methods of execution and partners description from other countries).

Table 2. Polish experts of the ADAGIO project

Institutions	Experts
Poznań University of Life Sciences	
Department of Agrometeorology	J. Olejnik, J. Leśny, R. Juszczak, T. Serba
Department of Pomology	R. Kurlus
Department of Plant Protection Methods	H. Ratajkiewicz
Research Centre for Agricultural & Forest Environment PAS	A. Kędziora, Z. Kundzewicz M. Szwed
Wrocław University Of Environmental And Life Sciences, Department of Mathematics	L. Kuchar
National Hydrometeorological Service	R. Farat, P. Mager, T. Kasprowicz,
Marshal's Office of the Wielkopolska Region in Poznan, Department of Agricultural Development	A. Bobrowski
Regional Extension Service Centre in Poznan	R. Jaworski
University of Szczecin Dept. of Meteorology and Climatology	Cz. Koźmiński
Western Pomerania Technical University in Szczecin Dept. of Meteorology and Climatology	B.Michalska M. Czarnecka
University of Warmia and Mazury in Olsztyn Dept. of Meteorology and Climatology	Z. Szwejkowski, M. Panfil, E. Dragańska
Institute of Soil Science and Plant Cultivation Puławy, Department of Agrometeorology and Applied Informatics	J. Kozyra
Institute for Land Reclamation and Grassland Farming, Depart. of Regional Studies for Develop. of Rural Areas	L. Łabędzki, B. Bąk E. Kasperska Wołowicz
Institute of Plant Protection	F. Walczak, A. Tratwal, M. Ruszkowska
Insurance agency (PZU)	K. Szczepański
Institute of Plant Breeding and Acclimatization	H. Czembor
The Institute of Environmental Protection	M. Sadowski

In order to identify the most vulnerable regional issues through climate change the first national meeting/conference of the Polish ADAGIO working group (24 April 2007) was organized. It was mainly the national meeting of „experts" together with

„applicants". During this conference the decisions related to Pilot Assessments (who will be responsible for what and when these tasks will be finished) were undertaken. 18 speakers from: scientific institutes, agricultural universities, regional extension service centre, regional policy makers and insurance agency gave a presentation and took part in final discussion during this meeting. The leaflet and handouts informing about ADAGIO were prepared and disseminated between conference participants.

In order to control the progress in the pilot assessments realization, the second national meeting of „experts" together with „applicants" was arranged. 14 speakers from scientific institutes, agricultural universities, regional extension service centre and regional policy makers gave presentation during the meeting. In total, 35 people took part in the conference.

Conclusions after two of the Polish ADAGIO conferences:

- water stress will be the main limitation factor in plant cultivation,
- extreme hydrometeorological events will be more frequent and destructive,
- changes in pest cycles caused by climate change are poorly recognized,
- there is no long-term agriculture policy which would consider any predicted climate changes.

Additional the questionnaire for farmers, based on questionnaire prepared by Spanish ADAGIO partner were prepared and adopt to Polish conditions. More than 1300 questionnaires were distributed and sent to farmers with the help of the 16 divisions of the Farmers Advisor Services (ODR) who have contacted with farmers in the regions of their responsibilities. About 1200 filled questionnaires were sent back to PULS. Questionnaire included 22 questions about farmers knowledge on potential/visible impacts of climate changes, farmers ability to adaptations, applied irrigation systems etc.

IDENTIFYING FEASIBLE POTENTIAL ADAPTATION MEASURES

One of the main feedbacks of the WP3, was a paper presented ADAGIO activities and goals, that was published in the national Report: "Climate Changes, agriculture and rural areas" (ISBN 978-83-924319-3-0, in Polish language) of the Foundation for Development of Polish Agriculture. The report present climate change influence onto an agriculture sector and rural areas in Poland as well as demonstrate possibilities of minimizing negative effects of those changes through adaptation activities. Also possibilities of climate protection through certain agrarian practices were presented.

Two pilot assessments in cooperation with national ADAGIO experts were prepared: "*Analysis of feasibility of adaptation measures for Polish agriculture*" and "*Assessment of technical equipment (available on Polish market) which is helpful/needed to adapt agriculture to climatic risks (in terms of costs, modern technical* *solutions, accessibility)*". Prof. dr hab. Cz. Koźmiński, prof. dr hab. B. Michalska, prof. dr. hab. M. Czarnecka, prof. dr. hab. L. Łabędzki, doc. dr hab. M. Ruszkowska, dr. H. Ratajkiewicz were authors of the texts. They are the polish experts selected on the first part of ADAGIO.

The main message from the first pilot assessment is that the climate changes will impact mostly water resources and hydrologic cycle components. The main adaptation measures should lead to:

a. increase the amount of surface water resources,
b. increase in water use efficiency in agriculture,
c. decrease water needs of crops.

Other adaptation measures should be focused on minimizing negative effects of extreme climatic events on agriculture and to prevent agriculture sector against new/old pest occurrence.

The main message from second pilot assessment is that the 3-4% of arable land in Poland (without subirrigated area) should be urgently irrigated in the near future to avoid catastrophic yield losses through droughts. As far as the technique and the irrigation systems are concerned, they are and will be in the nearest future similar to the systems, used in the other European countries. They are and they will include the sprinkling machines in agricultural field cultivations, sprinkling machines and drip irrigation systems in vegetable farming, various microirrigation systems in greenhouses and orchards. In the near future, the role of microirrigation of intensive root crops, industrial and greenhouse crops, horticultural crops in open air and orchards in private farms will increase. On permanent valley grasslands, gravitational subirrigation systems will remain in the future as a source of fodder and a way of healthy feeding of cattle. It may be stated that it is not the technique which will be the barrier to the development of irrigation in Poland, but the economics and the availability of water, in sufficient quantities and of suitable quality.

Additionally, an article popularized ADAGIO project was published in biweekly journal "Farmer" (in Polish). This journal is destined for farmers and presents widely information dealing mostly with the modern agriculture issues. Polish agrometeorologists and climatologists involved in ADAGIO mat and discussed during the conference „*Environment in the face of expected climate changes*" hold in Olsztyn, Poland, in September 2008. Reviewed article "*Impact of climate changes on European agriculture, project ADAGIO*" that presented general impacts of climate changes on European agriculture and results of implementation of the ADAGIO in Poland was printed in Polish language in Acta Agrophysica journal (ISSN 1234-4125).

The main scientific results of the Polish experts involved within ADAGIO are presented in papers published in this monograph. These papers are results of investigations and discussions of polish scientists inter alia on ADAGIO meetings.

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2. CHANGE OF AIR TEMPERATURE AND PRECIPITATION IN POLAND IN 1966-2006

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INTRODUCTION

For almost three decades now, we have been witnessing the progress of global warming. The gradual rising of air temperature and ocean temperature is linked by scientists to increased concentrations of anthropogenic emissions of greenhouse gases to the atmosphere. The temperature increase is accompanied by an increased variability of atmospheric conditions, higher frequency and intensity of extreme phenomena events such as hurricanes, heavy rainfalls resulting in dangerous floods, long dry periods which in combination with hot weather cause acute droughts, etc. These phenomena have a direct negative impact not only on humans and human economy, but also on the natural environment, which, in many cases, might not adapt to the rapidly changing climate conditions. For this reason, besides the efforts to predict as accurately as possible the direction of climate evolution, growing attention is paid to present day climate analysis to see just how advanced these changes are at a regional level. This provides us with the information that allows us to assess the relationship between regional climate changeability and global climate processes.

This paper is yet another attempt to answer this question on the basis of meteorological observations from the last few decades up to 2006 conducted in Poland by the National Hydro-Meteorological Service.

A SHORT REVIEW OF SELECTED LITERATURE

Recently, Polish researchers have been focusing on the analysis of changeability of two basic climate parameters, i.e. air temperature and atmospheric precipitation. Their research is based on 1951-2000 hydro-meteorological data. One of such studies is the study of changeability of mean air temperature in Poland based on data from 51 meteorological stations done by Kożuchowski and Żmudzka (2001). The authors found statistically significant increase of mean annual temperature and temperatures in March and May in the analysed period. The authors point out that „in the studied period, winters have become visibly milder which affects, i.e. increases temperatures in spring season (particularly March) due to temperature inertia”. They also noticed a decrease in annual temperature amplitude, reversal of the relationship between mean spring/autumn temperatures (sprigs have become warmer than autumns), and more frequent occurrences of relatively early but mild winters in the last decades of the studied period. Similar conclusions were reached by Fortuniak, Kożuchowski and Żmudzka (2001) who, after the analysis of 1951-2000 period, confirmed that the warming is most pronounced in the 1980's and 1990's. They also indicated that by the end of the last decade, the temperature in September-December dropped to lower values, and mean temperature of the coldest months showed tendency to move toward zero „with long-term perspective of complete fading of thermal winter by the mid-21st century”. The analysis of spatial distribution of the mean annual air temperature led the authors to conclude that „the thermal contrasts within the area of Poland are slightly increased indicating that warming is more visible in warm regions of Poland than in cold ones”.

Contrary to changes in temperature, changes in precipitation in 1951-2000 are not so pronounced in the area of Poland. Żmudzka (2002) pointed out that despite an incrase of annual precipitation totals by 3 mm/decade and the increase of spring and autumn totals, these changes are not statistically significant. The author noticed that the highest precipitation increase was noted in the northern slope of the Pomeranian Lakeland and in the Podkarpacie region while there is precipitation decrease in the lowland belt.

Some interesting observations regarding changeability of selected climate parameters, i.e. air temperature and precipitation, are found in Kożuchowski (eds.), 2000. The comparison of thermal seasons in 1989-1998 with seasons in 1959-1968 showed that winter became visibly shorter while early spring − longer, and seasonal changes occured earlier than before. In terms of precipitation, the authors noted that although there were changes in pluvial regime indicator, this changes did not have the characteristics of maritime climate because the difference in precipitation volume was not recompensated during autumn/winter season.

The progress of warming process is also confirmed by the authors of Kundzewicz Z., Radziejewski M. (eds.), 2002, who analysed both mean values and 16 other selected indicators of extreme climate phenomena related to air temperature and precipitation. They emphasised, however, that while direction of changes concur with expectations most of the time, only few such changes are of high statistical significance.

THE AIM, MATERIALS AND METHOD OF THIS STUDY

The aim of this paper is to present direction and rate of change of mean air temperature and precipitation totals in the area of Poland. Data collected from 49 meteorological stations was the basis of this study. All stations are evenly distributed throughout the country, all are located no higher than 1000 meters above the sea-level (Fig. 1). Mean monthly values were calculated for each station, mean seasonal values (winter – DJF, spring – MAM, summer – JJA, autumn – SON) and mean annual values. The study aimed to analyse data as current as possible, thus the four decades of 1966-2005 were the basis of this work. Some analyses, such as trend analysis or moving average, also include year 2006.

Fig. 1. Locations of meteorological stations

For each analysed parameter, a linear regression function was calculated and statistical significance of regression coefficient was tested with Student's *t*-test. In order to better illustrate changeability of the studied parameters, each regression line is complimented by a 10-year moving average.

The study also involves a comparative analysis of two 15-year periods that was designed to better detect changes in the 40-year period under investigation.

Because researchers of climate change in Poland place the beginning of the warming process in the 1980's (Fortuniak *et al.* 2001), the first reference period includes years 1966-1980, right before the offset of the warming process. This period will be referred to as the *a* period. The second 15-year period, referred to as a *b* period, includes years 1992-2006, i.e. period where the warming process became most evident. Again, the mean and variance values were calculated, and after running statistical test, it was possible to detect differences between pairs of mean values and pairs of variances. The hypotheses were tested on 0.05 and 0.01 statistical significance level.

In the analysis of observation data, two methods were used. One was to average given parameter for the entire area of Poland. While discrepancies or errors in measurements at particular points can be ignored, the method gives an overview of the general direction of changes observed throughout the country. This procedure proves to be very useful for analyses of large areas (Kożuchowski and Żmudzka 2001, Przedpełska 1984, Zawora *et al.* 2000/2001, Żmudzka 2002). In the second method, the values of the analysed parameters were correlated to particular points which allowed to detect their spatial variability in the area of Poland.

REVIEW OF THE STUDY RESULTS

Air temperature

The mean air temperature for the area of Poland in 1966-2005 is 7.8°C. The lowest mean value (6.3°C) occurred twice: in 1980 (period *a*) and in 1987. The highest mean temperature value (9.3°C) took place in 2000 (period *b*). In the *a* period, there were six out of the ten coldest years and only one (1975) out of the ten warmest years. In the *b* period, on the other hand, these proportions are reversed: there were six warmest years out of ten and only one out of the coldest ones (1996). The period *b*, therefore, was substantially warmer (mean air temperature: 8.2°C) than period *a* (mean air temperature: 7.4°C) (Tab. 2). Statistical significance of the difference between these two mean values is 0.01. Figure 2 presents increasing trend of air temperature.

The direction coefficient of mean annual temperature trend in Poland is 0.025 which indicates 0.25°C temperature increase rate per decade (Tab. 1). Statistical significance of this increase rate is 0.05. According to Kożuchowski and Żmudzka (2001), the direction coefficient of trend of mean annual temperatures for 1951-2000 is 0.018 (Tab. 1). The comparison of direction coefficients in 1951-2000 and 1966-2006 shows an intensification of the warming process in Poland. Data presented here confirms the intensification of mean temperature increase process that has been continuing since the 1980's. The years following 2000 were warm making the1997-2006 decade the warmest decade since 1966. Furthermore, weather conditions in January-October 2007 established the year 2007 as the warmest year of the analysed period. Still, the rate of the warming process is not the same for different regions in Poland – regions with the highest temperature increase (over 0.3°C per decade) are in the western Poland, and regions with the lowest temperature increase (less than 0.2°C per decade) are in central-eastern and southern parts of Poland (Fig. 3). It is worth mentioning that changeability of mean annual air temperature measured with the value of standard deviation was the same for both *a* and *b* periods.

Table 1. The direction coefficient of linear change trends of mean monthly, anuual (a) and seasonal (b) air temperatures (°C/10 y) in Poland in different multi-year periods

a)

	Month												Year
	J	F	M	A	M	J	J	A	S	O	N	D	
66-06	0.57	0.25	–0.01	**0.47**	0.31	0.12	0.47	**0.39**	0.17	0.13	–0.03	0.21	0.25
51-00	0.42	0.64	0.56	0.24	0.30	–0.12	0.04	0.14	0.00	0.06	–0.18	–0.02	0.18
ΔT	0.15	–0.39	–0.57	0.23	0.01	0.24	0.43	0.25	0.17	0.07	0.15	0.23	0.07

b)

	Season			
	DJF	MAM	JJA	SON
66-06	0.29	0.26	**0.33**	0.09

J, F… − January, February etc.
DJF – winter, MAM - spring, JJA - summer, SON - autumn

66-06 − 1966-2006
0.47 − statistically significant trends at the α = 0.05 level
0.39 − statistically signifincant trends at the α = 0.01 level

51-00 − 1951-2000 (Kożuchowski and Żmudzka, 2001);
0.56 − statistically signifincant trends at the α = 0.05 level

ΔT − difference between 66-06 and 51-00.

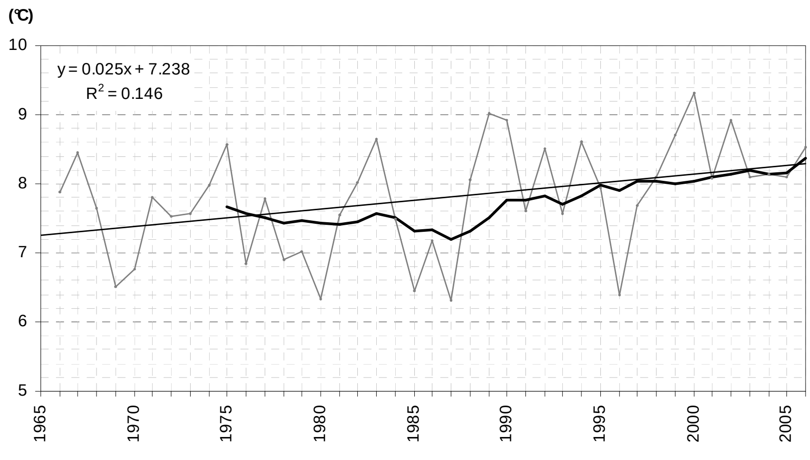

Fig. 2. Mean annual and decadal air temperatures (°C) in the area of Poland and trend line for 1966-2006

Table 2. Mean monthly, annual (a) and seasonal (b) air temperatures (°C) and their changeability (standard deviation) in Poland in periods *a* (1966-1980) and *b* (1992-2006)

a)

	Month												Year
	J	F	M	A	M	J	J	A	S	O	N	D	
Mean (°C)													
a	–3.2	–1.3	2.1	6.5	12.3	16.0	17.2	16.6	12.5	7.9	3.4	–0.7	7.4
b	–1.6	–0.4	2.1	8.0	13.4	16.4	18.7	17.9	13.0	8.3	3.1	–0.6	8.2
ΔT	1.6	0.9	0.1	**1.4**	1.1	0.4	**1.4**	**1.3**	0.5	0.4	–0.4	0.1	**0.7**
Standard deviation (°C)													
a	2.57	2.27	2.22	0.86	1.34	1.10	1.34	0.91	1.38	1.55	1.21	2.66	0.68
b	2.66	2.91	1.80	1.38	1.30	0.96	1.79	1.20	1.45	1.92	2.34	2.80	0.68
Δσ	0.09	0.63	–0.42	0.53	–0.04	-0.14	0.45	0.30	0.07	0.38	**1.13**	0.13	0.00

b)

	Season			
	DJF	MAM	JJA	SON
Mean (°C)				
a	–1.7	7.0	16.6	8.0
b	–1.0	7.8	17.6	8.1
ΔT	0.7	**0.9**	**1.0**	0.2
Standard deviation (°C)				
a	1.96	0.96	0.62	0.80
b	1.96	0.94	0.94	1.16
Δσ	0.00	–0.02	0.32	0.36

J, F… − January, February etc.
DJF − winter (Dec, Jan, Feb)
MAM − spring (Mar, Apr, May)
JJA − summer (Jun, Jul, Aug)
SON − autumn (Sep, Oct, Nov)

ΔT, Δσ − difference between periods *a* and *b*
1.1 − statistically significant trends at the α = 0.05 level
0.9 − statistically signifincant trends at the α = 0.01 level

The rate of the warming process is different for each particular season. Within the analysed period, the highest increase of mean areal air temperature occurs in summer season – ca. 0.3°C/10y, and then in winter and spring seasons – ca. 0.25°C/10y (Tab. 1). The season with the least increase is autumn – ca. 0.1°C/10y. The positive temperature trend, therefore, occurred in all seasons but it is statistically significant only for summer (at 0.01 and 0.05 levels). The 1°C difference between mean air temperatures of *a* and *b* periods is also statistically significant for spring and summer at the level of 0.01. The differences of mean air temperature in winter and autumn seasons do not satisfy the test of statistical significance criteria (Tab. 1). The analysis of mean seasonal air temperature in the last decade (1997-2006) shows that summer and autumn have a visibly increasing tendency while mean winter and spring temperatures have a decreasing tendency.

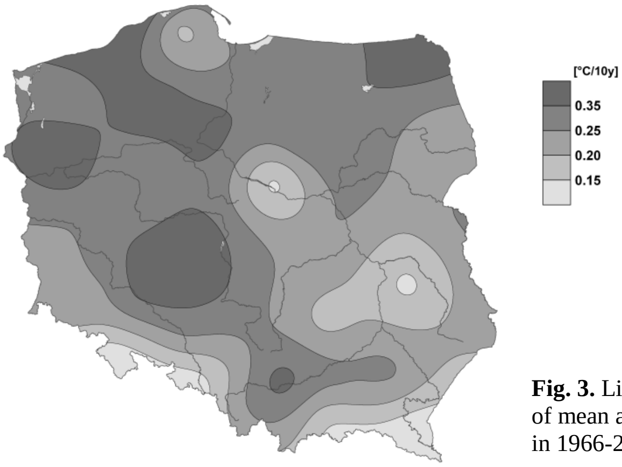

Fig. 3. Linear trend coefficients (°C/10y) of mean annual air temperature in Poland in 1966-2006

Not only does temperature change occur at different rate, but it also shows a varied spatial distribution in each particular season. The highest regional similarity of annual tendencies is in spring – maximum increases were observed in the western Poland, especially in north-west (>0.3/10y), and the minimum in the eastern and southern parts of Poland (<0.2°C/10y) (Fig. 4).

As mentioned earlier, both summer and winter seasons are characterised by an increased tendency of mean temperature regression coefficient in almost the entire area of Poland. Summer and winter, however, are almost perfect opposites (very much like their intensity) – the areas with the highest increase in summer usually have the least increase in winter, and vice versa. Trend coefficients indicating temperature changes show high spatial order – they increase during winter from south and south-west towards north and north-east. Their values in the south are lower than 0.20°C/10y (at some places they even reach negative values, i.e. Kłodzko (-0.07°C/10y), Racibórz (-0.04°C/10y), Lesko (-0.01°C/10y). In central Poland, they reach 0.25-0.35°C/10y with the maximum values occurring in south-east (>0.45°C/ 10y, Suwałki 0.62°C/10y). Summer shows opposite tendencies – the lowest values are in the north and the north-east (0.15-0.30°C/10y) and the highest in the south (>0.40°C/10y). Autumn shows the least differentiation of regional tendencies of temperature changeability with no visible spatial distribution pattern. The values oscillate between 0.01°C/10y (Lesko) and 0.21°C/10y (Kalisz) and are of no statistical significance (Fig. 4).

The comparison of mean temperature changeability of all seasons of the two 15-year periods showed that the difference is not statistically significant. However, the strongest tendency for temperature changeability occurred in summer and autumn (0.32°C and 0.36°C increase respectively) (Tab. 2).

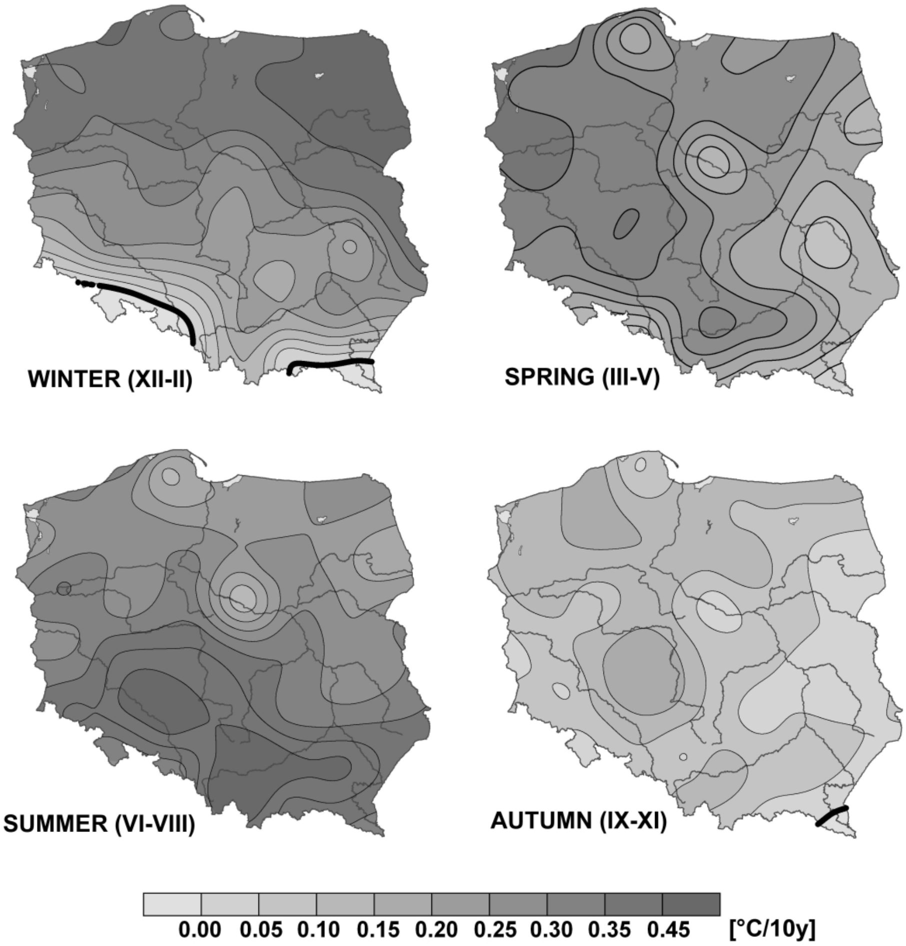

Fig. 4. Linear trend coefficients (°C/10y) of mean seasonal air temperature in Poland in 1966-2006

The analysis of mean seasonal temperatures included relationship between temperatures of spring and autumn. The analysis confirmed earlier findings that the difference between mean temperatures of spring and autumn has been getting smaller for a relatively long time now, and since the beginning of the 1980's spring has been warmer than autumn quite often (Fig. 5). The mean spring temperature in period *a* was 7.0°C compared to 7.8°C in period *b*, while mean autumn temperature were, respectively, 8.0°C and 8.1°C (Tab. 2). The temperature difference between those two seasons, therefore, decreased from 1.0°C to 0.3°C, although this change is not statistically significant at the 0.05 level. The rate of average "warming" of spring in relation to autumn based on the mean air temperature values for Poland in 1966-2006 is 0.16°C/10y. This, however, bears no statistical significance on the 0.05 level.

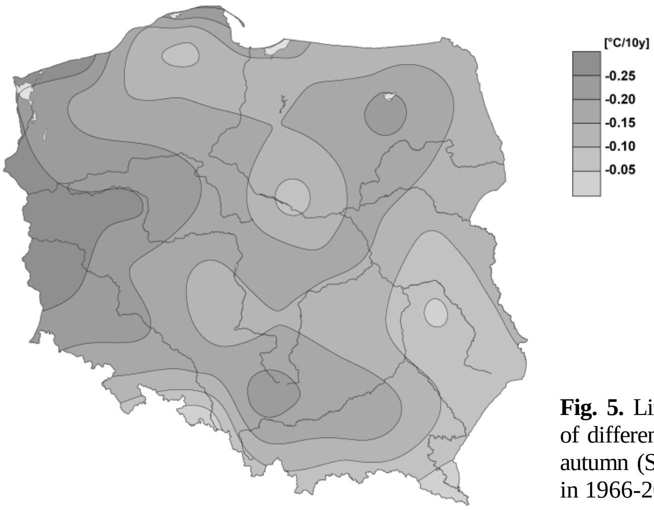

Fig. 5. Linear trend coefficients (°C/10y) of difference of mean spring (MAM) and autumn (SON) air temperatures in Poland in 1966-2006

Spatial distribution of this change is most affected in the western parts of the country including Wielkopolska region and the coast of the Baltic Sea (the rate of the average warming of spring in relation to autumn is >0.20°C/10y). The least changes occur in the south and south-east of Poland (<0.10°C/10y) (Fig. 5). Such spatial distribution is consistent with the influence of ocean (sea) on the climate, where spring temperature is more dependent on winter temperature in that water cooled by winter's low temperature stalls development of spring. If, then, winters are getting warmer, it will be reflected in spring temperature increase in the with maritime climate areas (not so much in areas with continental climate).

The observations of the last few years, however, make it difficult to predict the direction of changes in the future, i.e. in 2004-2006, autumns were warmer than springs (in 2006 there was the record difference of 3.8°C in 1966-2006), but in 2007, spring was again warmer than autumn.

The analysis of values of direction coefficients of linear trend of mean monthly temperature changeability (Tab. 1) shows that the highest statistically significant increase of mean monthly temperatures occurred in summer (July – 0.47°C/10y, August – 0.37°C/10y) and also in spring (April – 0.47°C/10y, May – 0.31°C/10y). During those months, with the exception of May, the abovementioned temperature trend fullfills the criteria of statistical significance. It may be mentioned that the strongest increase tendency expreseed by regression coefficient of mean monthly temperature occurs in January (0.57°C/10 lat) (Tab. 1). This increase, however, has no statistical importance since „signs of temperature increase in January are lost in a very high variability of winter temperatures" (Kożuchowski and Żmudzka, 2001).

The comparison of study results by Kożuchowski and Żmudzka (2001) for 1951-2000 with the results of this study reveals the increase of direction coefficient of mean monthly temperature trend values in June-September (especially high increase in July), November – January, and April. There is also a tendency of a slowing down of temperature decrease in November and a pronounced change of tendency in March with even small negative trend of mean monthly temperature (–0.01°C/10y) (Tab. 1). This might be explained by the fact that few years before 2007, mean areal temperature of March oscillated around the norm or was below the multi-year mean temperature, as it was the case in 2005 and 2006. It is possible, however, that 2005-2006 was a transitional period, because March 2007 was exceptionally warm. Its mean temperature reached almost 6.0°C making it comparable to the warmest March of the analysed period (6.3°C in 1990).

Trend coefficients are reflected in the temperature differences between the two fifteen-year periods. The corresponding months of period *b* were warmer than those in period *a* by over 1°C: January, April, May, July and August, and of those only January – despite the highest increase of mean monthly temperature (+1.6°C) – was not statistically significant (Tab. 2). Mean monthly temperature variability increased in case of 9 months in period *b*, but this change was statistically significant only for November at the 0.01 level (+1.1°C) and April at the level of 0.05 (+0.5°C).

Mean monthly air temperatures were used to analyse two more problems: changes in time of appearance of the warmest and the coldest months of a year, and annual temperature amplitude understood as the difference between mean monthly temperature of the warmest and the coldest months.

In 1966-2006, the coldest month tended to be December rather than January, and the warmest month tended to be August and not July. This phenomenon, as other authors pointed it out (Kożuchowski, 2000) deepened the asymmetry of annual temperature distribution – increase phase became longer (from winter to summer) and decrease phase became shorter (from summer to winter). Throughout the 1992-2006 period, January was the coldest month of the year 10 times, while December only twice. This is confirmed by the change of mean temperature of winter months – December became warmer by 1°C, January by 1.6°C, February 0.9°C. Consequently, December was slightly colder on average than February (Tab. 2) in the *b* period.

In summer, July remained the month with the highest frequency of the highest temperature occurrences in both periods (10 times). The increase of frequency of August as the warmest month occurred at the expense of June (2 and 3 times respectively in period *a*, and 0 and 5 in period *b*). This is also reflected in the relationship between temperatures in June and August: in period *a*, August was warmer than July by 0.6°C, and by 1.5°C in period *b*. Statistically, in a 3-year period, July was the warmest month twice, and August – once.

The period 1966-2006 is characterised by a higher stability of maximum temperature occurrences (July – 28 out of 41) than minimum temperatures (January – 19 out of 41). This is caused by a bigger influence of solar radiation on temperature in warm months and the impact of atmospheric circulation on temperature in cold months. Radiation is directly connected to Sun's height above the horizon which is consistent throughout the years unlike the unstable atmospheric circulation.

The direction of changes of annual air temperature amplitude is determined by maximum and minimum temperature values in the analysed period. The analysis performed by linear regression method showed a weak and statistically insignificant tendency of increase of mean monthly air temperature of the coldest month (0.13°C/10y) and a stronger, statistically significant at the 0.05 level, increase of mean monthly temperature of the warmest month (0.46°C/10y). In case of the mean temperature of the warmest month, the difference between periods *a* and *b* is statistically significant at the level 0.01. As the consequence of those two processes, we observe a systematic, but so far statistically insignificant, increase of annual amplitude of air temperature by 0.33°C/10y. This process is most evident in the central-south parts of Poland (amplitude increase >0.6°C/10y). It is the weakest in the north-east of Poland and in a relatively narrow zone along Baltic Sea coast, the Odra River valley up to the Nysa Łużycka inflow (<0.2°C/10y) (Fig. 6).

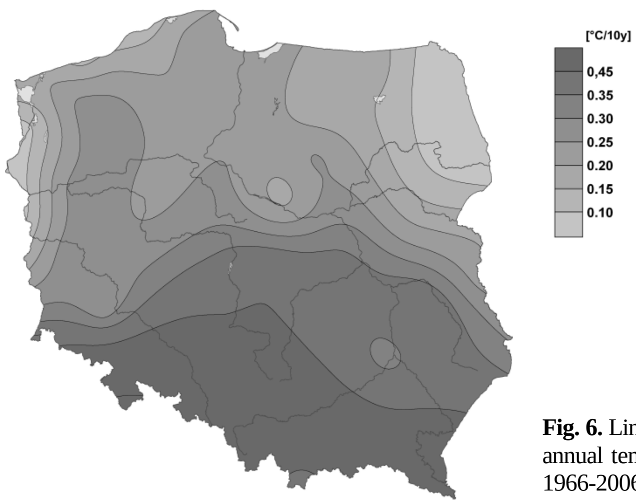

Fig. 6. Linear trend coefficients (°C/10y) of annual temperature amplitude in Poland in 1966-2006

Atmospheric precipitation

In 1966-2005, the mean precipitation total in Poland was 622 mm. The lowest mean total (445 mm) was registered in 1982, the highest (785 mm) in 1970 (period *a*). The first 15-year period (1966-1980) had six out of 10 wettest years and four out of the driest years. The second 15-year period (1992-2006) had half as many years with extreme totals (three „wet" ones and two „dry" ones). Such distribution indicates that period *a* is characterised by a higher changeability of mean annual totals. This is confirmed by the value of standard deviation which is 90.4 mm for period *a* compared to 60.0 mm for period *b* (Tab. 4). The mean annual precipitation total in 1966-1980 (647 mm) was 23 mm higher than in 1992-2006 which is reflected in the general change trend in the entire period (Fig. 7). Directional coefficient of trend of mean annual precipitation totals was –0.982 which indicates a decreasing, statistically insignificant, change by ca. 10 mm/10y (Tab. 3). The analysis of observation data from 1951-2000 by Żmudzka (2002) showed an increasing trend of annual precipitation (2.85 mm/10y). This indicates a change of this parameter which had a decreasing tendency in 1966-2006 especially after 2001.

Table 3. The direction coefficient of linear change trends of mean monthly, anuual (a) and seasonal (b) precipitation totals (mm/10y) in Poland in different multi-year periods

a)

	Month												Year
	J	F	M	A	M	J	J	A	S	O	N	D	
66-06	–1.18	1.45	2.10	–0.87	–1.02	–4.05	–0.12	–0.69	1.16	–2.97	–2.67	–0.95	–9.82
51-00	–0.58	–0.27	2.74	0.73	–0.18	0.93	–1.77	–1.60	2.10	0.53	–0.29	0.51	2.85
ΔP	–0.60	1.72	–0.64	–1.60	–0.84	–4.98	1.65	0.91	–0.94	–3.50	–2.38	–1.46	–12.67

b)

	Season			
	DJF	MAM	JJA	SON
66-06	0.58	0.20	–4.86	–4.48
51-00	–0.28	3.29	–2.44	2.35
ΔP	0.86	–3.09	–2.42	–6.83

J, F…, DJF, MAM… → see table 2.
66-06 − 1966-2006;
51-00 − 1951-2000 (Żmudzka 2002),
all trends are statistically insignifigant at the α = 0.05 level,
ΔP − difference between 66-06 and 51-00.

Decreasing tendency of mean annual precipitation total does not include the entire area of Poland. The comparison of isolines (Fig. 8) with a similar map by Żmudzka (2002) presenting changes in precipitation area in 1951-2000 shows that an area with the increasing tendency of precipitation is diminishing. The zone with decreasing precipitation tendency, on the other hand, has expanded in the central south, especially in central Poland and in the north-east. Precipitation increase is still present in south-east and in north-west parts of Poland. Out of 49 analysed stations only 12 shows this tendency, and only two (Resko and Elbląg) have an over 10.0 mm/10y increase of precipitation totals. Zone with decreasing tendency includes a wide area from Ziemia Lubuska and Dolny Śląsk through central Poland to Podlasie and Lubelszczyzna (Fig. 8). In the eastern part of Nizina Śląska up to Beskid Śląski (Wrocław-Bielsko Biała), there appeared an area with substantial decrease of precipitation totals − over 30.0 mm/10y.

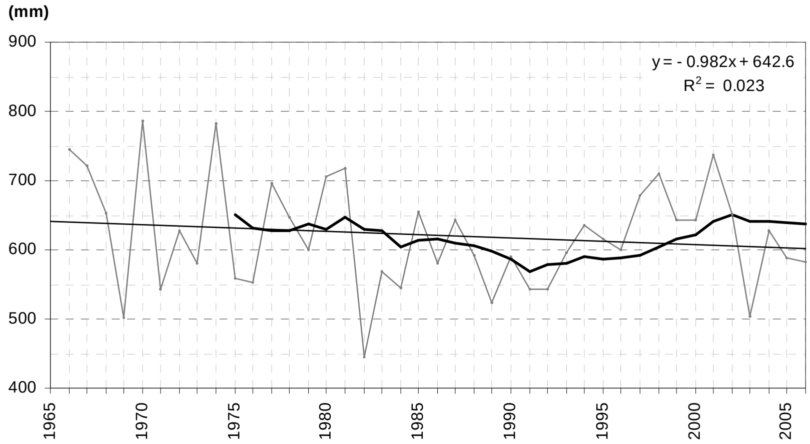

Fig. 7. Mean annual and decadal precipitation totals (mm) in Poland and trend line in 1966-2006

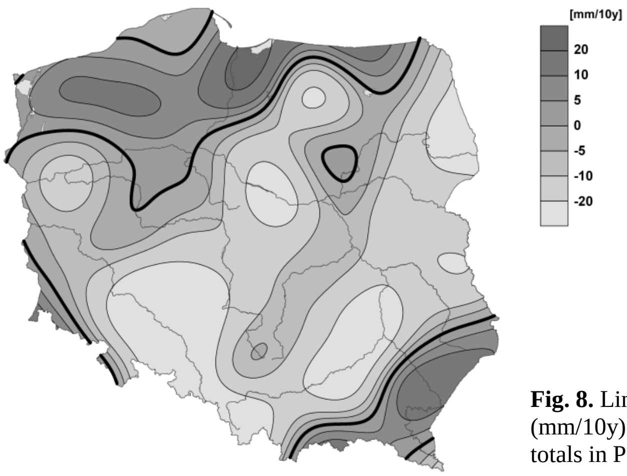

Fig. 8. Linear trend coefficients (mm/10y) of mean anuual precipitaton totals in Poland in 1966-2006

Nonetheless, in case of precipitation, all the changes are not statistically significant, and therefore, Żmudzka's conclusion (2002) is that “precipitation value in Poland's lowlands does not show any definite direction (significant trend) of change”.

The general tendency of decreasing mean annual precipitation totals is not evenly distributed throughout each season (Tab. 3). Winter and spring are characterised by a very weak tendency of precipitation total increase (0.6 and 0.2 mm/10y respectively) whereas summer and autumn are characterised by more evident tendency of precipitation to decrease (4.9 and 4.5 mm/10y respectively). Comparison of earlier analyses published by Żmudzka (2002) shows, above all, a distinct reversion of tendencies of precipitation totals in autumn (which is now decreasing), and change of winter tendency, which is now positive and, finally, lower increase of spring precipitation and its considerable drop in summer. It was the summer and autumn decreasing tendencies, therefore, that had a decisive influence on decreasing mean annual precipitation totals in 1966-2006. The highest negative difference between seasonal precipitation totals in periods a and b occurs in summer with the value of 20.2 mm (Tab. 4). Still, summer precipitation, despite the general decreasing tendency in this period, have been rising since 1992, where they were at their lowest in multi-year period.

Table 4. Mean monthly, annual (a) and seasonal (b) precipitation totals (mm) and their changeability (standard deviation) in Poland in periods *a* (1966-1980) and *b* (1992-2006)

a)

	Month												Year
	J	F	M	A	M	J	J	A	S	O	N	D	
Mean (mm)													
a	34.8	29.3	31.7	45.1	60.0	78.3	90.3	76.2	54.6	55.3	49.1	42.1	646.8
b	33.1	34.6	41.0	42.8	60.2	66.7	87.8	70.1	59.6	47.1	40.9	40.0	624.0
ΔP	–1.7	5.3	9.3	–2.3	0.2	–11.6	–2.5	–6.1	5.0	–8.2	–8.1	–2.1	–22.9
Standard deviation (mm)													
a	16.1	15.9	11.0	15.9	14.0	22.2	30.8	29.2	19.7	36.1	13.7	19.3	90.4
b	13.2	11.6	16.7	16.3	15.1	23.1	43.6	26.2	24.8	24.2	10.1	16.3	60.0
Δσ	–2.9	–4.3	5.6	0.4	1.1	0.9	12.8	–3.0	5.1	–11.9	–3.6	–2.9	–30.4

b)

	Season			
	DJF	MAM	JJA	SON
Mean (mm)				
a	104.7	136.8	244.8	159.0
b	108.6	143.9	224.6	147.7
ΔP	3.9	7.2	-20.2	-11.4
Standard deviation (mm)				
a	28.0	28.1	47.4	38.3
b	26.6	24.6	47.8	30.1
Δσ	–1.4	–3.6	0.4	–8.2

J, F…, DJF, MAM… → see table 2.

ΔP, Δσ − difference between periods *a* and *b*
all differences are statistically insignificant at the $\alpha = 0.05$ level

Spatial distribution of precipitation totals in each particular season is presented in Figure 9. The highest increase in winter is noted in the northern part of Poland, predominantly in Pomorze (above 10 mm/10y). Decreasing trends are recorded in the areas of Nizina Śląska, Ziemia Świętokrzyska, Lubelszczyzna and south Podlasie. Spring, like winter, is characterised by small values of directional coefficient of precipitation totals. A decreasing trend occurs mostly in Nizina Śląska, and increasing – mostly in Podkarpacie and Pomorze Gdańskie. The trend rate, however, does not exceed 10 mm/10y in most cases. The tendencies of change in all other regions are practically close to none. Summer is dominated by areas with decreasing precipitation, especially in central-south of Poland (Aleksandrowice 30 mm/10y) and in central Poland. Small increase is noted only in the Pomorze Zachodnie and western parts of Nizina Śląska. The negative trend occurs in autumn in all western part of Poland (max. up to 12 mm/10y) and in the central east (up to 10 mm/10y). A small positive trend is registered in Małopolska and Żuławy (up to 7.5 mm/10y).

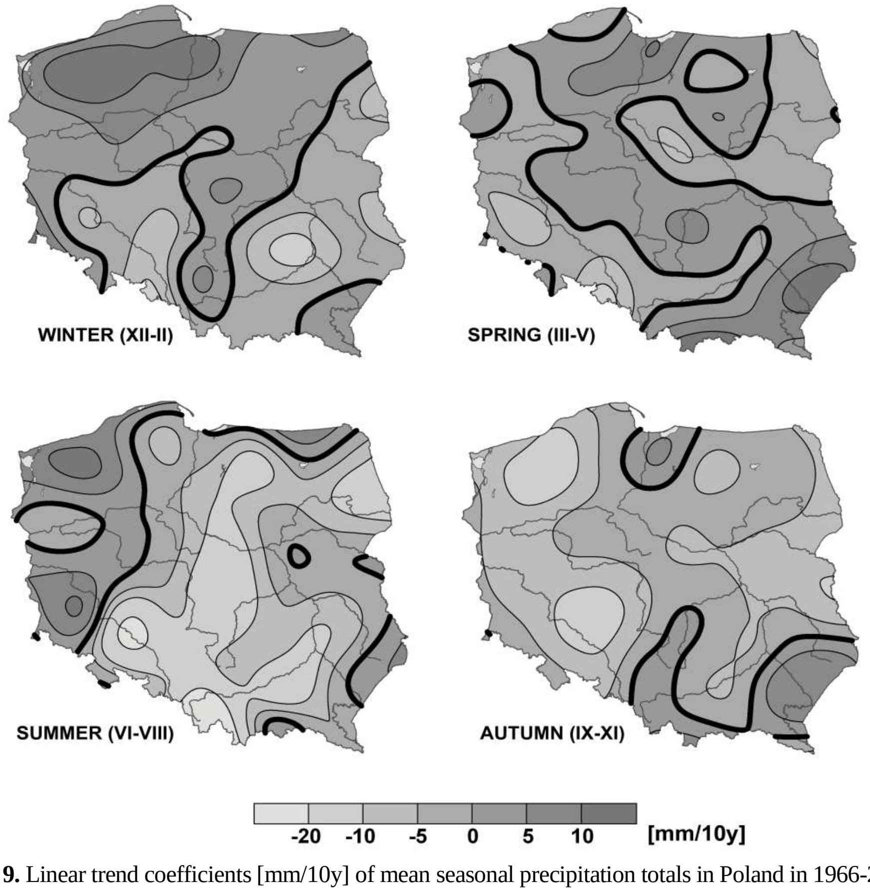

Fig. 9. Linear trend coefficients [mm/10y] of mean seasonal precipitation totals in Poland in 1966-2006

Winter precipitation in period *b* by 1.2% (up to 17.4%), spring precipitation by 2.1% (up to 23.1%), while the percentage of summer precipitation dropped by 1.8% (down to 35.9%) and autumn by 1.4% (down to 23.7%).

The dominance of autumn precipitation over spring precipitation is considered as characteristic to maritime climate (Paszyński and Niedźwiedź 1991). The comparison of period *a* (1.16) and *b* (1.03) mean precipitation total quotients of autumn and spring shows a decrease of this parameter value. This could indicate shifting towards continental climate (over maritime climate) in its precipitation pattern. At the same time, two other indicators – quotient of cold and warm season precipitation totals and quotient of winter to summer precipitation total, show precipitation increase sugges-ting an intensification of maritime characteristics. Calculations of those two indicator for periods *a* and *b* show that the first one is stronger than the second – the first indicator increased by 4.3% up to 61.1%, and the second one by 7.6% up to 52.2%). The increase of winter to summer precipitation total quotient is most visible in the area from Pomorze and Żuławy through Central Poland up to Wyżyna Śląska (increase >4%/10y) (Fig. 10).

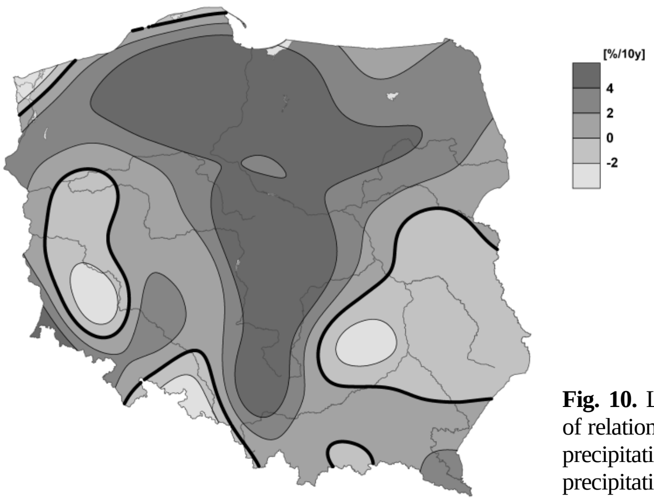

Fig. 10. Linear trend coefficients (%/10y) of relationship between mean winter (DJF) precipitation totals to mean summer (JJA) precipitation totals in Poland in 1966-2006

The analysis of mean monthly precipitation totals reveals that the rising tendency in winter is a result of higher precipitation in February, and in spring – March (Tab. 3). The third month with rising tendency is September. All other months are characterised by decreasing precipitation totals, especially June (4.0 mm/10y), October (3.0 mm/10y), and November (2.7 mm/10y), which determine the general loss of precipitation in summer and autumn. Earlier analyses by Żmudzka (2002) regarding 1951-2000 showed precipitation increase (change into positive trend, its increase or reduction of its negative value) in February, July and August, and precipitation decrease (change to negative tendency, strengthening of this tendency or decreasing positive tendency) occurred in June, October, November and December, and April (Tab. 3). The comparison of precipitation changeability difference in periods *a* and *b* measured with standard deviation shows an increase of changeability in months from March to July (with the high in July), September and a decrease in all other months (with low in October) (Tab. 4).

Another analysis was performed on annual precipitation amplitudes understood as the difference between the highest and the lowest values of monthly totals in a given year. On average, this amplitude in 1966-2006 was c. 90 mm in Poland, and its minimmal increasing trend (c. 2 mm/10 lat) is entrirely insignificant.

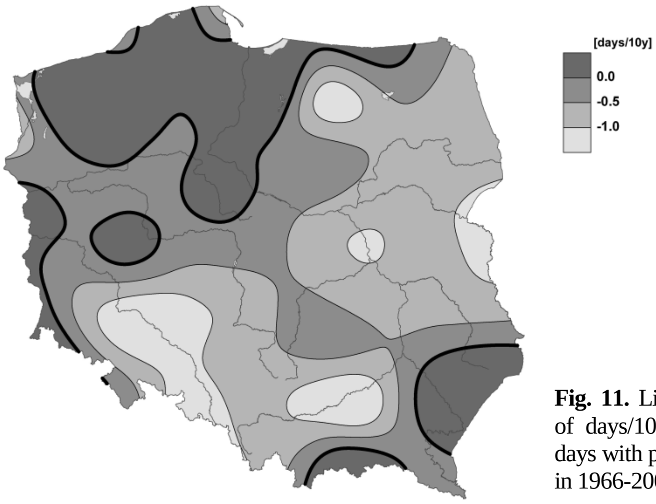

Fig. 11. Linear trend coefficients (number of days/10y) of mean annual number of days with precipitation >10.0 mm in Poland in 1966-2006

Basing on the daily data of each station, the number of days with totals over 0.0 mm, 1.0 mm and 10.0 mm was calculated. The averages for Poland in 1966-2006 are as follows: 171 days, 103 days and 14.7 days. In case of the first two indicatiors, due to the exceptionally low regression coefficient values, there is practically no regre-ssion (drop by 0.4 and 0.7 day/10y). There is, however, a relatively strong decreasing trend for days with >10 mm precipitation (0.4 day/10y), although it is also statistically insignificant. The zone with the most pronounced drop in this indicator is noted includes eastern Poland through Śląsk and up to Sudety. Increased frequency of such days is noted especially in Pomorze, Kujawy, northern Wielkopolska and Carprathian region (Fig. 11).

Mean annual maximim daily precipitation changeability for Poland was also analyzed. This indicator was calculated as an arithmetic mean of all the highest annual precipitation noted at each particular stations. Its mean value in 1966-2006 was 38.5 mm. As in other cases, the decreasing tendency is so weak that it may by ommited (0.35 mm/10y).

By dividing the annual precipitation total by the number of days with precipitation we receive the mean prepipication total per day with precipitation, i.e. mean precipitation intensity. The value of this parameter in Poland in 1966-2006 reached 3.6 mm/day. Change tendency was also decreasing and very weak (0.05 mm/day /10y). Spatial distribution of this parameters is presented in Figure 12. The difference of precipitation intensity in period *a* and *b* is quite noticeable and the prameter changeability decrease is statistically significant (α = 0.05). These tendencies indicate that annual precipitation totals decrease relatively faster than the number of days with precipitation and, therefore, there are gradually less precipitation totals per statistical day with precipitation.

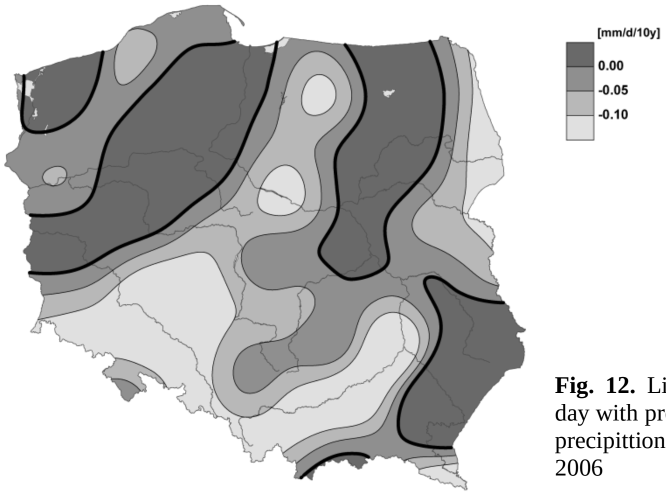

Fig. 12. Linear trend coefficients (mm/day with precipitation/10y) of mean daily precipittion intensity in Poland in 1966-2006

In conlusion, it needs to emphasize that value changes and changeability of tha analyzed parameters of precipitation in the area of Poland in 1966-2006 were not statistically significant at the the α≤0.05 level. The only statistically significant change at this level between period *a* and *b* is a decrease in precepitation intensity. In general, therefore, in case of precipitation, we may only speak – at the most – about more or less visible tendencies to change, which in fact, may proove to be very short-lived.

CONCLUSION

In this paper, we have presented the directions and the rate of change of mean air temperature and precipitation totals in relation to annual values and seasonal values in the area of Poland. The analysis included data collected in by 49 meteorological stations in 1966-2006. To indentify changes in time, we used such tools ans linear regression function, moving averages and comparison of two 15-year sub-periods: 1966-1980 (period *a*) and 1992-2006 (period *b*).

1. Warming that began in the 1980's is continuing into the present. The positive trend of temperature is indicated by mean annual values (increase of 0.25°C/10y – statistically significant at the 0.05 level) and for mean seasonal values (the largest increase occurred in summer season: 0.33°C/10y – statistically significant at the 0.01 level).

2. The tendency of decresing difference between mean temperatures of spring and fall, higher probalility of August as the warmest month of the year and December as the coldest month of the year and increase of annual temperature amplitude were confirmed.

3. This study also confirmed earlier analysis of Żmudzka (2002) who stated that "precipitation totals in the Polish lowlalnd do not indicate that there exists any specific direcion (significant trend) of change". We have not found any statiscically significant (at <0.05 level) changes in the analyzed relationships. It may be, therefore, concluded that presently, we observe only more or less evident tendencies to change that manifest themselves in different aspects of characterizing them parameters. The most important observation related to the general estimate of mean aeral annual precipitation total in Poland is the occurrence of not statiscically significant tendency of mean annual precipitation total to decrease (9.8 mm/10y).

4. A similar relationship is observed in summer (4.9 mm/10y) and autumn (4.5 mm/10y) but it is also not statiscically significant. The examination of the annual distrubution this climatic element showed the diminishing dominance of cold season (Novermber to April) precipitation over warm season (May to October) (weaker), summer precipitation over winter (stronger) and autumn precipitation over spring.

5. Mean precipitation total per day with rainfall (intensity) is slightly decreasing, total number of days with precipitation during the year is also decreasing, and the number of days with daily precipitation totals of >1.0 mm and >10.0 mm is also dropping. However, everything changes precipitation indices are not statiscically significant.

The main characteristics of the absolute values of air temperature and precipitation observed in 1966-2006 are generally consistent with the earlier forecasts based on climate models (IPCC). This statement is supported by statistically significant trend (significance level of $\alpha = 0.05$) indicating the increase of mean annual air temperature at the rate of 0.28°C/10y based on the 1966-2006 data and at the rate of 0.33°C/10y based on the 1987-2006 data. Similarity to the earlier predictions can also be seen in relatively small, statistically insignificant changes in precipitation values. On the other hand, analyses did not indicate any increase in changeability of the studied climate elements, while the majority of climate change scenarios predicted such increase. It has to be noted, however, that changeability analysis and its statistical significance included only two short periods i.e. two comparative 15-year periods. The results of this analysis, therefore, are by no means conclusive.

The authors would like to express their gratitude to Mr. Paweł Terlecki for his skillfull help in preparation of illustrations.

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3. IMPACT OF WEATHER CONDITIONS ON CROP PRODUCTION IN POLAND

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INTRODUCTION

The problem of forecast climate change is crucial for agriculture, since its functioning is closely dependent on weather conditions and any deviation from the maintained pattern constitutes a potential factor reducing production (Reddy and Hodges, 2000). With technical change taking place, the degree of dependence of this sector of economy on weather decreases slightly. This occurs as elements of the weather, being a source of resources and regulatory factors, are being replaced by artificial elements. Additionally, the above mentioned technical change considerably extends the adaptability of individual crops to changing conditions, as well as enforces the selection of an appropriate direction of production or changes in technologies (Hazell 1984, Morison 1996, Butterfield and Morison 1992). However, adaptation ability may turn out to be insufficient in view of expected changes resulting from global climate warming. Much concern is caused by the fact that contemporary models of climate change do not yield forecast data in such a time frame as it is required by the available weather-yield models (Stigter 2007).

All considerations concerning the past, current and future impact of climate on Polish agriculture have to take into account the fact that for decades it preserved traditional methods of production (Nowicki and Szwejkowski 2006). Such was the price which had to be paid for resisting the pressure of total nationalisation. Later, after the political and economic transformation, the situation changed little, apart from the elimination of state ownership. Polish agriculture is still to a large extent traditional, fragmented and continuously requires structural transformations. Thus it is an agriculture which obviously is less equipped to cope with climate threats than agriculture in most EU countries. For this reason it is justified to treat the problem of dependence of Polish agricultural production on weather conditions as unique and individual.

In view of this assumption it was decided to conduct analyses, the aim of which was to identify relationships between weather conditions and the level of mean national yields of crops grown in an economically and socially complicated past.

MATERIAL AND METHOD

The determination of reactions of individual crops to weather conditions is not very difficult at the level of laboratory, pot or even controlled field conditions. The problem is complicated in a situation when we need to answer the question how it is modified in the large spatial and time scale. In such a case it is necessary to have adequate and precise data concerning yielding of crops and the course of weather conditions (Semenov and Porter 1995).

In this study the effect of weather conditions on yielding of staple crops in Poland was determined, using data coming from official sources such as Statistical Yearbooks of the Central Statistical Office and agroclimatic analyses conducted in an earlier study (Szwejkowski *et al.* 2007). In view of the required continuity of meteorological observations (air temperature and precipitation) it was decided to cover in the analysis the four decades of 1966-2005, while the available data concerning yielding made it necessary to limit it to eight staple crops, i.e. winter rye, winter wheat, spring barley, oat, grain maize, rape, potatoes and sugar beet. Analyses of statistical dependencies between yields of crops in years and the course of weather conditions were conducted by first calculating the equations of trends in yielding of individual crops in the 4 decades analysed. Next, remainders of these equations, as dependent variables, were subjected to the analysis of multiple regression using the stepwise, progression mode. Independent variables in the equations were grouped as follows: total monthly precipitation, mean temperatures in months (together with winter for winter crops), mean temperatures and precipitation of growing periods (IV-IX), mean precipitation, and seasonal temperatures.

RESULTS AND DISCUSION

The final effect of the effect of weather combinations on yields of crops is very complex - for example drought does not reduce the intensity of photosynthesis, but rather LAI and leaf area duration, and in this way reduces the production of biomass (Wolf *et al.* 2002). This type of dependence considerably complicates the analysis of the situation, especially when it is attempted to determine large-scale effects in terms of space and time.

Statistical analyses of trends in crop yielding in the multi-annual period of 1966-2005 showed that they were manifested mainly in the liner and polynomial form in all analysed crops except for potatoes. Values of (corrected) coefficients R^2 turned out to be very high in winter wheat, maize and sugar beet. It means that in these species the highest technical change was observed in terms of production technology. The lowest value of R^2, among those statistically significant, was found in the equation of trend for winter rape.

In the analysed periods there were extreme situations, divergent from the overall trends of changes, evidently connected with an extreme course of weather conditions.

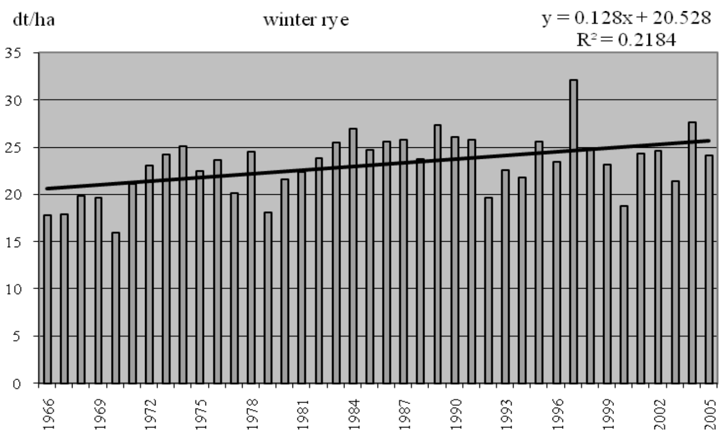
In the analysed 40-year period there were several significant cases of reduced yielding of winter rye and wheat. This pertains to situations of extremely difficult winter conditions which occurred in the years 1969/1970, 1979/1980 and 1978/1979 (Fig. 1). In the abovementioned years, losses in yields of rye, in relation to the values determined by the trend line, were approx. 4.5 dt ha^{-1}, while for wheat they were from 4 to 6 dt ha^{-1}. The next two cases of large reductions in yields, from approx. 4 to 7 dt ha^{-1} nationwide, concern the years 1992, 2000 and 2003, in which serious droughts were recorded. It is obvious that spring cereals did not suffer due to winters; however, the burden of dry years was also highly marked. Spring barley responded in those years by a drop in yields similarly as winter cereals, and the negative response of oat turned out to be even bigger.

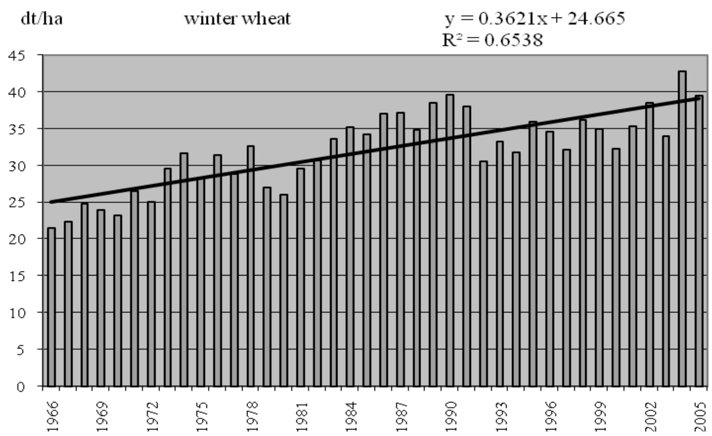
Maize, as practically an almost new species, was introduced with different results in cultivation in Poland after WWII. The variation in yields of this crop, recorded up to the 1990's, apart from the doubtless effect of the weather, was connected with the introduction of new cultivars, improvement of fertilisation, plant protection and harvesting techniques. In the last decade of the 20th century the situation stabilised and in this case the effect of the weather turned out to be more obvious – particularly during the drought of 2003.

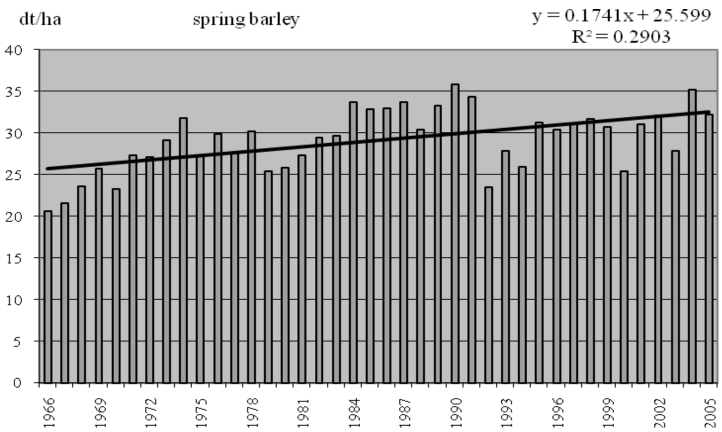
Winter rape showed an overall trend, the form of which was rather well represented by a polynomial function; moreover, in the analysed 40-year period oscillation of several years is relatively evident. Against this background we may observe the effects of extremely cold winters, as well as winters with a changeable course of weather conditions (which rape is more sensitive to than winter cereals), as well as drought periods.

In the case of potatoes, apart from exceptions concerning 1980, 1992 and 1994 when the marked drop in yields resulted from the weather together with cultivation factors, in the other years a more or less regular pattern was observed of alternating years of very good and bad harvest.

Surprisingly, less favourable vegetation conditions for sugar beet appeared after periods of difficult winter conditions, as manifested in the relatively lowest yields recorded in Poland in such situations. A direct and evident negative effect on yielding in this crop was observed for conditions of water deficits in 1992 and 1994. Considerable differences in yielding of sugar beet, found in many cases earlier and later, from year to year, need also to be attributed to the degree of water availability at the early vegetation period.


dt/ha
winter rye
y = 0.128x + 20.528
R² = 0.2184
35
30
25
20
15
10
5
0
1966
1969
1972
1975
1978
1981
1984
1987
1990
1993
1996
1999
2002
2005


dt/ha
winter wheat
y = 0.3621x + 24.665
R² = 0.6538
45
40
35
30
25
20
15
10
5
0
1966
1969
1972
1975
1978
1981
1984
1987
1990
1993
1996
1999
2002
2005


dt/ha
spring barley
y = 0.1741x + 25.599
R² = 0.2903
40
35
30
25
20
15
10
5
0
1966
1969
1972
1975
1978
1981
1984
1987
1990
1993
1996
1999
2002
2005

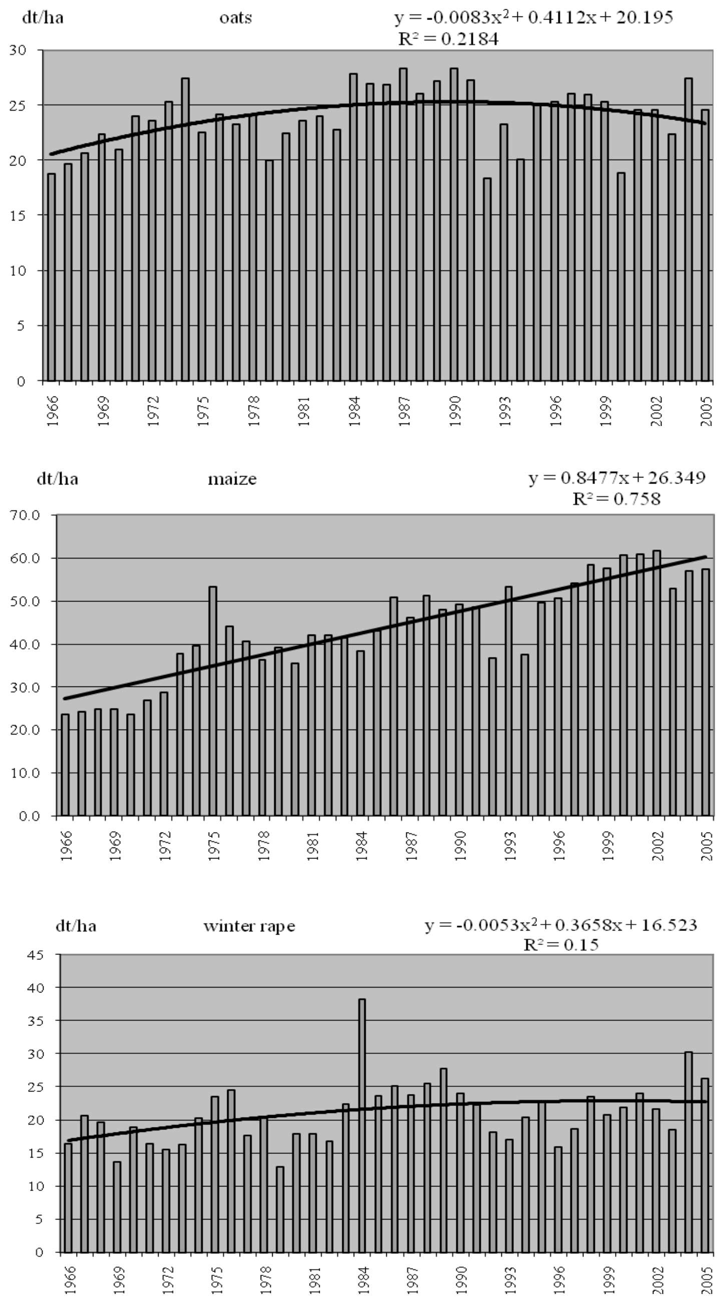
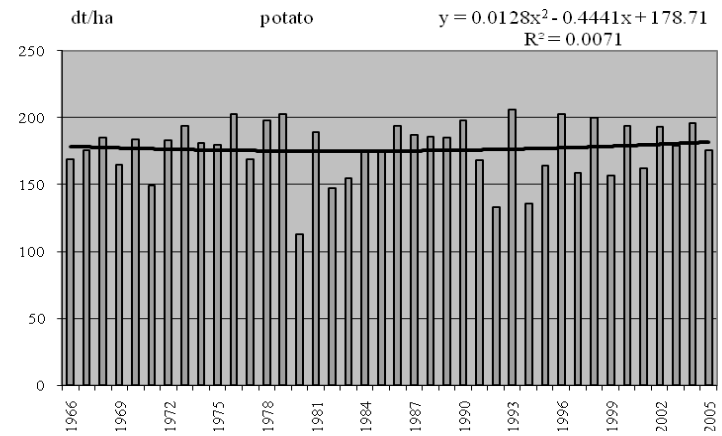


Fig. 1. Trends in changes of mean yields in Poland in the years 1966-2005



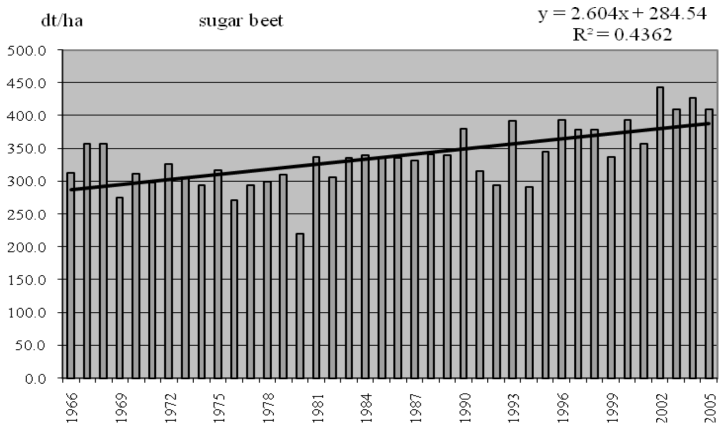


Fig. 1. Cont. Trends in changes of mean yields in Poland in the years 1966- 2005

Results of regression analyses of weather-yield for staple cereals (remainders calculated from equations of trends) showed that a set of variables, being mean temperatures of individual months of the year, in each case made it possible to obtain a statistically significant equation (Tab. 1). The highest value of the estimator of equations (R^2) was recorded in the case of spring barley. Among discussed crops, negatively correlated mean temperature of June was always found as a significant variable in the set of the optimal equation.

Almost all significant cases in equations with variables from the group of total monthly precipitation indicated negative correlations with yields of staple cereals.

Table 1. Summary of multiple regressions analyses: weather conditions-yields of cereals with different independent variables

Group of independent variables							
mean monthly temperatures		precipitation in months		temperatures and precipitation in months		temperatures and precipitation in months	
variables	slope	variables	slope	variables	slope	variables	slope
winter rye							
w	32.959	w	3.421*	–––	–––	–––	–––
t_{VI}	–1.806*	o_X	0.100*				
t_{II}	0.194						
t_X	–0.545*						
t_{XII}	–0.215						
t_{III}	0.214						
R^2 = 0,43		R^2 = 0.28					
winter wheat							
w	32.175*	w	3.309	w	32.165*	w	36.270*
t_{VI}	–1.567*	o_{III}	–0.0773*	t_{weg}	–1.786*	o_w	–0.035
t_{III}	0.378	o_{VII}	–0.037*			t_l	–1.879*
t_{VIII}	–0.470	o_{IV}	–0.064*			o_l	–0.022*
		o_{XI}	0.044			t_w	0.669
		o_{VII}	0.023				
R^2 = 0,36		R^2 = 0.42		R^2 = 0.20		R^2 = 0.39	
spring barley							
w	44.418*	w	2.1342	w	31.295*	w	24.625*
t_{VI}	–2.070*	o_{III}	–0.1208*	t_{weg}	–1.956*	o_w	–0.043*
t_{VII}	–0.480	o_{VII}	–0.0250	o_{weg}	–0.010	t_l	–1.110*
t_{III}	0.313	o_{VI}	0.0318	R^2 = 0.20		R^2 = 0.30	
R^2 = 0,47		o_{IV}	0.0298				
		R^2 = 0.49					
oats							
w	19.194*	w	–1.508	w	14.693*	w	1.440
t_{VI}	–1.204*	o_{III}	–0.089*	t_{weg}	–1.038*	o_w	–0.035*
R^2 = 0,28		o_{VI}	0.036*	R^2 = 0.11		o_l	0.014
		o_V	0.033			R^2 = 0.20	
		R^2 = 0.56					

According to the results of the analyses, winter rye in Poland responded negatively to temperatures of October, which means that the higher they were, the lower the recorded yields. This dependence may be explained by the fact that in most cases this would mean excessive exuberance before winter and entering the wintering phase in a worse condition. Temperatures of June, negatively correlated with yielding of this crop, were also significant. In this case it was probably connected with conditions of grain filling. In the case of total monthly precipitation it was only found that its level in October was positively correlated with grain yield. The lack of effect of precipitation in the other months resulted from the fact that water requirement in rye is closely related with development stages, not precisely concurrent with the calendar month system. In some studies by Bombik et al. (1977), taking into consideration production yields, the role of precipitation in the modification of yields of rye turned out to be significant, particularly after the spring onset of vegetation. The consideration in the analyses of a set of temperature and humidity factors in months and seasons did not make it possible to obtain in this case significant equations.

In Poland, winter wheat is considered to be a very sensitive species to weather conditions (Małecka 2000). Analyses concerning this crop exhibited a higher dependence, than those in rye, of yielding on temperatures and especially precipitation, treated as separate yield-forming elements acting in a monthly scale. The temperature of June was (significantly) negatively correlated with yield of wheat. The optimal equation containing temperature variables includes also partial non-significant temperatures of March and August (the latter with a negative sign). In the pair of variables "temperature and precipitation" in the vegetation period, only the former constituted a statistically significant factor for wheat, affecting the level of yielding. In turn, these factors, determining parameters of seasons of the year, formed a significant set of the optimal equation in the combination: precipitation in spring, temperature in summer, precipitation in summer, plus additionally temperature in spring. All significant variables obtained equation coefficients with a negative sign.

Higher temperatures in June resulted in a statistically significantly lower yield of spring barley grain in Poland. The other temperature variables complementing the form of the optimal equation are temperatures of March and July. The effect of the level of precipitation, as reflected in barley production and manifested in a significant effect on yield, was observed in February and additionally also in April and July. Mean temperatures and total precipitation in the vegetation period formed a pair of variables in another regression equation with a negative sign. Temperature and precipitation conditions, averaged for seasons and treated as independent variables, made it possible to create regression equations, on the basis of which it may be stated that spring precipitation and, additionally, mean temperatures in summer constitute factors determining yields in barley.

Table 2. Summary of multiple regression for variables: weather conditions-yields of maize and sugar beets in different configurations of independent weather variables

Group of independent variables							
mean monthly temperatures		precipitation in months		temperatures and precipitation in months		temperatures and precipitation in months	
variables	slope	variables	slope	variables	slope	variables	slope
maize							
w	20.110	——	——	——	——	w	–7.871
t_{VII}	–0.994					o_w	–0.111*
t_V	1.400*					o_l	0.039*
t_{VI}	–1.240					t_w	1.293
t_{IX}	1.078					$R^2 = 0.33$	
t_{VIII}	–0.866						
R^2 = 0,28							
winter rape							
w	19.063	w	–7.983	——	——	w	18.126
t_{VI}	–1.638*	o_I	0.112*			o_z	0.025
t_X	0.894*	o_{VI}	0.058*			t_l	–1.882*
t_I	0.311	$R^2 = 0.14$				t_w	1.441
R^2 = 0,37						t_z	0.636
						$R^2 = 0.27$	
sugar beet							
w	–28.695	w	–81.554*	——	——	w	136.94
t_V	9.939*	o_V	1.170*			t_w	10.74
t_{VI}I	–6.446*	o_{IV}	–0.384*			o_l	0.18*
R^2 = 0,19		o_{VII}	0.183			$R^2 = 0.13$	
		$R^2 = 0.27$					

Abbreviations for Tables 1 and 2, * significant variable – $p<0.05$, w – intercept,
t_I...t_{XII} – mean monthly temperatures,
t_w, t_l, t_j, t_z – mean seasonal temperatures: w – spring, l – summer, j – autumn, z – winter,
t_{weg} – mean temperature of growing season,
o_I...o_{XII} – precipitation in months,
o_w, o_l, o_j, o_z - total seasonal precipitation: w – spring, l – summer, j – autumn, z – winter,
o_{weg} – total precipitation of growing season.

Apart from mean temperature in June, no other temperature variable was found in the monthly scale, on which barley yield would depend in Poland. In turn, barley evidently responds to humidity conditions. The specific model of analysis results in a situation when the general assumption on water requirement of oat, i.e. its high requirement in the period from sowing to emergence, is not confirmed in its results at the statistical level. It turned out that total precipitation in March is negatively correlated with yield of oat and for total precipitation in June it is a positive correlation at the level of the national mean.

In the vegetation period a significant role is played by air temperature, whose relationship with yield of oat turned out to be negative, whereas, when considering seasonal effects of the weather, dependencies on spring and additionally summer precipitation were found (in the latter case the dependence appeared at the level of the total regression equation, rather than the partial one). Results obtained in relation to both spring crops correspond to a relatively high degree with the complex assessment of the effect of weather on yielding of these cereals, conducted for the moderate climate conditions of central Europe. It was also noted there that the period of the highest sensitivity lasts from May to July (Chmielewski and Köhn 1999).

In the case of maize, the high positive correlation of yield of grain on temperatures in May was confirmed. Temperatures in the other months of the vegetation period supplement the set of variables of the optimal regression equation. In view of other studies, the possibilities of evaluation of the situation on the basis of general meteorological data seem limited, since variation of maize yielding depends generally on values of extreme temperatures, particularly in the initial period of growth and development (Southworth *et al.* 2000). In contrast, no statistical relationships were manifested between the level of maize yield and total precipitation in individual months. However, it is characteristic that precipitation aggregated to the form of seasonal totals for spring and summer turned out to be statistically significant in the partial regression equations.

In relation to rape, the variables that appeared in equations which characterised mean temperatures in June (negative correlation) and October (positive correlation) were significant at the partial regression level, and January (also positive) – significant at the total regression level. Yields of rape depended statistically also on total precipitation in January (higher precipitation in this case could have had a positive effect on winter survival of this crop) as well as June. In terms of seasons, relationships were manifested between yield of rape and summer temperatures (partial negative significance), and additionally with spring and winter temperatures and precipitation in winter.

Sugar beet is known as a crop sensitive to weather conditions (particularly humidity) in the period of emergence and initial growth. German studies, representative also for Polish conditions, proved that also temperature conditions in the summer season are important, with mean daily temperature above 18°C, at an adequate water supply (Märländer *et al.* 2006). In this context, results of analyses conducted nationwide seem to confirm the above mentioned dependence. Regression analyses showed a relationship of yields with mean temperatures in May and July, as well as with precipitation in April and May. Although high temperatures in July were correlated with lower yields, their quality could have been higher. The negative partial correlation of precipitation in April and yield of beets could have been manifested as related with the delayed sowing date, whereas a positive correlation of yield with precipitation in May confirms the above mentioned thesis on the importance of water supply for the initial vegetation of beets. As a result of analyses including temperatures and precipitation in terms of seasons, equations were formulated indicating rather the importance of summer precipitation (significant partial dependence) and temperatures in spring (significant total dependence).

A review of the situation in relation of yields of crops in Poland and the course of weather conditions, presented in this paper, shows that in the past crop production in our country was highly sensitive to extreme weather conditions. No agriculture worldwide is resistant to such situations; however, it may be assumed that in the past many of possible counteraction measures were not applied.

An attempt to present statistically the dependence of weather conditions-yield in many cases did not confirm the dependences which we observe at the level of precise experimental data. This is understandable, since both values of mean yields and mean meteorological parameters came from a large number of complex configurations and relationships, arranged spatially over the territory of Poland. However, in studies concerning this problem it is stressed that modelling of the weather-yield relationship should consider the so-called marketable yield and not the yield of biomass (*McKeown et at.* 2006) – in character data used in this study are approximately marketable yields. Moreover, statistics of this type show that, in view of such a large approximation of results, dependences of crop yields on weather conditions are found in Poland; however, they are not sufficiently evident to draw conclusions on their basis on the future and forecast yields in the context of expected climate change. Similar studies conducted on the basis of historical data in California, USA, showed that under those conditions as much as 50% variation in yields in that region is explained by mean temperatures of 2 months of the vegetation period, while 70% – by three mean monthly temperatures (Lobell *et al*. 2007). For Polish conditions, in order to forecast yields it is necessary to use mathematical models created on the basis of more precise methods (Dragańska *et al*. 2004, Dragańska and Szwejkowski 2004).

CONCLUSIONS

1. A search for trends in yielding of crops in the multi-annual period of 1966-2005 using statistical methods showed that they were manifested mainly in the form of linear and polynomial functions in all investigated crops except for potatoes.
2. Results of regression analyses of weather-yield (remainders calculated from equations of trends) make it possible to state that sets of variables, being mean temperatures of individual months of the year, in each case yielded statistically significant equations. Almost all significant variables from the group of total monthly precipitations indicated in the equations negative correlations with yields of staple cereals. Moreover, several significant equations were obtained, and in these - significant variables from the group of mean temperatures and total precipitation of vegetation periods as well as distinguished seasons were found for cereals and other analysed crops.

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4. APPLICATION OF MATHEMATICAL METHODS FOR CROP YIELD ESTIMATION UNDER CHANGING CLIMATIC CONDITIONS

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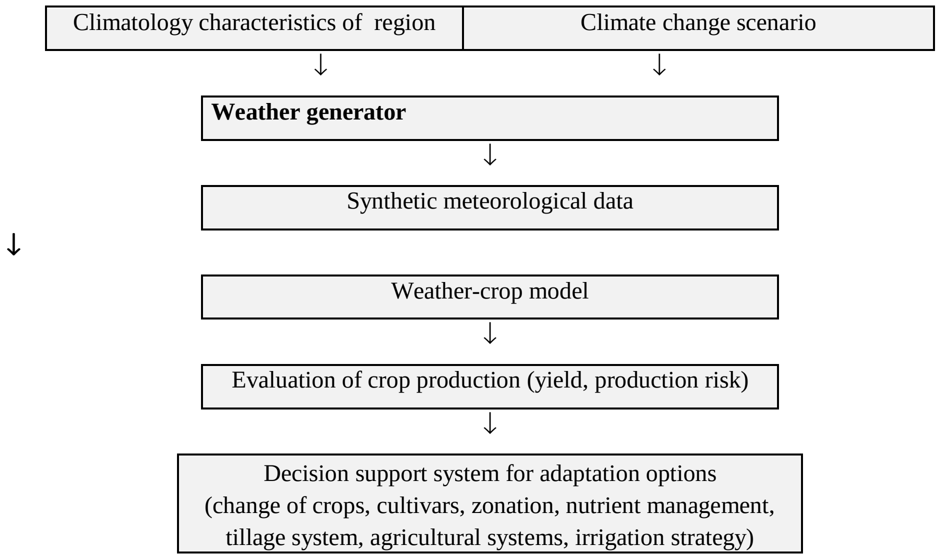
INTRODUCTION

Mathematical modelling methods are currently the basic tools used to investigate and describe phenomena in agricultural sciences. Technical change and especially the development of computers and scientific software have resulted in a dynamic development of computational methods. It has been evident since the early 1960's; however, in the last twenty years, thanks to the common access to equipment and first of all extremely rich software, it has attracted attention and had a marked impact on research results. An important element in the popularization of modelling methods is the easy availability of computational methods guaranteed by the Internet and existing data bases and virtual libraries. Apart from software developed for well-known methods, novel ones have been created, which application has become possible thanks to super fast computations and processing of huge amounts of data (Muller 1999, Thornley and France 2007). In this context we need to focus on increasingly precise mathematical methods applied to describe natural phenomena, the dynamic development of simulation models and the common use of statistical methods (Jame and Cutforth 1996, Rivington *et al*. 2006, Walpole *et al*. 2002). The above mentioned facts concern also well-known problems of plant growth, yielding and forecasting as considered under changing climate conditions (Hansen *et al*. 1994, Richardson 1985, Thornton 1990).

The problem of the effect of a changing climate on agriculture has had a significant effect on the development of research, since methodology has been developed, at present being a standard used in the simulation and evaluation of agricultural production under new conditions (Hansen *et al*. 1994, Kuchar 2004, Semenov 2006). In accordance with the above mentioned methodology, the primary simulations determining the effect of climate on crop yield are performed using a crop model (the weather-crop model, crop simulation model), a weather data generator and information obtained from the climate change scenario (Katz 1996, Mc Carthy *et al*. 2001, Smith and Pitts 1997). The difference in relation to the typical application of crop growth and weather-crop model consists in the introduction of modified data for calculations, illustrating future rather than current potential values of meteorological variables (Hansen *et al*. 1998, Kuchar 2006, Soltani *et al*. 2000). Such simulations may be presented according to schema 1.



Schema 1. Simulation of crop production for future climate

Information at the output of the computational block is the basis for decision support concerning future selection of cultivars and species, zonation of crops, selection of tillage systems as well as fertilization and irrigation systems (Hansen *et al*. 1994, Jame and Cutforth 1996).

Despite the known and described procedures, there still exist basic problems connected with the selection of a weater-crop model, weather generator and accuracy of determination of a climate change scenario (Bannayan and Hoogenboom 2008, Houghton *et al.* 2001, Srikanthan and Mc Mahon 2001, Thornley and France 2007).

CROP YIELDING MODELS

Crop models division

Crop growth models or weather-crop models may be divided in various ways and these divisions depend on the adopted criteria. The most commonly applied division is that based on the used mathematical methods. From this point of view models are divided into deterministic and statistical models.

Deterministic methods are based on the physical description of crop growth with the use of mathematical apparatus (from simple function dependencies to complicated partial differential equations). Among deterministic methods predominant methods are those, which interpretation is closely connected with the physiological development of plants and the soil-atmosphere-crop interaction, thus these methods are referred to as simulation methods (Hansen *et al.* 2002, Thornley and France 2007).

Statistical methods are based on the mathematical description of a phenomenon, most frequently – in contrast to deterministic methods – they contain a random element. These methods significantly utilize probability distributions of random variables and facilitate testing of statistical hypotheses (Dowdy *et al*. 2004, Walpole 2002).

The selection of a model may be performed according to many criteria and correspond to the application of a model. Table 1 presents basic properties of simulation and statistical models, which are used to select or construct a method.

Table 1. Primary characteristics of models facilitating appropriate selection of a method depending on destination

Characteristics and properties of the model	Type of model	
	Simulation	Statistical
1. costs of collecting data for the model	small	high
2. model fitting possibility	medium	high
3. problems with model calibration/estimation	big	slight
4. use of large numbers of parameters	exists	limited
5. comprehensiveness of model	high	limited
6. verification of model	arduous	arduous
7. potential of model interpretation	high	limited
8. limitations due to introduction of new cultivars	slight	very high
9. chance to hypothesis testing	none	exists
10. applications resulting from model construction	high	limited
11. applications to investigate effects of climate changes	wide	wide
12. required mathematical knowledge	small	medium
13. potential for unassisted model construction	limited	high
14. availability of models	high	high
15. availability of software	high	high
16. time outlays of investigating climate change effects	high	very high
17. educational purposes	excellent	limited

Selection of type of model assessing climate change

Assuming that a given model already exists, it has been properly developed, model calibration has been performed or parameter estimation has been conducted based on existing data, properties may be considered, facilitating an evaluation of its suitability for the assessment of climate change. In this case a crucial characteristic is the outlay of time for simulations – due to the complexity of the description and automation of computations and software, these outlays are smaller in case of simulation models.

The complexity of a simulation model makes it also possible to calculate other, side effects, such as e.g. the rate of depletion of water reserves or nitrogen utilization rate. In turn, statistical models make possible calculations with a smaller error and they are more user-friendly (Hansen *et al*. 1994, Thornton 1990, Thornley and France 2007).

A comparison of the application of statistical and simulation models in Poland and worldwide in the last ten years (Tab. 2) indicates that in Poland statistical models are predominantly used, whereas in the world it was simulation models that are used more commonly. Also many more studies have been devoted to analyze the effect of climate change on yielding of crops. The fact of the common use of simulation models worldwide (especially in the West) is mainly connected with the lower costs of simulation. In contrast, in Poland a considerable limitation for the application of simulation methods is connected with model calibration and the related need to conduct highly specialized plot experiments.

Table 2 indicates also a very limited interest in climate change in Poland in the context of crop yielding. In this case it may be assumed that the knowledge on state-of-the-art methods of generating meteorological data is still too small, at the simultaneous difficulties with extrapolation based on trends.

Table 2. Percentage distribution of publications concerning the application of simulation and statistical methods used to determine growth of crops (with simple applications) and applied to determine the effect of climate change on yielding in Poland and worldwide

Methodology		Models	
		Statistical	Simulation
Poland	crop models and applications	~90%	5%
	effect of climate change on yielding	5%	<1%
World	crop models and applications	15%	60%
	effect of climate change on yielding	5%	20%

METHODS OF GENERATING METEOROLOGICAL DATA

Methods to generate meteorological data are an element linking methods of modelling crop growth and yield in case of long-term forecasts. This is done because of the fact that in case of such long forecasted time periods (30 years and more) extrapolation methods based on assumed trends prove to be useless (Dowdy *et al*. 2004, Walpole *et al*. 2002). A lack of certainty on the course of trends and resulting very wide interval forecasts have brought about the development of novel methods, which have eliminated drawbacks of classical methods.

Construction of data generation model

The first, commonly applied generator of meteorological data for the needs of agricultural models was the WGEN model (Richardson 1985, Richardson and Wright 1984), developed by Richardson for the area of United States. This model constituted the basis for further numerous elaborations and adaptations for local needs. Many modifications of the model have been created, in which it was attempted to eliminate drawbacks of that method (Castellvi and Stoekle 2001, Hansen *et al*. 1994, Hayhoe 2000, Kuchar, 2004).

In case of the most frequently used methods, generation of data consists in the formation of a sequence of daily observations of solar (accumulated) radiation (SR), minimum (Tmin) and maximum temperatures (Tmax) and precipitation (P) – consistent with the climatic characteristics of the location, for which they are prepared (Richardson and Wright 1984, Hayhoe 1998). Thus the characteristics of the distribution of random meteorological variables, i.e. such values of means, variances, correlations and autocorrelations determined in different time periods /year, vegetation period, season of the year, month/ calculated for generated data, approximate respective values calculated for observed data (Bruhn *et al*. 1980, Richardson and Wright 1984).

The WGEN model, commonly applied to generate daily data, as well as its numerous versions, is composed of two blocks: the water and the energy-thermal one. In the water block, using primary Markov chains, the status of the current day is determined (day with precipitation/without precipitation) and values of precipitation are generated using a two-parameter gamma distribution $\Gamma(\alpha,\beta)$. In turn, in the energy-thermal block for a specific status of a day accumulated (solar) radiation and temperatures are generated using a generalized linear model (Bruhn *et al*. 1980, Hansen *et al*. 1994, Hunt *et al*. 1998).

Generation of values of solar (accumulated) radiation (SR), minimum temperatures (Tmin) and maximum temperatures (Tmax) as well as precipitation (P) begins on January 1. In the first step two numbers from the [0,1] interval are generated according to the uniform distribution, which in comparison to empirical probabilities of precipitation for the current and the previous day determine its status.

In case of the determination of a day with precipitation its amount is generated according to the gamma distribution $\Gamma(\alpha,\beta)$ with parameters estimated based on the sample for the i-th day of the year and next daily values of solar radiation (SR), maximum (Tmax) and minimum temperatures (Tmin) are generated based on the linear model.

After a sequence of observations is formed for January 1, a number from the [0,1] interval is again generated, the probability of a day with precipitation/without precipitation is generated under the condition of the previous day, the day is classified (with precipitation/without precipitation) and the generation procedure described above is repeated. The process is completed on the last day of the year, when the pre-declared number of created years of observation is generated (Hansen *et al*. 1994, Wilks and Wilby 1999).

Evaluation of existing models

The first models of data generation estimated well or very well (in accordance with theoretical distributions) mean monthly values of accumulated radiation, temperatures, precipitation totals and variances of radiation and temperatures. In turn, they did poorly in case of variances of precipitation, extreme precipitation and correlations between variables of the energy-thermal block (Kuchar 2004, Hayhoe 1998).

Currently these drawbacks have been to a considerably degree eliminated. Hanson *et al.* (Hanson *et al.* 2002), when improving the model, included seasonality and the spatial dependence of the correlation by introducing a function with sections of the constant in monthly periods. Also the transition probability and parameters of distribution of random variables of precipitation (originally approximated with constants in monthly or biweekly periods) were replaced by Hansen et al. with a continuous function with linear sections (a broken function) (Hansen *et al*. 1994). In the WGENK model (Kuchar 2004) daily values of cross, lag and lag-cross type correlations of the energy-thermal block, values of transition probability and parameter α of distribution of random variables of precipitation Γ were approximated using a trigonometric polynomial representing seasonal changes in the "smooth" manner (Kuchar 2004). Independently, in order to provide a better representation of variances of precipitation totals by the model, for each month in the year coefficients k_i ($i = 1,2,...,12$) were introduced, scaling the course of distribution Γ in each day t ($1\leq t \leq 365$), (Kuchar 2006). It seems that currently the only drawback of WGEN models is the maintenance of the climatic structure of precipitation sequences (the application of primary Markov chains in the model consciously neglects this postulate). It was attempted to remove this drawback in other constructions, which leads to the formation of generators based on another philosophy, non-parametric estimation and problems with estimation of parameters (Schoof and Pryor 2008, Semenov 2006, Wilks and Wilby 1999). Taking into consideration the potential application of models based on Richardson structures and their advancement in the description of the process, it needs to be considered that they are currently the best models generating weather data.

Data required for generation

The WGEN model requires climatic information in the form of mean monthly values and standard deviations of accumulated radiation, maximum and minimum temperatures with the division into wet and dry days (this division is not required for minimum temperatures). Moreover, the required parameters are monthly values of precipitation totals, the number of days with precipitation, values of parameter α of distribution $\Gamma(\alpha,\beta)$ (parameter β is estimated based on the mean and variance) and probability P(D/W) of observation of a day without precipitation under the condition that the previous day was a day with precipitation (Richardson 1985, Richardson and Wright 1984). On the basis of the described climatic characteristics the model approximates values for each day in the year, using them directly for generation. It is assumed that the described collective characteristics may best be formed based on the 20-year sequences of daily observations.

Basic applications of weather generators

In literature published worldwide a series of applications has been given for synthetic weather data in agricultural sciences. Their first, basic and common application was to simulate changes in yield of basic crop species as a result of human economic activity or expected climate change. Results of computations are used to determine profitability of production, facilitate forecasting of yields and support decision-making in such areas as crop zonation, breeding and selection of new cultivars, irrigation, changes in tillage techniques, etc. (Mc Carthy *et al.* 2001, Thornton 1990). Moreover, novel applications have been introduced, such as studies on profitability of dehydration industry under new environmental conditions, changes in water balance, forecasting of soil droughts or the incidence of diseases and pests (Houghton *et al.* 2001, Kuchar and Bac 2001, Muller 1999, Zang *et al*. 2004).

CLIMATE CHANGE SCENARIOS

Information on forecasted climate changes is a necessary element for the simulation of effects of climate change.

Climate changes are investigated using mathematical models describing in a comprehensive way the climate of the planet Earth (Global Climate Model or General Circulation Models – GCM /both have an identical abbreviation/). Forecasts, commonly referred to as climate scenarios, assume a certain industrial and economic development of the world, based on which the incidence of changes in basic climate characteristics is forecasted. According to the assumed hypotheses external factors (the amount of solar radiation reaching Earth) or internal factors (human activity, natural factors) are responsible for climate change. The importance and significance of the above mentioned factors for climate change have been extensively discussed and there is no consensus on their effect or role (Houghton *et al*. 2001, Kittel *et al*. 1998, Mc Carthy *et al*. 2001).
Despite different opinions on the situation and the applied methods determining climate change on Earth, it is accepted that a key causative factor is connected with changes in the amount (concentration) of carbon dioxide in the atmosphere.
Currently numerous models describing climate change are used, of which the best known are GISS, GFDL, CGCM, HDCM and ECHAM (Houghton *et al*. 2001, Kittel *et al*. 1998).

Forecasted changes for Poland

Despite differences concerning forecasted climate change there are several accepted opinions. Particularly, in case of Poland in most scenarios with a doubled CO_2 content in the atmosphere it is forecasted that by the year 2060 (in relation to 2000) the following phenomena will take place (Kittel *et al*. 1998, Mc Carthy *et al.* 2001):

- an increase in mean air temperature by over 2 degrees Celsius, while in the winter season this increase is to amount to over 2.5°, while in the summer season it will be by almost 2° Celsius;
- an increase in total annual precipitation by 10 to 15%; in the winter season by 15 to 20%, while in the summer season the level of precipitation is to be reduced by as much as 20%.

In case of precipitation researchers have more mixed opinions; however, it is commonly accepted that precipitation will be uniformly distributed throughout the year (Tab. 3).

Table 3. Characteristics of climate change according to GISS, CCC and GFDL scenarios for Central Europe for a doubled CO2 concentration (change in relation to 2000)

Variable	Parameter	Period	Change according to the model		
			GISS	CCC	GFDL
Temperature	Mean	Winter	+2.6°C	+2.2°C	+2.4°C
		Summer	+1.8°C	+1.8°C	+2.0°C
	Standard deviation	Year	+12%	+8%	+10%
Precipitation	Mean	Winter	+15%	+15%	+20%
		Summer	0%	–10%	– 20%
	Standard deviation	Year	+15%	+5%	+20%

In the presented scenarios forecasts are also included on the variation of both factors: an increase in variance of temperatures is to exceed 25%, while that of precipitation is to be almost 35%. This information is of particular importance, since it is equivalent to the occurrence of series of days with high fluctuations of temperatures (e.g. frosts, extreme heat waves) and what is particularly dangerous – after long dry periods, intensive and torrential precipitation. Thus an increase in variance of both factors has a significant effect on the incidence of extreme values, i.e. those potentially adverse for agriculture.

PREDICTION OF YIELD TAKING INTO CONSIDERATION A CLIMATE CHANGE SCENARIO

Evaluation of crop yielding and related effects as a result of potential climate change has been conducted in accordance with the schema presented in the beginning of the paper. The foundation for the presented procedure is a yielding model with parameters obtained for a given area. On the basis of historical data a characteristic of climate is prepared for the area of the study, which is next modified, based on information coming from scenarios of climate change. In the next step of the procedure weather data are generated, which represent a potential course of weather under new conditions. Following suggestions, the number of generated years should be high enough to include different courses of weather – also these extreme cases. Data provided by the generator constitute input data for the simulation/statistical models of crop yielding. As a result of calculations the number of predictions obtained for yield or a simulated effect (e.g. the effect of fertilizer use) is equivalent to the number of years of previously generated data (Hansen 1994, Kuchar 2004, Muller 1999, Wilks 1992).

The procedure is completed with the analysis of results, which may be conducted in many ways. The construction of probability distribution of random variables is very useful (if possible), thanks to which we may obtain complete information on the investigated variables, including also critical values, quantiles of distributions and estimation of risk probability (Dowdy *et al*. 2004, Walpole *et al*. 2002).

CONCLUSIONS

1. Simulation and statistical methods of modelling crop growth and yield are two equivalent ways to describe a phenomenon. An advantage of the former over the latter may be manifested at the moment of determination of precise criteria for the selection of a model.
2. In Poland in studies on crop growth and weather-crop statistical methods predominate, although there is a need to apply simulation models.
3. Methods of modelling crop growth and yielding using generated data are the most effective ways to determine effects of climate change.

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5. SCENARIOS FOR DEVELOPMENT OF AGROCLIMATIC CONDITIONS AND ESTIMATION OF THE INFLUENCE OF EXPECTED GLOBAL WARMING IN 2050 ON THE YIELDS OF MAJOR CROPS IN POLAND

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INTRODUCTION

Farming systems and agricultural production techniques are developed on the basis of numerous factors among which climatic conditions play one of the major roles. Progressing changes of climate will create an absolutely new situation in agriculture and they mean both an immense opportunity and risks unknown so far (Bombik *et al.* 1997, Nowicki and Szwejkowski 2008). As a consequence, in the nearest future, agriculture will evolve adjusting to the changing climate (Reddy and Hodges 2000).

The cause of the global climate warming – increase in the concentration of carbon dioxide in the atmosphere – should increase productivity of ecosystems and, as a consequence, the level of cultivated crops yields (*McKeown et al*., 2006, Morison 1995, Reddy and Hodges 2000, Southworth *et al.* 2000). On the other hand, however, the increase in temperature will be coupled with changes in other components of the weather, frequently poorly predictable, such as for example the spatial and time distribution of precipitations, which does not offer the absolute certainty as concerns the final effect of the progressing process in agriculture (Climate Change 2007).

As changes in the farming systems cannot be achieved from day to day, it is necessary to undertake actions in advance on the basis of projected climate changes as well as the probable scenarios of the future weather systems (Wilbanks 2003).

To make appropriate climate projections for the future, material illustrating the current development of conditions should be collected because every expected change will represent evolution of the situation from the past (Wolf and van Oijen 2002, Dragańska and Szwejkowski 2004, Szwejkowski *et al*. 2007). Numerous research centres deal with forecasting climate changes; the specifications from those activities are reflected in the periodic reports by the IPCC (Climate change, 2007). Based on the options of scenarios presented in the last, IV Report by the IPCC (International Panel For Climate Changes), one can only get the impression concerning the scale of the future warming projected by the experts. Considering that in general it is very difficult to design a good global climatic model, this type of estimation is valuable. On the other hand, for the purpose of charting the prospects for agriculture, it would be good to know not only what the prospects for the climate change are, but also what the weather would be like in several years or some decades (Smith and Pitts 1997)

In this chapter of the monographic study the concept of using the scenarios of climate changes created as a result of work on climatic models was employed for generating weather data using the weather models (Richardson 1985). As a result of conducted analyses a statistically probable image of the situation in the perspective of the middle of the current century was formed. After performance of that task and considering further works on determining the scenarios of changes that, among others, Polish agriculture will be facing as a result of the expected global warming, an assessment of the future agricultural climate of Poland was carried out. On the basis of the data from that assessment and estimations of the dependence between the yields of the major species of crops and weather development, the influence of numerous possible weather variants on the yields of those crops was determined with the perspective of the year 2050, assuming the main direction of the climate change.

MATERIAL AND METHODOLOGY

Weather data generated for the lowland areas of Poland for the year 2050 using the WGENK model (Kuchar 2004, 2005) formed the basis for the analysis conducted. Basic characteristics of the climate obtained on the basis of the data recorded at meteorological stations evenly spread throughout the country during the period of 1958-2005 were used as the input material for the generator.

The assumed climatic forecast on the basis of which the weather data was generated in linked to scenario A1 according to IPCC Special Report on Emissions Scenarios (SRES, 2000) and computations made on that basis using models. Climatic characteristics that formed the patterns for generation of future weather scenarios by the weather data generator consisted of data covering the sums of total day radiation (SR), minimum temperatures (T_{min}), maximum temperatures (T_{max}) and the sum of day precipitations (P). The weather forecast, similar to the approximation of the weather data, involved generating values for each day of the year according to the principles described by Kuchar (2005). As a result of generator operation, 300 scenarios of year weather development were obtained for each of the 15 locations (the cases considered here were reproduced on the basis of weather mechanisms functioning at a given point with all possible deviations from the standards assumed) that could appear as a consequence of the assumed variant of climate change. On the basis of the 300 weather variants obtained, the characteristics of the possible situations were formulated by applying the criteria of the minimum, maximum, average and median values for the four weather components computed for the entire year, the vegetation period and the spring period. Additionally, the duration of vegetation period, of the period of intensive vegetation with average day temperature exceeding 10°C and of the summer period with temperatures exceeding the threshold value of 15°C was computed. The data obtained also allowed determining the scope of weather hazards, such as periods without precipitations exceeding 10 days and the number of ground frost appearance during the vegetation period.

To determine the influence of the future weather conditions on yields of major crops in Poland the data contained in this monographic work in the component concerning assessment of the correlation between the productivity of crops in years and the weather conditions development, and in particular the statistical functions of weather-yield obtained were used (Szwejkowski et al., 2009). The day after day weather data generated for 15 locations for the year 2050 using the WGENK model were used as the basic variables for the functions obtained. As the available number of weather scenarios was 13500 data (15 objects x 300 scenarios), 3 scenarios from each location were used for computations assuming the average, minimum and maximum values of year temperatures for the selection criteria.

RESULTS AND DISCUSSION

Each weather system analysed in this study satisfies one common condition of the average year temperature corresponding to the level determined by the climatic scenario assumed. The same value of the year average, as it is known, may be obtained for highly diversified systems of other weather elements. The specification of the results of analyses presented below gives the answer to the question in what systems.

The average year minimum temperature will probably range from 2.5 to 11.1°C (Tab. 1). The average value of that parameter for the area will be 6.8°C. As a consequence, in general terms, both a decrease and an increase of the minimum temperature by 1.1 and 7.5°C, respectively, in relation to the values currently recorded in the area of Poland is possible. This means in the future both a significant reduction of those values and the probability of a very high increase in them. The average maximum temperatures will definitely exceed the current maximum values. In the case of the average for a long-term period at 12.2°C, the lowest maximum temperature can be higher by 2.0°C, and the highest can exceed the current one by 5.0°C. At the level of average values of minimum and maximum temperatures, the differences between the situation characterising the years 1985-2005 and the prospects for 2050 are 3.2°C for the minimum and 3.5°C for the maximum. The entire consideration then leads to the conclusion that climate warming will probably take place in a symmetrical way in the system of year minimum and maximum temperatures. The median values of the expected maximum and maximum temperatures are almost equal to their average values.

Table 1. Cross-sectional values of meteorological elements from 300 weather scenarios on year 2050 in Olsztyn area

Meteorological elements	Values in time scale	Values in relation to the variants of prediction set			
		minimal value	maximal value	mverage value	median
Minimal temperature (°C)	annual values	2.5	11.1	6.8	6.4
	values for growing season	9.1	14.8	11.9	11.4
	values for the period March-May	2.2	10.1	6.1	6.0
Maximal temperature (°C)	annual values	14.2	17.2	15.7	15.9
	values for growing season	21.4	24.8	22.9	21.9
	values for the period March- May	11.2	21.8	16.2	15.4
Totals of precipitation (mm)	annual values	402.6	816.2	582.5	575.2
	values for growing season	206.3	560.5	354.3	333.8
	values for the period March-May	44.0	216.3	108.1	96.6
Irradiation (MJ m^{-2})	annual values	3478.2	4017.5	3737.2	3773.3
	values for growing season	2698.8	3206.7	2951.8	2997.3
	values for the period March-May	317.1	494.9	405.6	409.5

During the vegetation period the minimum temperature can be higher by from 0.5°C to 6.2°C than the current one, while the maximum temperatures can be higher by from 2.2 even to 5.6°C than the current ones. The possible values by which the current extreme temperatures can be exceeded to increase during the vegetation period were at a similar level as for the entire year. The average minimum temperature during the vegetation period will be higher by 3.6°C, and the average maximum temperature computed from the data generated might exceed the current maximum average for the period of 1985-2005 by 3.7°C. As a consequence, also during the vegetation period similar changes in extreme temperatures should be expected in the future as concerns their values and directions as were computed for the entire year.

Analysing the distribution of generated average month temperatures, it can be noticed that the values of minimum temperatures will be close to the current ones (Tab. 2). The number of months with negative average minimum temperature will decrease by 1 (March), while during the warm season the future average minimum temperatures will be higher by 2 to 3°C. The maximum average temperatures during all months will be positive, and their highest increase will be probably manifested during the month of August in the increase by 3.9°C.

Table 2. Cross-sectional values of meteorological elements from 300 weather scenarios on year 2050 in Poland

Months	Minimal temperature (°C)	Maximal temperature (°C)	Monthly precipitation (mm)	Irradiation (MJ m^{-2})
I	–1.2	4.4	37.6	72.4
II	–0.7	6.5	38.8	128.0
III	1.8	9.8	44.7	248.3
IV	5.5	16.6	48.6	390.9
V	10.9	22.8	71.8	578.4
VI	13.5	24.3	81.1	562.1
VII	15.2	26.2	102.7	589.5
VIII	15.0	26.7	71.2	521.1
IX	11.3	21.1	69.5	311.1
X	7.7	16.4	48.6	204.6
XI	3.2	8.8	46.4	87.2
XII	–0.5	4.5	51.2	54.3

The specific spring period is the time that to a large extent determines the future yields of crops. Currently, low temperatures during the months of March – May represent a factor limiting the possibility of achieving high yields of many stenothermal species (Illustrated guide…, 2001). The expected warming should change that situation. The generated data indicate that during that period the minimum temperatures may be slightly lower, by 0.2°C, than currently or higher because the minimum for the spring months may reach even 10.1^{o}C. This is an immense difference indicating a possibility of a significant increase in the productive capacity of plants. The maximum spring temperature may also be lower by 1.0^{o}C or higher by 2.6^{o}C. In case of such high temperatures in the spring all the additional thermal limitations will disappear, although, probably, other limitations will appear and, as a consequence, the increase in productivity of crops will be linear (*McKeown et al.* 2006).

It is obvious that changes in the levels of atmospheric precipitations do not follow those of the temperature (Tab. 2). For that reason, the minimum year precipitations in the generated variants of weather set were lower than the current average by 217.3 mm. The maximum value from the set of 300 variants was of course higher than the current average by as much as 196.3 mm. Achievement of that level of exceeding the current situation is possible, as the data generator based on current regional patterns, at one of the lower levels of maximum temperatures. In the analysed future (year 2050), it is probable that the vegetation periods will either be much dryer than the current ones, even by 151.7 mm, or much wetter, by 202.5 mm. The average value of that parameter from 300 variants generated for 2050 is close to the average value for the period of 1966-2005 in Poland: 582.5 as compared to 619.9 mm. The system of numbers representing the relation between the current and the future sums of precipitations during the spring period of March-May forms a slightly different pattern. The average values of precipitations differ evidently (108.1 and 133.3 mm), while the projections at the minimum and the maximum levels indicate possible variants that are almost two times below or almost two times above the current sums. As a consequence, the future of the agricultural climate seen from the perspective of plants supply with water is not so straightforward as in the case of the determined changes in temperature. To a large extent, the current distribution of monthly precipitations characteristic for the domination of continental climate will be established. The maximum value generated for the month of August that might occur in the year 2050, i.e. 102.7 mm, is worth noticing.

The expected climate changes will be correlated with increased possibilities of solar energy accumulation in the atmosphere and a change in the activity of the Sun. That second effect will probably have less influence on the changes occurring. As a consequence of the above, the generated weather scenarios indicate a possibility of lower sums of solar irradiation than those recorded currently (3478.2 MJ m^{-2}, as compared to the current average of 3569.4 MJ m^{-2}). That situation occurs during each of the separated periods of the year and results from the system of weathers with high sums of intensive precipitations, which will be linked to increased level of coverage with clouds. The monthly sums of irradiation in the summer (May-August) will be only slightly higher, while bigger differences will be manifest during the other seasons of the year.

Even the extreme values of the above-analysed meteorological elements, as can be assumed, will not form a major problem as a consequence of high adaptation potential of agricultural systems. For that reason this analysis was complemented with the appearance of certain harmful meteorological phenomena such as ground frost and periods without precipitations that could be assumed on the basis of the generated data (Tab. 3).

Table 3. Frequency of the weather harmful phenomena for farming determined on the basis of 300 weather scenarios for year 2050 in Poland

Meteorological elements	Values in time scale	Values in relation to the variants of prediction set			
		minimal value	maximal value	mean value	median
Frost day events	values for growing season	0	12	3.1	3
	values for the period March-May	0	9	2.4	2
Non precipitation periods over 10 days	annual values	0	7	1.9	2.4
	value for growing season	0	6	2.1	2
	values for the period March-May	0	3	0.9	1

The data presented in the Table indicate that in the minimum variant it is possible that none of such phenomena will appear. The maximum number of ground frost cases is 12, which means that there might be even more of them than indicated by the long-term averages for the area of Poland. All the cases of ground frost of the vegetation period will probably appear during the spring season.

The maximum number of periods without precipitations exceeding 10 days may be 7 per year and 6 during the vegetation period, a majority of them during the key spring season, which means that the current standard would be maintained.

The final element of this analysis is the computation of the expected length of periods important for vegetation of plants (Tab. 4). The current length of those specific periods determines the lower agricultural potential of the production space in certain areas of the country. Thanks to the increase of the average temperatures the situation will change. As indicated by the computations, the expected minimum value of the length of that period may be similar to the current one, but the expected maximum length of that period could mean that the entire year would become a vegetation period in the lowlands of Poland. The average vegetation period length computed on the basis of the analysed weather variants for 2050 is up to 249 days, that is equivalent to the maximum that currently appears in Poland.

Table 4. Number of days of meteorological periods determined on the basis of 300 weather scenarios for year 2050 in Poland

Values in time scale	Values in relation to the variants of prediction set			
	minimal value	maximal value	mean value	median
Length of growing period, t>5^{o}C	197	365	249	239
Length of intensive growing, t>10^{o}C	150	327	198	182
Length of a summer temperature period, t>15^{o}C	86	201	142	132

Exceeding the thermal threshold of average day temperature at 10^{o}C means the time of intensive vegetation of plants and its length is particularly important for stenothermal plants. Already at the expected minimum level that period may last as much as five months; in maximum case it may reach almost 11 months per year. That would open entirely new quality prospects for agricultural production. At the same time, summer temperatures exceeding the day average of 15^{o}C can continue for from 3 to over 6 months.

The above-presented analysis of the basic meteorological factors gives the general idea of the future weather conditions in Poland in about 40 years. The credibility of that analysis and its accuracy are difficult to establish, although operation of the WGENK generator has been verified positively on numerous occasions on the basis of actual data (Kuchar 2005, Richardson 1985). It does not, as a consequence, represent a kind of a weather forecast in such a long time perspective because even short-term forecasts are highly unreliable. Its scientific, and partly practical, value is that it presents the outline of possible weather systems and, computed on that basis, estimates of derivatives given in the form of 300 variants.

The next area of analysis encompassed determination of the meteorological conditions influence on the yields of crops in the perspective of the year 2050. In that case the mathematical functions discussed in the earlier chapter of this monographic study were used (Szwejkowski *et al*. 2009).

Treating the equations obtained as reliable, and for sure they are such according to the criteria of regression calculus, it was established what effects on yields of crops could appear in slightly over 40 years' time (in the year 2050) if the assumed climatic scenario meaning an increase of the average global temperature by almost 3°C (GISS, model E) is fulfilled. The future value of the average, after conversion to local conditions, as shown above, can be manifest in the form of numerous variants of weather development during the year. Out of those numerous possibilities only one will be fulfilled, although today it is not, and in the more distant future it will not be known which one. As a consequence of the above, also the projected yields of crops in the perspective of the year 2050 can only be based on numerous weather systems possible. Although the use of the WGENK model allowed obtaining as many as 300 weather variants, the specification of projected yields of crops in the region was based only on the results representing the extreme, average and median values considering the equations with thermal and precipitation variables (Tab. 5-8). As the residual values from the equations of trends were the independent variables in the weather-yield equations, the numbers presented in those Tables represent the increase or decrease of crops computed from those equations in relation to the average yield in 2050, whatever it is. This specification of results is rational as there are no bases to consider in the computations the current trends of changes in the yields in the perspective of up to the year 2050 and use them for computation of absolute values of the yields.

The average value of the difference in the yield of winter rye determined by the future thermal conditions was ca. 6 t ha^{-1} (Tab. 5). This means that such a drastic change in the climate as is expected can result in a large deviation of the yield from the level determined in the future by the non-weather factors and as a consequence of a significant increase in the yield of that cereal. Considering the least favourable weather conditions that result from obtaining the lowest value of deviation from the regression equation, it can be expected that even then the yield would increase by 1.48 t ha^{-1}. A much larger increase of the yield, reaching as much as 10.57 t ha^{-1}, could be expected under the most favourable thermal conditions. Considering the current average yields of rye, and in particular the expected increase in 2050 resulting from technological development, it seems that the regression equation obtained for that crop with participation of thermal variables overstates the yield-forming influence of the weather strongly.

Further computations showed that the increase in the yield of winter wheat under the influence of the future weather systems could be lower than those of rye. The possible average yield surplus above the trend value can be slightly over

4.54 tons of grain per hectare. The least favourable weather conditions can offer the surplus of just 0.86 t ha^{-1} and the most favourable ones - of 8.26 t ha^{-1}

Table 5. Selected expected differences of yields, according to mean values, gained in respect to 300 possible variants of weather conditions in year 2050, in the range of mean monthly temperatures (in t ha^{-1})

Species of plant	Values in relation to the variants of prediction set			
	minimal value	maximal value	mean value	median
Winter rye	1.48	10.57	6.06	6.07
Winter wheat	0.86	8.26	4.54	4.67
Spring barley	0.43	12.28	6.31	6.52
Oats	-1.05	5.97	2.62	2.58
Maize	3.13	8.63	6.26	6.05
Winter rape	-0.42	8.18	4.16	4.35
Sugar beets	-40.01	45.67	3.11	2.01

The distribution of possible differences in the future yields of spring barley is similar to that in the case of rye. In this case the smallest expected increases in the yield above the value resulting from the trend may reach 0.43 t ha^{-1} while the highest ones can reach 12.28 t ha^{-1}, which causes that despite the statistical significance the regression equation used for computations causes evident overestimation. In the case of oats both a decrease of the yield relative to the trend value and a surplus caused by the distribution of air temperatures can appear.

Stenothermal maize represents hope for improvement of the fodder base in Poland in the situation of climate change. It is found out that the increase of temperature in one of the possible year distribution patterns can mean an increase in the grain yield by from 3.13 to 8.63 t ha^{-1}. These values are similar to those for the basic cereals, although in this case the overestimation probably does not occur because those values are relatively lower than the average yields of maize than was the case for rye or barley.

Winter rape is the crop that can fail during years with severe and unfavourable development during the winter. It is found out that the weather, under conditions of the nearing warming, does not always have to mean a mild winter. Under such circumstances the yields can decrease by 0.42 t ha^{-1} (in the regression equation the winter temperature – for January, and autumn temperature – for October) is one of the variables. Nevertheless, in general, global warming will result in warmer winters and, as a consequence, under favourable weather the rape yields can be higher than the estimated trend values by up to 4.16 t ha^{-1}.

Thermal conditions in the future can have a relatively large influence on the yields of root crops. In the case of sugar beet the yield of roots can decrease by 40.1 t ha^{-1} or increase by 45.67 t ha^{-1}. This means, even at the current level of the yields, a value higher by 100%.

Table 6. Selected expected differences of yields, according to mean values, gained in respect to 300 possible variants of weather conditions in year 2050, in the range of total monthly precipitation (in t ha^{-1})

Species of plant	Values in relation to the variants of prediction set			
	minimal value	maximal value	mean value	median
Winter rye	–10.92	3.67	–0.12	1.33
Winter wheat	–49.76	6.72	–10.23	–5.92
Spring barley	–40.28	7.20	–5.40	–3.36
Oats	–1.46	22.08	5.38	3.19
Maize	2.89	68.82	20.50	16.74
Winter rape	–7.79	17.57	1.15	–0.48
Sugar beets	–41.24	231.22	24.02	4.04

Application of regression equations considering the future yields of crops in Poland conditioned by variable precipitations during individual months (Tab. 6) caused that the minimum values of deviations from the trend obtained exceeded significantly or were close to the expected levels of yields in the year 2050. As a consequence, those equations have minimum predicative value even considering all the limitations that should be considered while applying statistical models. Dismissing the circumstance that the obtained statistical models are imprecise, they have one common characteristic – they indicate the fact that precipitation conditions in the future may limit the yields of basic crops cultivated in Poland significantly.

The next two Tables 7 and 8 show the possible patterns of yields computed on the basis of thermal and precipitation variables computed for the vegetation period and individual seasons used in the regression equations. In the first case, statistically significant models were obtained only for the basic cereals, excluding rye. The vast majority of data indicates possible decreases of yields as compared to the values resulting from the trends. In the case of spring barley the model used, even in the extremely favourable, as should be assumed, case shows that the yields in the future will be suffering from negative influence of the weather conditions. Similarly, negative average values computed using thermal and precipitation variables were obtained from analysis of the seasonal models. Also in this case the scale of indicated decreases in yields in extreme weather cases, which anyway are possible, is such that although they are statistically significant it is hard to consider them as the appropriate tools of prediction for the yields in the year 2050.

Table 7. Selected expected differences of yields, according to mean values, gained in respect to 300 possible variants of weather conditions in year 2050, in the range of temperature and total precipitation in growing season (in t ha^{-1})

Species of plant	Values in relation to the variants of prediction set			
	minimal value	maximal value	mean value	median
Winter rye	—	—	—	—
Winter wheat	–38.67	2.77	–30.25	–31.25
Spring barley	–11.56	–2.12	–7.25	–6.52
Oats	–7.78	1.79	–3.31	–3.47
Maize	—	—	—	—
Winter rape	—	—	—	—
Sugar beets	—	—	—	—

In cases such as that, described statistical models play a perfect role as opposed to the deterministic models. In this monographic work Kuchar writes about the character of the models used for projecting the natural phenomena, and the situation described here confirms all his conclusions. Despite objections, attempts at estimating the influence of climate changes on the yields of crops are undertaken as they are a consequence of the need for considering the levels of the future agricultural production in long-term strategic economic planning. As is the case of all estimations, the results of projections leave many ambiguities, although it is hard to negate the need for working on them.

Considering the imperfection of the method chosen, in view of the fact that as for today far better methods do not exist, it can be concluded in general terms that the prospects for cultivation of major crops under Polish conditions, assuming climate changes, means that weather conditions can be both particularly favourable and particularly unfavourable for them. It should be highlighted, as a consequence, that the possibility could not be excluded that those changes can even be dramatic from the perspective of the future economic systems.

Table 8. Selected expected differences of yields, according to mean values, gained in respect to 300 possible variants of weather conditions in year 2050, in the range of temperature and total precipitation in seasons (in t ha^{-1})

Species of plant	Values in relation to the variants of prediction set			
	minimal value	maximal value	mean value	median
Winter rye	—	—	—	—
Winter wheat	–27.03	8.19	–2.46	1.35
Spring barley	–23.72	0.97	–5.74	–2.81
Oats	–37.07	0.96	–11.21	–7.41
Maize	–45.85	18.63	–1.25	3.40
Winter rape	–12.40	8.73	–8.36	–9.38
Sugar beets	–111.60	–48.19	–74.52	–75.81

CONCLUSIONS

1. Climate warming in 2050, assumed according to scenario A1 (IPCC), can translate into a highly diversified pattern of day thermal conditions in Poland, which was shown by the set of data generated using the WGENK model. The lowest obtained value of the minimum temperature was 2.5°C, the highest 11.1°C (the average at lowlands in Poland); the first one is lower than the current average. The corresponding values for the maximum temperatures were 9.1 and 14.8°C.
2. The average minimum temperature of the vegetation period can be higher than the current one by 3.6°C, and the future maximum temperature of that period can be higher from the current average by 3.7°C.
3. Data generated for the spring period (March-May) shows that the minimum temperatures can be slightly lower (by 0.2°C) than the current ones, or higher than the current ones, while the average minimum for the spring months can reach even 10.1°C. The maximum temperature of the spring can also be lower by 1.0°C or higher by 2.6°C.
4. The minimum year precipitations according to the generated weather scenarios were lower than the current long-term average by 217.3 mm. The

maximum value from the set of 300 options proved, obviously, higher than the earlier mentioned average by as much as 196.3 mm.

5. In the analysed future, the vegetation periods can be either significantly dryer than the current ones, even by 151.7 mm, or more moist by 202.5 mm. The system of numbers representing the relation between the current and the future values of sums of precipitations during the spring period of March to May developed in a similar way.

6. The maximum number of expected ground frost days during the vegetation period (average in Poland) is 9 and all of them will probably take place during the spring period. The largest number of periods without precipitations exceeding 10 days can be 7 cases per year and 6 during the vegetation period, and a majority of them will appear during the spring period.

7. According to the analyses performed, the expected shortest vegetation periods can cover fewer days than the current ones, while the expected maximum lengths of that period might mean year-round vegetation.

8. The diversity of weather variants in 2050, in the form of average monthly temperatures, creates the perspective of appearance of the largest diversities in the yields of spring barley and rye. The analyses also showed that in the case of sugar beet in the minimum variant the values appear representing a possible dramatically low level of the future yield of that crop.

9. In the case of analysis considering the possible variants of precipitation conditions formed by the expected climate changes it was established that the most favourable prospects formed for the cultivation of maize, and in the case of the other crops they were not straightforward – in view of the multiplicity of probable variants of distributions of precipitations during the year the appearance of highly favourable as well as extremely unfavourable conditions is equally probable.

10. The results of analyses obtained should result in reflection as concerns formulation of forecasts for the future considering the consequences of progressing climate warming as it is found out that assuming the specific result of temperature increase forecast we must expect that it means the probability of development of very many weather scenarios because, as opposed to climatic indicators, it is impossible to forecast it precisely in the distant time perspective.

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6. CLIMATIC RISKS FOR PLANT CULTIVATION IN POLAND

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INTRODUCTION

In Poland progressing climate changes cause an increased frequency and extreme character of weather phenomena, exhibiting an adverse effect on agriculture, particularly in early spring and summer. Until the 1980's dry periods were observed most frequently at the turn of March and April, May and June, and September and October, while in the last 20 years it has also been in the summer (July-August), becoming increasingly longer and more intensive (Atlas ... 1990, Atlas ... 2001). At the same time a change has been found in the structure of land use resulting in changes in the components in the thermal balance of active surface, most frequently from evaporation to radiation, which results, among other things, from the expansion of cities, roads, industrial plants and warehouses. This contributes to local and regional changes in energy and matter cycled in the agricultural landscape, often stimulating the incidence of atmospheric phenomena adverse to plant production (Kędziora 1996). As a consequence relationships between energy, thermal and water balances in the geographical landscape also change. Winters become increasing warm (especially in January) and sunny, while particularly in December and January they are characterized by a shorter deposition of snow cover and its decreasing thickness (Atlas ... 2001, Atlas... 2004). Trends in changes observed in winter on the one hand contribute to the accumulation of water in winter and on the other hand cause increased evaporation from topsoil and reduced winter water reserves in soil (Koźmiński 2002, Koźmiński and Michalska 2005).

In atlases prepared at the Department of Meteorology and Climatology of the Agricultural University in Szczecin (1990, 1995, 2001 and 2004) the time and spatial distribution and probability of incidence were assessed for over twenty atmospheric phenomena with an adverse effect on agriculture as well as soil moisture content, and next the level of climatic risk for yields of staple crops in Poland was determined.

This study presents a reduction of yields of crops due to minimum air temperature at the absence of snow cover or its thickness up to 5 cm, atmospheric thaws, excessive thickness of snow cover, delayed spring resumption of vegetation, deficiency or excess of precipitation, as well as frosts, hail and extreme moisture content.

MATERIAL AND METHODS

The study was based on daily, 10-day and monthly records of weather data from approx. 70 stations of the Institute of Meteorology and Water Management (IMGW) as well as agriphenological data from approx. 60 agricultural testing stations of COBORU, together with materials from the Central Statistical Office and the PZU insurance company for the basic period of 1971-1995. Meteorological materials included actual insolation, mean and extreme air temperatures from 200 and 5 cm above the ground level, total precipitation, the height of snow cover and atmospheric phenomena such as frost and hail. In turn, agriphenological data concerned dates of most important phenophases of 12 crops and their yields. Moreover, information was used on moisture content of topsoil (excessive and insufficient) under winter crops and potatoes, reported every 10 days from March to October by field correspondents of the IMGW in the period 1964-1998.

Using single and multiple regression, potential reduction of yield was determined for the analyzed plant due to the adverse meteorological factor in comparison to the multi-annual mean value for a given COBORU station or province (Czarnecka 1997, 1998, 2004, 2005, Koźmiński and Michalska 1998, 1999, 2000 a,b; 2002, 2005 a,b). Next the frequency of incidence was determined for individual adverse climate elements and atmospheric phenomena throughout the country.

Under climatic conditions of Poland a potential threat for crops is posed by the following factors and atmospheric phenomena in two periods.

A. Plant wintering period:
- Adverse weather in the autumn during frost hardening of winter crops,
- Incidence of subzero temperature (5 cm above ground) at the absence of snow cover or its thickness of less than 5 cm,
- Strong and chilly winds at the absence of snow cover or its insufficient thickness,
- Thermally severe and snowy winters,
- Long-term snow cover,
- Thawing weather and soil thaws,
- Snow cover at above-zero temperature of topsoil,
- Vertical soil movements,
- Ice cover,
- Violent snow melt.

B. Vegetation period:
- Delayed beginning of the following periods: economic (>3°C), vegetation (>5°C), active plant growth (>10°C) and ripening (>15°C).
- Excessive shortening of vegetation and active plant growth periods,

- Deficient winter water reserves in soil in a layer of up to 50 cm deep,
- Frosts,
- Insufficient insolation,
- Insufficient solar radiation,
- Insufficient accumulated heat,
- Changes in heat balance of active surface as a result of changes in land use,
- Deficiency and excess of precipitation,
- Atmospheric and soil droughts,
- Deficit in climatic water balance,
- Hail,
- Atmospheric storms,
- Strong winds,
- Rotary storms, hurricanes,
- Adverse climate changes,
- Floods,
- Insufficient and excessive soil moisture content.

ANALYSIS OF RESULTS

Climatic risk for plant wintering in Poland

Yielding stability of winter crops is primarily determined by their winter survival, which depends on the biological resistance of plants and site conditions, but also to a considerable extent on the course of weather in the autumn, winter and early spring periods (Czarnecka 1998, Czarnecka and Raszka 2001, Czarnecka and Kalbarczyk 2002, 2004). In Poland most cultivated species usually winter well, since losses in their crops most frequently do not exceed 5% cropping area, while for rye and wheat it is as little as 2% (Fig. 1).

Typically the biggest damage in rye crops of over 2% are recorded in the Mazury Lake District, in wheat of over 2.5% – south-western Poland, triticale damage of over 3% – central Poland, while damage of red clover of over 2% is observed in central and south-western regions of Poland (Atlas… 2001). In contrast to the above mentioned species, a significant economic problem is poor winter survival of barley and rape. The biggest risk of poor winter survival of barley (except for eastern regions of the country, where its cultivation is least reliable) is found for central Poland, where mean damage amounts to over 8% cropping area and damage of over 10% is recorded on average every five years. However, the most threatened crop is rape, since almost over the entire area of the country mean winter losses are estimated to be over 10%, while in the central-eastern part it is even over 20% (Fig. 2). Winter losses exceeding 30% cropping area are observed in Poland with a frequency of 10 to 30%.

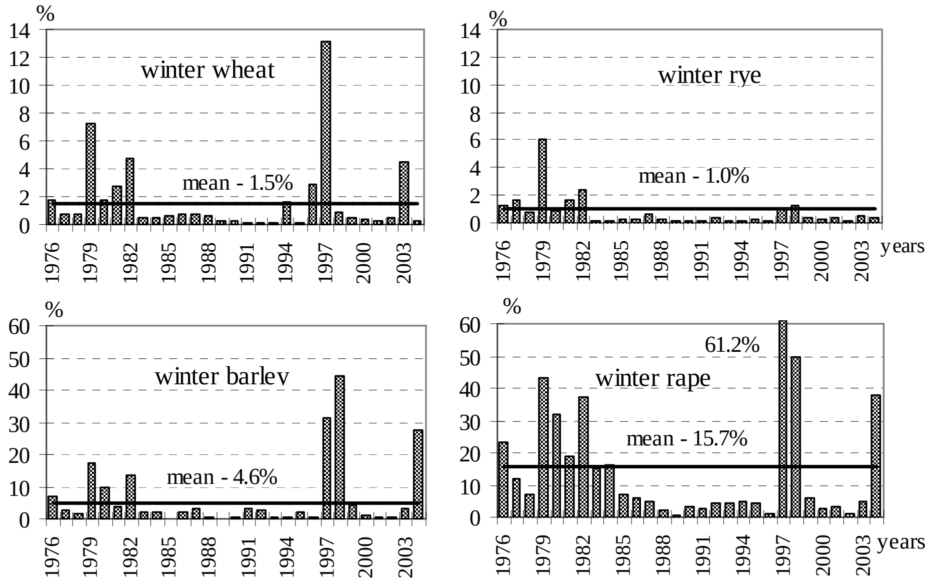


Fig. 1. Mean winter losses in Poland (%) in cropping of rye, wheat, barley and rape in the years 1976-2004

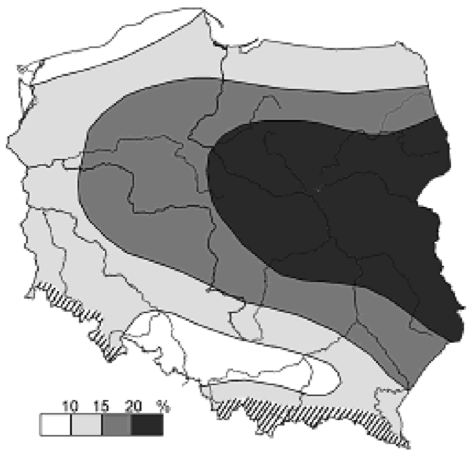


Fig. 2. Mean winter losses (%) in cropping of rape. Years 1976-1998

Very high variability of weather, characteristic of our climate especially in the colder seasons of the year, result in a situation when wintering is of a typically random nature. In extremely adverse years losses may be even 4-10 times higher than average and not only in cropping of less winter hardy species such as barley and rape, but also in crops of less sensitive species, i.e. rye and wheat. As it results from Fig. 1, winter losses in barley and in rape are at times disasters in character, resulting in plantations being ploughed and re-sown. Moreover, areas of poorest winter survival may during individual winters be completely opposite in their ranges, also differing from their average range, as may be shown by the distribution of losses in rape and turnip-like rape crops in the years 1978/79 and 1996/97 (Fig. 3). After the first of the above mentioned winters the highest losses were recorded in north-eastern Poland, where over 75% cropping area was qualified to be ploughed, while in 1966/1997 even higher losses of over 90% were found mainly in the central part of the country (Czarnecka 1999). In the same years the highest losses in the cultivation of barley were over 32% in the northern part and over 75% in the central and south-western part of the country. In the years 1976-2004 definitely the most adverse conditions for the wintering of wheat, barley as well as rape and winter turnip-like rape were found in 1996/97, while for rye extreme conditions were recorded in the winter of 1978/79. It is estimated that adverse conditions for wintering of rye in Poland occur on average once every ten years, for wheat and triticale it is twice, for barley – three times, and for rape – even five or six times (Czarnecka 1998).

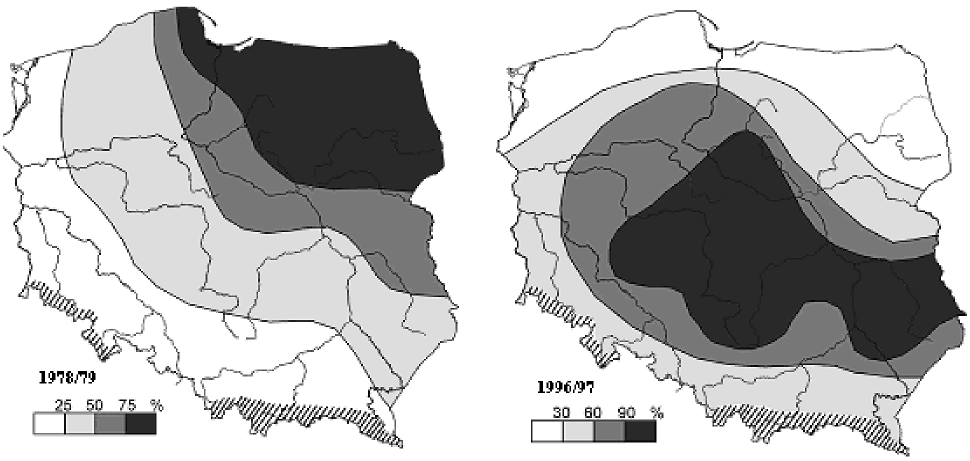


Fig. 3. Winter losses (%) in cropping of rape and turnip-like rape after unfavourable winters of 1978/79 and 1996/97

Almost throughout the whole Poland wintering has a statistically significant effect on yielding of winter crops, the highest in cropping of rape, while in north-eastern Poland – in cropping of rye, with its role in production conditions being many times bigger than in the experiments, when proper cultivation practices are maintained. Wintering of cereals in the years 1976-1998 explained in 15 to 45% variation of their yielding, while for rape – in even approx. 60%, the strongest in regions of poorest winter survival of individual species (Atlas…2001).

Winter losses usually have not one, but several causes, occurring simultaneously or in succession, which definitely hiders their evaluation and forecasting. In the complex of meteorological factors, directly or indirectly determining the occurrence of winter losses, a primary role is played by thermal air and soil conditions, in combination with snow conditions. They are the main causes of winter losses in crops, i.e. winter killing and smothering of crops, as well as infestation with snow mould. Moreover, damage to crops, but typically at a lesser scale, is caused by soaking, salinity, frost lifting, ice sheet, eolic erosion, in the occurrence of which, apart from thermal and snow conditions, an important role is also played by anemometric relations. The biggest potential risk of winter killing is posed by frosty winters with little snow, but such winters are rarely found in Poland, while frosty and at the same time snowy winters are frequent (Atlas…1990). Despite that fact, winter killing may occur at the regional and local scale almost every winter. This results from the very high time and spatial variation in thermal and snow conditions as well as varying degrees of winter hardiness of plants. Killing temperature for winter crops grown in Poland ranges from –15 to approx. –30°C. A drop of minimum temperature below critical values for individual species and cultivars may be observed throughout winter, although it is most frequent in January and February, even in coastal regions (Fig. 4).

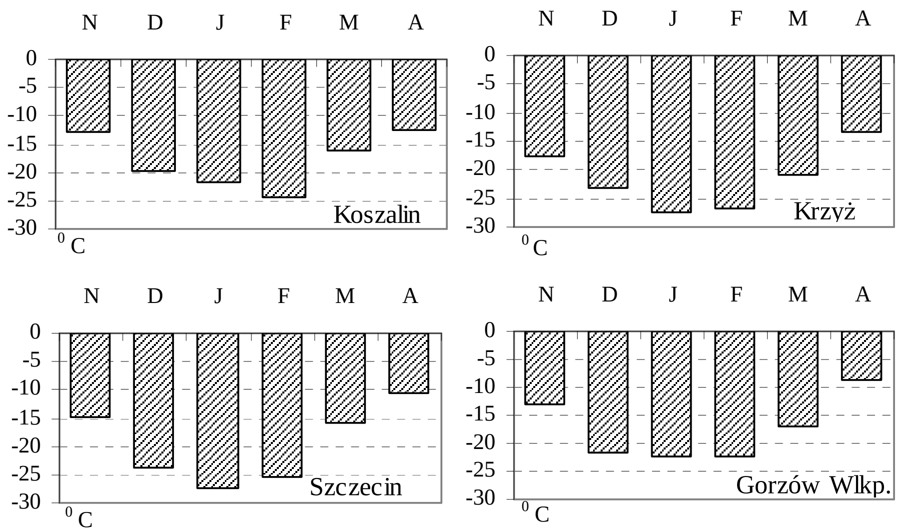


Fig. 4. Absolute minimum air temperature at 5 cm above ground at a lack of snow cover or its thickness up to 5 cm (November – April). Years 1961-2000

In the years 1976-1990 the biggest effect on winter survival of wheat, barley and rape was observed for the number of days with minimal temperature below –10 or below –15^{o}C (depending on the region of the country and species), at a lack or insufficient thickness of the snow cover (Czarnecka 1997, 1998). Minimum temperature below – 10°C is recorded on average during 6-16 days and only on 2 up to 6 days the temperature drops below –15°C (Fig. 5). However, frequently winter killing occurs at a temperature much higher than the critical one for a species or a cultivar, which is determined by the current winter hardiness of a plant, which even under conditions of thermally stable winter decreases gradually towards spring with dehardining of plants. In Poland this process is very often disturbed by the influence of thaw. Thawing weather is observed on 25 to 45 days of the calendar winter (December-February), which in western Poland accounts for almost 50% its duration (Fig. 6). Even in the coldest months of the year, i.e. in January and February, thaws occur on almost 50% of days and on average reach the intensity from 2 to 4°C, at even a maximum 13°C. At the same time this phenomenon exhibits a marked upward trend (Fig. 7). In the years 1961-2000 the number of days with thawing weather as a rule increases by 7 to 8, and in some regions, mainly north-western, by as much as almost 9 per each 10 years (Atlas 2004, Czarnecka 2005). On almost all dates of atmospheric thaw this phenomenon covers also topsoil to the depth of 5 cm. The mean number of days with soil thaw in the period of calendar winter ranges from approx. 20 in eastern Poland and it increases to over 30 in the west or even over 35 at the Wrocław Lowland, also exhibiting an upward trend. An adverse, although indirect role of atmospheric and soil thaws is manifested in the premature decrease of resistance in plants, which may be damaged at a temperature much higher than the critical level for their winter killing, particularly in the early spring.

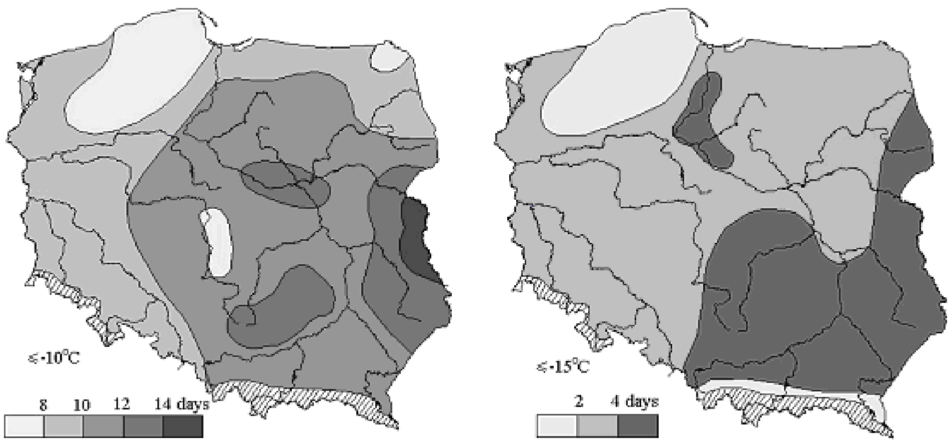


Fig. 5. Mean number of days with minimum air temperature ≤-10°C and ≤-15°C at a lack of snow cover or its thickness up to 5 cm from November to March. Years 1971-1995

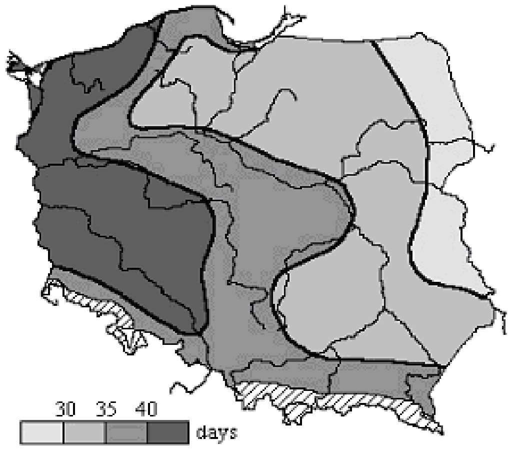


Fig. 6. Mean number of days with thawing weather during calendar winter (December-February). Years 1961-2000

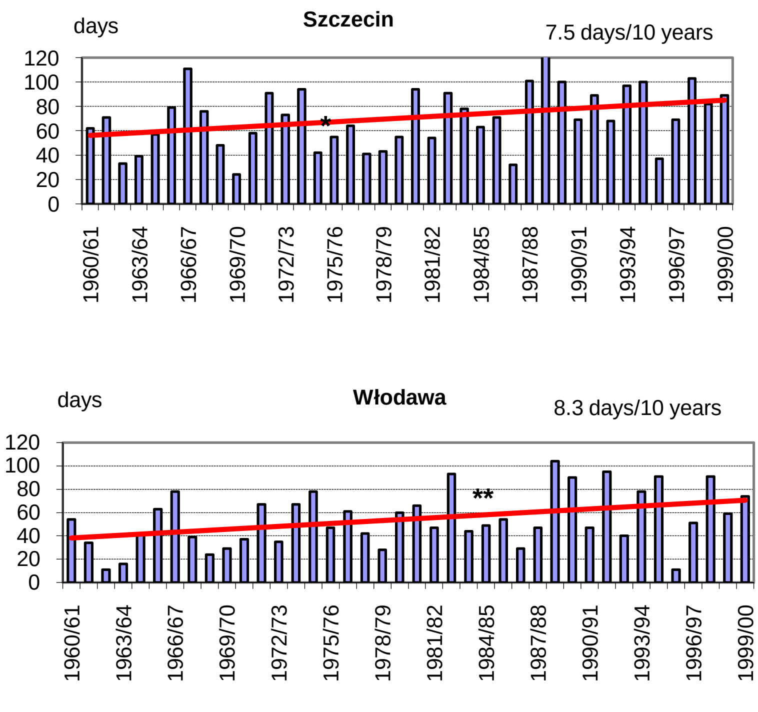


Fig. 7. Variation in the number of days with thawing weather during calendar winter (December-February) in the years 1961-2000

A significant factor reducing the risk of winter killing in winter crops may be the snow cover, which results from its thermoinsulating properties, determined first of all by its thickness and density. It is estimated that the snow cover with a thickness over 5 cm for many frosty days provides a difference of 10 between air temperature and the temperature of soil at a depth of 5 cm, which as a rule prevents both tillering nodes of cereals and apical buds of rape. However, the cover of this thickness is found only in approx. 50% days of snow cover. A thickness of over 10 cm is observed over a majority of Poland's area only for 10 to 20 days, while that of over 20 cm – for 5 to 10 days (Atlas…2001). Thus poor winter survival of crops in Poland is caused by an insufficient thickness of snow cover on frosty days, rather than by a decrease of air temperature below critical values for a given species. Even in typically most snowy and frosty winter months, i.e. in January and February, in western Poland, the thickness of snow cover on the day of the lowest minimum air temperature at the ground level, is generally below 6 cm, while in December and March it does not exceed 2 cm (Fig. 8).

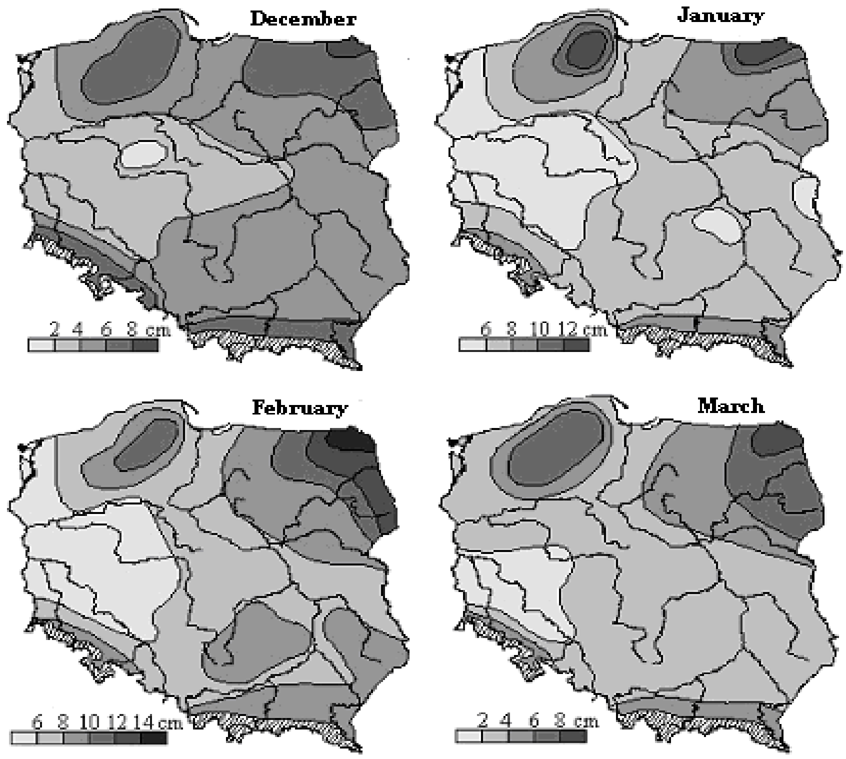


Fig. 8. Thickness of snow cover (in cm) on day of the lowest minimum air temperature at 5 cm above ground. Years 1971-1995

However, snow cover may also create a real hazard for wintering plants when it is too thick, when it remains too long, especially on unfrozen or insufficiently frozen soil, resulting in frost lifting and snow mould infestation. In the years 1976-1990 the most adverse for wintering of plants is snow cover with a thickness of over 20 cm, deposited continuously for at least 30 days (Czarnecka 1998). Excessive and long-term snow cover is most damaging for rye, which is also confirmed by the fact that in the post-WWII period definitely the biggest losses in this species were recorded after the most snowy winter of 1969/1970, followed by those in winter of 1978/79. The biggest hazard of winter damage connected with the long-term and excessive thickness of snow cover is observed in southern, submontane regions of Poland, but also in the Mazury Lake District, whereas in the west it is slight (Fig. 9). A negative result of the alternating frosty and thawing periods is connected with mechanical damage to winter crops caused by the formation of ice sheet, as well as frost lifting of plants, as a consequence of vertical soil movements, especially rape. Rapid winter thaws and melting of snow cover, as well as floods create a hazard of crops being flooded by water and their soaking. In turn, snowless and frosty winters and at the same time windy periods during winter pose a threat of salinity, while the accompanying eolic erosion may cause exposure of tillering nodes and roots, particularly on lighter soils and windward slopes. The highest potential hazard to winter crops posed by salinity is observed in the Mazury Lake District (Atlas…1999). However, damage caused by the formation of ice-sheet, frost lifting, soaking (except for floods) and salinity are most frequently local in range.

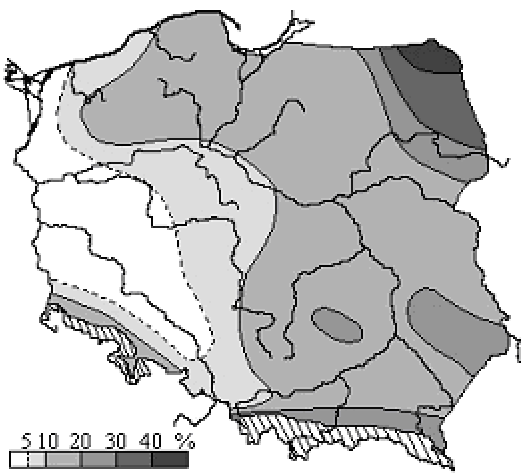


Fig. 9. Frequency (%) of snow cover with thickness of over 20 cm, found continuously for at least 30 days. Years 1961-2000

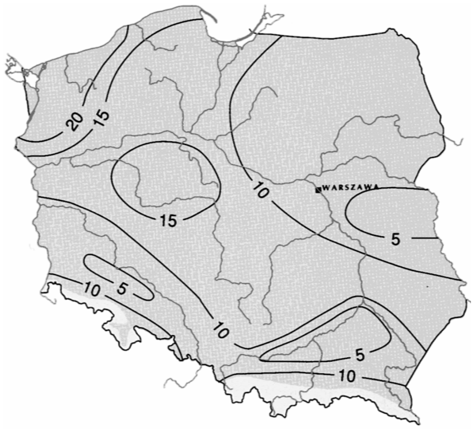
The potential human effect on the weather is still highly limited, but thanks to rational cultivation practices the risk of poor winter survival of crops may be reduced. An element of cultivation technology of particular importance for winter hardiness of winter crops is the observation of an optimal sowing date, which determines good hardening of plants under the most advantageous thermal and photoperiod conditions. Moreover, for the course of wintering a significant role is also played by the selection of a cultivar with good winter hardiness, tillage, sowing density and depth, determining an appropriate development of their root system and the location of the tillering node, adequate fertilization as well as the selection of the habitat (an appropriate soil complex, regulation of water relations, consideration of local surface feature conditions).

All scenarios of climate change forecast progressing warming, especially in the winter period (Kożuchowski 1996). Although the forecasted reduction of snowfall and the incidence of frost would indicate improved conditions of crop wintering, in reality it undermines the possibility to grow winter crops, which in their development cycle require vernalization, a process occurring under the influence of low temperature. The phenomenon of an increase in mean temperature over 0^{o}C, i.e. the disappearance of thermal winter in Poland, is according to one of the moderate scenarios of climate change the prospect for after 2040. Irrespective of this trend, we need to consider the incidence of extreme winter conditions, both such as those recorded in the frosty and snowy January of 2006, in which the mean monthly temperature was by 4 to 6.5^{o}C lower than the norm, as well as the warm winter of 2007, which not only in Poland, but almost throughout Europe was the warmest in the history of meteorological measurements.

Climatic risk for the cultivation of crops in the vegetation period

Depending on the type and intensity of the adverse meteorological factor and on the crop species and development period, the soil complex and the standard of cultivation practices, as well as weather conditions before and after the occurrence of a given factor, the volume of crop yield losses in Poland may range from several to several dozen percent (Atlas ...1995, Atlas ...2001, Koźmiński and Michalska 1988).

Potential reduction of yields of winter crops (winter wheat, rye, winter barley) as a result of a delay in the spring resumption of vegetation by 15 days in comparison to the mean date, increases from south-west to north-east from 0 to 15%, with the highest frequency of such years, from 10 to 20%, being reported in north-western and southern part of Poland (Figs. 10 and 11).



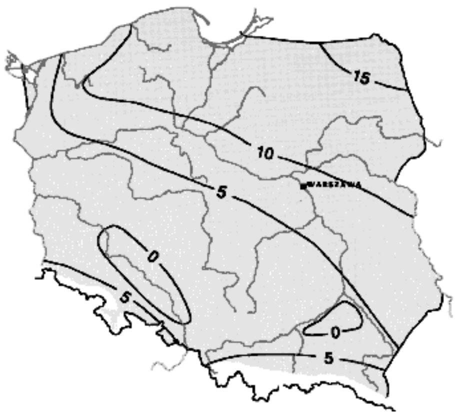


Fig. 10. Potential reduction of yields of winter wheat caused by delayed spring resumption of vegetation by 15 days

Fig. 11. Frequency of years (%) with delayed spring resumption of vegetation by 15 days

Spring cereals are sensitive, among other things, to delayed sowing (Koźmiński, Michalska 1992). Thus, already a delay of 10 days, in comparison to the average date, a reduction in yield may range in Poland e.g. for spring wheat from 5 to 10%, with the repeatability of these years increasing from south west to north-east from 10 to approx. 20% (Figs. 12 and 13).

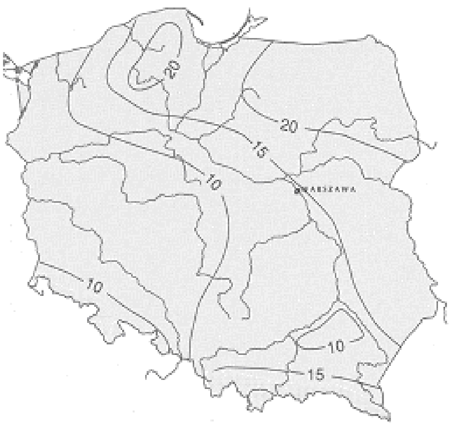


Fig. 12. Potential reduction of yields of spring wheat caused by sowing date delayed by 10 days

Fig. 13. Frequency of years (%) with sowing date of spring wheat delayed by 10 days

Another adverse factor reducing yields of winter and spring cereals is connected with excessive precipitation in the early spring period, especially in March in April, which in some years, in combination with high winter water reserved in soil, cause yield losses, depending on the plant species from 10 to approx. 18%. The effect of excessive precipitation on yields varies and it depends on the date and area. For example for rye three areas were established with the adverse influence of total precipitation, causing a reduction in yield by 5% in comparison to the mean in a given province (Fig. 14). In western Poland (area A) excessive precipitation has an adverse effect mainly in March, in the north-eastern part (area B) – in March and April, while in the south-eastern part of the country (area C) – in January, March and April. Potential reduction of yields in rye due to excessive precipitation ranges from 10 to approx. 15% (Fig. 15).

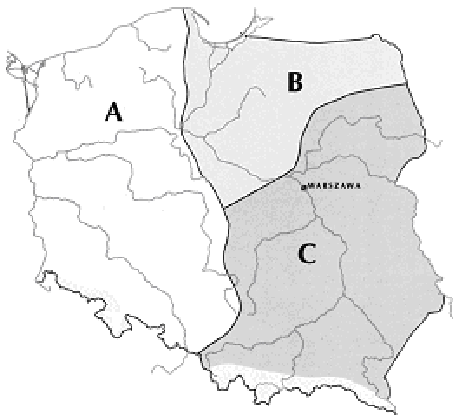


Fig. 14. Areas with adverse effect of excessive precipitation on yields of rye in March (A), in March and April (B) and in January, March and April (C)

Fig. 15. Potential reduction of yield of rye (%) caused by excessive precipitation

After winter water reserves in the soil are depleted, which most frequently occurs in May, starting from June water relations of crops are dependent mainly on the course of current climatic water balance. For these reasons as a result of periodically recorded water deficits in the summer yields are decreased on average from 5 to 10%. This reduction is the biggest in oat, for which four areas were established in Poland with an adverse effect of precipitation deficits in different periods (Fig. 16). For example, in area A – in the Pomerania region, the biggest risk for cropping of this plant is observed from 21 June to 20 July, and over a vast majority of Poland's area (B) from 1 to 30 June, whereas in the Lower Silesia (area C) from 11 May to 10 June, while in south-eastern Poland (area D) from 1 June to 10 July. Potential reduction of oat yield due to the deficit of precipitation ranges from 6 to 10%, with the highest risk observed in the eastern part of the Wielkopolska Lake District, the Krajeńskie Lake District and at the confluence of the Warta to the Odra (Fig. 17).

Fig. 16. Areas with adverse effect of deficit of precipitation on yields of oat in periods: 21 June-20 July (A), 1-30 June (B), 11 May-10 June (C), 1 June-10 July (D)

Fig. 17. Potential reduction of yield of oat (%) caused by deficit of precipitation

A higher potential yield reduction than that observed in spring cereals, as a result of precipitation deficit, is recorded in potato plantations. In the vast majority of Poland (area A) the biggest hazard for potato cultivation due to a lack of precipitation is found in the period of 21 May – 10 August, while in the other, south-eastern part (area B) – from 1 June to 20 August (Fig. 18). Risk for potato growing caused by the analyzed factor increases from south-east, approx. 5%, towards north-west with approx. 20% (Fig. 19).

It may be assumed that in Poland on light soils precipitation-free sequences lasting for over 20 days in periods of the highest water needs in plants as a rule cause reduced yields and on heavy soils it is true for sequences of over 25 days. Such long precipitation-free periods reduce yields e.g. in oat from 10 to 20%, in potatoes from 5 to 15%, while in beets from 5 to 10%.

The visual and organoleptic evaluation, conducted in the years 1964-1998 by IMGW, concerning excessive, sufficient and insufficient moisture content in topsoil under winter crops and potatoes, constituted the basis for time and spatial variation in this element of soil fertility in Poland. In Poland the risk for plantation due to excessive soil moisture content is observed as early as after 10 days, while due to insufficient moisture content after as long as 20 days. As a result of insufficient soil moisture content yields of winter rape may be lower in relation to the mean from individual provinces from approx. 15% in southern Poland to approx. 25% in the Kujawy region (Fig. 20). Excessive soil moisture content causes losses in winter rape from approx. 8% in central western Poland to approx. 14% in the western part of the Mazowsze Lowland and the Polesie Lubelskie region (Fig. 21). Among crops the species least sensitive to insufficient soil moisture content is spring barley, in which losses amount to 6-10% (Fig. 22), while in case of excessive soil moisture content losses in yields of spring barley are identical to those of rape (Fig. 23).

Fig. 18. Areas with adverse effect of deficit of precipitation on yields of potatoes in the periods: 21 May-10 August (A), 1 June-20 August (B)

Fig. 19. Potential reduction of yield of potatoes (%)caused by deficit of precipitation

Fig. 20. Potential reduction of yield of winter rape (%)caused by insufficient soil moisture content

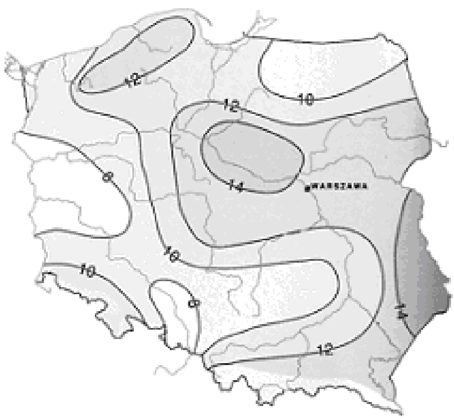


Fig. 21. Potential reduction of yield of winter rape (%) caused by excessive soil moisture content

Fig. 22. Potential reduction of yield of spring barley caused by insufficient soil moisture content (%)

Fig. 23. Potential reduction of yield of spring barley (%)caused by excessive soil moisture content

In the spring a disadvantageous, frequently observed phenomenon in plant production is frost, causing losses from several to around a dozen per cent in cultivation of vegetables and in orchards, while in years with extremely low temperatures complete destruction of plant inflorescences is observed. Taking into consideration the date and intensity of frost, particularly after the incidence of the period of active plant growth (>10^{o}C), zones of crop hazard were distinguished in Poland in terms of this adverse phenomenon (Fig. 24 and Tab. 1). The lowest hazard posed by spring ground frost is observed in the central and western part of the coast (zone Ia), followed by the Szczecin Lowland, the Ziemia Lubuska region, the Silesian Lowland, the Wyżyna Woźnicko-Wieluńska region and in the Sandomierz Basin (zone Ib). A high hazard posed by frost (zone IIIb) is found in north-eastern Poland, along the Noteć valley, in the Obra Basin and in the Karpaty Lowland and the Sudeten Foothills. A very high hazard posed by this phenomenon (zone IV) is recorded in depressions of the Bytów Lake District and the Kaszuby Lake District, as well as the region of the Obra Canal (Fig. 24 and Tab. 1).

In the spring and summer a high risk for crops is also posed by hail, especially combined with atmospheric storms. The highest losses in cereals from 4 to 12% annually are recorded along hail tracks (Fig. 25). At present the authors are working on the study of resources and climatic hazards in different regions of Poland as they are collecting phenological and meteorological data. For example in the Pomerania, using data on deficits and excess insolation and precipitation, as well as insufficient accumulated temperatures, the number of days with daily precipitation >20 and >30 mm, the number of days with frost and hail, as well as days with glazed frost, fog, thaw and excessive snowfall, zones of potential climatic hazard were identified for the four seasons of the year, i.e. I – very small, II – small, III – medium and IV – big (Fig. 26).

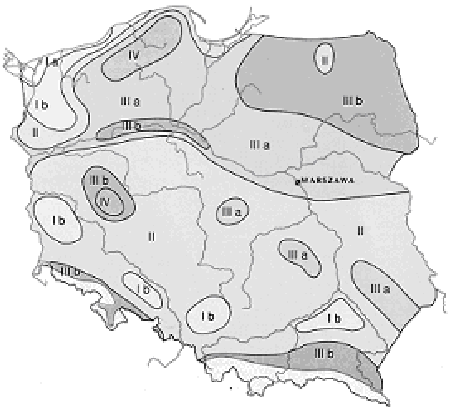


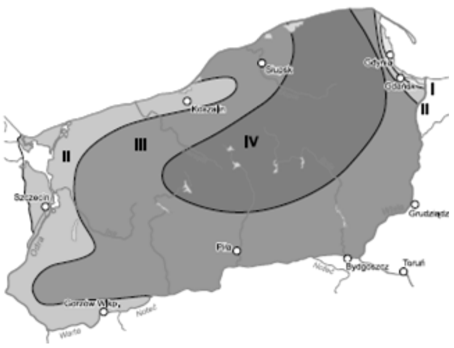
Fig. 24. Hazard zones of crops caused by ground frost

Fig. 25. Mean hail losses in cereals (%)

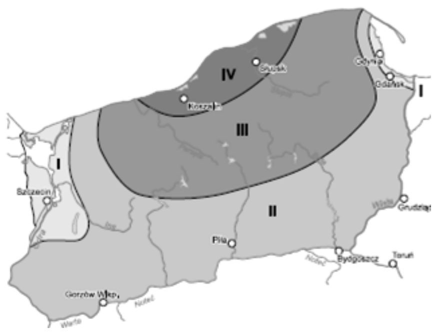
Table 1. Characteristics of hazard zones for crops caused by frost

Zona		Threat	Mean numer of days after the occurence of air temperature of 10^{o}C	Mean lowest temperature in May
I	a	Very small	up to 2.5	up to –1.5°C
	b	Small	2.6-3.5	–1.6 up to –2.0°C
II		Mean	3.6-4.5	–2.1 up to –2.5°C
III	a	Moderately great	4.6-5.0	–2.6 up to –3.0°C
	b	Great	5.1-5.5	–3.1 up to –3.5°C
IV		Very great	> 5.5	< –3.5°C

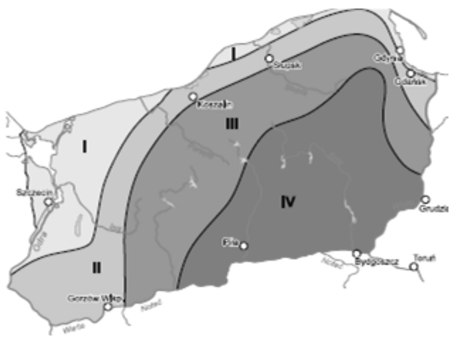
Zona		Lowest temperature in May	Mean dates of latest ground frost	Dates of latest ground frosts
I	a	up to –5°C	up to 10 May	up to 5 June
	b	up to –6°C	up to 15 May	up to 10 June
II		up to –6°C	16-20 May	11-15 June
III	a	up to –7°C	21-25 May	16-20 June
	b	up to –8°C	21-25 May	21-25 June
IV		< –8°C	after 25 May	after 25 June



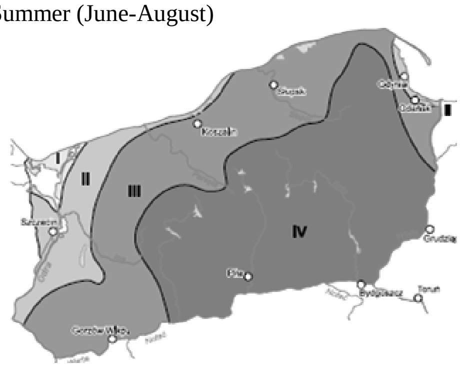
Spring (March-May)



Summer (June-August)



Autumn (September – November)



Winter (December-February)

I – very small, II – small, III – medium, IV large

Fig. 26. Climatic hazards in the Pomerania region

CONCLUDING REMARKS

Taking into consideration crop wintering conditions, delayed spring resumption of vegetation and sowing date, hail, frost, excessive insolation in June and excessive precipitation, as well as extreme soil moisture content, hazard zones were distinguished in Poland for 9 crops. Mean annual reduction of yields ranges from 6 to 18%, with the highest losses recorded in plantations of spring cereals and winter rape – from 9 to 18%, while the smallest in plantations of sugar beets – from 6 to 10%.

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7. DROUGHTS IN POLAND – THEIR IMPACTS ON AGRICULTURE AND MITIGATION MEASURES

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INTRODUCTION

Among the possible aspects of climate change in temperate climatic zones are temporal fluctuations of meteorological elements. Climate variability and change threatens local water resources availability. Climate change results in extreme meteorological events, among them droughts. There is a critical need for reliable information relevant to impacts of droughts and hazard mitigation.

The need for dealing with droughts and their effects in Poland arises from the unfavorable impact they exerts on agriculture. Considering global climate changes and their effects in the forecasted increase in temperature and decrease in precipitation in Central Europe in the future, it is very likely that the frequency of drought occurrence and its severity will increase in Poland.

An analysis of the impacts of droughts in agriculture as well as the determination of now-a-day actual and possible future effects on crop production should be undertaken. Their results will be a basis for the complex program for counteracting the negative effects of droughts. Such program should determine directions and measures as well as the intensity of organizational, technical, R&D and innovative actions, which would aim at counteracting droughts and serve to limit their effects on the national economy and on agriculture in particular. It should contain descriptions of mitigation measures and of continuous, preventive actions to be carried out before, at the beginning of, during and after the cessation of a drought. The actions should consider regional differentiation of the drought phenomenon.

The program for combating droughts may assume a form of programs and politics, and sometimes as appropriate legal acts, or in the form of descriptions of short- and long-term actions.

DROUGHTS IN POLAND, THEIR RANGE AND FREQUENCY

Poland is situated in a transitory temperate climate zone, nonetheless droughts occur posing a serious economic, social and environmental problem. Droughts in Poland have a character of atmospheric anomaly following the rainless period. In dependence on the amount of precipitation deficit and on its long-term, annual or seasonal distribution we are dealing with the hydrologic, atmospheric or soil drought. The direct effect of a drought is a disturbance in the water budget of an area caused by a precipitation deficit and a large amount of evaporation (atmospheric drought), which is manifested by excessive soil drying (soil drought) and by lowering the ground water table and decreasing water flow in rivers (hydrologic drought). Each of these droughts causes great losses, which are suffered by national economy and a society.

Droughts in Poland are hardly predictable. It is difficult to forecast the term of their occurrence, duration, territorial range and intensity. This leads to trouble in operational planning and in undertaking the proper advance measures to mitigate the negative effects. In spite of this unpredictability and irregularity of drought occurrence in Poland, one may observe some statistical properties of their frequency, duration and the regions affected.

Drought phenomena in Poland have been mentioned in the chronicles since the fourteenth century and were found to occur many times a century (Kaca *et al*. 1993): in the XIV century – 20 times, in the XV – 25 times, in the XVI – 19 times, in the XVII – 24 times, in the XVIII – 22 times. Since the XIX century, when permanent precipitation records have been started, the number of droughts were estimated as 23 in the XIX century and 20 in the XX century. It is assumed that droughts appear in Poland once every 3-4 years; sequences of years with precipitation deficit are observed to be followed by sequences of years with excessive or close to average precipitation. In the last 55 years, deep droughts occurred in the years: 1951, 1953, 1959, 1963, 1964, 1969, 1971, 1976, 1982-1984, 1988-1995, 2000-2006 (Bąk and Łabędzki 2002, Bobiński and Meyer 1992a,b, Czaplak 1996, Łabędzki 2006). Between 1951 and 1990, twenty one atmospheric droughts were distinguished (Farat *et al*. 1994). They lasted a total of 107 months, which is 22% of the analyzed period. The longest took place in the years: 1982 – 11 months, 1959 – 10 months, 1951-1952 – 9 months, 1983 – 7 months and in 1989 – 7 months. Droughts in the years 1951-1995 varied in their intensity, duration and the period of their occurrence, but the most intensive and widespread was in 1992.

The driest regions of Poland are: almost the entire central region, as well as northwestern and mid-eastern parts. These are the regions most threatened by droughts. The Wielkopolska and Kujawy region in central and central-west part of the country is the area with the considerable degree of aridity. It is the region with the lowest annual precipitation amount in Poland. The most frequent and most severe droughts occur in this area, which sometimes experience extremely long periods without rain. The average annual precipitation rate for this area is about 500 mm. The average sum of precipitation in the growing season is 300 mm, but it varied within the range of 500 mm (in 1985) to 90 mm (in 1989). Besides the average mean daily values of air temperature are high and air humidity – low. It causes the occurrence of the severe and frequent droughts and scarcity of water resources. The periods of rainfall excess also occur, especially in spring and in July. The value of reference evapotranspiration according to the Penman-Monteith method is much higher than precipitation in the growing season. The precipitation deficit reaches 200 mm in an average year (at the 50% probability) and can be equal to 330 mm in a dry year (at the 20% probability). In the vegetative season of 1982, in Kujawy and northern Wielkopolska for example, precipitation was nearly half that from 1951-1990. In the very dry year 1989, precipitation was so low that the probability of not exceeding it was less than 1%.

A long-term drought in 1992 was a disaster that spanned almost the entire country with the most intensive effects being felt in the north-western and middle part of the country. In some regions it lasted for the whole vegetative period (April-September). It was characterized by high air and soil temperatures, very high insolation and a negative climatic water budget. From the middle of April precipitation did not exceed 50% of the average and in June in the northwestern part of the country there was no precipitation at all. In the Kujawy region, precipitation during the second half of the vegetative period was 40-55% of the multiannual average.

IMPACTS OF DROUGHTS IN AGRICULTURE

The negative effect of droughts in Poland is complex and can be observed in various branches of the national economy. It is particularly visible in agriculture. The effect in agriculture is differentiated and depends on the amount and distribution of precipitation before and during the drought. Droughts negatively affect crops, but the effect varies for various plants, soils and geographic regions and a crop decrease depends largely on the duration and intensity of the drought. Autumn and early spring droughts usually cause a decrease in winter crops while spring droughts – a decrease in spring crops, the first hay cut and pasture efficiency. Summer droughts usually negatively affect potato crops, the second hay cut and the field fodder crops.

In the two very dry years 1982-1983, an average decrease in grain crops was 5-30% in various regions of Poland and that of potatoes – from 10% to 40% as compared to the average crops amounts in 1985-1987 (Kaca *et al*. 1993, Problems ... 1993). In the valley of the Upper Noteć, covering a part of Kujawy and Northern Wielkopolska – the regions of substantial and frequent water deficits in plant production, in the very dry year 1989 (when the probability of such a low precipitation as that actually present was 1%), the yield of hay from non-irrigated grasslands was 5 t ha^{-1} while in an average year (1987) the mean yield was 8-10 t ha^{-1} (Łabędzki 1992).

The drought in 1992 was a disaster. Its negative consequences were: long-lasting, burdensome heat, dried soil, grasslands yellowed in midsummer, a lack of the second and the third grass cuttings, a deficit or a total loss of the grain and potato crops, lack of fodder and consequently – an increase in food prices. It is estimated that this drought decreased the value of crops by 25%. Total crops of grain, potatoes and bulk fodder, expressed in cereal units were lower in 1992 by 31% than those in 1991. Meadow hay crops (mean for the country) decreased by 27% in comparison to the average from 1986-1990. In the region of the Upper Noteć watershed, 6-10 t of hay per ha were obtained after irrigation while non-irrigated grasslands on better soils yielded no more than 2 t ha^{-1} of hay and on worse soil – they were completely dried (Łabędzki 1997). The precipitation shortage was reflected in very low water tables and outflows from the rivers and in a significant decrease of the shallow ground water table. Such a situation caused an almost complete drying of the smaller streams, whose watershed covered several hundred km^2, and thus deprived any life dependent on them. A critical situation arose in retention reservoirs, which were filled only to 10% of their average levels. This caused difficulties in supplying water for irrigation. The drought was also a factor in the increased frequency of fires, resulting in the burning of thousands of hectares of forests and peatlands.

The above effects, observed at such an extreme intensity in 1992, appeared with smaller or greater intensity and with varying territorial range in other years, when droughts were also present in Poland. The 2000 year was the next one with high drought risk. In April and May 2000 non-typical meteorological conditions occurred. In Kujawy region precipitation in the autumn-spring period of 1999/ 2000 approximated normal. After-winter soil water reserves were sufficient at the beginning of the growing period of 2000 (approximate to field water capacity). Groundwater table was at the depth of 50-60 cm, which was optimal for grassland vegetation. From the beginning of April drought event occurred in the region, classified as moderately dry. The last significant rainfall occurred on the 16th April, with the sum of precipitation from the 10th to 20th April equal only to 9 mm. It caused systematical decreasing of soil water reserves and groundwater tables. In the period between the 20th and 30th April there was only 2 mm of rainfall. Soil moisture content decreased below the minimum admissible value and groundwater tables decreased below 1 m from which capillary rise did not meet crop water demands. The conditions changed for the worse radically in the first ten days of May by completely lack of rainfall (extremely dry period). This situation with additionally high evaporation was a threatening event for most crops. The beginning of June was the driest what caused that the whole month was classified as severely dry. Meteorological conditions in the next months of the growing period were normal, but they did not reduce the negative effects of spring drought in that year.

Droughts in the two years 2005-2006 caused considerable losses in crop production, especially central part of Poland, from west to east. In 2006 due to several-week lasting hot weather and lack of precipitation in June and July, the greatest losses in yields of spring cereals, maize, potatoes, sugar beets and grasslands were observed. According to the evaluations made by the Ministry of Agriculture and Rural Development, the losses in yields from meadows and pastures were 40-100%, spring cereals – 20-60%, winter cereals – 15-50%, rape – 15-45%, potatoes and sugar beets – 20-60%, vegetables – 30-60%.

As shown by the above data, droughts in Poland can be dangerous and may bring large losses to the national economy in spite of its irregularity and seeming insignificance due to the geographic location of Poland. All of this justifies and points to an urgent need for working out and implementing local, regional and national programs of drought control. Actual programs, actions, methods and measures focusing on mitigation of the negative effects of droughts are usually of local, provisional and temporary character.

MITIGATION MEASURES

Actions and measures for mitigating the effects of droughts as well as uncertainties as to how the climate will change and how it will influence agriculture are the challenges that planners, designers, farmers, agricultural and extension services will have to cope with. How agriculture will have to adapt to climate changes is the serious question to be answered in the near future.

Because of possible increase in water shortage in agriculture due to droughts and unfavourable climate changes the main actions and measures should lead to:

- increase of local water resources and their availability,
- increase in water use efficiency,
- decrease in water needs for crops,
- intensification of irrigation.

The actions should modify the needs of water users to force the need for saving water during droughts. A modification of the technology of water use on farms and in the field should play a great role. Minimizing the useless water discharges from reclamation systems, including drainage outflows and limiting crop water use are necessary.

Particular actions and measures should include:

1. increasing water resources retention (in open waters) available for agriculture, mainly for irrigation by water retention in the periods of its excess – in the spring and after abundant intensive precipitation (construction of small retention reservoirs, construction of water structures to restrict water outflow from fields),

2. increasing soil water retention and its availability for plants by:
   - technologies of soil cultivation that increase soil moisture and the degree of water utilization, among them:
     - soil loosening,
     - deep plowing,
     - improvement of soil structure,
     - improvement of physical and water properties of deeper soil layers,
     - retention of localized precipitation,
     - increased infiltration,
     - enlarging the active layer of roots water uptake,
     - deeper rooting,
     - increased amout of water available for plants,
   - plant species selection in crop rotation (drought resistance, a shorter vegetative period meaning lower water requirements, a deeper root system),
   - fertilization and reclamation measures that aid the development of a strong root system,
   - introduction of deep-rooted plants with low water requirements,
3. modification of the technology of water use on farms and in fields towards:
   - saving water,
   - increase water use efficiency by multiple use of water,
   - minimizing useless water discharges from reclamation systems, including drainage outflows,
   - limiting water consumption for evapotranspitation,
4. improvement in the social awareness of droughts, their effects and countermeasures.

Various actions and methods for counteracting drought effects in agriculture are now being implemented in Poland, all of them are means to accomplish the strategic goal – mitigating the negative effects of droughts. The most visible actions are now being accomplished small water retention programs throughout many regions of Poland. These works are co-financed by the local, regional and national funds of environmental protection and water management.

The other important actions are the regional programs of irrigation development. The programs being under preparation in several regions of the country and for the whole country can play an important role in rational planning and implementation of irrigation as an effective measure to mitigate the negative effects of droughts in agriculture.

Under the economic conditions of Polish agriculture irrigation of most field crops is an unprofitable measure. Irrigation of potatoes, vegetables and orchards is profitable (Gruszka 2004, Jankowiak *et al*. 2006, Jankowiak and Rzekanowski 2006, Rzekanowski 2000). That is why the existing irrigation systems and facilities are only used to a small extent. Irrigated area decreased by 75% since the beginning of the nineties, due to changes in national economy and economic conditions in agriculture (Łabędzki 2007). On the average the area irrigated is 0.5% of the total agricultural land area in the country (Environmental Protection 2008, Łabędzki 2007). In the driest region of Poland – the Kujawsko-Pomorska province – 1.1% of agricultural land area was irrigated. Sprinkling irrigation of arable lands under field production covered only 5 thousand hectares and subirrigation of permanent grasslands – 94 thousand hectares (Environmental Protection 2008). In the official government publications there is no data on microirrigation but total area under microirrigation in Poland can be estimated to about 5000-10000 ha.

Pressure irrigation is concentrated chiefly in the western and central part of the country, in regions with relatively low precipitation and of fertile soils. This type of irrigation is interventionary in character, it has to supplement the multiannual average if there is a precipitation deficit and thus maintain crops at the planned high level. In dry years, the sprinkling irrigation is a prerequisite to obtain field plant yields at least an average level. It enables supplementing the precipitation deficit and maintaining the crop yields, but is also able to elevate them in average years. The effects of sprinkling in 1992 were exceptionally high. An increase of crop yields, in relation to crops from non-sprinkled areas, exceeded 100% that of tuber crops, fodder plants – above 200% and that from grasslands – 150-200%.

The effects of subirrigation of permanent grasslands with the subirrigation systems are associated with the quality of exploitation of these systems. Where exploitation of facilities is proper and water uptake is provided, one may avoid the negative effects of droughts and even obtain higher productivity. There are not many subirrigation systems – on only about 20% of grasslands. To achieve a high efficiency of these systems during a drought, systematic conservation of the network of ditches and facilities is necessary in the period preceding the drought. Subirrigated systems are largely degraded and used only to a small extent if at all. In order to be used more effectively, it is necessary to reconstruct and modernize these systems. A lack of modernization and improper exploitation of the systems and facilities restrict competent water management and result in decreased crop production. The proper use of the systems and facilities allows for effective water management on irrigated areas and greater stability in grassland yields. Irrigated areas in the Upper Noteć and Narew valleys, along the rivers of Kuwasy, on the Żuławy and Szczecin polders and in the region of the Wieprz-Krzna canal are examples of such actions.

At present, increase in the area of irrigated land, especially in vegetable and fruit farming using drip irrigation, has been observed. It is assumed that the development of this type of irrigation will run parallelly to the development and intensification of agriculture.

Increased frequency and intensity of droughts, the intensification of agricultural production, being forced by the internal domestic and all-European free-market competition and the necessity of reaching high quality of the majority of agricultural products are the factors accelerating the development of irrigation. The significance of irrigation will increase with the intensification of agriculture (e.g. in horticulture, orchards, seed crops) and with negative effects of climate changes.

Predicted climate changes and increase in frequency and intensity of droughts in our climate zone will cause increased crop water demands, irrigated area and irrigation water requirements. For example crop water demands will increase by 2-4% for maize and by 6-10% for potatoes (EEA 2008, IPCC 2007, Olesen and Bindi 2002). In 2020 in south-east England net irrigation water requirements will increase by 70% in comparison with 1995, and in north Germany – by 40% (Döll 2002). One can expect similar increase in Poland. Under conditions of climatic and economical changes, the irrigation area will increase up to 2.1 mln ha, of which 1.6 mln ha on permanent grasslands and 0.5 mln ha on arable land and in orchards (Nyc and Pokładek 2007). According to Mioduszewski (2007), 3-4% of arable land (without subirrigated area) should be irrigated in the near future. Rzekanowski (2000) writes that till 2025 pressure irrigation should be used on 1 mln ha, mainly on very light and light soils in central Poland.

Particular actions developed for the strategy of drought mitigation on agriculturally-used protected areas, especially in river valleys with organic soils are utilized in Poland. These actions aim at improving the effectiveness of water consumption for irrigation purposes and at optimizing water distribution in subirrigation systems and in the river valley. Research and implementation studies are being carried out to improve the methods of the assessing plants' water requirements and on an operational model of water distribution. These actions give rise to the water unit productivity, they decrease water losses and useless water discharges, and decrease the risk of droughts by collecting water in advance or mitigate the negative effects in periods of water deficit. Controlled water management in a watershed equipped with retention reservoirs and raised lakes also leads to shortening the low water periods in running waters and alters the frequency of their occurrence. An operational system of controlled water management in the Upper Noteć watershed is an example of such activities (Kaca and Łabędzki 1995).

It is estimated that in many regions of Poland, further development of irrigation could be determined and restricted to a great extent by the availability of water resources. In many cases the factor preventing irrigation system is the lack of water due to the co-occurrence of drought and low water tables in rivers and consequently, the decreased useful capacity of lakes and retention reservoirs. Then, the important role in water management is regulation of outflow, which consists of controlling the minimum water discharge from systems in the spring and after a large amount of precipitation, thus in retaining water in the soil and in the network of ditches.

Drainage can play a large role in mitigating the negative effects of droughts on crop yields. The role of draining consists of lowering the ground water table in the spring, which allows field works to be started earlier and thus earlier plant growth and root development, enabling the root systems to take up water from the deeper parts of soil during drought conditions.

In plant technologies, processes should be recommended, that allow one to obtain the beneficial effects of plant growth under drought conditions. Economic losses due to decreased yields can be minimized by the introduction of deep-rooted plants with low water requirements in the most affected regions.

Agro-reclamation measures, mostly soil loosening and deep plowing, can also mitigate the negative effects of drought. These measures consist of the improvement of the soil structure and of the physical and water properties of the deeper soil layers, which enables deeper rooting of plants and increases the amount of water available for plants.

Moreover, various technical, reclamation, hydrologic and anti-erosion measures can be used, which mitigate negative effects of droughts in agriculture. They serve to improve water cycling and the water balance within the watershed, the reclamation system and the soil. They should lead to a change and optimization of productive space utilization, to modifications in crop rotation, to selection of the proper drought resistant plant species and varieties and to changes in agricultural technique. The preparation of a list of plant varieties commonly cultivated on a given area and resistant to drought is desirable. All complex reclamation measures like forestation, introduction of grasslands and proper fertilization fall within these types of actions. They all may restrict the negative effects of droughts on a given area to a large degree.

One of the basic preventive actions is drought forecasting and early warnings. Forecasting and early warnings are of great importance in planning and preparing to undertake actions aimed at avoiding or minimizing the negative effects of droughts.

One has to take into account some risk, restrictions and losses in crops and incomes. That is why an acceptable level of losses on various management levels – in a region, in a commune, on a farm and on an area – should be determined within the strategy. A list of priorities is to be prepared to determine the permissible level of losses in agricultural production. This would enable planning the respective tasks and an optimum allocation of means for their accomplishment.

One may expect that further work should result in documents providing for the implementation of regional small retention development programs and irrigation development programs.

Institutional activities will be of substantial importance in planning and in accomplishing a complete strategy for drought control. Their contributions will include using of operational planning models of collection and water transfer within a watershed, decisive models of water management in retention reservoirs and water systems, changes in water distribution management from the local level to the central one (within a system), changes in the organization of the administrative water management and new legal regulations. Institutional solutions should consider local problems within a region, which result from the frequency of droughts, their character and the impact they exert upon various water users as well as those problems originating from the expected economic losses due to the water deficit.

Actual determinants of various activities against drought in Polish agriculture are strictly connected with the state of water management in agriculture, particularly with the state of land-reclamation (amelioration). Basic reasons for the restricted possibilities of drought counteraction on agricultural areas lie in the negligence of the proper use of agricultural water systems and reclamation systems and facilities. Improvement of management, operation and maintenance of these systems will make mitigation measures more effective.

CONCLUSIONS

1. All of the above mentioned actions and measures should be addressed in long-term strategy for drought control, for mitigating effects of droughts and climate change as well as for adaptation of agriculture and agricultural water management to predicted climate change. Preparation of such a strategy together with programs for the accomplishment of the relevant tasks is indispensable in the nearest future in Poland.
2. In view of the drafted actions undertaken in Poland during droughts aimed at limiting their negative effects, one may conclude that they do not form a consistent system and result from in consistent partial strategies of drought control. The problems of drought control and the resulting activities are a challenge to Poland to have a drought mitigation strategy and to look for new and more perfect solutions and their implementation in regions with a high risk of droughts. This basis for any activity should be a strategic program, which would determine how and in which way to achieve the requested strategic goals.
3. There is an urgent need to improve the uniform national strategy of drought and climate change mitigation including a national water saving policy and its legal aspects, the issuing of drought advisories and warnings, the creation of guidelines on how to prevent and counteract the effects of drought and to release recommendations stating the most adequate measures to be undertaken.

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8. IMPORTANCE OF PESTS AND DISEASES OBSERVED IN AGRICULTURAL PLANTS IN POLAND IN THE YEARS 1991-2008 IN THE CONTEXT OF CLIMATE CHANGES

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INTRODUCTION

The agrophages economic importance is determined by various environmental factors, namely: intensified farming, simplified agro technology, varieties with different level of disease and pest resistance and the global warming effect within the last few years.

The global climate changes give rise to new challenges for plant protection. Temperature, humidity of the air and soil are very important factors affecting agrophages developmental rate, quantity, population dynamics, range and intensity of occurrence, feeding intensity and harmfulness.

In Poland every year Plant Protection and Seed Health Inspection Service provide detailed field observations in order to get the information about phytosanitary state of agricultural plants. Obtained results from pests/diseases monitoring in connection with observations provide at the Plant Protection Institute at the Department of Forecasting and Registration Pest and Diseases, are the base of "Phytosanitary state of agricultural plants in Poland with prognosis to the next year" which is issued every year.

The aim of the research was evaluation of pests/diseases observed in agricultural plants in the years 1991-2008 and their importance as a consequence of climate changes.

MATERIAL AND METHODS

In Poland the harmfulness and occurrence of the agrophages has been monitored from 1950. Such information are the base of the evaluation the tendency of pests and diseases spread as well as their economic value affected among other factors by climate changes. Pest/diseases monitoring is provided by Plant Protection and Seed Health Inspection Service in collaboration with the Department of Forecasting and Registration Pest and Diseases at the Plant Protection Institute, Poznań, Poland.

Information concerned on the agrophages (pest/diseases) occurrence and harmfulness are collected according to the methods. Methods were published by the Department of Forecasting and Registration Pest and Diseases, Plant Protection Institute (Pruszyński *et al*. 1993, Walczak *et al*. 1998, Węgorek *et al.* 1976, 1982).

Every year at the end of the year, information about pests/diseases occurrence and harmfulness are send to Plant Protection Institute (to The Department of Forecasting and Registration Pest and Diseases). Then all data are transformed and showed as a maps and graphs. On the maps for the branches within the voivodeships the average percentage of agrophage harmfulness is shown – in the circle the average for voivodeship is presented. On the graphs average percentage pest/ disease harmfulness for years is shown.

Nowadays, in Poland pests and diseases occurred on agricultural plants with economic meaning and which are observed according to "detailed registration" regulations are:

Cereals

Winter wheat: powdery mildew – *Blumeria graminis*, brown rust – *Puccinia recondita*, septoria leaf spot – *Septoria nodorum*, take-all diseases – *Pseudocercosporella herpotrichoides* and *Gaeumannomyces graminis*, cereal leaf beetle – *Oulema* spp., bird cherry aphid – *Rhopalosiphum padi*, cereal aphid – *Sitobion avenae*, saddle gall midge – *Haplodiplosis equestris.*

Spring barley: powdery mildew –*Blumeria graminis.*

Mays: frit fly – *Oscinella frit* and *Oscinella puzilla,* european corn borer – O*strinia nubilalis.*

Root crops

Potato: late blight **-** *Phytophthora infestans*, colorado leaf beetle – *Leptinotarsa decemlineata,* evaluation of potatoes tubers damages – wireworms i.e.: *Elateridae,* grubs – *Melolonthinae, c*utworms – *Noctuinae.*

Sugar beet: cercospora leaf spot – *Cercospora beticola, b*eet fly – *Pegomyia hyoscyami, b*ean aphid - *Aphis fabae*.

Oil crops, rape: dry-rot of cabbage– *Phoma lingam*, rape blossom beetle - *Meligethes aeneus,* cabbage stem-weevil – *Ceutorhynchus quadridens,* stem-mining weevil – *Ceutorhynchus napi*, rape-seed weevil – *Ceutorhynchus assimilis,* brassica pod midge – *Dasyneura brassicae*.

Vegetables

Tomato: late blight – *Phytophthora infestans*

Cucumber: downy mildew of cucumber – *Pseudoperonospora cubensis*, angular leaf spot on cucumber – *Pseudomonas syringae pv. lachrymans*.

Onion: downy mildew of onion – *Peronospora destructor* (Berk.).

Cabbage: large cabbage white – *Pieris brassicae*, cabbage armyworms – *Barathra brassicae*, cabbage aphid – *Brevicoryne brassicae*.

Carrot: carrot root fly – *Psila rosae.*

Orchards

Apple: apple scab – *Venturia inaequalis*, apple sawfly – *Hoplocampa testudinea*, codling moth apple worm – *Laspeyresia pomonella*.

Plum: plum sawfly – *Hoplocampa* spp. tortricid plum moth – *Laspeyresia funebrana*.

Cherry and sweet cherry: monilia brown-rot – *Monilinia laxa*, cherry maggot – *Rhagoletis cerasi*.

Strawberry: grey mould of strawberry – *Botrytinia fuckeliana*.

Papilionaceous plants

Lupine: anthracnose – *Colletotrichum gloeosporioides*.

Peas and field pea: pea moth – *Laspeyresia nigricana*

Snails – ***GASTROPODA*** – on cereals, potatoes, sugar beets, rapes, papilionaceous plants, vegetables and orchards

Rodents – during spring, summer and autumn time.

In the future the list with important pests/diseases which are observed according to "detailed registration" can be changed. During last years some agrophages started to be more important. It means that one can observe higher incidence and more agricultural plants damaged by particular pests/diseases, namely: cereal ground beetle (*Zabrus tenebrioides*), frit fly (*Oscinella frit*), wheat bulb fly (*Phorbia coarctata*), gout fly (*Chlorops pumilionis*), thrips (*Thrips*), leaf miners (*Agromyzidae*), leaf hoppers (*Cicadellidae*), cabbage stem flea beetle (*Psylliodes chrysocephala*), cabbage gall weevil (*Ceutorhynchus pleurostigma*).

Because of longer than usual autumns and winters without frost and snow agricultural plants can be damaged by snails, nematodes, rodents, birds and games.

On the other hand long, warm autumn and winter also create favorable development conditions for bacteria, viruses and fungi which can reduce hibernated stages of pests/diseases.

RESULTS

Climate changes affect the length of vegetative period which is prolonged by one month due to warmer autumn. For example October, November and December 2006 were the warmest months in last 50 years. As a result in the last few years the harmfulness of the agrophages of small economic importance has increased and their significance can alter.

Moreover the harmfulness of some economic significant agrophages has been increasing therefore their harmfulness is monitored in Poland.

Due to warm and long autumn harmfulness increase in last years has been observed for:

- *Zabrus tenebrioides* – cereal ground beetle, *Oscinella frit* – frit fly, *Phorbia coarctata* – wheat bulb fly, *Chlorops pumilionis* – gout fly, *Thrips* – thrips, *Agromyzidae* – leaf mines, *Aphididae* – aphids, *Cicadellidae* – leaf hoppers, rusts, *Fusarium* spp. and *Septoria nodorum* – septoria leaf spots – on cereals,
- *Psylliodes chrysocephala* – cabbage stem flea beetle, *Athalia colibri* – coleseed saw–fly, *Phorbia brassicae* – cabbage root fly, *Alternaria* spp. – alternaria diseases
- on rapes,
- *Ustilago maydis*, *Ostrinia nubilalis* – european corn borer, *Oscinella frit* – frit fly, *Aphididae* – aphids, *Thrips* – thrips, *Diabrotica virgifera* – western corn rootworm – on maize.

Cereal ground beetle (*Zabrus tenebrioides)* – the larvae (Photo 1) feeding was observed even in December 2006. Information about that pest harmfulness were collected from seventies last century – in 1970, locally, near by Lublin even 30% damaged plants was noticed. In eighties cereal ground beetle occurrence decreased and in nineties increase again. More than 17% damaged winter cereals in 1993-1995 were observed near by Kraków, Katowice, Opole, Chełm (south part of Poland). Since 2000 higher incidence of the pest has been observed around Poznań, Leszno, Legnica, Wrocław, Zamość and Chełm.

In autumn frit fly (*Oscinella frit*) infects winter cereals, moreover as a result of global warming there are four generations within a year. In 1970, around Rzeszów 8,1% infected winter cereals stems were observed, in 1971 around Koszalin – 5,2%, in 1976 11% near by Poznań. In eighties in some regions of Poland frit fly harmfulness increased, namely: 1985 – around Chełm 25% infected winter cereals stems were observed; 1988 – around Leszno15%; Wałbrzych – 17,3%; Przemyśl – 31,3%. In nineties frit fly harmfulness decreased – 1991, Wrocław – 14,3% infected stems; 1995, Krosno – 8%. In last few years, harmfulness of the pest has been increasing again: around Jelenia Góra in 2002 70% infected stems were noticed and near by Wrocław 30%.

Photo 1. Larvae of cereal ground beetle (*Zabrus tenebrioides)*

In autumn there has been additional infection of wheat bulb fly (*Phorbia coarctata*) observed in winter cereals. Long vegetation season in autumn and winter gives rise to increased infection of gout fly (*Chlorops pumilionis*), thrips (*Thrips*) and leaf mines (*Agromyzidae*). Information about pests occurrence and harmfulness were collected since 1970, pests were observed commonly but without economic meaning. Since 2000 their harmfulness has been increasing.

Thrips – 2000, around Siedlce 19% infected stems, Bydgoszcz 25%; 2002 – Jelenia Góra 20%, Bielsko Biała 30%, Białystok 40%.

Leaf mines – 2000, around Sieradz 9% infected stems, Katowice 12%; 2002 – Poznań and Piotrków Tryb. 10%, Bielsko Biała 6%, Białystok 40%.

Other pests which caused significant yield losses in last twenty years were: saddle gall midge (*Haplodiplosis equestris*) (Photo 2) – monitored from 1984, grain aphid (*Sitobion avenae*) – monitored from 1985 and cereal leaf beetle (*Oulema* spp.) (Photo 3) – monitored from 1991. Longer vegetation season favors development of aphids and leaf hoppers generations which increases the risk of viral disease infection in winter cereals. This species are the pest of economic value, therefore their harmfulness is being assessed in the area of the whole country.

Photo 2. Saddle gall midge (*Haplodiplosis equestris*)

Photo 3. Larvae of cereal leaf beetle (*Oulema* spp.)

Winter oil seed rape is threatened by cabbage stem flea beetle (*Psylliodes chrysocephala*) that is resistant to low temperatures. In case of warm autumn its activity and harmfulness increases. Similarly, in autumn there were observed increased number of: cabbage gall weevil (*Ceutorhynchus pleurostigma*), coleseed saw-fly (*Athalia colibri*) and cabbage root fly (*Phorbia brassicae*) in winter seed rape. Their activity and damages were observed even in November. The larvae of cabbage root fly damage the roots of winter seed rape that weakness the plant before winter season.

Winter cereals and seed rape infections in autumn are the main reasons of contaminated seeds material in spring and summer. It gives rise to extended diseases occurrence.

Photo 4. Brown rust (*Puccinia recondita*) on winter wheat

Climate warming in spring and summer seasons results in increasing quantity of some cereal diseases and pests such as brown rust (*Puccinia recondita*) (Photo 4), powdery mildew (*Blumeria graminis*) (Photo 5), fuzarium diseases on ears (*Fusarium* spp.) (Photo 6), septoria leaf spot (*Septoria nodorum*), tan spot (*Drechslera tritici*). There has been several symptoms of alternaria diseases (*Alternaria alternata*) infections on seed rape.

Photo 5. Powdery mildew (*Blumeria graminis*) on winter wheat

Photo 6. Fuzarium on winter wheat ears (*Fusarium* spp.)

As it comes to maize, higher temperatures in spring and summer favor infection conditions for common smut (*Ustillago mays*) (Photo 7) and therefore its more frequent occurrence. Common smut occurs in particular in regions affected with severe drought. Dry winds enhance the spore spraying. The number of soil pests increased in maize (contamination can lead to plantation destruction).

Photo 7. Common smut (*Ustillago mays*) on maize

In addition aphids and thrips feeding in drought season can cause fading in maize. Maize producers should be aware that global warming can lead to increased corn ear worm (*Helicoverpa armigera*) contamination. In Poland in order to prevent the spread of western corn rootworm (*Diabrotica virgifera*) the affected plantation is qualified for quarantine.

On the base of obtained results from 2008 (agrophages observed according to "detailed registration") and last 18 years it can be said that in Poland decrease of incidence of majority of pests/diseases is observed. It is a result of few factors: better knowledge about pests/diseases and their control, better cultivars and of course climate changes.

Harmfulness analysis in 2008 showed that some pests and diseases were observed in higher incidence (more than 10% of damaged/infected plants/stems/buds), namely: powdery mildew on winter wheat (*Blumeria graminis*), late blight (*Phytophthora infestans*) and colorado leaf beetle (*Leptinotarsa decemlineata*) on potatoes, cercospora leaf spot – *Cercospora beticola* and bean aphid - *Aphis fabae* on sugar beets, rape blossom beetle (*Meligethes aeneus*) on rape, downy mildew of cucumber – *Pseudoperonospora cubensis* and apple scab – *Venturia inaequalis* (Walczak *et al*. 1998).

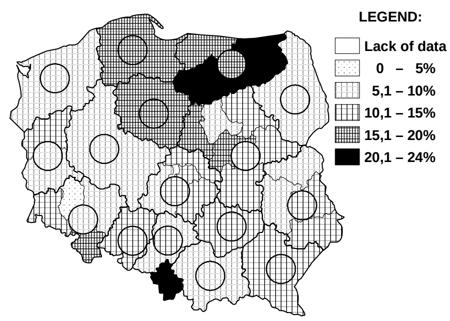
Powdery mildew on winter wheat (*Blumeria graminis*)

Average harmfulness in years 1991-2008 is 25.6% of infected stems. Since 2002 average disease incidence for Poland is below many years average (Fig. 1). Map 1 shows regions where more than 20% infected stems by powdery mildew were observed.

Late blight on potatoes (*Phytophthora infestans*)

Average harmfulness in years 1991-2008 is 47% infected potatoes plants. Similar to powdery mildew, since 2002 average disease incidence in Poland is below many years average (Fig. 2). Map 2 shows regions where more than 40%, even 60% of potatoes plants were infected by disease.

Blumeria graminis (DC.) Speer
2008



Map 1. Percentage of winter wheat stalks infected by powdery mildew (*Blumeria graminis*) in 2008

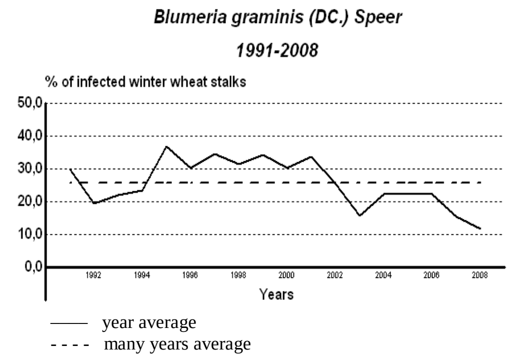
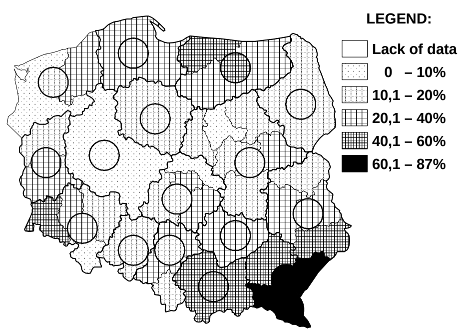


Fig. 1. Winter wheat stalks infected by powdery mildew (*Blumeria graminis*) in 1991-2008

Phytophtophthora infestans (Mont.)de Bary
2008



Map 2. Percentage of potato plants infected by late blight (*Phytophthora infestans*) in 2008

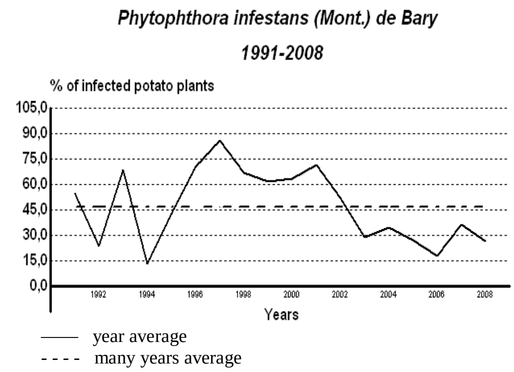


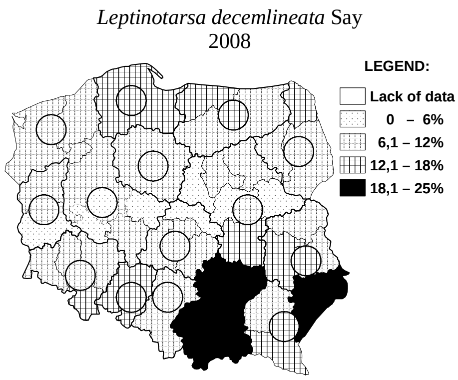
Fig. 2. Potato plants infected by late blight (*Phytophthora infestans*) in 1991-2008

Colorado leaf beetle (*Leptinotarsa decemlineata)*

Since 2003 decrease of average percent of damaged potato plants is observed (Fig. 3). In 2008 11,3% damaged potatoes plants were noticed. There were regions in Poland with higher colorado beetle harmfulness (close to many years average – 24.1%) – Map 3.

Cercospora leaf spot (*Cercospora beticola)*

Average harmfulness of disease in years 1991-2008 is 13.4% infected sugar beets plants (Fig. 4). In 2008 average for Poland was 16.7% infected plants but in some regions one could observe higher than many years disease incidence, even 50-77.3% – south-east part of Poland – Map 4.



Map 3. Percentage of potato plants damaged by colorado beetle (*Leptinotarsa decemlineata*) in 2008

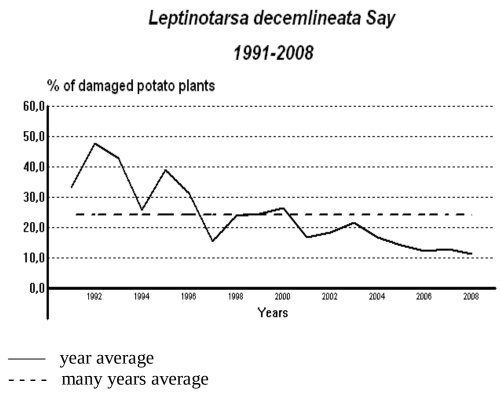
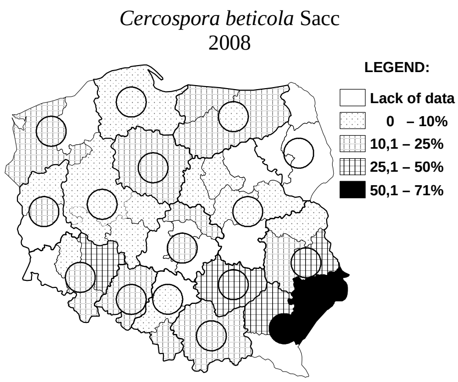


Fig. 3. Potato plants damaged by colorado beetle (*Leptinotarsa decemlineata*) in 1991-2008



Map 4. Percentage of sugar beet plants infected by cercospora spot (*Cercospora beticola*) in 2008

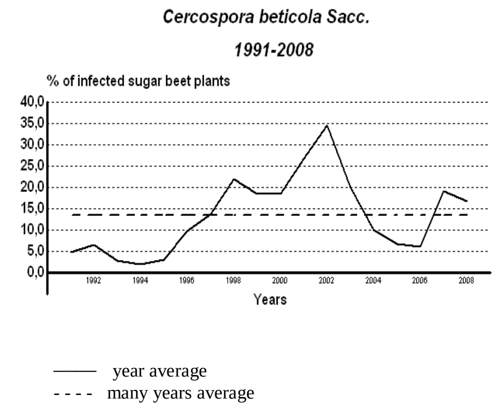


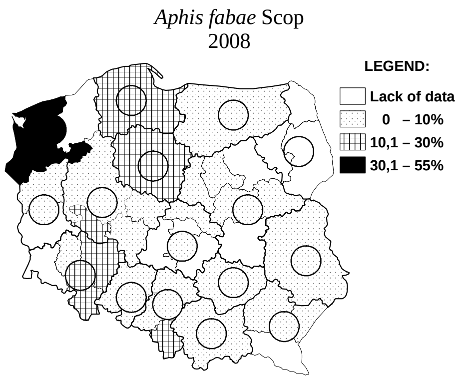
Fig. 4. Sugar beet plants infected by cercospora spot (*Cercospora beticola*) in 1991-2008

Bean aphid – *Aphis fabae*

Average harmfulness of bean aphid in years 1991-2008 is 10.2% damaged sugar beets plants (Fig. 5). In 2008, first time from five years average for Poland was higher than many years average. Map 5 shows regions with bean aphid incidence higher than 30% infected plants.

Rape blossom beetle (*Meligethes aeneus*)

Average harmfulness in years 1991-2008 of rape blossom beetle is 12.2% damaged rape buds (Fig. 6). In 2006 average for Poland was 10.6% damaged rape buds but in some regions one could observe higher than many years pest incidence (Map 6).



Map 5. Percentage of sugar beet plants damaged by bean aphid (*Aphis fabae*) in 2008

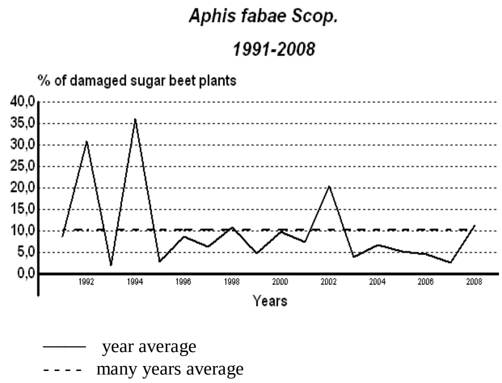
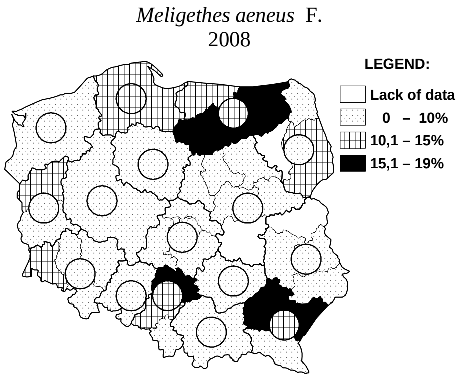


Fig. 5. Sugar beet plants damaged by bean aphid (*Aphis fabae*) in 1991-2008



Map 6. Percentage of winter rape buds damaged by rape blossom beetle (*Meligethes aeneus*) in 2008

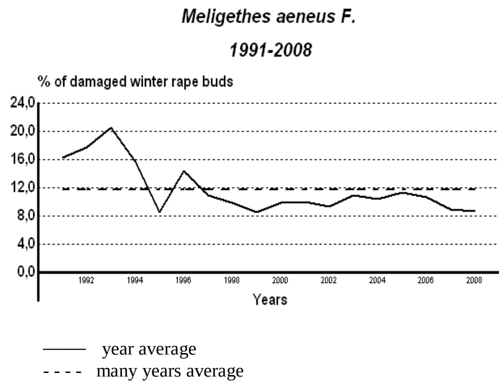
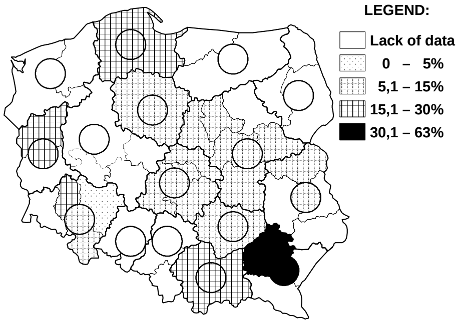


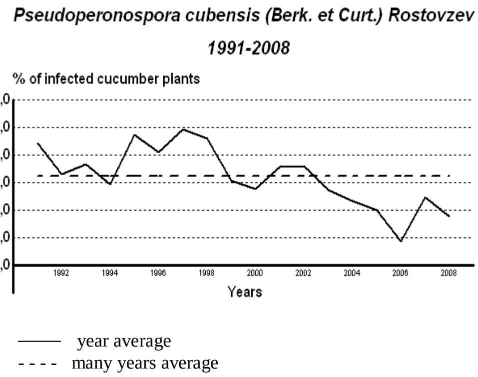
Fig. 6. Winter rape buds damaged by rape blossom beetle (*Meligethes aeneus*) in 1991-2008

Downy mildew of cucumber (*Pseudoperonospora cubensis)*
Average harmfulness of disease in years 1991-2008 is 32.4% infected cucumber plants (Fig. 7). In 2008 average for Poland was 17.8% infected plants but in some regions one could observe higher than many years disease incidence, even 63% - south-east part of Poland - Map 7.

Apple scab (*Venturia inaequalis)*
Average harmfulness in years 1991-2008 is 23.2% of infected apples. Since 2001 average disease incidence for Poland is below many years average (Fig. 8). Map 8 shows regions where more than 40% infected apples by apple scab were observed.

Pseudoperonospora cubensis (Berk. Et Curt.) Rostovzev – 2008

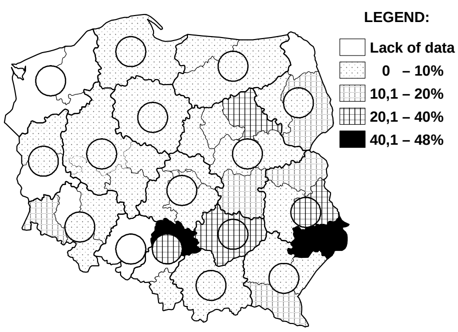


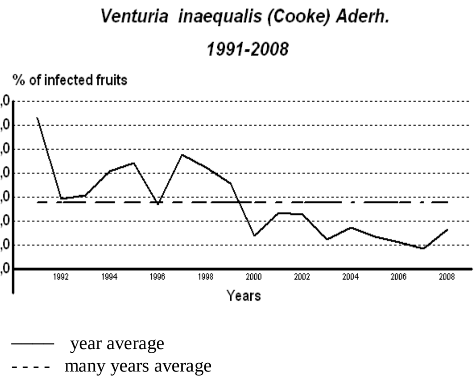


Map 7. Percentage of cucumber plants infected by downy mildew of cucumber (*Pseudoperonospora cubensis*) in 2008

Fig. 7. Cucumber plants infected by downy mildew of cucumber (*Pseudoperonospora cubensis*) in 1991-2008

Venturia inaequalis (Cooke) Aderh. 2008





Map 8. Percentage of apples fruits infected by apple scab (*Venturia inaequalis*) in 2008

Fig. 8. Apples fruits infected by apple scab (*Venturia inaequalis*) in 1991-2008

CONCLUSIONS

1. Some present and further changes regarding the economic importance of the agricultural plants agrophages as a result of climate changes/global warming are observed.
2. In Poland observation of economic significant agrophages enables to assess the health condition of the agricultural plants and also determine the changes in the quantity of particular agrophage species. Moreover it helps to determine the changes in pests and disease occurrence.
3. Further study on biology and morphology of new pest species will enable to determine the prevention methods of their harmfulness.

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9. CUMULATIVE DEGREE-DAYS AS AN INDICATOR OF AGROCLIMATIC CONDITION CHANGES IN THE WIELKOPOLSKA REGION. IMPLICATIONS FOR CODLING MOTH DEVELOPMENT

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INTRODUCTION

Degree-days concept and applications

The concept of "heat units" or "thermal time", in relation to plant development rate, was introduced first by the Reaumur in 1735. Since that time many methods of calculating heat units have been applied successfully in the agricultural sciences, mainly for description and prediction of specific phenological development events of plants and poikilithermic invertebrate species (insects & nematodes) as well as building population dynamics models (e.g. Gilmore and Rogers 1958, Allen 1976, McMaster and Wilhelm 1997). There are a lot of models presented in literature describing the phenological response of a specific species to temperature (e.g. Kramer *et al.* 2000). The modeling approaches are often different, but most models are based on temperature (Cesaraccio *et al*. 2001).

Developmental rates (1/time to develop) of plants and invertebrates are assumed to increase approximately linearly as a function of temperature (from a lower to an upper threshold temperatures, if specified), and heat units are a measure of the time duration at various temperatures (e.g. Roltsch *et al.* 1999, Synder *et al.* 1999, Bonhomme 2000). Therefore, heat units expressed as degree-hours or degree-days (*DD*), which are an accumulated product of time and temperature between developmental threshold for each hour/day, are commonly used to quantify phenological development (often called as "physiological time") of above mentioned organisms (Allen 1976, Baskerville and Emin 1969, Roltsch *et al.* 1999, Synder *et al.* 2001). Although nonlinear developmental rate models are common, linear-based degree-days models have been proved to provide much better predictive capability in the field conditions (e.g. Roltsch *et al.* 1990, Hochberg *et al.* 1986, Fan *et al*. 1992). However, regardless of calculation method, degree-hours/days are never more than only estimates of developmental time (Higley *et al.* 1986).

One degree-hour is observed, when the air temperature is one degree above a lower threshold temperature for 1 hour (Snyder *et al.* 1999). It is assumed that the development rates of considered organisms are insignificant below the specified lower temperature threshold and above an upper threshold (defined for some organisms, when no further increase in development rates is expected). In such a case, the number of degree-hours equals the observed air temperature minus the lower threshold temperature, only when the air temperature is more than one degree above lower threshold temperature and below upper threshold temperature for 1 hour. Degree-days are calculated as the total number of degree-hours for a day, divided by 24. As a consequence, a bigger difference between air and lower threshold temperatures implies more degree-days and faster developmental rates (Snyder *et al.* 1999). Therefore, the number of days needed for the growth or phenological development of plant and invertebrate species decreases at higher temperature (Cesaraccio *et al.* 2001).

Degree-days values are estimated with the greatest accuracy only when they are calculated based on the hourly weather data. Nevertheless, in most cases when hourly data are not available, the daily maximum (T_{max}) and minimum (T_{min}) temperatures are used to estimate *DD* by approximating diurnal temperature curves (Snyder *et al.* 1999). The calculation of degree-days based on the daily min/max temperatures relies on the assumption that a daily temperature profile can be represented by a specific geometric shape (Roltsch *et al.* 1999). Therefore, variety of methods with varying degrees of complexity have been developed to approximate diurnal temperature curves and to estimate *DD* (Cesaraccio *et al.* 2001). Several most commonly used methods of degree-days estimation were compared and evaluated by Roltsch *et al.* (1999). The results of their analyses showed that the single triangulation and sine-wave methods should be preferred for *DD* estimation, as they are less complicated than other more sophisticated methods, giving very satisfactory results (in comparison to degree-days calculated based on the hourly data). In a sine-wave method, the single symmetrical sine-wave curve is fitted to the daily curves of temperatures (Baskwerwill and Emin 1969, Allen 1976, De Gaetano and Knapp 1993, Roltsch *et al*. 1999, Yin *et al.* 1995). This method is recommended to be applied at field conditions for estimation of degree-days (Pruess 1983, http://www.ipm.ucdavis.edu/).

Climate change vs. pests occurrence

Insects are the most diverse class of organisms on the Earth. Because insects have mostly detrimental effects on natural ecosystems and human, more and more studies are concentrated on the potential impact of the global environmental changes onto them (e.g. Harrington *et al*. 2001). This is known that the climate is the dominant factor determining the distribution and abundance of most insect species (Sutherst 2000). The habitats of insects and survival strategies are strongly dependent on local weather conditions, and are essentially sensitive to temperature as they are cold-blooded. Insects respond to higher temperature with increased development rates and less time between generations (Rosenzweig *et al*. 2001).

Over the last 100 hundred years (1906-2005) the global average temperature has increased by 0.74°C. The linear warming trend over the 50 years from 1956 to 2005 (0.13°C per decade) is nearly twice that for the 100 years from 1906 to 2005, while the eleven of the last twelve years (1995-2006) ranked among the twelve warmest years in the instrumental record of global surface temperature (since 1850) (IPCC, Climate Change Synthesis Report 2007). These facts need to be taken into account at any discussions related to pests and their impacts on ecosystems, as the temperature is the key environmental driver of insect's development (e.g. Edelson and Magaro 1988, Harrington *et al.* 2001). The predicted temperature change will definitely increase the cumulative degree-days values (Bergant *et al.* 2006). Through the temperature and *DD* changes, the climate changes are strongly affecting the insects' phenology, physiology and spatial distribution (e.g. Harrington *et al.* 2001, Yamamura *et al*. 2006). Warming conditions will affect insect populations by extending the growing season, altering timing of emergence, increasing growth and development rates, shorting generation times and consequently increase the number of generations, reducing overwintering mortality and consequently increase insect populations in subsequent growing season, increasing risks of invasion by migrant pests and altering their geographical distribution (Porter *at al.* 1991, Sutherst 2000, Rosenzweig and Hillel 1998, Rosenzweig *et al.* 2001, Strand 2000, Bergant *et al.* 2006, Olfert and Weiss 2006, Trnka *et al.* 2007). Many species have already responded to warming conditions that have occurred over the last century. For example, Root *et al.* (2003) reported that changes in spring timing of events (breeding, blooming) occurred 5.1 days earlier per decade. While, observed warming trends, for example, in the Canada and U.S. led to earlier spring activity of insects and proliferation of some species, such as the mountain pine beetle (Crozier and Dwyer 2006, IPCC 2007). Importantly, increased climate extremes may promote also pest outbreaks (Alig *et al.* 2004, Gan 2004).

Considering above, the main goal of this paper is to estimate how the observed climate changes over the last 34 years period affected the timing of some pest (e.g. Codling Moth) appearance in the southern part of the Wielkopolska Region (Poland). The degree-days are calculated to present: *1)* trends of changes of their cumulative *DD* values, and *2)* to estimate dates of appearance of some development stages of selected pest, in the past and present climate conditions, and 3) to proved that the cumulated degree-days values analyzed over longer period can be used as an indicator of agroclimatic condition changes.

METHODS

Degree-days calculation

Considering the above mentioned recommendation of Pruess (1983), the single-sine method was applied within our study for degree-days estimation. The single-sine technique uses a day's minimum and maximum temperatures to produce a sine-wave curve within a 24-hour period, and then estimates degree-days for that day by calculating the area between the defined temperature thresholds (lower and upper) and below the curve (Baskerville and Emin 1969, Allen 1976, Zalom *et al.* 1983). This method assumes the temperature curve is symmetrical around the maximum temperature (Fig. 1).

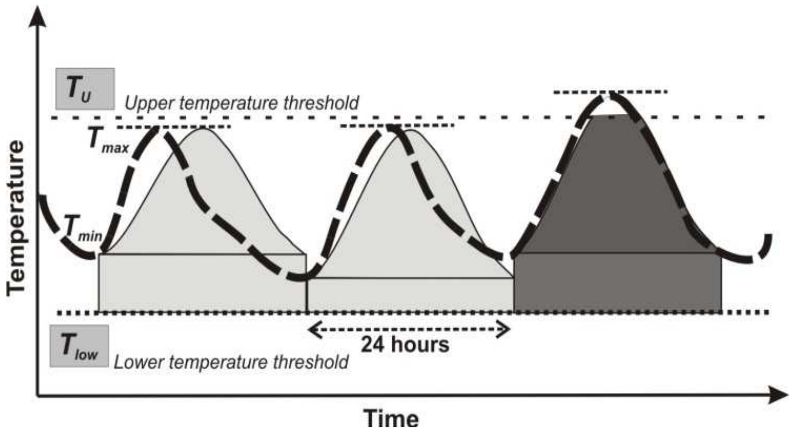

Fig. 1. The graphic interpretation of single-sine method used for approximation of daily temperature curve and estimation of degree-days (based on: http://www.ipm.ucdavis.edu/)

Formulas used for degree-days calculation for 24-hours period are different and depends on if and where a sine curve is intercepted by temperature thresholds (Tab. 1). In our study degree-days were calculated based on an air temperature measured at 2 m above surface. For all degree-days calculations a lower temperature thresholds of 0.0°C and 10.0°C were utilized. The 10.0°C threshold is commonly used in many studies, as this lower threshold temperature is representative of many insect species (Preuss 1983), for instance, for Codling Moth (*Cydia pomonella* L.), which has the greatest potential for damage of any apple pests. The upper temperature threshold for Codling Moth is 31.1°C (http://www.ipm.ucdavis.edu).

It was assumed that there are no upper temperature thresholds in all calculations (with T_{low} 0.0°C and 10.0°C) done in our analyses, besides the degree-days estimation carried out for Codling Moth, where the T_U is defined (31.1°C). In such a case, when the upper threshold is utilized, the horizontal cut-off method was applied, to subtract the area between above the upper threshold and sine curve, from the area above the lower threshold. This cutoff method assumes that development of the insect continues at a constant rate at temperature in excess of the upper threshold and is not increasing or stopped above this threshold (http://www.ipm.ucdavis.edu/).

Table 1. Formulas used for degree-days calculation (based on: (http://www.ipm.ucdavis.edu/)

No		Formulas
1	$\boldsymbol{T_{max} > T_U}$, $\boldsymbol{T_{min} < T_{Low}}$ *Sine curve is intercepted by both thresholds*	$DD = \frac{1}{\pi}\left\{\left(\frac{T_{max} + T_{min}}{2} - T_{Low}\right)(\theta_2 - \theta_1) + \alpha[\cos(\theta_1) - \cos(\theta_2)] + (T_U - T_{Low})\left(\frac{\pi}{2} - \theta_2\right)\right\}$, were: $\theta_1 = \sin^{-1}\left[\left(T_{Low} - \frac{T_{max} + T_{min}}{2}\right) \div \alpha\right]$ $\theta_2 = \sin^{-1}\left[\left(T_U - \frac{T_{max} + T_{min}}{2}\right) \div \alpha\right]$
2	$\boldsymbol{T_{max} > T_U}$, $\boldsymbol{T_{min} > T_{Low}}$ *Sine curve is intercepted by upper threshold*	$DD = \frac{1}{\pi}\left\{\left(\frac{T_{max} + T_{min}}{2} - T_{Low}\right)\left(\theta_2 + \frac{\pi}{2}\right) + (T_U - T_{Low})\left(\frac{\pi}{2} - \theta_2\right) - [\propto \cos(\theta_2)]\right\}$, where: $\theta_2 = \sin^{-1}\left[\left(T_U - \frac{T_{max} + T_{min}}{2}\right) \div \alpha\right]$
3	$\boldsymbol{T_{max} < T_U}$, $\boldsymbol{T_{min} < T_{Low}}$ *Sine curve is intercepted by lower threshold*	$DD = \frac{1}{\pi}\left\{\left(\frac{T_{max} + T_{min}}{2} - T_{Low}\right)\left(\frac{\pi}{2} - \theta_1\right) + \propto \cos(\theta_1)\right\}$, where: $\theta_1 = \sin^{-1}\left[\left(T_{Low} - \frac{T_{max} + T_{min}}{2}\right) \div \alpha\right]$
4	$\boldsymbol{T_{max} < T_U}$, $\boldsymbol{T_{min} > T_{Low}}$ *Sine curve is between both thresholds*	$DD = \frac{T_{max} + T_{min}}{2} - T_{Low}$
5	$\boldsymbol{T_{max} < T_U}$, $\boldsymbol{T_{min} < T_{Low}}$ *Sine curve is completely above both thresholds*	$DD = T_U + T_{Low}$
6	$\boldsymbol{T_{max}}$ **&** $\boldsymbol{T_{min} < T_{Low}}$ *Sine curve is completely below both thresholds*	$DD = 0$

Where:

T_U – Upper temperature threshold
T_{Low} – Lower temperature threshold
T_{max} – Maximum daily temperature
T_{min} – Minimum daily temperature
$\alpha = (T_{max} - T_{min})/2$

Codling Moth (*Cydia pomonella* L.) **ecology and modelling parameters**

The larva of the Codling Moth is the famous "worm in the apple" of vernacular fame. Left to only natural controls, the Codling Moth can infest even 90 percent of an apple crop. The primary means of controlling the codling moth is one to four insecticidal cover sprays over growing season. Appropriate timing of cover sprays is a critical factor in obtaining adequate control of the Codling Moth with minimum insecticide usage (Brunner and Hoyt 1987). This is very important to control the development of the Codling Moth, as this insect is able to produce, dependently on the climatic zones, even up to 3-4 generations during one year (in Poland up to 2 generations). Pupation of wintered caterpillars begins at an average daily temperature of 10°C, and it takes 1-2 months. Mass pupation coincides with flowering of early varieties of apples. Flight of imago occurs in spring at temperatures not lower than 16-17°C, and starts to be visible soon after flowering of apple, reaching a maximum in 2-3 weeks during the formation of seed-buds. Moths of a 2^{nd} generation appear usually during the flight of the moths of a 1^{st} generation. Therefore, all stages of the pest development may be observed in nature (http://www.agroatlas.ru/en/content/pests/Cydia_pomonella/).

To approximate the time, when the Codling Moth will reach a particular development stage during the growing season, the degree-days method is most often applied by orchardists. Degree-days necessary for the estimation of development stages of Codling Moth are most often calculated based on the single sine method with horizontal cut-off technique (Brunner and Hoyt 1987).

Experimentally was proved that the first flights of imago are observable when cumulative degree-days values reach about 110-130*DD* (this is so called Codling Moth model BIOFIX which is defined each season as a biological cue used to initiate the modelling to define the dates of covering sprays), while 50% of moths flights happened when *DD* are about 230-250, when calculated since beginning of the year (this is also the time when the first larvae are hatching from eggs and first cover sprays needs to be applied). The first generation of Codling Moth requires about 600*DD* to finalize its development, while the first moths flights of a 2^{nd} generation appears when cumulative degree-days reach 650-670*DD*. When, however, degree-days values reach 1200-1250*DD*, about 95% of larvae of a 2^{nd} generation is already hatching. That means, this is really possible that the imago moth of a 3^{rd} generation will start to be active at this time if the air temperature is above 16^{o}C (Brunner and Hoyt 1981, 1982, 1987). Degree-days are estimated in such studies based on temperatures expressed in ^{o}C.

In our paper we calculate cumulative degree-days values for the whole 34 years period since 1972-2005, for both lower thresholds T_{low} 0.0^{o}C and 10.0^{o}C in the way described above, and then we looked for the dates when 110*DD*, 230*DD*, 650*DD* and 1200*DD* were reached, to estimate the time of appearing some developmental stages of the Codling Moth (as described above).

The 34 years temperature data were taken from the Turew station of the Polish Academy of Science (southern part of the Wielkopolska Region).

RESULTS

Air temperature changes

The average annual air temperature of the Turew station equals 8.9°C. However, in the coolest 1980 year the average temperature of the year was 7.0°C, while in the warmest 2000 year it reached a value of 10.6°C. The distribution of an average yearly air temperature over the whole 34 years period, since 1972 till 2005, is presented in Figure 2.

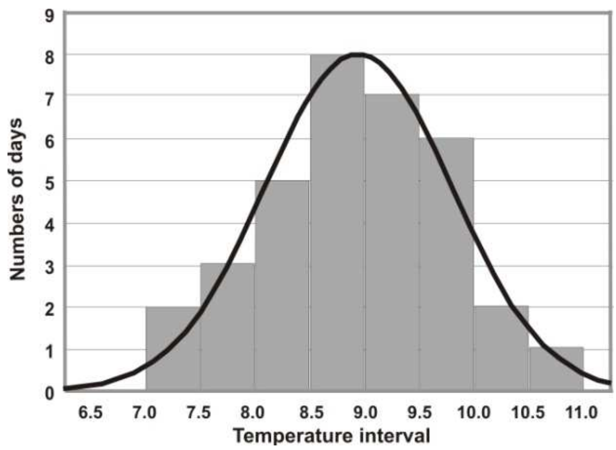

Fig. 2. Histograms of an average annual air temperatures for the Turew station over the period 1972-2005

The average yearly air temperature increased over the whole period at 0.33°C per decade. These temperatures changed from 8.4°C in 1972 till ca. 9.5°C in 2005 (calculation based on the linear equation trend). However, the observed linear warming trend was much more significant for the period from April till June (three most important months of a growing season in the Wielkopolska Region), when temperature increased about two times faster than for the whole year (0.57°C per decade) (Fig. 3, Tab. 2). These temperature changes are assumed to have essential influence onto the rate of many plant species and pests development over the growing season.

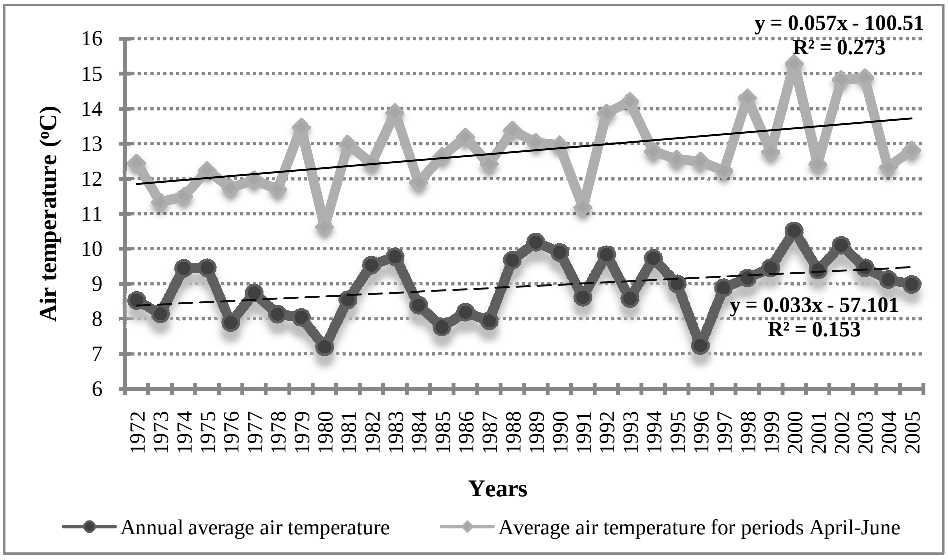

Fig. 3. Average annual air temperature and average temperature of 3-months periods from April to June for the period 1972-2005, Turew station (southern part of the Wielkopolska Region)

Degree-days values changes

Considering above mentioned temperature changes it was interesting to check how the cumulated degree-days values are changing over the whole 34 years period. Degree-days were calculated based on the assumption that the lower temperature thresholds are 0.0°C and 10.0°C. In these calculations we did not establish any upper temperature thresholds. All analyses were carried out based on quarter's cumulated degree-days values.

The maximum cumulated degree-days values reached 3920*DD* in the year 2000, when they were calculated for T_{low} = 0.0°C (average for the whole 34 years period is 3471*DD*). While, for T_{low} = 10.0°C, the degree-days exceeded 1370*DD* at the end of the year 2003 (average 1100*DD*) (Tab. 2). In both cases, the degree-days increasing linear trends were observed over the seasons and the whole year and they were statistically significant for the second, third and fourth quarters. In the first case (T_{low} = 0.0°C), cumulated maximum degree-days values (at the end of the year) increased over the whole period at the rate of 117*DD* per decade, while in the second example (T_{low} = 10.0°C), they increased at about 80*DD* per decade (Fig. 4 and 5). These trends and changes of cumulated degree-days values needs to have an essential effect on a phenology of pests and plants.

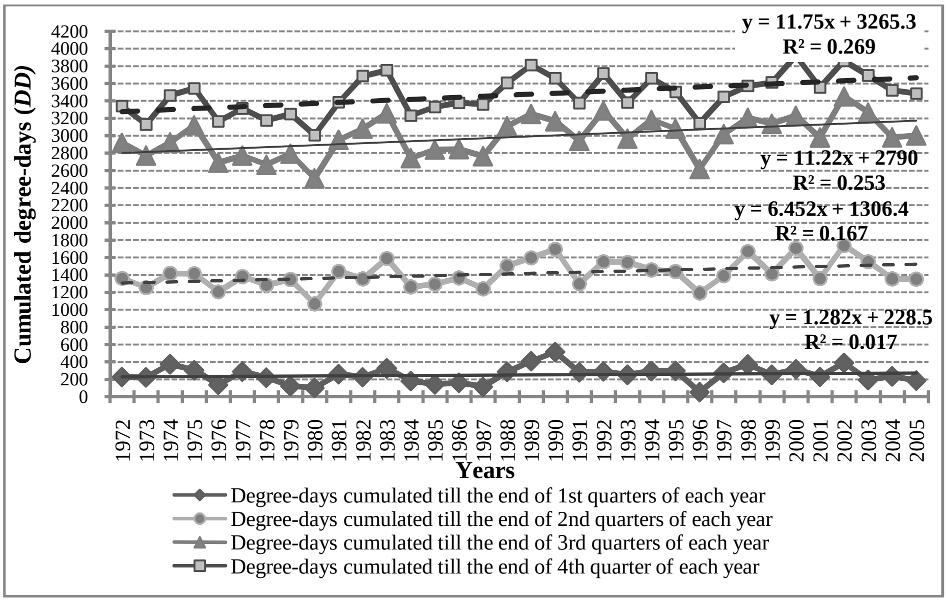

Fig. 4. Degree-days values cumulated till the end of each quarter of each year for $\boldsymbol{T_{low}}$**=0.0°C** and for the period of 1972-2005, Turew station (southern part of the Wielkopolska Region)

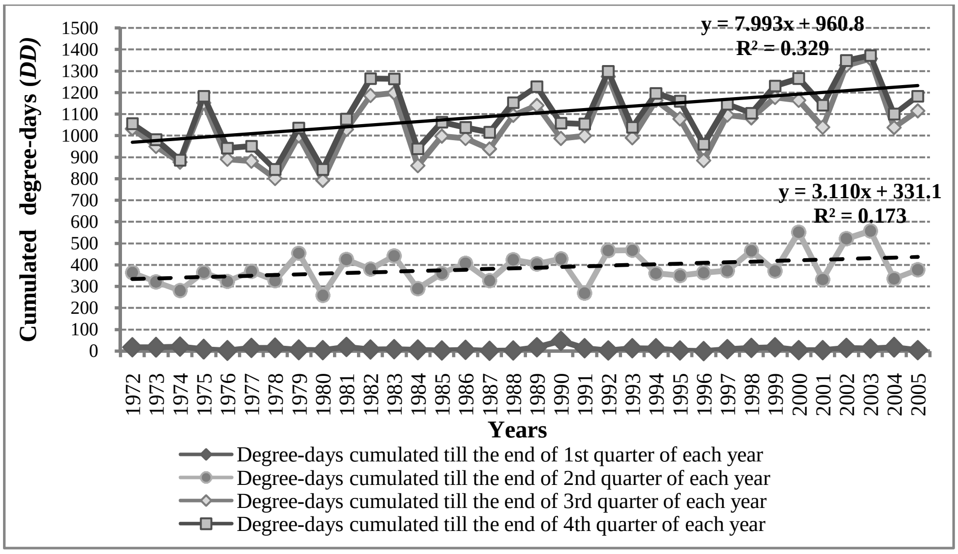

Fig. 5. Degree-days values cumulated till the end of each quarter of each year for $\boldsymbol{T_{low}}$**=10.0°C** and for the period of 1972-2005, Turew station (southern part of the Wielkopolska Region)

Table 2. Main statistical characteristics of the analyzed temperature and degree-days series for the period of 1972-2005

	Yearly average air temperature	*year*	*Average air temperature for period April-June*	*year*
MIN	7.0	1980	10.6	1980
MAX	10.6	2000	15.3	2000
AVERAGE	8.9		12.8	
STAND. ERROR	0.9		1.1	
'a' parameter	0.033		0.057	
Trend significance	*significant*		*significant*	

LOWER TEMPERATURE THRESHOLD (T_{low} = 0.0°C)

	1st quarter	year	*2nd quarter*	year	*3rd quarter*	year	*4th quarter*	year
MIN	53.4	1996	1079.6	1980	2510.7	1980	3006.0	1980
MAX	513.9	1990	1739.4	2002	3452.5	2002	3920.9	2000
AVERAGE	250.9		1419.3		2986.8		3471.0	
STAND. ERROR	96.9		157.2		222.3		225.6	
'a' parameter	1.282		6.452		11.223		11.753	
Trend significance	*NOT significant*		*significant*		*significant*		*significant*	

LOWER TEMPERATURE THRESHOLD (T_{low} = 10.0°C)

	1st quarter	year	*2nd quarter*	year	*3rd quarter*	year	*4th quarter*	year
MIN	0.0	1996	257.6	1980	792.6	1980	842.2	1980
MAX	47.7	1990	556.6	2003	1358.0	2003	1372.9	2003
AVERAGE	10.5		385.5		1046.4		1100.6	
STAND. ERROR	9.0		74.4		140.6		138.8	
'a' parameter	-0.062		3.110		7.396		7.993	
Trend significance	*NOT significant*		*significant*		*significant*		*significant*	

Changes of appearance dates of some developmental stages of Codling Moth (*Cydia pomonella* L.)

To estimate the appearance of some developmental stages of Codling Moth, degree-days were calculated based on T_{low}=10.0°C, and T_U=31.1°C. Fourth stages of development of Codling Moth were selected and analyzed based on the cumulative degree-days values: *1)* first flights of imago moths of a 1st generation (110*DD*); *2)* flying of 50% of imago moths of a 1st generation (230*DD*); *3)* first flights of imago moths of a 2nd generation (650*DD*); *4)* 95% of larvae of a 2nd generation is hatching and possible appearance of imago moths of a 3rd generation (1200*DD*).

All of the above mentioned development stages of the Codling Moth were appearing earlier from year to year (Fig. 6 and 7). Decreasing trend of dates when these development stages can appeared are significant statistically. According to our study, the first flights of imago moths were appearing earlier at about 4 days per decade within analyzed 34-years period, starting at about 142 day of a year (DOY) in 1972 and finishing at about 130 DOY in 2005, in average at 137 DOY (Fig. 6, Tab. 3). 50% of imago moths flights were appearing at about 167 DOY in 1972 and at the end of analyzed period they appeared at 152 DOY (in average at 159 DOY), that means about 4 days earlier from decade to decade. What seems to be most important, however,

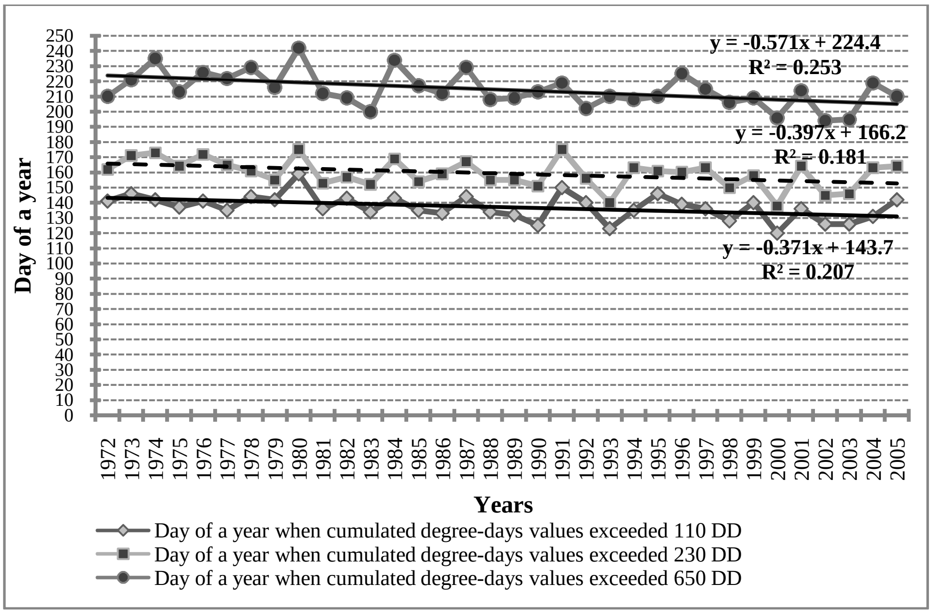

Fig. 6. Days of a year when cumulated degree-days values (T_{low}=10.0°C) reached specified threshold values (110*DD*, 230*DD*, 650*DD*) and some developmental stages of Codling Moth can appear, for the period 1972-2005, Turew station (southern part of the Wielkopolska Region)

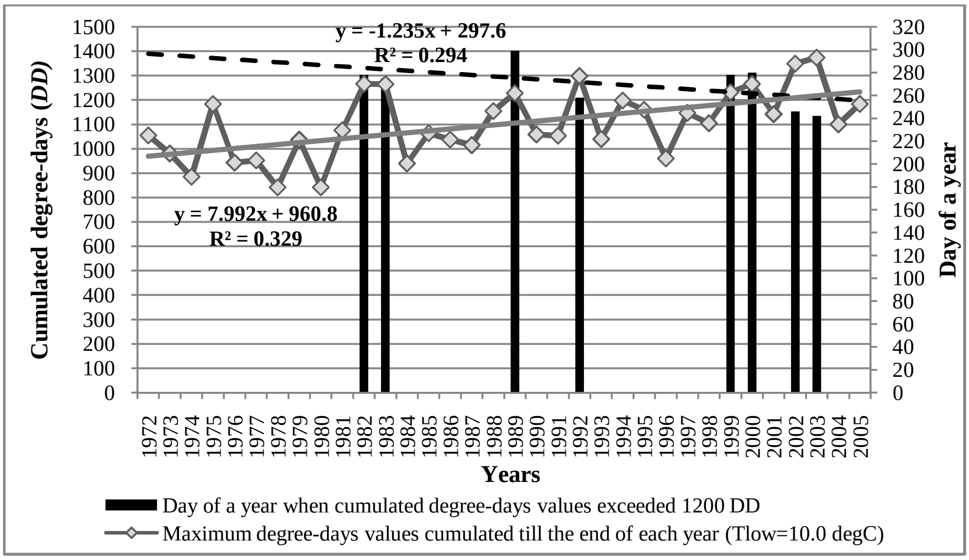

Fig. 7. Days of a year when cumulated degree-days values (T_{low}=10.0°C) reach a threshold value of 1200*DD*, when theoretically 3rd generation of Codling Moth can appear

Table 3. Main statistical characteristics of analyzed data series of a time when some degree-days thresholds were reached in the period of 1972-2005 (Turew station)

	Day of a year when cumulated degree-days values reached:							
	110*DD*	year	230*DD*	year	650*DD*	year	1200*DD*	year
MIN	120	2000	138	2000	194	2002	242	2003
MAX	159	1980	175	1980	242	1980	299	1989
AVERAGE	137		159		214		270	
STAND.ERROR	8,1		9,3		11,3		19	
"a" parameter	–0.37		-0.40		-0.57		–1.03	

the 2nd generation of Codling Moth were appearing about 6 days earlier per decade (at about 225 DOY in 1972, and at 205 DOY in 2005). This change could have probably essential influence on apple orchards management practices, as orchardists will have to take much more attention on possible appearance of a 2nd generation of Codling Moth than e.g. 30 years ago, as this could have economic consequences.

According to our studies, there is only little chance to develop a 3rd generation of Codling Moth in the Wielkopolska Region. Within the analyzed series of data there were only 8 years, when cumulated degree-days calculated between thresholds T_{low}=10.0°C and T_U= 31.1°C exceeded 1200*DD* (Fig. 7). However, four of these years occur within 5 years between 1999-2003. The linear increasing trend of days when 1200*DD* were exceeded is statistically less significant, but the trend is visible and it has to be assumed that this *DD* threshold will be exceeded in future much frequently than before. Of course, this threshold is reached definitely too late (the average air temperature can be too low) to develop the 3rd generation of Codling Moth, but theoretically this would happen possible in future.

DISCUSSION AND CONCLUSIONS

Analyzes carried out within our studies, on example of one 34-years temperature series from Turew station in southern part of the Wielkopolska region, confirm the globally observed climate warming trend. However, it seems that the observed temperature changes over time are getting about 3-times bigger per decade in the Wielkopolska Region, than the average global linear warming trend reported in the IPCC (IPCC, Climate Change Synthesis Report 2007). Nevertheless, we would like to emphasize that the rate of temperature changes was the biggest for the first part of the growing season (April, May, June), what could have essential influence for instance on growing plants, pests, and as a consequence on all management practices (sowing dates, covering spraying etc.). Spring season is getting warmer and warmer decade per decade and this will definitely affect the physiology and phenology of different pests, what have been already reported and predicted for example by Porter *at al.* (1991).

Our results confirm that the pests development is depending on temperature changes and some stages of insects development can appear much earlier in present climate conditions than e.g. 30 years ago. The cumulated degree-days values were increasing over analyzed period and statistically are getting bigger and bigger year by year, analogous with observed temperature changes. Consequently, the key thresholds of cumulated degree-days values, determining the appearance date of some developmental stages of pests, were reached much earlier over time, even 4-6 days earlier per decade in case of Codling Moth. This trend is in agreement with the results reported for example by Root *et al.* (2003). This change needs to be taken into account by farmers, orchardists and farmers advisors, as in the predicted climate conditions (when average annual temperature will increase at few degrees Celsius), these changes will accelerate a timing of pests appearance on crops. That means, also some protective actions (e.g. covering sprays) will have to be taken earlier than before.

Thanks to our analyses we proved that cumulated degree-days can be used as an indicator of an agroclimatic condition changes. This is very worthy to have determined degree-days key-thresholds, for both plant and pests most important developmental stages, to better determine timing of their appearance on field.

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10. ADAPTATION STRTEGIES OF AGRICULTURE TO CLIMATE CHANGE IN TERMS OF PLANT PROTECTION

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INTRODUCTION

Global climate change is not only going to cause many, still difficult to identify processes in the natural environment and agriculture, but it is also going to modify socio-economic processes and phenomena (Bański and Błażejczyk 2008). Climate scenarios for Poland forecast an increase in the concentration of greenhouse gases in the atmosphere and air temperature, together with a higher or lower level of precipitation. This will facilitate an extension of the range of cultivation of more thermophilous crops, while in the scale of individual plants evapotranspiration is going to decrease at an increased CO_2 content, water utilization will be more efficient and the rate of photosynthesis will increase. Forecasted climatic conditions will have a significant effect on the soil medium, stepping and erosion processes as well as changes in the cropping structure adapted to the changed habitat. A significant effect on modifications of crop production will be found for relations between crops and their agrophages (Wyszyński *et al*. 2008, Pradeep and Shane 2003).

The importance of weather conditions for the growth and development of crops and their agrophages is well-known, thus it is required to indicate necessary adaptation activities to climate change in terms of plant protection in Poland.

THE EFFECT OF CLIMATE ON DISPERSAL AND IMPORTANCE OF AGROPHAGES

The incidence of agrophages is directly and indirectly dependent on climate conditions, which determine the biology of organisms and their behaviour and eventually also the quantitative parameters of their populations. Because of the great variation of organisms in terms of species-specific responses to meteorological conditions, the relationships between pests and weather are not susceptible to overall characterization. The incidence of agrophages results also from the influence of climatic phenomena on other, biological, technological and socio-economical factors, exhibiting a significant effect on the economic importance of agrophages.

Two main groups of factors are crucial in this respect:

1. Changes in cropping structure and crop properties, including species composition of plants, the duration of their vegetation period, but also plant morphology and physiology,
2. Changes in cultivation technologies, particularly plant protection, as well as soil cultivation techniques and technologies, crop cultivation, fertilization (especially foliar application of fertilizers) and irrigation.

Potentially the fastest rate of conquering new territories is observed for pathogens, followed by pests and finally weeds. The degree to which a given pathogen conquers a new environment is dependent on the mechanism of pathogen dispersal, suitability of the environment for dispersal, survival between seasons, and physiological and ecological changes in the host plant (Ghini *et al*. 2008). However, even pathogens under climate change may potentially be unable to migrate or adapt as rapidly as environmental conditions change (Garret *et al.* 2006). Forecasted spatial and time distribution of certain agrophages may be followed based on simulations. Carter *et al*. (1996) using a simulation of climate change in Finland presented probable trends in the dispersal and importance of potato cyst nematode (*Globodera rostochiensis*) and potato blight (*Phytophthora infestans*). These and other pioneering studies assumed constant increments in temperature, precipitation, or other climate variables (Ghini *et al*. 2008).

In recent years a relatively large number of simulation studies have been conducted on the dispersal of agrophages, based on the continuously improved General Circulation Models (GCM) and climate change scenarios (A1, A2, B1 and B2) of the Intergovernmental Panel on Climate Change (IPCC), referring to the forecasted emissions of greenhouse gases. Based on the GCM model Bergot *et al*. (2004) presented the expansion of *Phytophthora cinnamomi* in oak. Salinari *et al*. (2006) investigated downy mildew of grape, caused by *Plasmopara viticola*. Evans *et al*. (2008) simulated the dispersal of phoma stem canker epidemics on oilseed rape in the UK. Several simulations studies were conducted in Brazil (Ghini *et al*. 2008), concerning black-sigatoka of banana (*Mycosphaerella fijiensis*), *Meloidogyne incognita* and leaf miner (*Leucoptera coffeella)* for the coffee crop. Moreover, modelling of weed incidence is also developed, which seems particularly significant in case of invasive species (Crossman *et al*. 2008).

Lipa (2008) pointed to the need to conduct such model studies in Poland. A lack of detailed models of agrophage dispersal as a consequence of climate change is going to reduce to a certain degree the precision of adaptation activities in terms of plant protection, although it will not change its essence. In turn, for many years now continuous monitoring of agrophage incidence has been conducted, which facilitates the recreation of changes in the history of their incidence and importance (Walczak and Tratwal 2008). Obviously we need to take into consideration changes in the spatial dispersal of agrophages, the intensity of their occurrence as well as changes in their economic importance. The penetration of new invasive agrophage species to Poland is inevitable, while on the other hand it is also true of other organisms, including parasites and predators of these agrophages (Korbas 2008, Lipa 2008, Walczak and Tratwal 2008). Despite these changes, yielding potential in Poland, belonging to the continental north zones of Europe, is also expected to increase, the same trend being forecasted also for the boreal and Atlantic central zones of Europe. A study by Jaczewska-Kalicka (2008) indicates the effect of climate change on the quality and yields of cereals in Poland. The importance of problems resulting from the incidence of diseases and pests as well as their control, is considered to be medium in the overall picture of phenomena resulting from climate change (Iglesias *et al*. 2007). At the same time a high risk of increased crop hazard posed by diseases, pests and weeds is indicated in almost all parts of Europe, except for the Alpine regions and the Atlantic north zone. In a report prepared for the European Commission on Adaptation to Climate Change in the Agricultural Sector (Iglesias *et al*. 2007) the relationship between forecasted directions of changes in basic climatic factors and crop hazard by agrophages in Europe was presented as follows:

1. a medium hazard of altered weed ecology with potential for increased weed competition with crops is related with an increase in the amount of CO_2,
2. a high hazard of losses caused by agrophages is connected with precipitation intensity intensifying the hydrological cycle, but with regional variations,
3. a high hazard of changes in the incidence of weeds, pests and plant diseases is connected with an increase in temperature,
4. a high risk of increased crop hazard posed by pests is connected with water stress.

CULTIVATION TECHNOLOGY, PLANT PROTECTION MEASURES AND CLIMATE CHANGE

Prevention of water losses in soil will first of all impose the need to apply adequate cultivation technologies and techniques minimizing its reversal and transport and this will have an effect on the incidence of pests, weeds and diseases. This will result in better conditions and more intensive incidence of agrophages connected with this type of land use, generally perennial weeds and pests with the development cycle extending over several years, i.e. grubs, wireworms and secondary and soil-borne pathogens.

Climate also has an impact on the action of plant protection products. The intensity and timing of rainfall influence pesticide persistence and efficiency, while temperature and light affect pesticide persistence through chemical alteration (Rosenzweig *et al*. 2001). Under conditions of a warmer climate, pests may become more active than currently and may expand their geographical range, resulting in an increased use of agricultural chemicals (Rosenzweig *et al*. 2001). A study by Chen and McCarl (2001) showed that with an increase in precipitation or temperature the use of pesticides increased in corn, cotton, soybean and potatoes, as evaluated in several locations in the USA, while it decreased in wheat.

Morphological and physiological changes in plants, being a consequence of increased CO_2 concentration and drought, will have a significant effect on the uptake, translocation and metabolism particularly in case of systemic plant protection preparations (Patterson 1995). Poorer efficiency may, among other things, result from an increase in the thickness of the epicuticular wax layer (Coakley *et al*. 1999) or increased leaf pubescence, which may reduce the penetration of substances into plants. Studies by Ziska *et al*. (1999 and 2004) indicate a decreased efficiency of the action of glyphosate at an increased CO_2 level. However, biological activity of most pesticides increases generally with an increase in temperature, although some respond in an opposite way, e.g. insecticides from the group of pyretroids. A higher efficiency may also be a consequence of faster uptake of substances by plants at a higher temperature or changes in the functioning of stomata.

Drought is mainly the cause of a weaker action of soil-applied herbicides, due to their reduced availability for the most susceptible stages of weeds. Water relations and temperature play a very important role in the efficiency of action of biological plant protection agents. Drought reduces the microscale living scale and effective action, particularly of microorganisms and eelworms. On the other hand, torrential rains may wash out considerable proportions of populations of these organisms from their habitats.

At an increase in temperature the daily period most advantageous for plant protection measures will be shortened, especially in summer. The risk of phototoxic action and the drying rate of liquid droplets, limiting the penetration of substances to plants, increase with growing temperatures.

ADAPTATION STRATEGIES

Climate changes occur relatively slowly; however, some phenomena may be intensified rapidly or even become extreme. In the long run this makes it possible to methodically and systemically prepare to these changes (Wyszyński *et al*. 2008).

Wyszyński *et al*. (2008), after Riebsame *et al*. (1995), expressed an opinion that by adaptation of agriculture to climate change we have to understand "each activity aiming at a reduction of negative or an enhancement of positive effects of climate change". Adaptation activities may anticipate the occurrence of certain phenomena and their effects or they may an ex-post response to their occurrence (Pradeep and Shane 2003, Adger *et al*. 2007).

From the point of view of farming systems we have categorized three types of adaptation options in the agriculture sector: management, technical/equipment and infrastructural (Iglesias *et al*. 2007).

From the point of view of the time perspective Pradeep and Shane (2003) distinguished three types of adaptation: short-term, long-term and irrespective of the time role of climate change. In terms of plant protection the most important short-term adaptations include Farm Response and insurance including also disasters resulting from the epidemic incidence of agrophages; to long-term – development of new technologies and modernization, improving water management; to those independent of the time role of climate change – investment and accumulation of capital, reform of pricing schemes, development of open markets, and other reforms, adoption of new technologies, extension services, dissemination of climate data, institutional planning and implementation.

Adaptation activities are planned for different administration levels, local, governmental and private; they include science and transfer of technology and information, and finally financial enterprises. They are undertaken in all regions worldwide (Adger *et al*. 2007). An example in this respect may be Finland's National Adaptation Strategy, which includes actions in the public sector concerning administration and planning, research and information, economic and technical measures as well as the normative framework, while the task realized by the private sector, i.e. farmers, includes implementation of new cultivation methods, cultivated crops and technology (Iglesias *et al*. 2007).

ADAPTATION STRATEGIES

Adaptation strategies in plant protection include in their scope first of all actions minimizing forecasted hazard and losses resulting from the incidence of agrophages, both in the short- and long-term perspective.

In the report to the European Commission Iglesias *et al*. (2007) presented an assessment of adaptation measures with priorities and timescale in terms of an increased risk of agricultural pests, diseases and weeds. This study is based primarily on adaptation actions proposed by Iglesias *et al*. (2007) and Pradeep and Shane (2003), supplemented with the author's observations.

Farm Response

Farmers have always carried out adaptive changes to their businesses based on the weather and respond in the short-term by altering cropping, management and other practices, also those connected with plant protection. However, this is unlikely to be enough to ensure that livelihoods can be sustained in the face of climate change.

Crop Diversification and Changes in Timing of Farm Operations

Actions presented below in most cases do not go beyond the requirements of ordinary good farming practice, being a pre-condition for the participation of the farmer in the national agri-environmental program.

The selection of crop and changes in crop rotation are the primary causes for adaptation action undertaken in terms of plant protection. Adequate crop rotation, particularly mixed farming systems of crops and livestock, are conducive of spreading the risk of infrequent, and uncertain, pest and disease infestations. In this respect a significant role is played by the maximum extension of soil vegetation cover during the year, taking into consideration catch crops and forecrops. Also planting hedges, tree plantings and other ecological areas enhance biodiversity and resistance of the environment against agrophages.

Cultivation measures undertaken in order to improve physical properties and structure of soil, resulting also in limitation of losses of water and organic carbon in soil, being beneficial from the point of view of plant protection. Such activities include cultivation measures reducing aeration and turning of soil, including deep plowing, organic fertilization and application of effective microorganisms. Simplified tillage technologies also lead to negative consequences, intensified incidence of certain species of weeds, pests as well as diseases – especially in monoculture. Such a condition requires the improvement of tillage technologies in terms of minimization of these hazards in the long-term perspective - in crop rotation. Significant benefits are also brought about by modifications in sowing, planting and cultivation measure dates, aiming at the limitation of infestation with agrophages, particularly pests and weeds, resulting from changes in dates of their incidence caused by climatic factors. A practical source of such information is connected with continuously improved plant protection programs.

The selection of cultivars, which currently make it possible to obtain the highest possible marketable yield and financial results within the applied cultivation technology, is the priority for every farmer. Advances in breeding facilitate the identification and selection of cultivars giving better yields at higher temperatures. Tolerance or resistance of crops to environmental stresses will result in healthier crops that are better able to resist disease and produce improved yields. Moreover, we may observe an increasing number of cultivars selected towards gaining resistance to diseases and insects and obtained using traditional breeding methods, as well as genetic engineering. Genetic manipulation may also help to exploit the beneficial effects of CO_2 enhancement on crop growth and water use (Boland *et al*. 2004; Iglesias *et al*. 2007). The stability of resistance to pathogens and pests may be reduced as a result of the increased number of generations and infection cycles during the vegetation season. This may lead to a more rapid formation of new aggressive pathogen forms (Coakley *et al*. 1999), while on the other hand it should lead to the development of resistance monitoring.

Temperature control

It is a solution aiming first of all at the creation of optimal conditions for plant growth; however, thermostats and rapid cooling may be used to reduce pest and disease infestation. In this application temperature (or rather climate) control is developed solely indoors.

Sustainable integrated plant protection products strategy

Improvement of programs of integrated agrophage control and the application of plant protection agents adequately to climate change is the basic task of efficiently managed plant protection (Downing *et al.* 1997, Parry *et al.* 2000). Within the framework of Integrated Pest Management (IPM) programs technologies of weed, pathogen and pest control will be developed and implemented, and their intensity will increase with climate warming, particularly: finding mare advantageous conditions to ensure winter survival; requiring a higher thermal threshold for development – species extending their range in Poland (*Ostrinia nubilalis*, *Diabrotica virgifera*) or new invasive species; finding advantageous conditions for feeding in the period of extended autumn and finally having a short development cycle, producing many generations within a year (mites, thrips, aphids, leafhoppers, fungal and bacterial pathogens, insect-borne viruses). Warming will contribute to an increased competition between weeds and crops, while longer periods of drought will enforce improvement of control technologies of perennial weeds, weeds with photosynthesis type C4, as well as certain pests. Intensified occurrence of less frequent, but heavier precipitation will more often make it necessary to reduce the effects of diseases connected with underground plant parts.

In terms of the optimization of application of plant protection agents, different aspects of application technology of plant protection agents and their assortment will be further improved. It is generally expected that the frequency of plant protection measures within a year, e.g. in relation with extension of the vegetation period.

The importance and improvement of foliar applications, especially in case of herbicides, are expected to improve – in view of the deepening limitation of soil-applied herbicides under drought conditions. Moreover, the importance of acaricides and insecticides is going to increase. In case of plants requiring successive protection against disease (orchards, ornamental plants, some vegetables, potato) the use of fungicides and bactericides will increase, since more advantageous growth conditions will result in fasted increments and as a consequence the need to protect them. Development of foliar applications of plant protection agents will be connected with attempts to reduce vehicle passage and application of mixtures of preparations, particularly in combination with adjuvants, which will promote increased retention and faster penetration of substances to plants.

Moreover, knowledge on the optimal utilization of diurnal weather conditions will be improved and popularized in order to perform plant protection procedures with special emphasis on temperature and relative humidity in view of properties of a given plant protection agent and its spray liquid.

Programs aiming at the minimization of the risk of agrophage immunization will be implemented on a broader scale, taking into consideration the currently available assortment of preparations and non-chemical methods. This will be a reaction to the increased frequency of performed procedures. On the other hand, we may expect the realization of programs aiming at the minimization of ground water and aquatic environment contamination by pesticides.

As far as the assortment of plant protection agents is concerned, the importance of many biologically active agents (microorganisms, nematodes, insects, mites) and their application technologies will increase due to the climate conditions approaching the temperature optimum for their development. However, efficient application of biological plant protection measures will require the introduction of new comprehensive crop protection programs and frequently - professional support offered by advisers. For reasons unrelated with climate change, the proportion of pesticides posing a higher threat for the natural environment will decrease to the advantage of new, more selective preparations, with lower persistence in the environment. At the same time the assortment of available preparations will be extended, making it possible to reduce negative effects of water and thermal stress in crops.

Improving biodiversity and improving water management

Agroecosystems rich in terms of species composition offer many direct and indirect benefits for the farmer, such as e.g. pollinators and natural predators, as they enhance the natural resistance of the environment preventing and weakening the intensity of agrophage infestation dynamics. The primary role of the farmer in this respect is to care for an appropriate crop rotation and maximum extension of soil vegetation cover. Other actions creating a richer agroecosystem structure, mentioned in chapter 4.6. are also recommended (agricultural change, agro-ecosystem balance and biodiversity), among which improvement of local water relations is one of the priorities. Development of town and country planning, aiming at the enhancement of biodiversity at the regional, local and farm levels, will also bring about limited susceptibility of the agrarian system to climate change.

Insurance

The insurance system makes it possible to eliminate financial losses resulting from climatic phenomena, first of all extreme in character. It may also prove advantageous to provide insurance related to epidemic infestation with certain agrophages, especially taking into consideration quarantine organisms.

Extension service

Efficient transfer of knowledge, information and know-how in terms of long- and short-term adaptation activities increases thanks to qualified adviser staff. In plant protection the implementation and control of action of new, integrated crop protection programs with the reducing utilization of pesticides require constant cooperation between farmers and advisers. An equally important aspect is support in terms of formation of an optimal farm infrastructure with special emphasis on biodiversity and management plans, ensuring success when applying for funds for agri-environmental activities and loans from commercial institutions.

Research and information

The creation of efficient and detailed actions in terms of adaptation strategies require integration of analyses, evaluations, forecasts and simulation, as will as verification of these actions in model systems and in practice. One of the most important final results obtained by farmers in terms of plant protection will be a sustainable program of agrophage control. In terms of conducted research on primary problems of crop protection resulting from climate change at least the following issues need continuous improvement:

IPM programs;
Recording and long- and short-term forecasts of agrophages and assessment of their importance;
Models of agrophage dispersal;
National and international systems and services warning on the incidence and dispersal of agrophages during the vegetation period;
Solutions delaying penetration and dispersal of new agrophages in Poland and minimization of their influence;
Assessment of suitability of plant protection methods and measures under changing climate conditions;
Breeding of new cultivars;
Assessment and introduction to cultivation of new plant species;
Assessment of biodiversity and measures to enhance it.

Comprehensive adaptation strategies in terms of the effect of climate change on plant protection in Poland still need to be created. They are not truly developed in most European countries either. Great Britain has an adaptation program in plant protection designed in view of agricultural conditions (Iglesias *et al*. 2007).

Legal and administrative actions

Climatic phenomena frequently cause catastrophic losses, which minimization is possible thanks to the undertaking and maintenance of proactive adaptation actions in local communities, regions and nationwide.

The local and regional level

At the local and regional scale it seems advisable to undertake actions in biological, technical and information infrastructure, the creation of local town and country development plans. A more local task is to realize actions enhancing biodiversity and the natural potential of the environment to regulate quantitative interrelations between populations. A more regional task is to create or support the establishment of commercial integrated systems of weather stations and services providing data and forecasting incidence of agrophages and conditions conducive of plant protection measures as well as warning against extreme phenomena.

The national level

In the Polish agricultural and environmental policy it seems advisable to identify, as one of the strategic goals, the protection of the national territory against the adverse effect of climate change. Legal and administrative actions in terms of the adaptation of plant protection methods to climate change include first of all the allocation and distribution of funds for research, implementation and support of local projects and the establishment or adaptation of respective legal framework for the undertaking of administrative actions in terms of basic plant protection problems. Major problems are connected with the hazard for Poland posed by invasive agrophage species. Dispersal of certain invasive species in Poland seems inevitable, thus it is necessary to conduct a more detailed evaluation of economic and social effects of the appearance of individual species and preparation of realistic plans to restrict their dispersal and procedures in case they occur.

Increased crop hazard posed by agrophages, and on the other hand the evaluation of ecological effects connected with the cultivation of genetically modified crops in comparison to the application of plant protection measures is the cause of continuous investigation of the legal status of transgenic crops both in Poland and many other developing countries (Iglesias *et al*. 2007)

Agricultural changes, agro-ecosystem balance and biodiversity

Changes introduced to agricultural production, resulting from adaptation to climate change, will eventually affect biodiversity, sometimes leading to its reduction. In respective corrective programs it is necessary to enhance balance in the agri-ecosystem thanks to the enhancement of its structure and its more responsible management. In effect the natural resistance of the environment to occurring climate change also increases. Actions undertaken in this respect include hedgerow and woodland restoration/planting; ditch restoration/management; pond and scrape restoration/creation; water level management; grass strip margins in arable fields; crop-free margins in arable fields; reduced pesticide/herbicide usage; crop patterns to encourage wild birds; flower-rich (pollen/nectar) grassland seed mixes; winter stubbles and summer fallows (Iglesias *et al*. 2007).

COMPETITIVENESS

One of the priorities in the implementation of climate adaptation actions is to conduct training sessions and information campaigns. In this respect plant protection is one of the issues which need to be presented comprehensively, in view of interrelations contributing to increased competence and superior utilization of potential of adaptation actions.

CONCLUSIONS

1. The incidence and importance of agrophages is directly and indirectly dependent on climate conditions, which influence the biology of organisms and adaptation strategies in agriculture.

2. Adaptation strategies have complex character and may anticipate the occurrence of certain climate phenomena and their effects or they may an ex-post response to their occurrence. Adaptation activities are planned for different management levels, local, governmental and private and they include science and transfer of technology and information, and finally financial enterprises.

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11. SUMMARY

The impact of progressing climate change is becoming increasingly evident, both in the small (regional, national) and large scale (continental, global). Changes are found primarily in the seasonal cycles of weather conditions, and as a consequence it affects the functioning of the natural environment and agriculture – the sector of economy with closest ties with nature. These changes are manifested worldwide, including Europe. In view of this information 11 research teams from different European countries and from Egypt created a consortium and prepared the ADAGIO project embedded in the European program supporting the agricultural policy of individual countries. The responsibility of each partner is to identify potential problems of agriculture connected with the probable effect of forecasted climate change, to determine potential adaptation mechanisms in selected regional agricultural systems based on identified problems, as well as popularize and disseminate developed adaptation strategies of agriculture among decision-makers so that they may be incorporated in the agricultural policy of a given country. This publication contains results of studies of the Polish group of experts, who have identified hazards and proposed potential actions adapting agriculture to climate change. It describes what climatic changes are already visible. A gradual increase in temperature has been confirmed, which is manifested primarily in a decrease in differences in mean temperature of spring (an increase in temperature) and autumn (no significant change). Moreover, an increased hazard has been identified, resulting from the growing number of extreme phenomena, including droughts being particularly dangerous for agriculture. The above mentioned changes have already affected agriculture and in the future their effect will be even more evident, e.g. as the increased importance of certain agrophages or the appearance of new ones. In order to alleviate the consequences of hazards several adaptation strategies have been proposed; however, it needs to be stressed that they have to be implemented in a comprehensive way for their corrective effects to be mutually enhanced. The introduction of new crop cultivars, more tolerant to drought, should coincide with the simultaneous development of irrigation systems. At the same time we may not neglect the detailed monitoring of the appearance of agrophages with the introduction of more efficient and at the same time less noxious plant protection methods. However, since certain hazards, and as a consequence also losses are inevitable, it is necessary also to develop the system of insurance policies, which will increase economic security of farms. Summing up, although the observed and future climate changes affect the functioning of agriculture in Poland, the comprehensive introduction of adaptation actions mentioned in this publication will definitely limit potential losses resulting from climate change.

Keywords: hazards and potential actions adapting agriculture to climate change, supporting the agricultural policy

12. STRESZCZENIE

Skutki postępujących zmian klimatycznych są coraz bardziej widoczne i to zarówno w niewielkich (region, kraj) jak i w dużych skalach (kontynent, glob). Zmianom ulegają głównie sezonowe cykle przebiegu pogody, a w konsekwencji wpływa to na funkcjonowanie środowiska przyrodniczego i rolnictwa – dziedzinie gospodarki najbardziej związanej z przyrodą. Zmiany te są widoczne na całym globie, w tym i w Europie. Mając na względzie te informacje 11 naukowych zespołów z różnych państw europejskich oraz z Egiptu stworzyło konsorcjum i przygotowało projekt ADAGIO wpisujący się w europejski program wspierania polityki rolnej poszczególnych państw. Zadaniem każdego z partnerów było określenie potencjalnych problemów rolnictwa związanych z prawdopodobnym wpływem prognozowanych zmian klimatu, określenie potencjalnych mechanizmów adaptacyjnych wybranych regionalnych systemów rolnych w oparciu o zidentyfikowane problemy oraz popularyzacja i rozpowszechnianie opracowanych strategii adaptacyjnych rolnictwa wśród decydentów celem ich wdrożenia do polityki rolnej danego kraju. Niniejsza publikacja zawiera wyniki prac polskiej grupy ekspertów, którzy zidentyfikowali zagrożenia oraz zaproponowali potencjalne działania przystosowujące rolnictwo do zmian klimatycznych. Opisano w niej, jakie zmiany klimatyczne są już zauważalne. Potwierdza się stopniowy wzrost temperatury, co głównie przejawia się spadkiem różnic średniej temperatury wiosny (wzrost temperatury) i jesieni (brak istotnej zmiany). Zidentyfikowano też wzrost zagrożenia wynikającego z powodu zwiększającej się ilości zjawisk ekstremalnych, zaliczono tu, szczególnie uciążliwe dla rolnictwa susze. Wspomniane powyżej zmiany już wpływają, a w przyszłości będzie to jeszcze bardziej zauważalne, np. na wzrost znaczenia niektórych agrofagów lub pojawianie się zupełnie nowych. Aby złagodzić skutki zagrożeń wymienia się cały szereg działań adaptacyjnych, należy jednak podkreślić że bardzo istotne jest aby wprowadzać je w sposób kompleksowy, aby wzajemnie wzmacniać ich łagodzące efekty. Wprowadzanie nowych odmian rośli, bardziej odpornych na suszę, powinno następować z równoczesnym rozwojem systemów nawadniających, jednocześnie nie należy pomijać szczegółowego monitoringu pojawiania się agrofagów wraz z wprowadzaniem skuteczniejszych, a jednocześnie mniej szkodliwych dla środowiska sposobów ochrony roślin. Ponieważ jednak pewnych zagrożeń, a w konsekwencji i strat nie da się uniknąć konieczne jest także rozwijanie systemu ubezpieczeń, który zwiększy ekonomiczne bezpieczeństwo gospodarstw. Reasumując, obserwowane i przyszłe zmiany klimatyczne wpłyną na funkcjonowanie rolnictwa w Polsce, ale kompleksowe wprowadzanie działań adaptacyjnych wymienianych w niniejszej publikacji z pewnością ograniczy potencjalne straty z tego wynikające.

Słowa kluczowe: zagrożenia oraz potencjalne działania przystosowujące rolnictwo do zmian klimatycznych, wspomaganie polityki rolnej