Impact of Climate Change and Adaptation in Agriculture

International Symposium, Vienna, 22-23 June 2009

EXTENDED ABSTRACTS

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INTRODUCTION - THE ADAGIO PROJECT

Josef Eitzinger

University of Natural Ressources and Applied Life Sciences Vienna (BOKU), Institute of Meteorology (BOKU-Met)

The International Symposium „Climate Change in Agriculture and Adaptation Options“, June 22-23 2009, was hosted by the University of Natural Ressources and Applied Life Sciences Vienna (BOKU), Institute of Meteorology (BOKU-Met) and supported by the EU-projects ADAGIO and CECILIA, the COST action COST734 and World Meteorological Organization (WMO). It was held in the frame of the last general meeting of the EU project ADAGIO (ADAPTATION OF AGRICULTURE IN EUROPEAN REGIONS AT ENVIRONMENTAL RISK UNDER CLIMATE CHANGE, Specific Support Action, FP6). The aim of the project was to evaluate and disseminate potential adaptation measures to climatic change in agriculture, considering 3 main vulnerable regions of Europe (Southern Europe and Mediterrranean Area, Middle Europe and Eastern Europe) in cooperation with 11 Partners (Austria, Spain, Bulgaria, Serbia, Czech Republic, Poland, Greece, Italy, Russia, Egypt, Romania).

Compared to the manyfold potential impacts of climate change on agroecosystems, potential adaptation measures are even more complex because of the high number of options available through the human factor. New policies must therefore be adopted under climate change conditions considering all potential and realistic adaptation measures especially on the regional and farm level to secure sustainability of agricultural production. Despite of the recognised relevance of climate risk assessments for agroecosystems, they have been not noticeable applied for supporting adaptation within agricultural decision-making within Europe, neither worldwide, because of its uncertainty and lack of knowledge by decision-makers. On the other hand, the European research funds concerning agricultural climate-change impact assessments have been addressed mainly to theoretical issues rather than to research-results applications.

ADAGIO investigated not only future scenarios and results based on modelling tools, but also already visible (or known) ongoing changes of adaptation measures for a better and realistic assessment of potential future adaptation measures at the regional level. For that a bottom-up approach was applied rather than the top-down approach, which included to gather feedbacks from local experts and farmers by e.g. using questionnaires. Finally, ADAGIO should establish a continuously interacting information and discussion network, connecting the research level with decision makers and support a holistic approach to solve the related problems. Further information on the ADAGIO project and related reports and results as well as contacts the to national related web sites can be received under www.adagio-eu.org.

At the International Symposium „Climate Change in Agriculture and Adaptation Options“ more than 45 contributions on the topic were presented from all over Europe, which are presented as Extended Abstracts in this report. The topics cover a wide range of aspects on climate change impact related problems on agriculture and potential adaptation options. As the assessment of adaptation optiona always needs to consider a local perspective, most of the contributions focus on regional aspects, showing the complexity and regional variability of related main problems. We thank all the contributors for their efforts in this crucial field, which in many aspects is still on a starting point, supporting the development in the field of adaptation to climatic change.

Vienna, in July 2009.

WMO OPENING REMARKS AT THE INTERNATIONAL SYMPOSIUM ON CLIMATE CHANGE AND ADAPTATION OPTIONS IN AGRICULTURE

Robert Stefanski

World Meteorological Organization
(Vienna, Austria, 22 June 2009)

Distinguished Representatives and Guests,
Dear Colleagues, Ladies and Gentlemen,

On behalf of Michel Jarraud, Secretary-General of the World Meteorological Organization (WMO), it is a pleasure to attend this International Symposium on Climate Change and Adaptation Options in Agriculture, which is being sponsored and organized by the Austrian Institute of Meteorology, "Adaptation of agriculture in European regions at environmental risk under Climate Change" (ADAGIO), the EU COST ACTION 734 "Impact of Climate Change and Variability on European Agriculture", "Central and Eastern Europe Climate Change Impacts and Vulnerability Assessment" (CECILIA) , and WMO and generously hosted by the University of Natural Resources and Applied Life Sciences here in Vienna. This symposium will be held in conjunction with the WMO Commission for Agricultural Meteorology RA VI Working Group on Agricultural Meteorology meeting.

On a personal note, I am glad to see many friends and colleagues again that are attending this symposium.

Colleagues,

The International Meteorological Organization (IMO) was established in 1873 and was responsible for international cooperation in meteorology. In 1950, the IMO became WMO, a specialized agency of the United Nations, with a mandate in weather, climate and water and a key role in the area of sustainable development.

It is widely recognized that human activities are now modifying climate at an increasingly alarming rate but such was not the case in 1976, when WMO issued the first authoritative statement on the accumulation of carbon dioxide in the atmosphere and the potential impacts on the Earth's climate. In 1979 WMO organized the First World Climate Conference, as a result of which in 1988 WMO and the United Nations Environment Programme (UNEP) jointly established the Intergovernmental Panel on Climate Change (IPCC), which they have continued to co-sponsor in successful partnership to this day. The IPCC, which is now entering its twentieth year, was recently distinguished in 2007 with the prestigious Nobel Peace Prize. WMO would therefore like to reiterate its appreciation and recognition to the hard and productive work of all IPCC experts, in particular those from Europe.

I would like to digress for a moment and point out that the WMO Commission for Agricultural Meteorology also contributed to the work of the IPCC Fourth Assessment Report. In October 2002, an International Workshop on Reducing the Vulnerability of Agriculture and Forestry to Climate Variability and Climate Change was held in Slovenia before the 13th Session of the CAgM. Papers from the proceedings of this Workshop were published in the journal Climatic Change, Volume 70 in 2005 and 8 of these papers were cited by the IPCC Working Group in Chapter 5 on Food, Fibre and Forest products. I should also point out the WMO and Cost Action 734 collaborated last year in organizing a Symposium on Climate Change and Variability – Agrometeorological Monitoring and Coping Strategies for Agriculture that was held in Norway. I am proud to announce that Idojaras, the Quarterly Journal of the Hungarian Meteorological Service, just published the proceedings in their January to June 2009 issue.

In 1990, the Second World Climate Conference was held and called for the establishment of a climate convention and ultimately resulted in the development of the United Nations Framework Convention on Climate Change (UNFCCC) "*to achieve stabilization of greenhouse gas concentrations in the atmosphere at a low enough level to prevent dangerous anthropogenic interference with the climate system*".

Having warned the global community about the dangers posed by anthropogenic release of greenhouse gases into the atmosphere, WMO is now supporting the needs of climate prediction for societal benefits. To set the stage for a new era in forecasting as well as to generate the awareness of users and commitment by governments, WMO is organizing with partners the World Climate Conference Three (WCC-3), which will be held in Geneva from 31 August to 4 September 2009. The main theme of the WCC-3 will be "*climate prediction for decision-making*". We are confident that it will be as successful as the two previous conferences and WMO looks forward to the fullest participation of its European Members, including the participation of many heads of state and of government during its high-level segment.

<u>Excellency, Ladies and Gentlemen,</u>

Following the approval of the IPCC Fourth Assessment Report in the second half of 2007, there has been considerable global refocusing on climate change, its future impacts and the potential adaptation strategies. Improved weather and climate information can and should be used to assist agricultural communities in taking the best possible decisions, and thus making their contribution to adaptation and mitigation measures.

In coping with climate variability, climate change and the potential impacts on the frequency and intensity of natural hazards, disaster risk management will necessarily become a key adaptation strategy. The latest scientific knowledge and capacity building will have to be translated into operational products, in order to better enable all countries to enhance their natural disaster risk management capabilities and their resilience, in particular through multi-hazard early warning systems designed to appropriately handle the most common hydrometeorological events – which statistically comprise 90 percent of all natural hazards - as well as the less frequent ones.

The IPCC report suggested several adaptation strategies to deal with projected climatic changes which include, changing varieties; more efficient water use; altering the timing or location of cropping activities; improving the effectiveness of pest, disease and weed management practices, insurance, and making better use of seasonal climate forecasts to reduce production risks. If these adaptations are widely adopted, they could have substantial potential to offset negative impacts from climate change and take advantage of positive impacts.

The scientific communities, academia and the National Meteorological and Hydrological Services (NMHSs) of European countries will therefore have an essential role in contributing to climate change adaptation and to the mitigation of its impacts. Among these impacts, by far the most critical will be those with the potential to affect human life and socioeconomic development, as well as to disrupt food and water supplies, transportation and human health.

<u>Dear Colleagues,</u>

Before concluding, I would like to reiterate WMO's appreciation to the Austrian Institute of Meteorology, ADAGIO, EU COST ACTION 734, CECILIA Project, and especially to the University of Natural Resources and Applied Life Sciences for hosted this symposium.

Therefore, on behalf of the Secretary-General of WMO, I wish this Symposium a very fruitful and productive meeting.

Thank you

COST 734 - CLIVAGRI : IMPACTS OF CLIMATE CHANGE AND VARIABILITY ON EUROPEAN AGRICULTURE

Simone Orlandini

University of Florence, Italy

COST is an intergovernmental framework for European Cooperation in Science and Technology, funded by its member countries through the EU Framework Programme. The objective of COST is to coordinate, integrate and synthesise results from ongoing national research within and between COST member countries to add value to research investment. COST Actions aim to deliver scientific syntheses and analyses of best available practice to aid problem identification, risk assessment, public utilities and policy development.

During 2006, COST Action 734 (CLIVAGRI-Impacts of Climate Change and Variability on European Agriculture) was launched thanks to the coordinated activity of 15 EU countries. The main objective of the Action is the evaluation of possible impacts from climate change and variability on agriculture and the assessment of critical thresholds for various European areas. Secondary objectives are: the collection and review of existing agroclimatic indices and simulation models, to assess hazard impacts on various European agricultural areas relating hazards to climatic conditions; building climate scenarios for the next few decades; the definition of harmonised criteria to evaluate the impacts of climate change and variability on agriculture; the definition of warning systems guidelines. Four working groups, with the integration of remote sensing sub working group 2.1 were created to address these aims:

WG1 - Agroclimatic indices and simulation models
WG2 – Evaluation of the current trends of agroclimatic indices and simulation model outputs describing agricultural impacts and hazard levels
WG3 – Development and assessment of future regional and local scenarios of agroclimatic conditions
WG4 – Risk assessment and foreseen impacts on agriculture

At present 28 countries join the Action with the collaboration of National Drought Mitigation Centre, University of Nebraska–Lincoln USA; Lincoln University, Canterbury New Zealand; Joint Research Centre Ispra, Agriculture Unit (ex-Agrifish) Italy; WMO – Agricultural Meteorology Division.

During the first year a survey of agrometeorological practices and applications in Europe regarding climate change impacts was completed and the results were included in a book disseminated among the European countries. At present the WG activity is focussed on the analysis of specific case studies planned to collect information and data. The activity of WGs has been structured like a matrix, presenting on the rows the methods of analysis and on the columns the phenomena and the hazards. Each intersection point describes the evaluation of past, present and future trends of climate and thus the impacts on agriculture. Based on these results, possible actions (specific recommendations, suggestions, warning systems) will be elaborated and proposed to the end-users, depending on their needs.

The collaboration with research projects or international organisation represents one of the most important outcomes of the Action. From this point of view, the International Symposium "Climate Change and Adaptation Options in Agriculture", based on the collaboration among Adagio, Cecilia and COST 734 projects and World Meteorological Organization, was a very good example and the presentations and discussions were really a very important support for all the COST members.

HIGH RESOLUTION REGIONAL CLIMATE CHANGE MODELLING – CECILIA CONTRIBUTION TO THE ADAGIO THEMES

Tomas Halenka

Charles University, Prague, Fac. of Mathematics and Physics, Dept. of Meteorology and Environment Protection

One of the objectives of EC FP6 Project CECILIA (STREP) dealing with climate change impacts and vulnerability assessment in targeted areas of Central and Eastern Europe is to study the impacts of climate change on agriculture and forestry, which provides common platform for more development of ADAGIO themes. Emphasis in CECILIA (www.cecilia-eu.org) is given to applications of regional climate modelling studies at a resolution of 10 km for local impact studies in key sectors of the region, the project involves the analyses of changes in crop yield, pests and diseases appearance, forestry management and in general, carbon cycle as well. The high spatial and temporal resolution of dense national observational networks at high temporal resolution and of the CECILIA regional model experiments will uniquely feed into investigations of climate change consequences for weather extremes impacts in the regions under study. Statistical downscaling methods for verification of the regional model results will be developed and applied, and assessments of their use in localization of model output for local impact studies will be performed.

In the region of central and eastern Europe the need for high resolution studies is particularly important. This region is characterized by the northern flanks of the Alps, the long arc of the Carpathians, and smaller mountain chains and highlands in the Czech Republic, Slovakia, Romania and Bulgaria that significantly affect the local climate conditions. A resolution sufficient to capture the effects of these topographical and associated land-use features is necessary. That is why 10 km resolution has been introduced in EC FP6 project CECILIA.

In decision making process for adaptation and mitigation purposes, there is significant problem arising from the weak link between climate change information based on global climate models and local impact studies necessarily based on regional climate change signal. Global Circulation Models (GCMs) can reproduce reasonably well climate features on large scales (global and continental), but their accuracy decreases when proceeding from continental to regional and local scales because of the lack of resolution. This is especially true for surface fields, such as precipitation, surface air temperature and their extremes, which are critically affected by topography and land use. However, in many applications, particularly related to the assessment of climate-change impacts and possible adaptation measures, the information on surface climate change at regional to local scale is fundamental.

The main goal of regional climate modelling activities in CECILIA project is to produce regional scenarios on high resolution of 10 km for time slices 2021-2050 and 2071-2100 based on ENSEMBLES 6FP EC IP A1B GCM simulations. Results of model validation and climate change signal based on these simulations will be open for further use in the impact studies in the studied regions and thus we hope, despite of ADAGIO accomplishment, our results will contribute to the common ADAGIO – CECILIA themes.

CLIMATE CHANGE IMPACTS AND ADAPTATION OPTIONS FOR AGRICULTURE IN COMPLEX TERRAIN AND SMALL SCALE AGRICULTURAL SYSTEMS – RESULTS FROM CASE STUDIES IN AUSTRIA

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Abstract

Austria covers a wide range of climates ranging from cool and humid (e.g. alpine region) to warm and semiarid/humid (mostly lowland areas) of the transition of continental type to atlantic and to mediterranean type of climate in the south. Austria, as a mainly mountainous region will be significantly affected by the expectations of the climate scenarios (IPCC, 2007). For example, an increase of 2°C will shift temperature (and related agroecological) zones 400m in elevation. Climate change impacts on agricultural production and potential adaptation options of the relevant agroecosystems are affected by these conditions significantly, beyond structural problems such as the dominating small farm sizes in Austria.

All main arable crop production regions in Austria are affected by increasing drought conditions and water shortage during the summer period, which leads to several recommended adaptation options regarding the protection and efficient use of the agricultural water resources. Also adaptation options to avoid soil erosion and to improve crop management are a critical frequently reported issue for agricultural land use types with temporal open soil surface, as a trend of increasing heavy precipitation events is observed in many regions.

Agricultural grasslands (in combination with dairy farming) in regions below approximately 800 mm annual precipitation were shown as most vulnerable to the ongoing warming trend, which comprise relatively large regions, especially with increasing distance from north, south and east of the Alps. Because of the fact that grassland production systems are much less flexible than arable farming systems regarding to a change in production techniques and production type it is considered as the most critical sector and emphasis has to be paid on developing feasible adaptation options. For example, for regions, where a change to crop production or other alternatives by changing land use is difficult due to terrain or soil conditions, there are only few potential adaptation options possible for grassland farming alternatives. Perennial cropping systems, such as orchards and vineyards, will be probably mostly affected by changed pest and disease occurrence, which leads to the conclusion that adaptation measures should focus on this topic. Especially for vineyards many new production areas are possible under a warmer climate in Austria.

Mostly named limitations of adaptation options, related to socio-economic conditions, are structural changes, which are mainly driven by economic reasons rather than by climatic ones. Among these are too small farm sizes or complex terrain limitations and high production costs. Too low income at small farms (esp. related to family business) leads to abandoning small farms or reduction of agricultural used land. Farmers of small farms are often also less educated in agricultural production (often part time depending on other income sources) leading to a decreasing success or interest in farming. The adaptive capacity of small farms seems however to be better in well developed regions, where already many small farms could successfully change to ecological production or alternatives and niches. Other limitations are too high costs of certain adaptation options, terrain and soil restrictions, no (or still no) market for the specific products. Market price uncertainties lead to increasing risks for sustainable implementation of adaptation measures; especially those which are related to investments (e.g. change of land use or production system).

Arable cropping regions in Austria

Decreasing summer precipitation under a warming climate will have a significant effect on summer crops (Eitzinger et al., 2009). However, on a local to regional scale climatic variations interact with soil conditions, especially for crop water balance. Climate change impact simulations, for example, show a considerable influence of soil water storage capacity on future trends in crop evapotranspiration, crop water stress (as shown in Fig. 1 for spring barley) and yield potential under climate scenarios, such as in the Marchfeld region of North-east Austria. It is shown that spatial variability of the climatic production potential is increasing in this semi-arid region under climate scenarios due to the limitations of soil water storage capacity. Soil conditions contribute to the spatial variability of limiting growing conditions of crops beyond the microclimatic conditions, and interact to each other. However, winter crops such as winter wheat are less affected than spring or summer crops, as winter crops can better use the soil water reserves which accumulate during winter (Fig. 2). This leads to an expected increase on winter wheat yields for the 2050s in most Austrian cropping regions, whereas for spring barley decreasing rainfed yields are expected, especially on soils with low water storage capacity and in dry regions. For maize, rainfed yield increases in Austria are expected only in regions with ample precipitation, e.g. for Upper Austria or regions close to the Alps. Especially the potential change to later ripening and higher yielding cultivars will contribute to that trend, indicating significant potential land use changes in Austria under the conditions of the expected climate scenarios (e.g. from grassland to maize production).

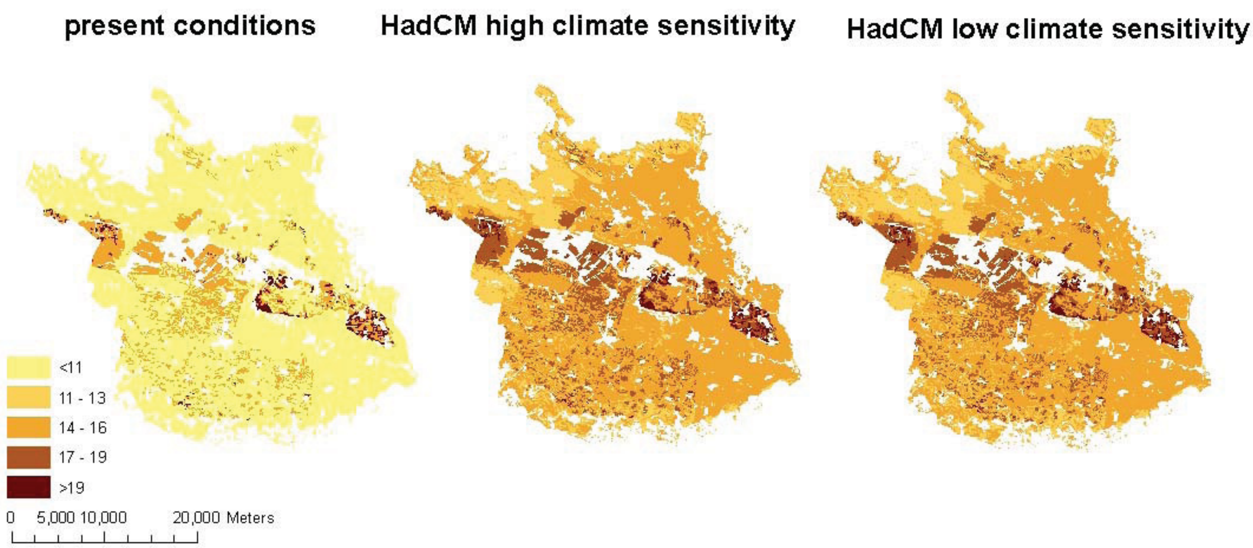

Fig.1. Spatial simulated (CERES-barley model) change of water stress days for spring barley for the 2050s under the HadCM scenario in the Marchfeld region (dark areas represent sandy soils with increasing water stress).

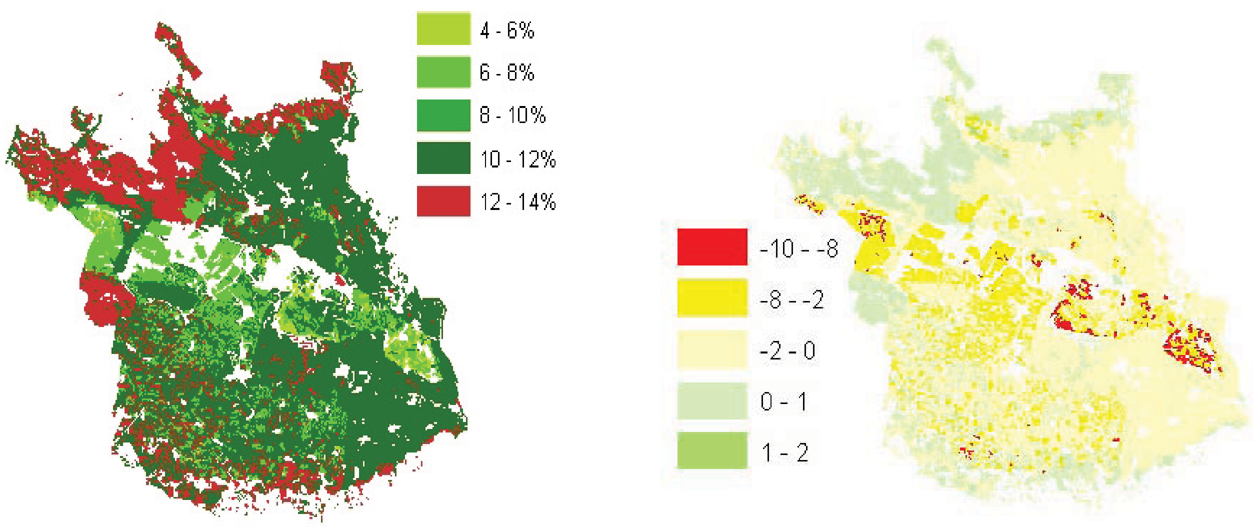

Fig. 2. Relative simulated (CERES Wheat and CERES Barley models) change of winter wheat (left) spring barley (right) yields for the 2050s under the HadCM scenario in the Marchfeld region (with considered adapted sowing dates and direct CO_2 effect).

Austrian permanent grasslands and increasing summer droughts

Increasing summer drought conditions will especially affect grasslands as a type of vegetation with permanent high demand of water for significant biomass production. In Austria, especially regions which are close to a critical limit of about 800mm of annual precipitation and locations with low soil water storage capacity will be affected, as indicated in Fig. 3.

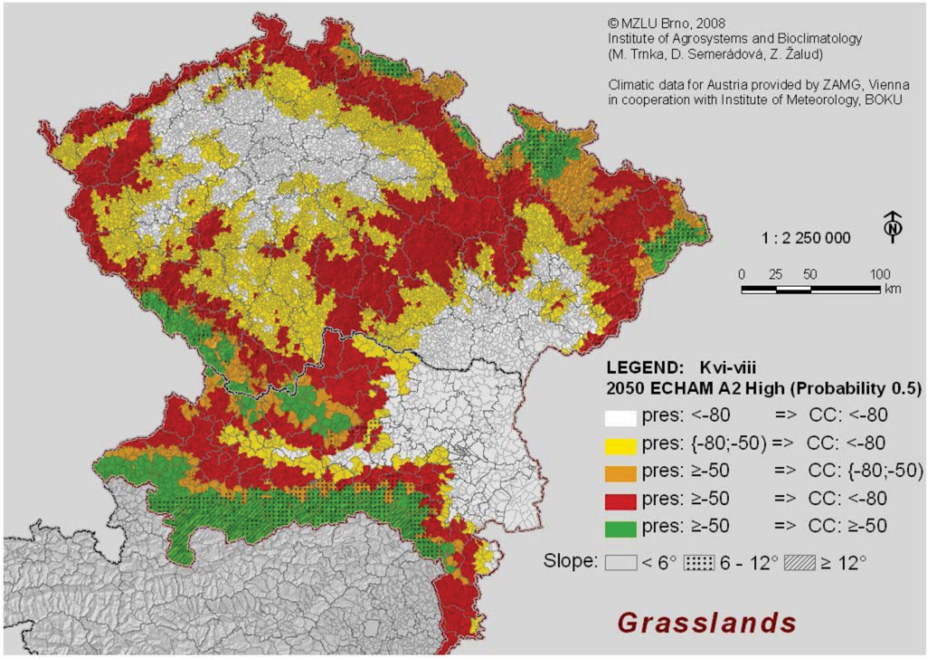

Fig. 3. Increasing risk of grassland production in Austrian and Czech Republic grassland dominated areas by increasing summer drought conditions (water balance deficit from June to September in mm). Red color represents areas under risk for suitable grassland production (according to current conditions) under the ECHAM SRES A2 scenario for the 2050s.

In many grassland dominated regions in Austria there will be a significant shift of agricultural land use in case of increasing summer drought conditions (see grassland regions under risk in Fig. 3), whereas in regions with ample precipitation (mainly alpine and near alpine regions) under climate change scenarios the grassland production potential will increase due to a longer vegetation period. However, a potential change in land use has many consequences and can lead to further risks for sustainable agricultural production. For example, a change from permanent grassland to maize production will not only force carbon dioxide emissions from soils and decrease organic contents in soils. It can have very negative impacts on regional water resources and balance due to increasing soil erosion or increasing runoff, beside other effects on landscape functions (e.g. tourism).
A change from grassland to crop production however has also natural limitations such as terrain and soil characteristics. In Fig. 4 (left) a study for Upper Austria (the north-western part of Austria) showed that approximately only 50% of current grassland areas would be suitable for arable crops (e.g. a change to fodder crops) due to terrain limitations (slope). Other adaptation options than a change to crop production could be however wood biomass production, orchards or vineyards, when climatic conditions are suitable. In Fig. 4, for example it is indicated for the same region, which areas would be suitable for vineyards under future climatic conditions, which comprise about 15 % or 100.000 ha of the agricultural land use of Upper Austria for the 2050s, however only partly also for grassland dominated regions.

In summary following recommendations for adaptation options in Austrian agriculture can be drawn:

In the short term:
• Introduce soil water conservation techniques (mulching, reduced and minimum tillage)
• Measures against soil water erosion (interactions to changing land use and regional increasing heavy precipitation)
• Improving irrigation scheduling (e.g. by using agrometeorological stations)

• Change to heat tolerant cultivars
• Change cultivars and crops according temperature demands
• Change sowing date and shift timing of field works
• Improving and introducing monitoring systems for pest and diseases
• Adaptations in crop rotation (e.g. more winter crops)
• Ensure frost protection methods (and for hail in some regions)
• Effective insurance system including grasslands (ideally supported by government)
• Adapting animal stables for heat waves, ensuring power generation and increasing hygienic measures for farm food production (e.g. milk production)

In the mid term:
• Improving or establishing irrigation infrastructure and regional water resource management
• Breeding of adapted cultivars (e.g. for higher water use efficiency and heat stress)
• Increasing crop diversification (farm and regional scale)
• Increasing storage capacities (fodder storage for animal farming)
• Change of production system (e.g. grassland to fodder crops, grassland to vineyards, grassland or crops to biomass production)
• Landscape structure improvements for reducing evapotranspiration (by lowering the wind speed, in some flat semi-arid regions)
• Improve awareness of farmers and related education (schools, extension services); establish or improve effective risk reduction tools (insurance, diversification, adaptation measures); Increase public awareness and acceptance (media etc.)
• To ensure higher market price stability for agricultural products (which significantly can improve sustainable planning and implementation of adaptation options) by using appropriate tools (e.g. political measures, ecological farming, establishing regional food production and local markets, develop marketing concepts, such as “terroir” characteristics for wine quality aspects).

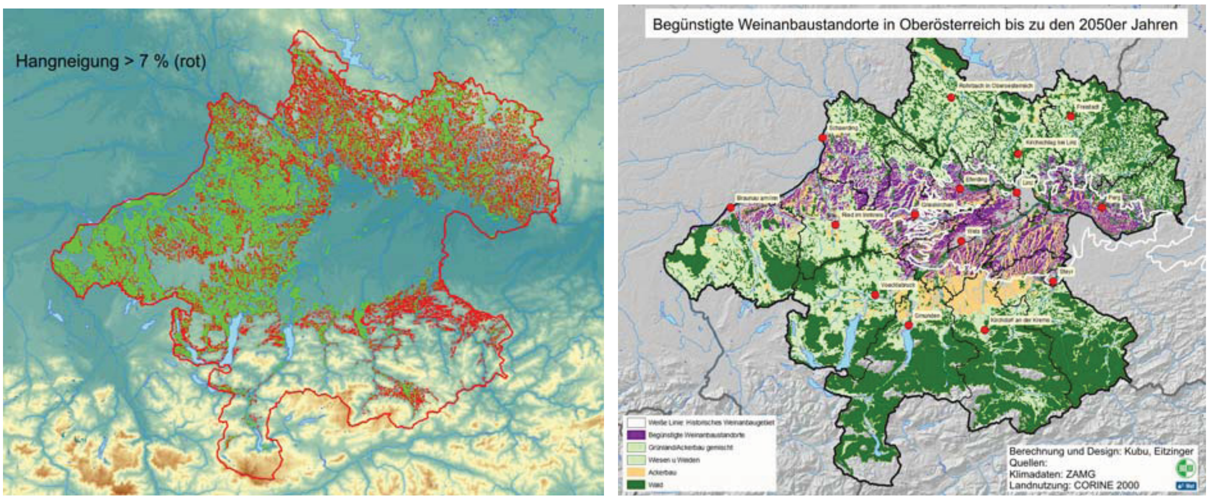

Figure 4. Grassland areas with slopes below 7% (green) are potential suitable for crop production in Upper Austria (left). Right: Potential wine growing areas in Upper Austria till the 2050s by application of the HUGLIN index and limitations by annual precipitation and terrain characteristics (in purple).

Keywords: **climate change impact on agriculture, adaptation options in agriculture, Austria**

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VULNERABILITY AND ADAPTATION OF AGRICULTURE UNDER CLIMATE CHANGE IN BULGARIA

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Abstract

In the last decade, natural severe meteorological events occurred worldwide, raising the decision-makers' awareness of these recurring dangers. Over the 20th century, southeastern Europe experienced a drought warming at a level, that is higher than the global average. Projected climate would exacerbate water shortage and quality problems in many water scarce areas in the region. Heat waves in the summer as well as intense precipitation events will become more frequent throughout Europe. Due to envisaged climate change scenarios risk of drought is likely to increase in central and southern Europe. In recent years, drought conditions have endangered water resources in south-eastern Europe and adversely affected the livelihood of many people (e.g. IPCC, 207).

In the last few decades it became more and more evident that in all countries in the Balkan sub-region and in the surrounding countries as well drought has a major impact on any forms and areas of life and economy, on the whole society and on the environment, too. Drought is the natural phenomenon probably most damaging to agriculture - which is the first economic domain and the most severely affected - yet eventually everyone feels the impact. Declining productivity affects rural and national environment and economy.

In the last few years the tendency is towards warmer and drier climate. 1998 had warm and dry winter, hot dry summer, cool dry spring, and cold and very rainy fall. These abrupt deviations from the normal climatic conditions reflect increased climate instability. Thus, the temperature amplitude recorded a maximum for the last decade. Significant are the amplitudes of the other climatic characteristics as well. 2000 was the warmest year in 30-year period, while the rainfalls were 60% less compared to standard values. Drought is a natural, recurrent feature of the climate of Bulgaria.

There are two main tendencies: growing air temperature, and decreasing precipitation amount. As a result soil drought during the second half of the twentieth century have increased its frequency and intensity. Many drought episodes occurred especially during the last decade of the previous century. Soil drought conditions were registered also during the first years of the 21st century. All this comes to the conclusion that soil drought conditions were, are and will be observed in Bulgaria. It is necessary to point out, that climate change scenarios for the country project more drought events during the current century. That is why, monitoring, drought conditions in Bulgaria are important issue that must be considered by scientists, decision makers, policymakers and the whole society.

Soil erosion in Bulgaria is another vulnerable climate related factor for agriculture in the country. Soil diversity in Bulgaria is enormous. Soils have different characteristics, fertility and vulnerability to climate change. The temperature rise will increase the water deficit in soils with low precipitation rates that are prone to droughts. The most serious impacts will be observed for soils with light mechanical content and bad water characteristics and partly for heavy clay soils. About 30% of the soils in Bulgaria are prone to wind erosion.
Studies show that during the climate change in Bulgaria in the 21st century, most vulnerable will be: a) spring agricultural crops, due to the expected precipitation deficit during the warm half-year; b) crops cultivated on infertile soils; c) crops on non-irrigated areas; d) arable lands in south-east Bulgaria where even during the present climate, precipitation quantities are insufficient for normal growth, vegetation and productivity of agricultural crops (Fig.1).
Adaptation to a changing climate will occur in several forms, including technical innovations, changes in agricultural land use, changes in application of irrigation and changes in crop management. It is expected that farmers will react dynamically to changing environmental conditions. Different types of farm-level adaptation to climate change can be considered for evaluation. For example, the possibility of switching cultivars for a particular crop - some cultivars for each crop could be involved in any study. If climate change affects the length of the growing season, then farmers could use the adaptation strategy of switching to longer or shorter growing season duration. A second farm-level

adaptation strategy could be modification the cropping system in response to a change in climate. If climate change affects the relative yield and profitability of one crop in favor of another, then farmers should respond by making the appropriate change in crop mix. As a third adaptation, farmers may also make adjustments in scheduling of field operations in response to climate change. If climate change increases or decreases the amount of time that farmers can be in the field, this will affect planting and harvest dates, and therefore yield levels indirectly.

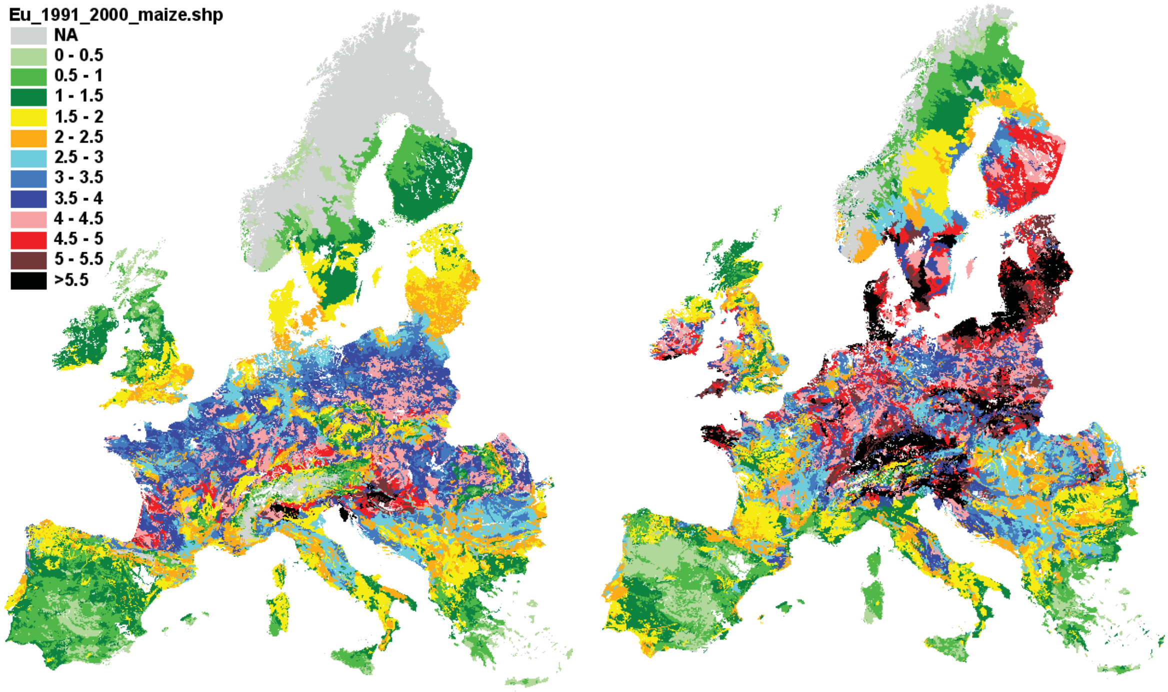

Figure 1. Maize yield (in t/ha) in Europe under recent climate conditions (left: 1991-2000) and HadCM3 A2 climate change scenarios for the 21st century (right: 2071-2080)

The objectives of adaptation measures in agriculture are to support and sustain the agricultural production and to bring to minimum the impact of climate change by reducing the vulnerability of the agricultural crops. The adaptation to climate change will be carried out in various forms, including technological innovations, changes in arable land, changes in irrigation, etc. Technological innovations include the creation of new cultivars and hybrids, which have higher productivity during changes in the climate. Farmers can start growing other crops or crops, prone to drought and diseases. The changes in arable lands, due not only to the needs of agricultural production following a population increase but also to climate change, are expected to be another form of adaptation. It is reasonable to expect that because of climate changes, there will be significant changes in arable lands. As the global climate has a tendency towards warming, a significant change in the irrigation of agricultural crops is expected. Some economic adaptation measures, such as substitution possibilities for other crops, availability, and costs of alternative production techniques, are recommended for evaluation in the future. the other major adaptation measures under consideration in Bulgaria are:

- Expanding areas of the most important agricultural crops over new regions characterized by improved thermal and moisture conditions.
- utilization of a variety of cultivars and hybrids, especially long-maturing, high-productive cultivars and hybrids with better industrial qualities.
- cultivation of new agricultural crops grown with Mediterranean origin.

The new cultivars of winter agricultural crops to pass through the winter season organogenesis under higher temperatures without deviations from the normal crop growth and development. The new cultivars and hybrids to be with higher dry-resistance, especially at the end of the vegetative period and at the beginning of the reproductive period. Higher maximal air temperatures not to provoke thermal stress effects, especially during crop flowering and formation of the reproductive organs. The new cultivars and hybrids to grow and photosynthesis under an increased concentration of carbon dioxide.

The adaptation measures presented bellow in relation to irrigation in the conditions of the present and future climate in Bulgaria are based on various: expert assessments, documents, action plans, and programs
The Bulgarian Government has clearly demonstrated strong commitment and willingness to join the international efforts in mitigating climate change by ratifying the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol to the Convention (KP). The Second National Plan on Climate Change (Second NAPCC) is a governmental plan to streamline and guide the efforts of the Bulgarian government in mitigating climate change.

Measures for improving irrigation under climate changes

- improvement of management, use and protection of water resources in irrigated agriculture;
- improving the efficiency of the management and use of the existing irrigation facilities and elaboration of the technological and technical facilities for irrigation;
- use of rational and economically sound irrigation regimes for the irrigated crops and elaboration of the technologies for cultivation of crops in the conditions of droughts and water deficit.

Measures for improve management, use and protection of water resources in irrigated agriculture

- establishing the impact of climate changes and drought on the quantity and quality of water resources used in irrigated agriculture;
- assessing the needs of water for irrigation of agricultural crops under climate changes and preparing long term projections for the required water resources to be used in agriculture
- Work is going on in various institutions like :
    - Institute of melioration and mechanization,
    - Institute of Water Problems,
    - University of Architecture, Civil Engineering and Geodesy
    - Institute of Soil Science and Agroecology "N. Pushkarov",
    - Higher Institute of Agriculture,
    - National Institute of Meteorology and Hydrology (NIMH),
- Numerical experiments to determine the optimal dates and water quantity for irrigation of the maize for various climate scenarios are carried out in NIMH, using computer system for agrotechnological decision taking DSSAT. The calculations are taken in regard to biophysical and economic analysis of the final yield and the received profit from the maize
- During limited precipitation in summer, irrigation facilities must be used, oriented towards design and operation of irrigation facilities, which use water resources in an economical way and have very low water transportation losses during irrigation.
- Gravitee feed irrigation and flooding of beds and rice fields should be used as a last resort, only when proven to be effective.
- Main and distribution canals of old irrigation systems must be coated to bring to minimum losses from filtration. Permanent canals in irrigation systems must be afforested on sufferance strips to utilize filtered water and to cover them aiming at the reduction of the physical evaporation from water surface in the canals

Adaptation measures to improve management efficiency and use of existing irrigation systems and elaboration of technological and technical means for irrigation

- To prepare up-to-date strategy and new program for the rehabilitation and restructuring of irrigation management and improving the efficiency of use of the existing irrigation infrastructure;
- To change legislation and regulation in the irrigation sector taking into consideration the altered agricultural conditions, the experience from the reforms carried out so far and to ask for free use of the technologically established hydromeliorative infrastructure and service facilities on the territory of the associations;
- To implement proper educational and training programs with emphasis on major issues on the involvement of users of water and the general public on drought problems;
- Preparation of information materials for water users on the benefits and good practices of agricultural crop irrigation.

Adaptation measures for use of rational and economically viable irrigation regimes

- Determining the vulnerability of agricultural crops under climate changes, long term droughts and water deficit in the major agroclimatic regions in the country, respectively their impact on the quantity and quality of the yield from them;
- Reassessment of the water and irrigation norms and legislative provisions of irrigation, new zoning for the irrigated crops in the country;
- Development and application of optimized irrigation regimes for the major agricultural crops for various agroclimatic regions in the country;
- Research on the effect from irrigation and sustainability of yields under various water saving methods and irrigation technologies;
- Creation and application of mineral fertilization systems and integrated weed fight during cultivation of agricultural crops under irrigation conditions;
- Application of proper moisture preserving technologies and techniques for soil treatment in irrigated lands;
- Adaptation and introduction in practice of information and advisory system for irrigation necessity forecast and defining the parameters of the irrigation regime for the irrigated crops;
- Technology changes for irrigated crop cultivation in various agroclimatic regions under water shortage conditions;
- Use of new cultivars and hybrids that adapt better to water deficit.

It was already mentioned adaptation in agriculture to a changing climate will occur in several forms, including for example technical innovations, changes in agricultural land areas, and changes in use of irrigation. As the climate warms there will likely be shifts toward greater use of irrigation systems to grow crops in Bulgaria. It is considered that available soil moisture for maize crop cultivation in the country is insufficient for normal crop growth even under current climate. Many farming technologies, such as efficient irrigation systems, provide opportunities to reduce direct dependence on natural factors such as precipitation and runoff. Improvements allow greater flexibility by reducing water consumption without reducing crop yields. The use of more efficient irrigation systems can be expected due to the need for tighter water management practices in order to counter increased demand. Water losses through seepage and evaporation in canal and flood irrigation systems can be minimized by lining the canals with cement or switching to pipe irrigation systems. The significantly higher costs of production related to irrigation systems will most likely result in shifts to less water demanding uses in areas where there are higher rates of moisture loss. Using more groundwater for crop irrigation is also a perspective way. First of all, however, the irrigation systems available till 1990s should be restored in the country.

The sowing dates of crops in Bulgaria would shift under the GCM climate change scenarios in order to reduce the yield loss caused by an increase in temperature. The selection of an earlier sowing date for maize will probably be the appropriate response to an increase in temperature. This change in planting date will allow the crop to develop during a period of the year with cooler temperatures, thereby increasing the growth duration, especially the grain filling period. The simulation results show that the sowing date of maize in experimental station Carev brod (Northeast Bulgaria) should occur at least 2 weeks earlier in the 2080s under the ECHAM4 scenario, relative to the current climate conditions. It should be noted, however, that although changes in sowing date are a non-cost decision that can be taken at the farm-level, a large shift in sowing dates probably would interfere with the agrotechnological management and other crops, grown during the remainder of the year.

Crop diversification allows farmers to cope with climate variation from year to year. This type of adaptation will likely occur at the farm system level. Switching from monocultures, which are more vulnerable to climate change, pest and diseases to more diversified agricultural production systems will also help farmers in coping with changing climatic conditions. Seed banks that maintain a variety of seed types provide an opportunity for farmers to diversify to counter the threat of climate change or to develop a profitable specialization. Another option for adaptation is to use different hybrids and cultivars. There is an opportunity for cultivation of more productive, later or earlier-maturing, disease- and pest-tolerant hybrids and cultivars. Switching from maize hybrids with a long to a short or very short growing season projected an additional decrease of final yield under an eventual warming in Bulgaria. However, using hybrids with a medium growing season, would be beneficial for maize productivity. The expected thermal and humid conditions in Bulgaria will permit to vary the assortment of many fruit and vegetable crops. Grape and fig production is expected to increase in the future. The climate in South Bulgaria is influenced by the Mediterranean. Warming may cause natural northward shift of some agricultural crops and trees grown in the upper areas of neighboring countries such as Greece and Turkey. Technological innovations, including the development of new crop hybrids and cultivars that may be bred to better match the changing climate, are considered as a promising adaptation strategy. However, the cost of these innovations is still unclear.

The greatest part of the national wheat and maize production under the current climate is concentrated in the areas with elevation below 800 m. New zoning of crop cereal production in agricultural land areas with elevation below 1000 m due to expected warming can be proposed. In this case, the agricultural land area for cultivation of cereal crops will increase approximately by 50, 000 ha.

Keywords: vulnerability, adaptation, agriculture, climate change, Bulgaria

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IS THE RAINFED AGRICULTURE IN CENTRAL EUROPE AT RISK? – USING A NOVEL METHODOLOGY TO PRODUCE HIGH RESOLUTION AND REGIONALLY RELEVANT SUPPORT FOR DECISION MAKERS

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Abstract

Growth and development of field crops are connected to the environment via a combination of linear and non-linear responses and are strongly affected by the weather and climate conditions. Extreme weather events that are a natural cause of climate variability such as drought, frosts or heat waves can also have severe consequences for crops. In the same time timing of the key field operations (i.e. sowing and harvest) depends the weather conditions influencing yield quantity and quality in each given season. The first aim of the study was to develop a methodology that would enable a sophisticated and flexible analysis of various agroclimatic indicators. The results of this effort were summarized into the AgriClim software package that provides range of agroclimatic indicators including: **i)** duration of growing season and of the vegetation summer, **ii)** number days suitable for sowing and harvesting; **iii)** accumulated water deficits during key parts of growing season (April-June); **iv)** number of growing degree days without significant water stress **v)** snow cover presence/absence during days with Tmin < -5°C and -15°C and duration of snow cover; **vi)** probability of serious frost damage to winter field crops; and **vii)** number of days during cereal anthesis with daily maximum temperature over 32 and 35°C.
The AgriClim was then within domain of the regional climate model ALADIN that covers the area of whole Central Europe between latitudes 45° and 51.5° N and longitudes 8° and 27° E including at least partly of Austria, Czech Republic, Germany, Hungary, Poland, Romania, Slovakia, Switzerland and Ukraine. The ALADIN model was run in 10 km resolution over the whole domain and the final maps were interpolated to 1 km resolution using digital terrain model (Fig. 1).

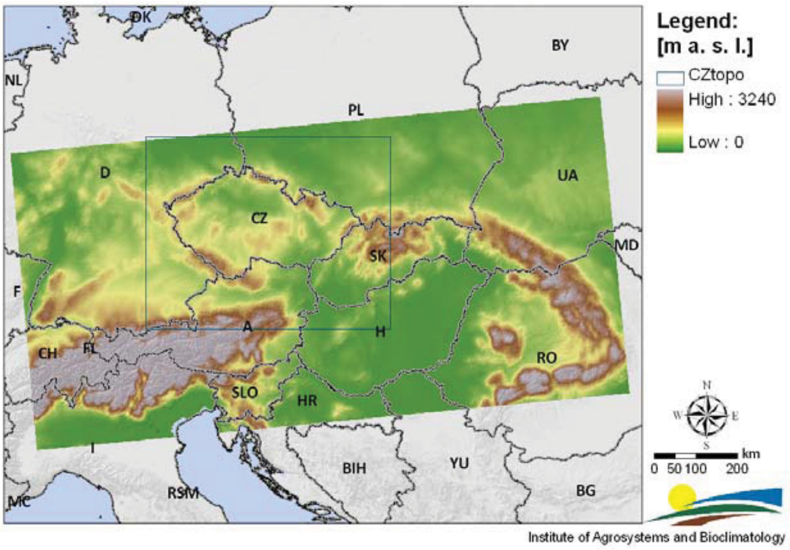

Fig. 1. Domain of ALADIN RCM model with representation of altitude in 10x10 km resolution.

The control run used observed boundary conditions (ERA40) and covered the period 1961-2000 with 1961-1990 period being used as a baseline to train a weather generator. Then a parameters of weather generator were perturbed based on the outputs of representative set of Global Circulation

Models (including HadCM, NCAR-PCM, ECHAM and ARPEGE) for various levels of climate system sensitivity and emission scenarios. This novel procedure significantly improves the reliability of RCM based projections combining RCM resolution while accounting for GCM related uncertainties. Future climate conditions were also represented by high resolution runs of ALADIN model for the future climate covered two time slices (i.e. 2021-2050 and 2071-2100 respectively) and boundary conditions were based on the ARPEGE global run using A1B emission scenario.
The selected agroclimatic indices were then calculated for each of over 10 000 grid points. The soil properties that were required for indices **ii – iv** were derived from the FAO 1:1000 000 soil map. The outputs of the control run were compared with 1 km resolution AgriClim runs for the Czech Republic and part of Austria based on the observational data (1961-2000) from 125 Czech and 35 Austrian weather stations. The values of the evaluated agrometeorological characteristics were calculated at the individual stations and were eventually interpolated over the territory depending on the parameter involved. The preliminary results indicate that : **i)** between 2021-2050 the combination of increased air temperature and changes in the amount and distribution of precipitation will lead to prolongation of growing season (Fig. 2) and significant shifts in the agroclimatic zones affecting e.g. potential for vine production (Fig. 3).

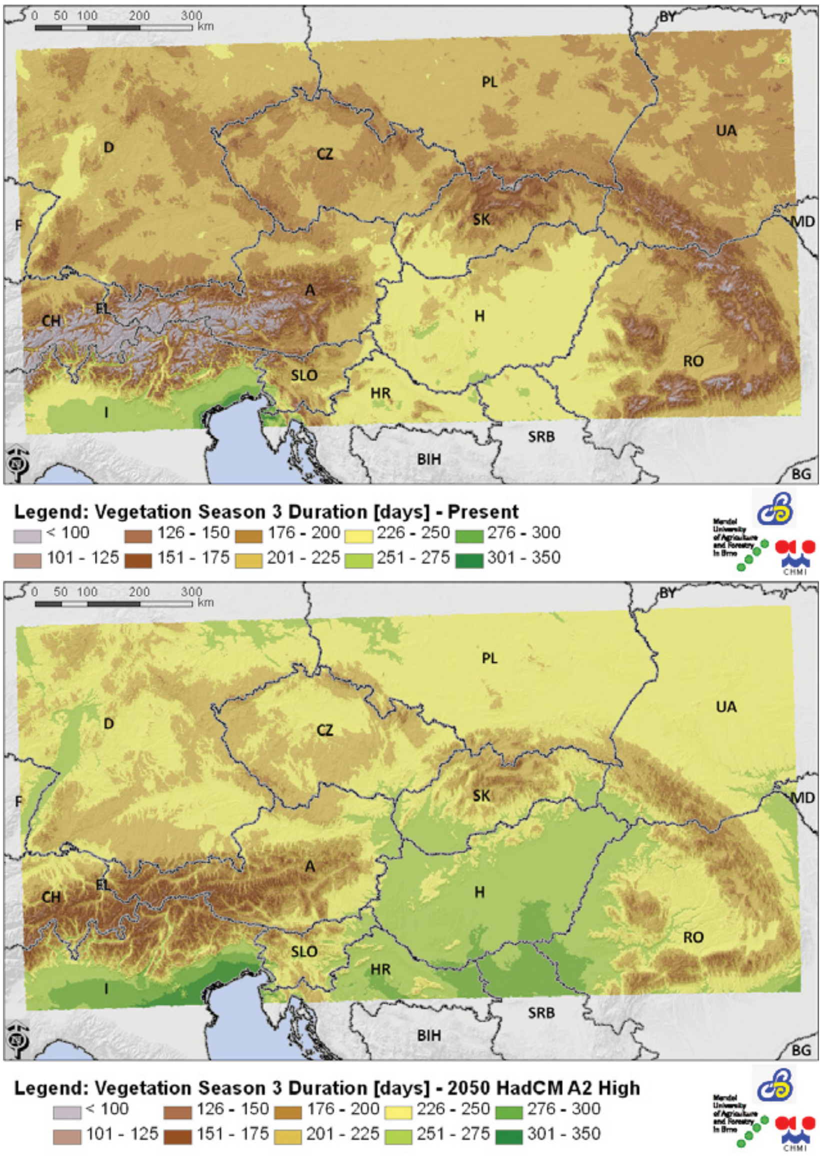

Fig. 2. Duration of growing season (continuous period with mean air temperature above 5°C and minimum daily temperatures above -2°C for the present (1961-2000) and expected conditions (SRES-A2 high climate sensitivity and HadCM3 global circulation model)

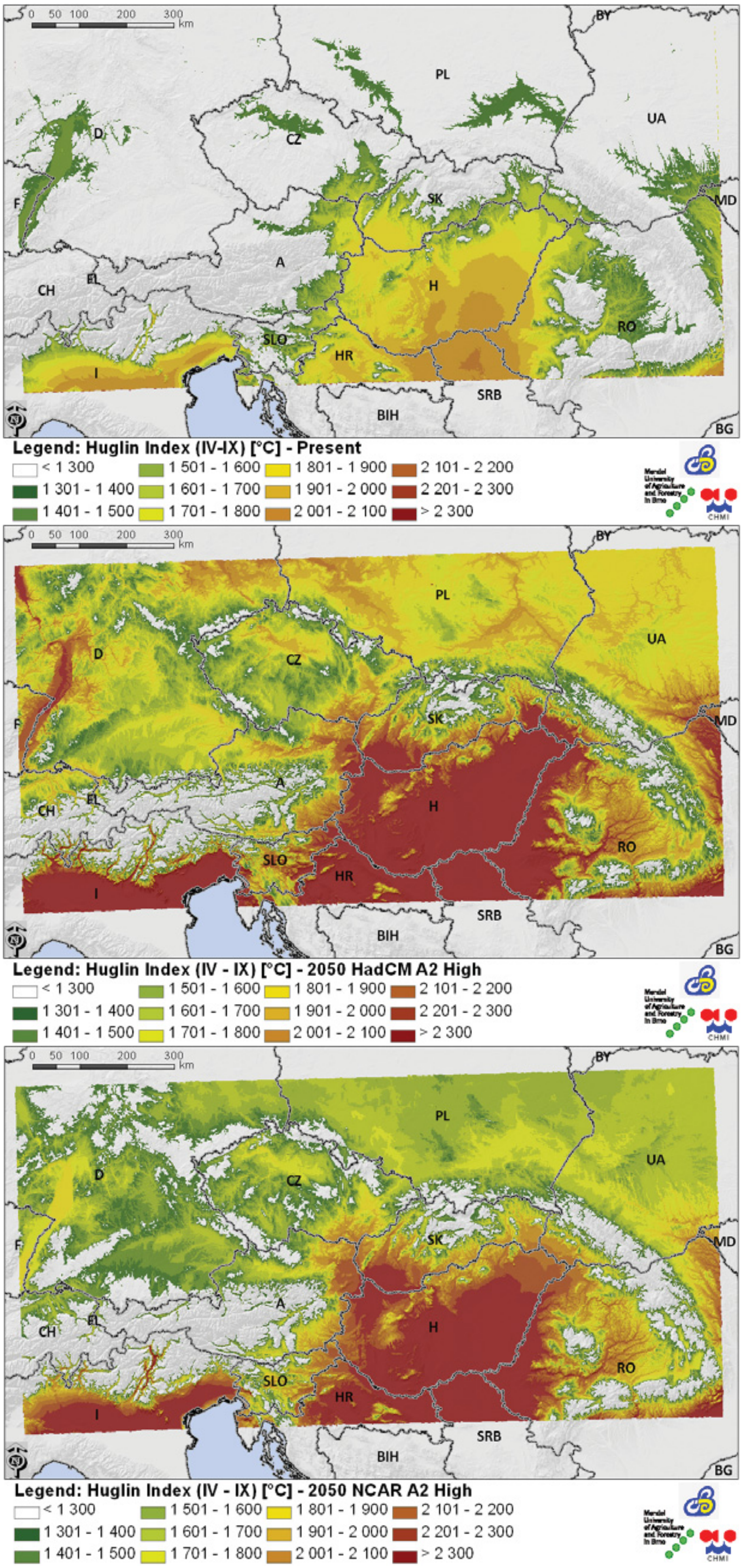

Fig. 3. Example of the Hughlin index (indicating climate dependent suitability for vine production) for the present (1961-2000) and expected conditions. Future climate conditions are based on the combination of SRES-A2 high climate sensitivity and HadCM3 and NCAR-PCM global circulation models.

The extent of the presently most productive areas will be reduced and replaced by warmer but drier conditions, which are less suitable for rainfed farming. **ii)** While the trends of the changes expected in lowlands are mostly negative according to the production potential of rainfed crops, the higher elevations will most likely experience improvement of their agroclimatic conditions. **iii)** Diary oriented agriculture (based on permanent grassland) at higher altitudes could suffer through an increased evapotranspiration demand combined with the decrease of precipitation leading to the intolerable water deficits. **iv)** The areas that are already warm and relatively dry we will experiencing 20-year drought intensity three times as frequently and water deficits that have not been encountered before.
v) Farmers will most likely be able to take advantage of earlier start of growing season at least in the lowland areas as the proportion of days suitable for sowing will increase. **vi)** Most of the changes listed might occur within less than 4 decades, which will pose serious adaptation challenges for farmers and governmental policies. The rate of the change might be so high that the concept of agroclimatology as a near static description of overall farming conditions might lose it relevance due to perpetual change.
The methodology used enabled to cover large territory with high level of detail accounting for various sources of uncertainty and surpases in our opinion presently available study in several aspects. The findings are crucial for tailoring the right adaption responses to the expected changes.

Acknowledgement : *This study was conducted with support of the* 6th FP EU project Adagio (*Adaptation of Agriculture in European Regions at Environmental Risk under Climate Change) SSPE-CT-2006-044210* and *6th FP EU research project CECILIA (no GOCE 037005). Research plan No. MSM6215648905 "Biological and technological aspects of sustainability of controlled ecosystems and their adaptability to climate change", which is financed by the Ministry of Education, Youth and Sports of the Czech Republic enable development of the AgriClim tool.*

Keywords: climate change impact, agriculture, AgriClim, agroclimatic indices

QUANTITATIVE ASSESSMENT OF SOME ADAPTATION MEASURES TO CLIMATE CHANGES FOR ARABLE CROPS

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Abstract

Various methods are proposed for adaptation of arable crop agriculture to climate changes. The most recommended measures are : changing the tillage practices from conventional to minimum tillage, irrigation or land use changes.
The effects induced by these measures at European scale were evaluated using two simulation models: an agro-pedo-climatic simulation model (ROIMPEL, Audsley et al., 2006) and a physical-based model predicting changes in pedotransfer functions related to various tillage works (SIDASS, Simota et al., 2005). Simulation models are linked with the digital Soil Database of Europe at scale 1:1,000,000 and the regioanalised climate data produced by ATEAM project (Schröter et al. 2004) for the baseline (1961-1990) and climate change scenario (2041-2050 HADCM3 – A2). Daily distribution of monthly average weather data (minimum, maximum and average air temperature, rainfall) is according with the differences between daily data and monthly average from the closest meteo station having measured meteo daily values (measured meteo dataset provided by Klein et al. 2002). Potential evapotranspiration was evaluated using Thornthwaite approach.
The crop used for simulation is a typical spring crop like spring wheat.
Indicators used for evaluating **conventional vs. minimum tillage** are: number of days with water stress below the 0.75 threshold and average daily water stress over various periods defined as: days with average temperature over 4, 8 or 10^{o}C or average daily water stress over april-september period. Water stress is defined as the ratio between actual and potential evapotranspiration, i.e. no water stress correspond to 1 and maximum stress to 0 value.
Figure 1 shows that for the baseline scenario 1961-1990 the number of days with significant water stress is higher in conventional tillage than in minimum tillage practices mainly on light and medium textured soils.

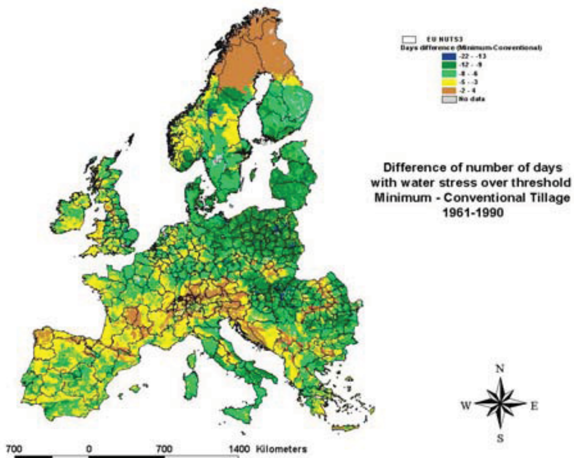


Figure 1. Difference in number of of days with water stress over the threshold between minimum and conventional tillage practices (Baseline 1961-1990)

Figure 2 shows that the conservation of water using minimum tillage practices is more efficient for 2041-2050 climate scenario (HADCM3-A2) than for the baseline.

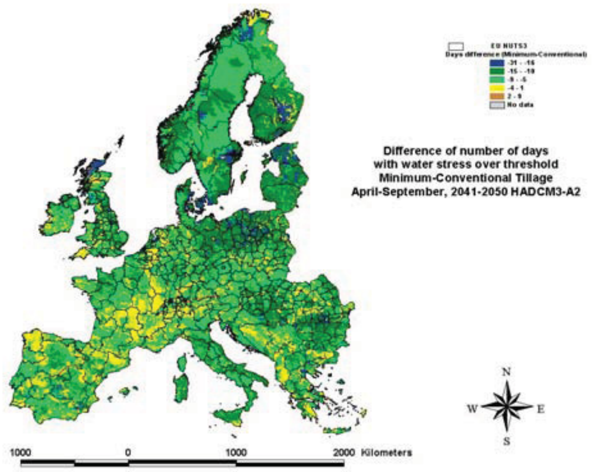


Figure 2. Difference in number of of days with water stress over the threshold between minimum and conventional tillage practices (2041-2050 HADCM3-A2)

The same trend show the daily average water deficit calculated for April-September time period: the minimum tillage is better for water conservation mainly on light and medium textured soils; the water conservation is more efficient for future climate change scenario (Figure 3).

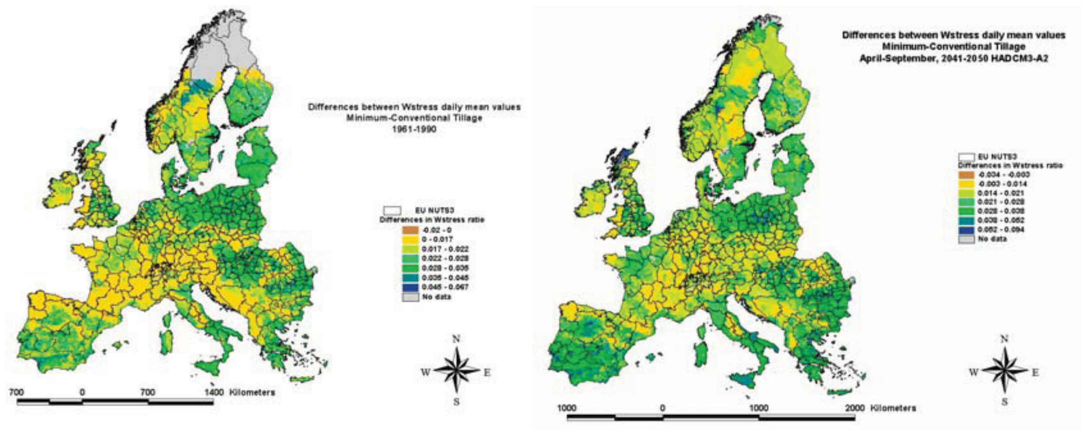


Figure 3. Average water stress difference between minimum and conventional tillage for baseline (1961-1990) and climate change scenario (2041-2050 HADCM3-A2) (1: no water stress, 0: maximum water stress)

The effect of water saving using minimum tillage on crop yields is significant only in South and South-East Europe. Figure 4 shows the percentage of spring wheat yield increase/decrease if minimum tillage is used instead conventional tillage.

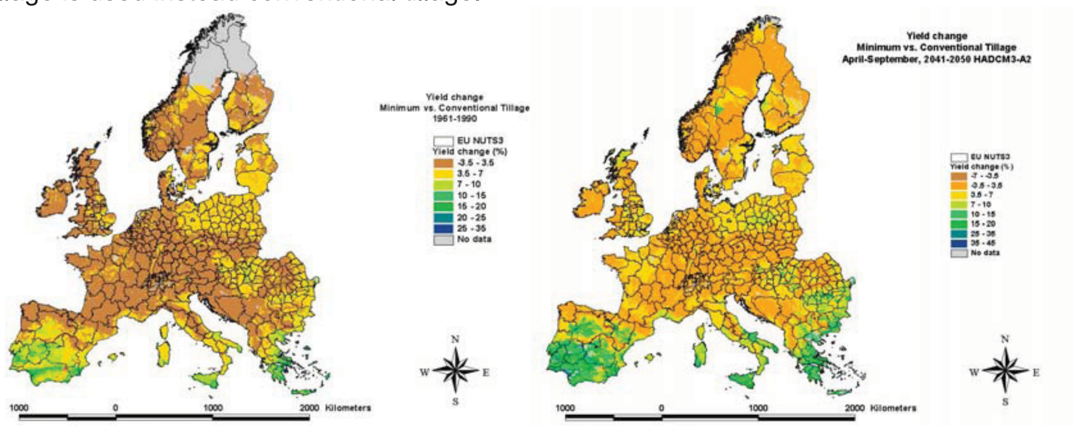


Figure 4. Yield change (%) between minimum and conventional tillage for baseline (1961-1990) and climate change scenario (2041-2050 HADCM3-A2)

The **irrigation needs** in climate change scenario will be higher than for the baseline (Figure 5). Significant increases in water demands in 2041-2050 time range will be for South Spain, Greece, Bulgaria, South Romania and Serbia

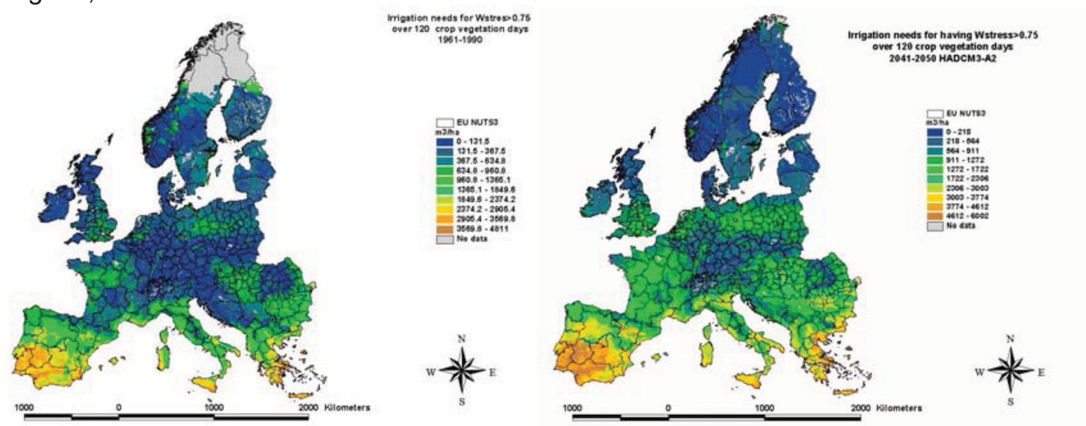


Figure 5. Irrigation needs (m^3 ha^{-1}) for having water stress not less than 0.75 (1: no water stress) considering 120 days crop vegetation period for baseline 1961-1990 and climate change scenario for 2041-2050 (HADCM3-A2)

In order to know if we have enough water for irrigation figure 6 shows the ratio between irrigation needs and rainfall during october-march period (charging time for water reservoirs used for irrigation)

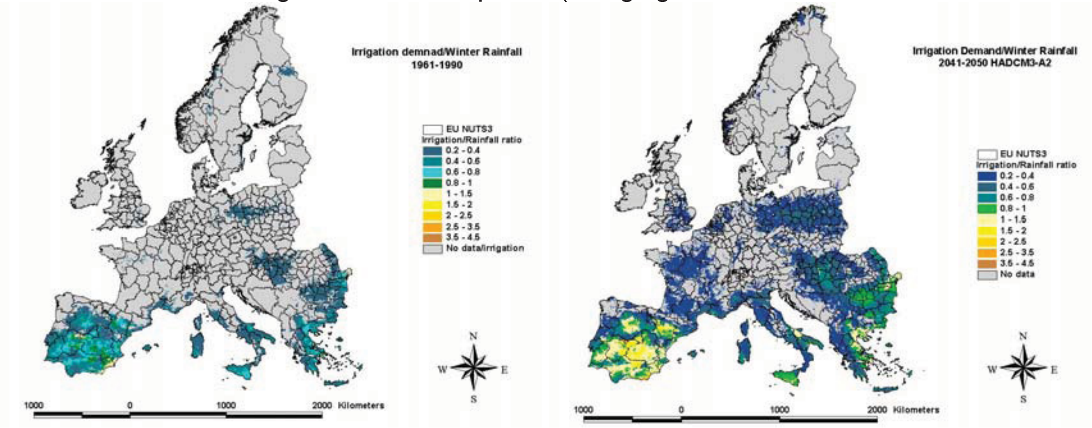
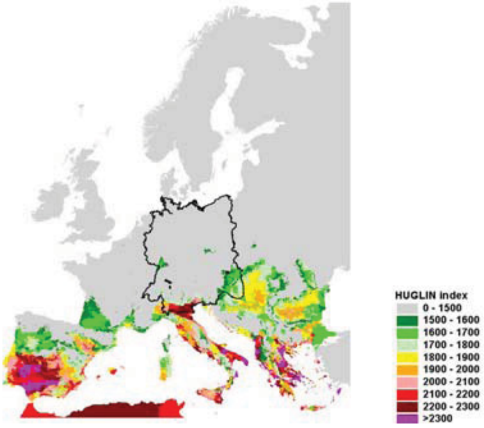


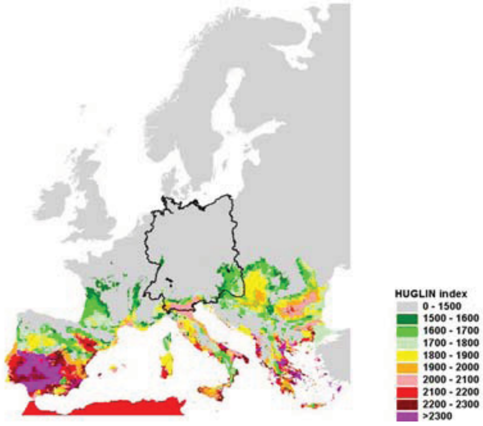
Figure 6. Ratio between irrigation demand and water rainfall during october-march period.

Figure 6 shows that for the baseline scenario (1961-1990) the water availability has constrains in Spain, South Italy, Greece, Hungary and South-East Romania. For 2041-2050 climate change scenario not enough water for irrigation will be in Spain, Greece, South-East Romania.

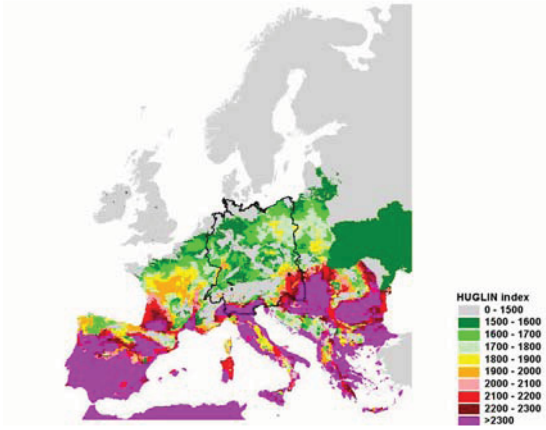
As for the evaluation of the adaptation to climate changes by **changing land use** the Huglin index was used to evaluate the suitability for vineyards (as an alternative to arable crops). Figure 7 shows the increasing suitable areas for vineyards for the following time periods: 1901-1930, 1961-1990, 2041-2050.



1901-1930



1961-1990



2041-2050

Figure 7. Huglin index (suitability for vineyards; higher marks more suitable) for a time sequence from 1901-1930, 1961-1990 to 2041-2050 (HADCM3-A2)

Keywords: adaptation to climate change, arable crops, minimum tillage, irrigation, Huglin index

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RELIABILITY OF CURRENT SPANISH IRRIGATION DESIGNS IN A CHANGED CLIMATE

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Abstract

A very serious effort aimed to modernise irrigation systems is being conducted in Spain, to reduce water and energy loses in an environmentally sustainable way. According to the large amount of funds involved, the new irrigation systems should work properly in a large period. The systems have been designed taking into account historical evapotranspiration averages, in the months of maximum demand, as well as the Kc coefficients of typical crops. However, the increment in evapotranspiration rates, due to global warming, could yield that these new and expensive irrigation systems become not able enough to fulfil the crop water requirements in a near future. On the other hand, the expected increment in CO_2 concentration could diminish crop transpirations rates for similar water demands from the atmosphere, reducing irrigation requirements. A methodology was developed in order to estimate crop water requirements under Climate Change conditions. The reliability of a new irrigation system designed to Valladolid, Northern Spain was tested. We used the regionalized climate-change scenarios for Valladolid, provided by the National Institute of Meteorology for the periods 2011-2040, 2041-2070 and 2071-2100; considering the ECHAM and CGCM global circulation models and the A2 and B2 emission scenarios. A historical series of daily meteorological data of Valladolid was used to generate statistical evapotranspiration distributions through the LARS-WG generator. Realizations considered each of the above periods, GCM models and emission scenarios. Furthermore, the Kc of maize, potato and sugarbeet; the typical irrigated crops of the zone were reduced for each period, GCM and emission scenario; according to the relationships between CO_2 concentrations and transpiration obtained by Kruijt et al. (2008). The results indicated that, in average, the historical evapotranspiration is a good enough indicator to estimate the crop evapotranspiration in the future, particularly considering the CO_2 effect in reducing crop transpiration. However, evapotranspiration variability is significantly incremented after 2040, especially for the A2 emission scenario. The results pointed out that evapotranspiration variability rather than global increment is the most serious risk that current irrigation systems must face in the near future in Northern Spain, as consequence of Climate Change. Such variability should be included in irrigation designs.

Keywords: irrigation designing, Spain, Climate Change scenarios, weather generator

INTRODUCTION

According to the last reports on Climate-Change effects (IPCC, 2007); Mediterranean region could expect higher temperatures, less water availability and an increment of drought frequency. Irrigated agriculture could face serious risks at South Europe in the near future, due to water scarcity and the potential increment of evapotranspiration rates (EEA, 2007). According to Iglesias et al. (2005), some Spanish regions could expect a reduction on water availability of up to 50% by the end of the century, although there are significant spatial variability and general uncertainty.

This is an important problem in Spain, where irrigation uses about 70% of the available water (MAPA, 2005). Irrigation allows farmers to obtain regular higher yields, provides jobs and helps to keep population in rural areas (MAPA, 2005). An investment of more than 5 billion Euros is being conducted in Spain, aimed to modernise and to reduce the water and energy loses, in an environmentally sustainable way (MAPA, 2005). Most of the investment is covered by public funds, but farmers pay about 15% of the total amount.

The new irrigation systems are designed considering with the existing climate data (MAPA, 2005). However, those system designs could be unable to supply the crop water requirements in the future, due evapotranspiration rising. Present paper provides a methodology to estimate Climate-Change effects on future water requirements. An example for the main irrigated crops in the Spanish Northern Plateau is shown and the reliability of an existing system, designed using historical data is evaluated.

MATERIALS AND METHODS

We have evaluated the capability of coping with future water demands of an irrigation system constructed in Valladolid, Northern Spain, (41º39'N, 4º43'W). An irrigation district of 610 ha received a new conduction, distribution and pumping system in the framework of the national irrigation plan; with a total investment of more than 800 000 €.

The system was designed considering July evapotranspirations. The water requirements were estimated for a typical combination of crops in the zone, using the corresponding crop coefficients (Kc) and subtracting the historical effective precipitation. An expected system efficiency of 0.75 was considered. The instantaneous maximum water supply was calculated for irrigation journeys of 18 hours, six days at week. Accordingly, the system must supply at least 1 l/s.ha in order to fulfil irrigation requirements in the zone.

We assumed that the 610 ha were dedicated to maize (40%), Sugarbeet (35%) and potato (25%). The Kc coefficients currently used for irrigation were linearly transformed to Priestly and Taylor values using the relationship found by Utset et al. (2004). Penman Monteith and Priestly and Taylor approaches have been found statistically equivalent while conducting modelling studies in Spain (Utset et al., 2004). Furthermore, Priestly and Taylor is the method considered in many crop models, which are routinely used in Climate-Change impact assessments in agriculture.

Daily values of precipitations and maximum and minimum temperatures of each of ECHAM4 and the CGM2 for the A2 and B2 emission scenarios for the 2011-2040, 2041-2070 and 2071-2100 periods were downscaled to the Valladolid station using the analogue method (Brunet, 2007). Furthermore, we used the solar radiation data provided by the IPCC data centre.

Instead of using direct downscaled data, we generated 150 realizations of daily weather data for each period, GCM and emission scenario; through LARS-WG (Semenov and Barrow, 2002). The perturbation files for the weather generator were created from the differences between monthly means of the downscaled climate scenarios of each period and the 1960-1990 baseline data for Valladolid for the ECHAM4 and CGM2 models (Brunet at al., 2007). LARS-WG accounts for temperatures variability while generating Climate-Change modified data, since the perturbation file includes changes in mean monthly standard deviations (Semenov and Barrow, 2002). Such deviations were calculated from the available scenarios and compared to the baseline data.

CO_2 enrichment could reduce the stomatal conductance and transpiration (Ainsworth et al., 2002; Bernacchi et al., 2007). However, CO_2 influence on crop photosynthesis and transpiration depends on other factors as well. Hence, it is difficult to determine a single crop response to a certain Climate-Change scenario (Bunce, 2004; Bernacchi et al., 2007).

Concerning CO_2 effects on reducing crop evapotranspirations, Bunce (2004) pointed out that results obtained in open top chambers might be not representative due to unnatural ventilation conditions. Only recently conducted FACE experiments might consider all the feedback processes.

Kruijt et al. (2008) introduced a simple approach to account for CO_2 effects on crop evapotranspirations. The effect would be considered for each crop in the known ET formula:

$$ET_C = a.K_C\, ET_{ref} \qquad [1]$$

Through a coefficient a, which can be calculated as:

$$a = S_{gs}.S_T\, F_T\, \Delta CO_2 \qquad [2]$$

Where ΔCO_2 is the change in atmospheric CO_2 concentration respecting the baseline (330 ppm), S_{gs} is the relative change in stomatal conductance with CO_2 concentration, S_T is the sensitivity of crop transpiration to stomatal conductance and F_T is the fraction of transpiration respecting total ET.

Kruijt et al. (2008) considered the published FACE data on CO_2 effects on stomatal conductance to develop Sgs equations regarding CO_2 concentrations. They considered highest sensitivity rates where advective transpiration plays a major role. This is just the case of irrigated lands in the Spanish semiarid conditions (Utset et al., 2004).

We used the SWAP approach to separate transpiration from evapotranspiration; considering the LAI values corresponding to July for each crop. The CO_2-dependant crop coefficients Kc' were determined through [2] for the expected CO_2 concentrations at each of the scenarios and periods considered.

RESULTS AND DISCUSSION

The average July evapotranspirations for each emission scenario, GCM and period are depicted in Figure 1. Evapotranspirations are higher for the A2 scenario, as well as the rising rate. Furthermore, variability is also higher for the A2 scenario. No significant differences were found between GCM.

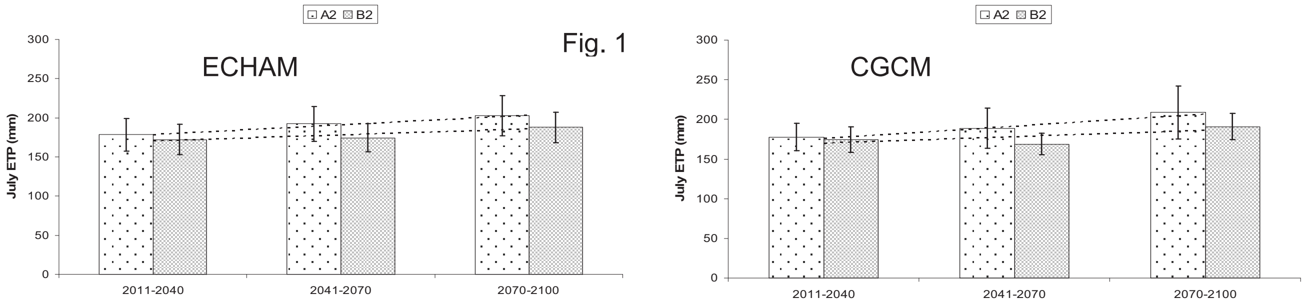

Fig. 1

Table 1 shows the Kc coefficients, as reduced according [2]. The reduction percents regarding current coefficients are shown also.

Period	SRES	Maize		Potato		Sugarbeet	
		Kc	%	Kc	%	Kc	%
2011-2040	A2	1.148	93.8	1.140	97.2	1.069	95.3
	B2	1.167	95.3	1.154	98.4	1.082	96.5
2041-2070	A2	0.955	78.0	0.993	84.6	0.931	83.0
	B2	1.053	86.0	1.067	91.0	1.001	89.2
2070-2100	A2	0.672	54.9	0.778	66.3	0.729	65.0
	B2	0.926	75.6	0.970	82.7	0.910	81.1

The Kc coefficients are notably lower for the A2 scenario at the end of the century. However, these results do not consider variability, which can be up to 50% in the case of maize (Kruij et al., 2008). Table 2 shows the calculated water supply (C), following the same methodology but considering future ETP rates. Both, the average and the 95th percentiles are shown. Furthermore, the Table shows calculation considering CO_2 effects on Kc (C-CO_2) and ignoring such effect (I-CO_2)

Kc-CO_2	Period	Model	Scenario	C_m (l/s.ha)	C_{95} (l/s.ha)
C-CO_2	2011-2040	CGCM	B2	0.945	1.209
			A2	0.950	1.212
		ECHAM	B2	0.930	1.270
			A2	0.953	1.257
	2041-2070	CGCM	B2	0.833	1.051
			A2	0.868	1.179
		ECHAM	B2	0.863	1.116
			A2	0.886	1.160
	2070-2100	CGCM	B2	0.857	1.075
			A2	0.729	1.045
		ECHAM	B2	0.842	1.092
			A2	0.707	0.933
I-CO_2	2011-2040	CGCM	B2	0.961	1.229
			A2	0.979	1.250
		ECHAM	B2	0.946	1.296
			A2	0.983	1.295
	2041-2070	CGCM	B2	0.925	1.167
			A2	1.047	1.421
		ECHAM	B2	0.958	1.239
			A2	1.068	1.399

	2070-2100	CGCM	B2	1.061	1.330
			A2	1.170	1.676
		ECHAM	B2	1.042	1.351
			A2	1.134	1.496

As average, the calculated water supply considering historical ETP (1 l/s.ha) would be enough to fulfil crop water requirements during the century. However, the system could fail after 2070 if the CO_2 effects on transpiration are lower than expected, especially for the A2 scenario.
The most important risk, however, regards variability. The current water supply could be not enough in the case of extremely hot summers, as might be expected in Spain in the next years. This risk can be even higher at the short and medium term, when CO_2 effect is not significant still.

CONCLUSIONS

The new irrigation systems in Spain, designed considering historical maximum demands, might be able, on average, to meet future demands for irrigation, even considering Climate Change. The increase in CO_2 concentrations could cause significant reductions in irrigation demands during the century. However, this issue has to be verified with additional experiments.
The increase of extreme events associated with Climate Change could notably increment evapotranspiration variability. This could mean the main risk of irrigation systems designed by considering only historical evapotranspiration averages. This risk could be more important in the short and medium terms, when the CO_2 effect of reducing crop water demand is still not significant.
The irrigation system designing should take into account the future increase of evapotranspiration variability.

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VULNERABILITY AND ADAPTATION OF SOME HERBACEOUS CROPS TO CLIMATE CHANGE IN SOUTHERN ITALY

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Abstract

Significant variations on climate, due to the human activities, with greenhouse gases increasing into the atmosphere and fastest global warming trend in the history of the Earth, are occurring with a great impact on agriculture activity and water resource availability. The Mediterranean areas seem to be interested by a greater increase of temperature than other regions with the rainfall predictions being more uncertain because of relationships between precipitations and local factors, like the orographic features and land use (IPCC, 2007).

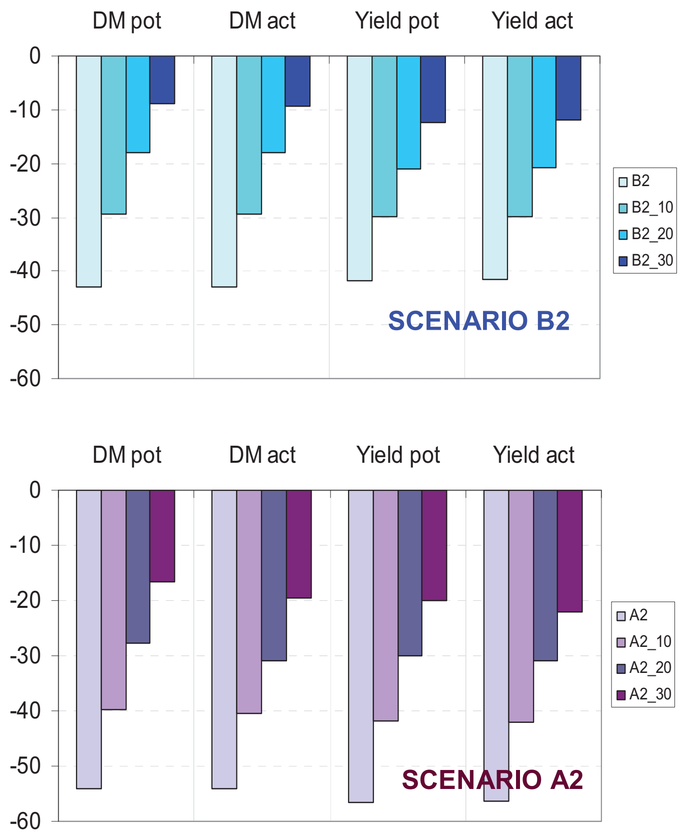

Fig. 1 – Average departure (%) compared to the past of total biomass (DM) and Yield for Sorghum under B2 and A2 scenario without and with advanced sowing time of 10, 20 and 30 days

The climate change (CC) may have a significant impact on plant phenology, crop growth and water requirement. For determinant herbaceous crops a reduction on growing cycle and a consequently decrease of yield is expected. The contrary could happen for crop with indeterminate cycle, if an increase of water resources will be available. The forecast increase of CO_2 may counterbalance these negative effects, at least for the C3 plants.

From these considerations the complexity to estimate the potential impact of CC on crop productivity appears evident and one of the possible approach is that to use the crop simulation models coupled to the outputs (temperatures, precipitation and global radiation) of General and Regional Circulation Model (GCMs and RCMs).

In the framework of ADAGIO (Adaptation of Agriculture in European Regions at environmental risk under climate change) project, the aim of this paper is to present the results of several pilot assessments carried out in order to estimate the vulnerability and adaptation degree to CC of some important crops of Southern Italy (scarola, water melon, sorghum, tomato and winter wheat), using SWAP and DSSAT models, that adequately describe bio-physical processes of soil, crop and atmosphere. The adaptation option considered in this paper is the optimization of sowing or transplanting time.

SWAP (Soil-Water-Atmosphere-Plant), a physically based model (van Dam et al, 1997) that resolves the Richard's equation in order to describe soil water fluxes and solute transport in saturated/unsaturated soil media, has been used in order to simulate the soil water balance under cultivation os Sorghum, Water melon and Scarola. For such pilot assessments, the Regional Circulation Models was HadRM3P, developed by the Hadley Centre, UK. HadRM3P has a spatial resolution of 0.44° latitude by 0.44° longitude and is the result of a dynamical downscaling. It takes boundary conditions from a coarser resolution global model and provides a higher spatial resolution of local topography and more realistic simulations of fine-scale weather features. In particular, the outputs from HadCM3 experiments provide the boundary conditions to drive a high resolution (~120 Km) model of the global atmosphere (HadAM3P). In turn, the outputs from this model in turn provide the boundary conditions to drive the HadRM3P. This double nesting approach is performed to improve the quality of the simulated climate.

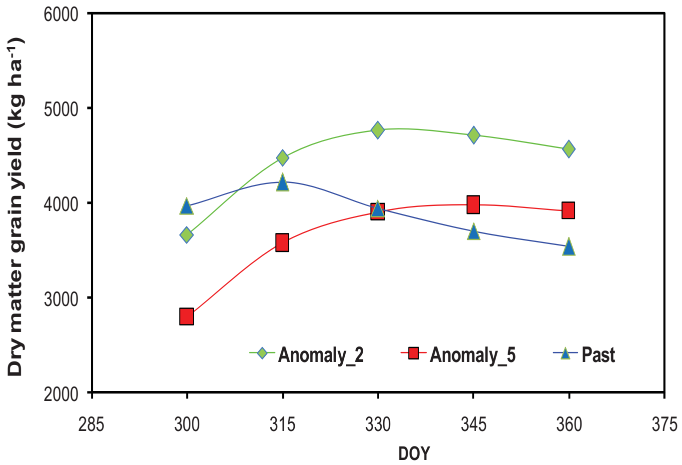

Fig. 2 – Response functions of Durum Wheat to sowing time under different scenarios

In order to simulate climate change, two emission scenarios (A2 and B2) were a selected among those proposed by the Special Report on Emissions Scenarios (IPCC 2000), to have a wide and representative range of changes in temperature patterns.

Regarding the cultivation of Winter Wheat and Tomato the DSSAT model (Jones at al., 2003) have been used. Due to the coarse GCM resolution, an empirical downscaling procedure was set up in order to reproduce, on a regional scale suitable for impact assessment in agriculture (i.e. 50kmX 50km), the future climate at the time of average global warming of 2°C and 5°C in a cell close to the "Capitanata area", a very important district for winter wheat and tomato production in the Southern Italy (Puglia Region). The procedure was based on the use of a weather simulator (LARS WG, Semenov and Barrow, 1997) that allowed including changes in mean climate as well as in climate variability as derived from a GCM in future climate simulations, for the time-slice corresponding to an average increase of +2°C (Anomaly_2) and +5°C (Anomaly_5) with respect to the pre-industrial period. In order to take in account the effect of $C0_2$ different values this gas atmpsphere conceration were adopted: 360 ppm for the reference scenarios (Past: 1975-2005), 550 and 700 ppm for Anomaly_2 and Anomaly_5, respectively.

In this work observed daily data (Tmin, Tmax, rainfall and radiation) for the period 1975-2005, spaced 50 x 50 km over the EU domain (MARS project http://mars.jrc.ec.europa.eu/) were used for the local calibration of the stochastic weather generator. After calibration, 100 years of synthetic daily weather data were produced for each one of 2248 grid points to represent the baseline period over the domain (Fig. 1).

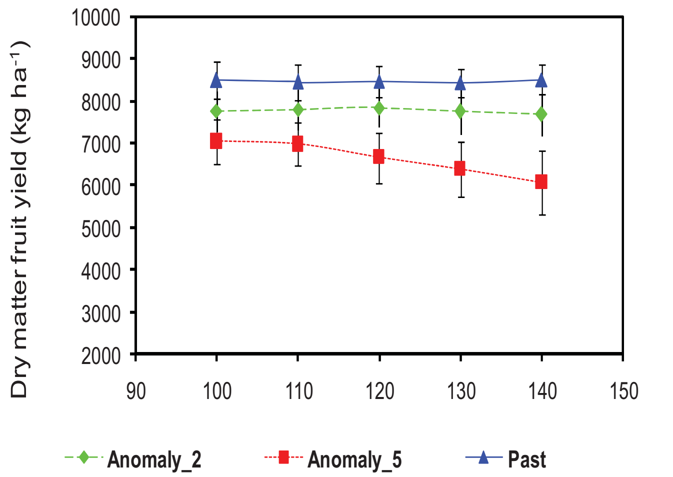

Fig. 3 – Response functions of tomato yield to transplanting time under different scenarios

The results of HadCM3 for A2 scenario for the time-slice 2030-2060 were used to derive the forcing factors for the downscaling procedure. These were computed for each one of 304 GCM grid points over the domain, as monthly average differences of Tmin, Tmax, rainfall and radiation between the future and the reference period (1975-2005). Finally, forcing factors calculated for each GCM grid were applied in the downscaling procedure to perturb the relevant climatology of the observed dataset generating stochastically 100 years of daily data for each 50x50 km grid point.

The results of the statistical downscaling procedure were used as input variables to drive DSSAT model simulation for present and future periods. For "SWAP" pilot assessments, the "Delta" approach was used. In particular the following equations were applied to calculate the average departures of selected indicators:

$$\Delta_{SC} = 100\frac{Y_{SC\_NST} - Y_{Past\_NST}}{Y_{Past\_NST}}$$ (Eq. 1)

$$\Delta_{SC\_AST} = 100\frac{Y_{SC\_AST} - Y_{Past\_NST}}{Y_{Past\_NST}}$$ (Eq. 2)

Where Y is the parameter considered, SC is the scenario (A2 or B2), NST and AST indexes refer to the normal and advanced sowing times, respectively.
For Sorghum cultivation, without adaptation, a very significant aspect is the shortening of growing season (from -20% to -35%). According with this reduction, precipitation, actual transpiration and evaporation are predicted to decrease at seasonal scale. We have a low variations on irrigation depth with average increase of 15% regardless the sowing time and the IPCC scenario.
The impact of climate change on sorghum productivity, on biomass an yield, was high with reductions that exceed the levels of 40% and 50% for B2 and A2, respectively. The yield decrement depended essentially by the shortening of reproductive phase when the assimilates accumulate in the grains.
The adaptation strategy of advancing the sowing time can be considered as positive because it is possible to reduce the negative impact of climate change on sorghum productivity. In particular, it is evident that a ten-day advance period decreased the biomass and yield losses by 10% under B2 scenario allowing a productive reduction of about 10% (starting from -40%) with the most advanced time sowing compared to the past situation (Fig.1).
Under A2 scenario the relationship "advancing time period/productivity" was about the same with the minimum losses of 20% that can be obtained with the most advanced sowing time.

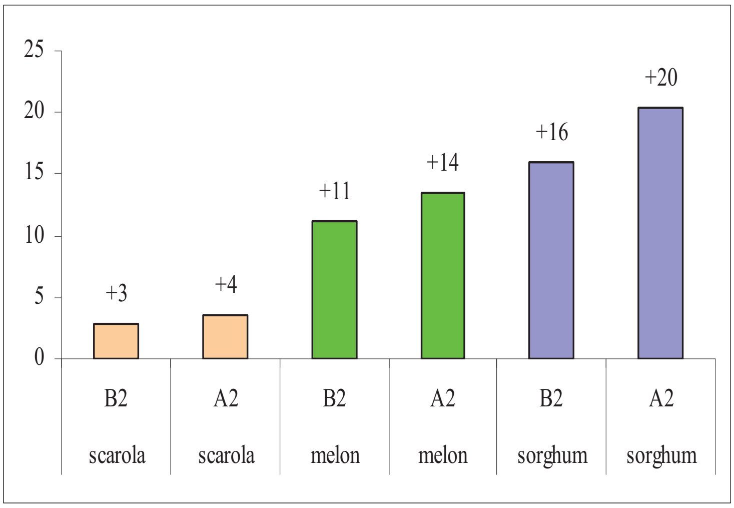

Fig. 4 – Average departure (%) compared to the past of daily evapotranspiration (Etc) for three crops

Without adaptation the cycle length of Water Melon decreased by 20% in both the scenarios. Like the Sorghum, this reduction determined a consistent decrease of rainfall at seasonal scale (-60%) and less variations on transpiration (-10%) and irrigation (5%). Higher reduction were expected under A2.
Also in this case, advancing of sowing time had important effects on the components of water balance and in general the tendency was to decrease the reductions and to restore the parameter values of past situation.
Also for Scarola, a winter crop, the main effect of CC was the reduction of cycle length with decrease of rain and evapotranspiration. In a such case, the ratio Ta/tp, without irrigation indicated more stress for the plant in B2 and consequently an increase of irrigation requirement.
Contrarily to summer crops, the delayed transplanting allowed to restore reference parameters but with a significant increase of irrigation requirement.
A relevant shortening characterized the cycle of winter wheat with 13 and 30 days for sowing-flowering period under Anomaly_2 and Anomaly_5, respectively. An other important point was that the reduction of vegetative period was larger than the reduction of reproductive period.
At normal sowing time, the central value (330 Doy) of Fig. 3, we had the same yield for past and Anomaly 5. Under anomaly2 there was an increase of productivity of about 1 t ha^{-1}. Under future scenarios, the crop responses were non linear with a the first part characterized by a increasing yield and the second part characterized by a plateaux
In the past period the advanced sowings give higher production. Under Anomaly_2 the best sowing times were in November and under anomaly5 the last times of December restored the yield obtained in the past period with normal sowing time
The Fig. 3 reports the main results of Tomato pilot assessment carried out with DSSAT. In average, there was a reduction of yield from the past to the future corresponding to 10% for Anomaly_2 and 20% for Anomaly_5. The second important finding is that the tomato was almost insensitive to

transplanting time for the past and anomaly2. Regarding anomaly 5 an advance of transplanting can increase the tomato productivity allowing a level of 70 t ha^{-1}. But it was no possible to compensate the negative effect of climate warming on yield.

Finally, the Fig. 4 shows the daily evaporative demand as affected by climate change for the crops simulated with SWAP. An increase of less than 5% characterized the cultivation of winter scarola, a value very low if compared to those of water melon (more than 10%) and sorghum (15-20%) , with the values of A2 scenairo being significantly higher than B2.

Early and delayed sowing time for summer (sorghum and watermelon) and winter crops (scarola and winter wheat), respectively, can be considered useful agronomic strategy could be strategies of adaptation to CC that can be optimized by using this approach based on crop simulation models coupled with climatic models. For tomato such optimization was effective only under the pessimistic scenario with the highest yield obtained with advanced transplanting times.

Keywords: agronomic adaptation, evapotranspiration, climate change impact, modelling.

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MULTI DECADAL SATELLITE SOIL MOISTURE DATASETS FOR AGRICULTURAL DROUGHT ASSESSMENT

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Abstract

Soil moisture is a crucial parameter for understanding climate change impacts on agroecosystems. It is the switch that controls the proportion of rainfall that percolates, runs off, evaporates from the land, and is finally available for plant take-up (Jackson et al., 1999). Soil moisture was therefore identified as an emerging essential climate variable (ECV) in the latest IPCC assessment report of 2008 (FAO, 2008). Climate model simulations suggest that soil moisture availability will decrease over major part of the global land surface (Gerten et al, 2007) but so far, observations to effectively constrain these models have been absent. Up to date, long-term satellite records have not been available and no significant trends in available in-situ data have been observed. Globally, the number of long-term in-situ monitoring networks is small and mostly restricted to mid-latitude regions. Also, the properties of the data may vary significantly between networks given that there is neither a standard measurement technique nor a standard protocol. These shortcomings were also recognised at the workshop "Future Climate Change Research and Observations: GCOS, WCRP and IGBP Learning from the IPCC Fourth Assessment Report" organised jointly by the Global Climate Observing System (GCOS), the World Climate Research Programme (WCRP), and the International Geosphere-Biosphere Programme (IGBP) in Sydney, Australia, 4-6 October 2007. The workshop report recommended the expansion, improvement, and assimilation of current in situ and remotely sensed observations of soil moisture.

Space-based observations have the potential of observing the highly dynamic spatiotemporal behaviour of top-soil moisture content on a global scale. For this purpose commonly active scatterometers and passive radiometers at low microwave frequencies are used. Whereas the lifetime of single instruments and missions might be too short to capture climate related trends, combining various observations into one common data set would provide a global data set dating back to late 1978 (Fig.1).

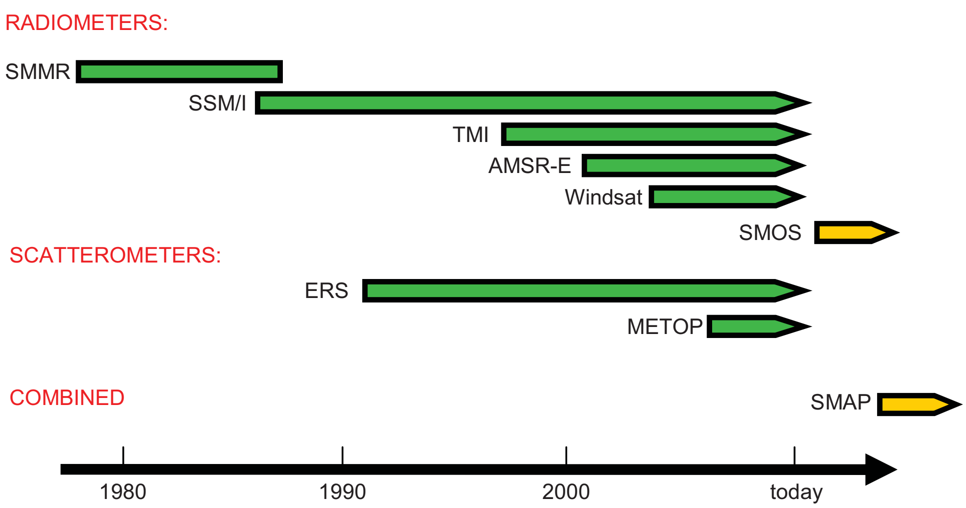

Fig. 1 Past, current, and future spaceborne microwave missions used for constructing a long-term soil moisture data set.

Within the ESA project WACMOS (Water Cycle Multi-mission Observation Strategy) the aim is to establish a solid scientific basis for the development of long-term coherent soil moisture products. The challenges when merging the different data sets are numerous as the globally available soil moisture data sets are based on sensors with different specifications and obtained using different retrieval concepts for passive and active observations. Thus, despite the large increase in temporal coverage obtained when combining the data sets, the use of multi-mission data also involves many scientific challenges, such as quantifying the temporal and spatial error fields for each satellite product, developing data assimilation systems using appropriate land surface parameterisation schemes, and understanding the complex effects of the various error sources (sensor calibration, retrieval errors, model parameterisation, etc.) on observed variations.

Initially, data from six passive (SMMR, SSM/I, TMI, AMSR-E, Windsat) and two active (ERS Scatterometer and METOP-ASCAT) microwave systems are harmonized, but the proposed methodology can be easily extended to future observation records such as SMOS and SMAP. The harmonized data set has a spatial resolution of 0.25° and a temporal resolution of one day. One of the major challenges is to bring soil moisture units and data ranges of the different data sets into a common format. This is done using the cumulative distribution matching (CDF) technique used e.g. by Drusch et al. (2005). The CDF technique calculates for each pixel the function that is needed to convert one data set into the other, while accounting for the variance of both datasets. Since not all data sets show consistent overlap in space and time to allow for a reliable matching, ECMWF modelled reanalysis products are used as a reference data set.

The use of a third, independent dataset such as the ECMWF reanalysis products (in addition to the radiometer and scatterometer derived data set) also facilitates assessing errors and systematic biases of the single data sets by triple collocation (Scipal et al., 2008). In order to be valid, this technique requires input data sets that are linearly dependent while the errors are uncorrelated between the data sets. As linearity between data sets is not given for each location on Earth (Fig.2) additional ways are being explored for characterizing errors of the merged data set. For example, uncertainty and quality indicators from the input data sets will be propagated into the merged product. Correlation statistics like presented in Fig.2 also help to identify those areas where one data set should be preferred over the other (e.g. active systems seem to perform better over densely vegetated tropical forests whereas passive observations do better over very dry areas).

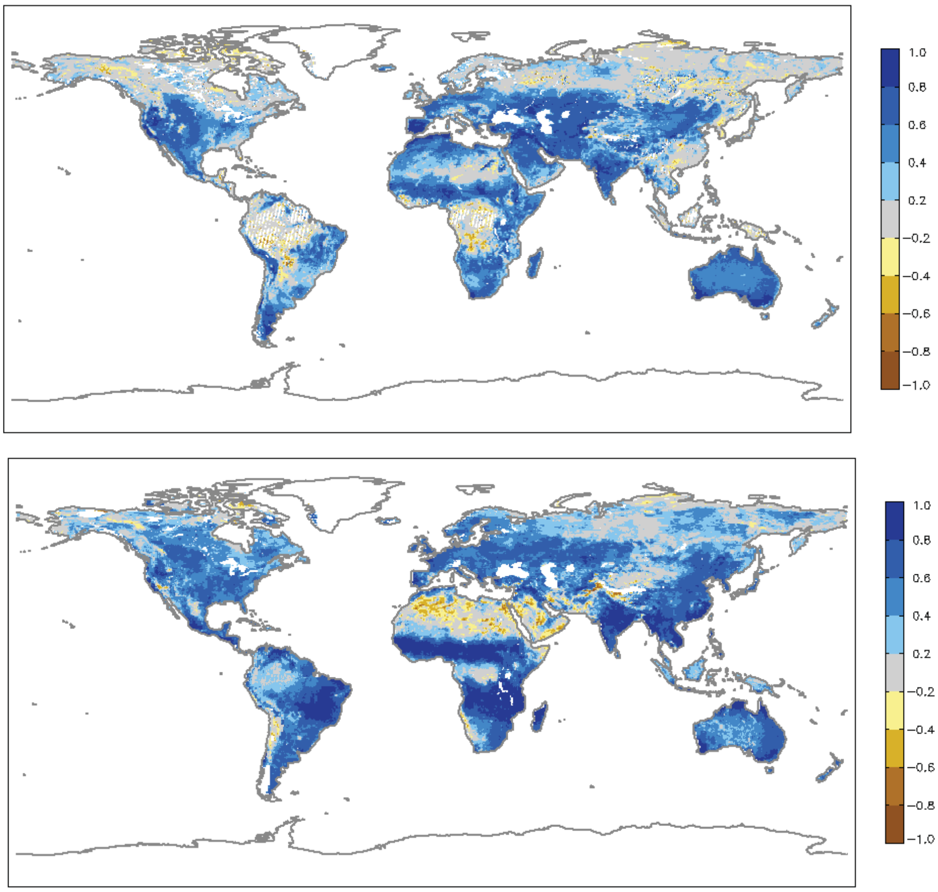

Fig. 2 Correlation coefficient maps between ERA Interim soil surface moisture and soil moisture retrieved from AMSR-E (top) and ERS Scatterometer (bottom).

First results of a long time merged satellite soil moisture data sets are promising: As a first test case, the harmonization routine was set up for mainland Australia using LPRM soil moisture products (Liu et al., 2009). A 29 year dataset (1978-2006) was derived from Nimbus SMMR, DMSP SSM/I, TRMM-TMI and Aqua AMSR-E products. In this case AMSR-E soil moisture was used as a reference. A trend analysis was applied from this long term time series and compared to other products. The observed trends in soil moisture closely followed those of observed for rainfall and vegetation over that period and were in good agreement with soil moisture derived from three macroscale hydrological models (CLM, MOS and NOAH-GLDAS). The next step will be to merge active and passive observations to obtain a global data set over more than 30 years. This will not only improve spatial and temporal coverage and resolution of the data record but also reduce errors when two or more observations overlap. The latter is particularly important if subtle climate related changes want to be detected and adequate adaptation strategies for agricultural land use and management need to be developed.

Keywords: soil moisture, water resources, climate change, agriculture, remote sensing, radar

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AGRICULTURAL DROUGHT MONITORING SYSTEMS (ADMS) – INCLUDING CROP SPECIFIC REQUIREMENTS AND SOIL MAP FOR THE DETECTION OF AREAS AFFECTED BY DROUGHT IN POLAND

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Abstract

Drought is one of the main items in discussion about climate change impact on agriculture, whilst monitoring system could support implementation of adaptation to climate change (IPCC 2007). In Poland one of the main climate change effects on agriculture recorded in the recent years is an increase in the frequency of drought (Górski et. Al 2008). However, the detection of areas and crops affected by drought is not easy, because the drought is determined not only by weather conditions, but also by the soil properties and the time where a water deficit for crops has occurred (Zdruli et al, 2001). That means for efficient agricultural drought monitoring it is crucial to use not only meteorological data but also soil map and phenological models.
The Agricultural Drought Monitoring System (ADMS) was created and designed to identify areas where there are crop losses caused by drought conditions in Poland (Doroszewski et al. 2008). In order to identify an agricultural drought, the entire complex of weather and soil conditions are taken into consideration. The characteristics of the soil retention are determined by the Soil Category, and are identified based on the soil-agricultural map (Fig.1).

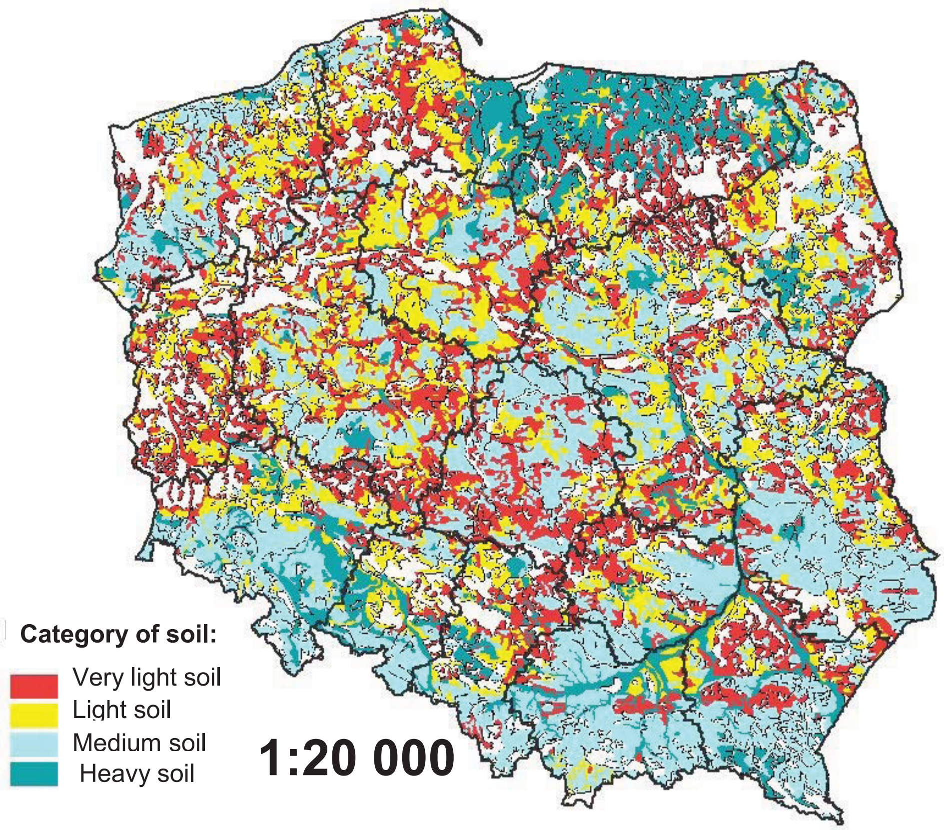

Fig. 1. Map of soil category used in ADMS

The ADMS analysis is based on meteorological data, but the system including soil map showing the spatial variation in water retention and a description of crops resistant to water deficits. To describe meteorological conditions that cause drought the Climatic Water Balance (CWB) is used. The CWB is calculated as a difference between the precipitation and potential evapotranspiration. The potential evapotranspiration is calculated from a simplified Penman method using meteorological elements that are normally measured by the weather stations in Poland. In determining the areas affected by the drought, besides the value of climatic water balance,. In this way, a strong diversification for the susceptibility of Polish soil cover and the effect of a shortage of water is taken into account.
Using the developed statistical-empirical models of yield, the thresholds that cause losses in specific crops or group of crops of the CWB was determined. The thresholds evaluated for certain crops depend on soil retention properties, and are determined by the soil agronomic category that was derived from soil-agricultural map. In order to take into account the differences in crop water demand during their development, the agricultural year was separated into five seasons, for which different thresholds of CWB were evaluated. For example: The occurrence of a climatic water balance -162 mm during the period from 1 April to 31 May, means that the drought threat affected winter and spring cereals on soils that are classified as category I (very light soils) and spring cereals on soils that are classified as category II (light soils) (Fig.2).

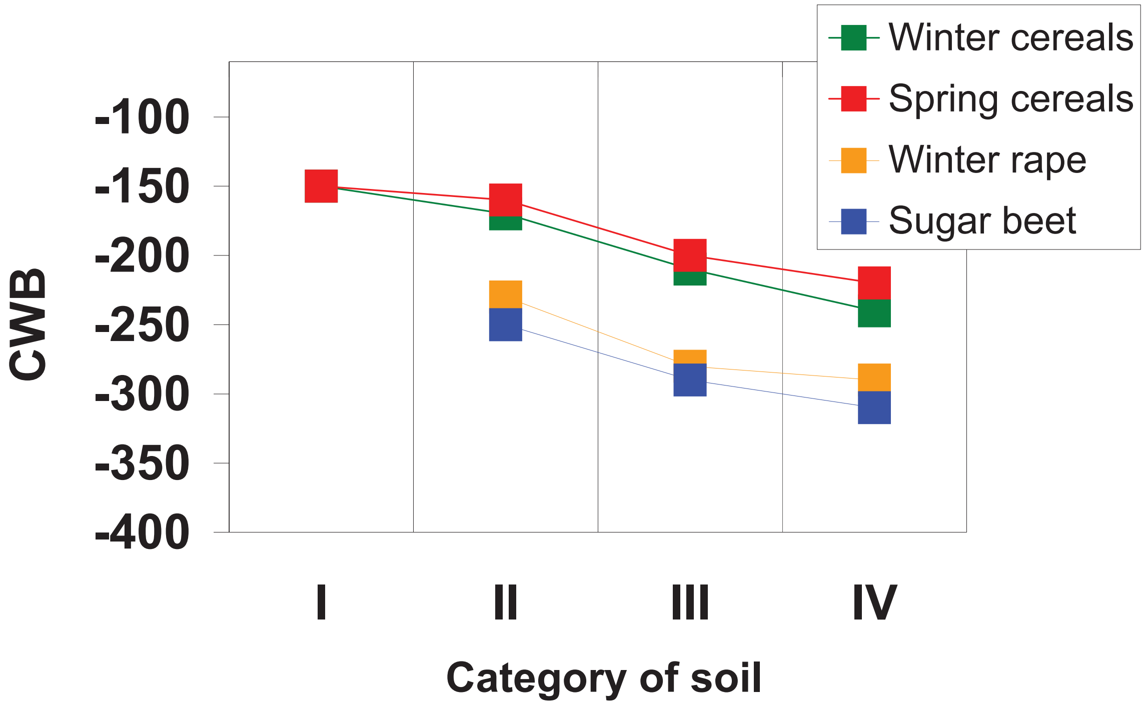

Fig. 2. The Climatic Water Balance (CBW) drought thresholds in the period from April to May for winter cereals, spring cereals, winter rape and sugar beet cultivated on different soil category

According to the definition used by the evaluated system, an agricultural drought is defined by the occurrence of a CWB below the defined thresholds for an individual species or groups of cultivated plants, as well as the soil category in any (60 days) period from 1 April to 30 September of that year. In 2008, the ADMS used data from 55 synoptic stations and about 220 rainwater stations operated by the Institute of Meteorology and Water Management (IMWM) in Poland. In 2009, ADMS will also include data from additional 35 rainwater stations operated by the Research Center for Cultivar's (COBORU) and automatic weather stations with measurement of soil moisture operated by Institute of Soil Science and Plant Cultivation – State Research Institute (IUNG-PIB) (Fig. 3).

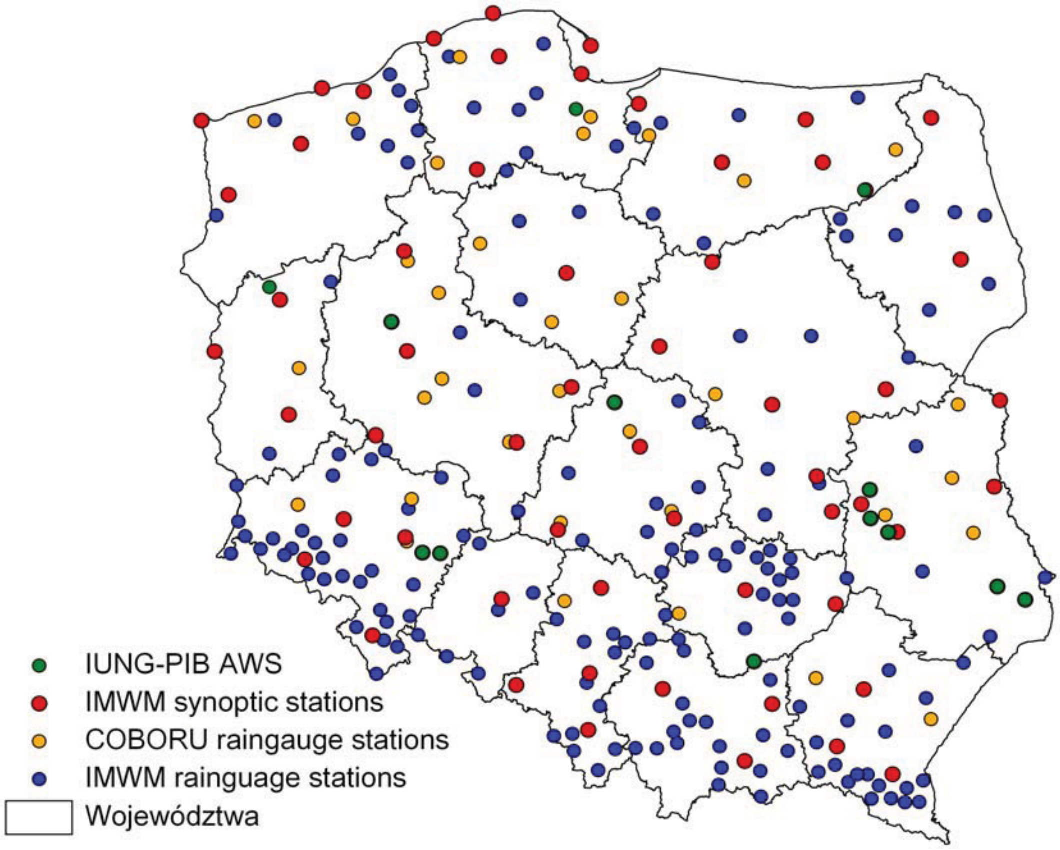

Fig. 3. The weather stations from witch data were available for ADMS in 2009

The ADMS includes computer applications that are integrating meteorological data needed to calculate the CWB, soil-agricultural digital maps and GIS decision-making model. Information regarding the appearance of the drought is delivered to the Polish Ministry of Agriculture and Rural Development and also is published on the website (www.susza.iung.pulawy.pl).

Keywords: drought, agriculture, monitoring system, climate change impact

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ANALYSIS OF THE RELATIONSHIPS BETWEEN CLIMATE VARIABILITY AND GRAPEVINE PHENOLOGY OF THE “NOBILE DI MONTEPULCIANO” WINE

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Abstract

Climate represents one of the main inputs necessary for plants to complete their vegetative-productive cycle and they have a direct effect on the onset and duration of phenological stages and development of crops. Equally important are also indirect effects of these variables, affecting field operations such as fertilizations, pruning, crop protection, finally determining the final yield.
In this study phenological stages of Sangiovese grapevine for the production of “Nobile di Montepulciano” wine data series were analyzed and related to historical series of meteorological information (since 1970 in Tuscany, central Italy, at the location of Montepulciano (SI) (lat 43° 05’, long 11° 46’)). Weather conditions were described through large-scale meteorological information; in particular, sea surface temperature (SST), 500 hPa geopotential height, North Atlantic Oscillation (NAO) were considered. All data were provided by the NOAA-CIRES Climate Diagnostics Center, Boulder, Colorado, USA, from the website http://www.cdc.noaa.gov/ and processed by the NCEP/NCAR Reanalysis Project.
Meteorological effects on crop (bud-break, flowering and harvest time) were investigated by means of regression analysis, while teleconnections between data and large scale meteo-climatological data (SST, etc.) were analyzed through correlation maps created using the interactive plotting and analysis link from the website http://www.cdc.noaa.gov. All correlations were calculated on a monthly to a multi-monthly basis, also in relation to the different physiological stages of the crop, from 1970 to 2006.
Bud-break date resulted to be negatively correlated with NAO (data not shown), 500 hPa geopotential height (GPH) and SST (Figures 1a and 1b) for the period February-March with a correlation coefficient (R) of -0.37, -0.6 and -0.5 respectively.

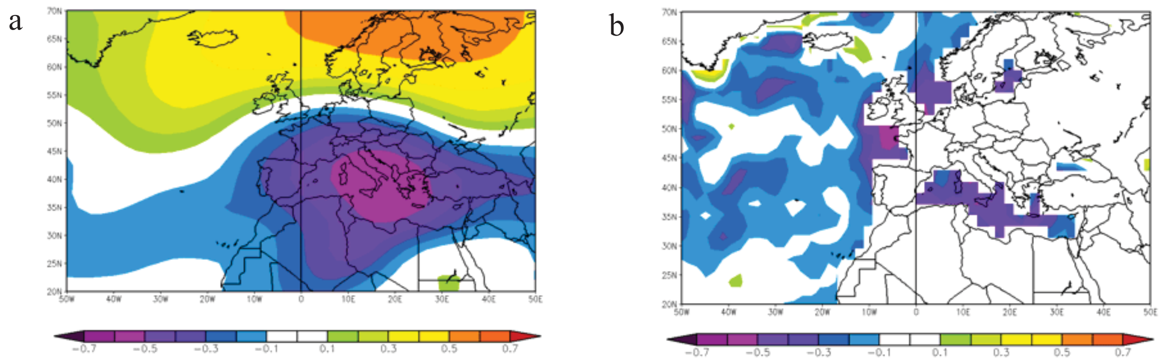

Figure 1. Correlation map between 500 hPa geopotential height (a) and sea surface temperature (b) and bud-break date of Sangiovese. Colour scale indicates correlation coefficient (R) value.

In the same way, negative correlations between 500 hPa GPH and SST were found for flowering date in the month of May (R= -0.6 in both cases) while only 500 hPa GPH was correlated to harvest time in August (R=0.5). On the other hand, NAO index of February-March still had a significant effect on flowering time, normally reached in April. These results were summarized in table 1.

Table 1 – Correlations between meteorological indices and phenological stages of Sangiovese. Legend: *=p<0.05; **=p<0.01; ns= not significant.

	NAO	GEOPOTENTIAL HEIGHT	SEA SURFACE TEMPERATURE
BUD-BREAK	February-March*	February-March***	February-March**
FLOWERING	February-March*	May**	May***
HARVEST	ns	August**	ns

The correlation of NAO index with bud-break date was due to its effect on weather at the beginning of the grapevine vegetative season. In fact, a high NAO determines scarcity of perturbations in the Mediterranean areas with a consequent higher availability of solar radiation during winter and early spring periods that, in turn, determines a higher surface temperature of plants. On the other hand, the correlation between NAO and flowering stage was probably an indirect effect of the autocorrelation between bud-break and flowering itself.
Concerning GPH, a high value of this index determines a situation of high surface pressure with consequent conditions of scarce precipitation and high air temperature; at the same time, air temperature is also affected by a high sea temperature. So both described indices were negatively correlated to the onset and duration of phenological stages, mainly determined by the achievement of specific thermal summations.
Harvest time, contrarily to the other analyzed stages, is not only determined by climatic factors, but also by the experience and decisions of operators. So that, NAO and SST seems not to have particular effects on harvest date while a high GPH in August, determining suitable meteorological conditions for harvest operations, showed again a significant correlation.
The trends of historical series, for the period 1948-2006, were analyzed for the evaluation of climate change and variability impacts on grapevine and so to identify possible short and long term adaptation options for Tuscany viticulture. Both 500 hPa GPH and SST over the productive area of Tuscany region showed a positive trend over time (Fig. 2). In particular, GPH had a continuous positive trend (Fig. 2a) while SST showed a break point in 1980 after which the trend changed from negative to positive (Fig. 2b). On the contrary, NAO index did not show any significant trend.
The relation between plant behaviour and climate, and the potential effect of climate change and variability on the finale production, is also confirmed by the modification of phenological stages. In fact, the onset of bud-break and flowering stages showed a negative trend that lead to an anticipation shortening of both phases (Figure 3).

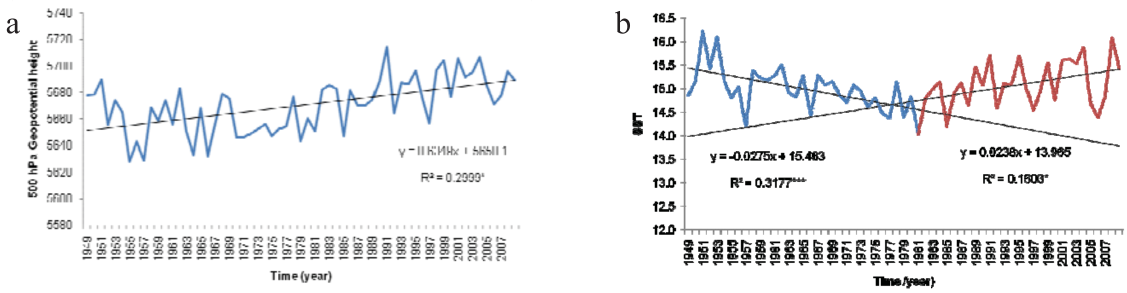

Figure 2 – 500 hPa geopotential height (a) and sea surface temperature(SST) (b) trends from 1948 to 2006. Legend: R^2=determination coefficient; *=p<0.05; ***=p<0.001.

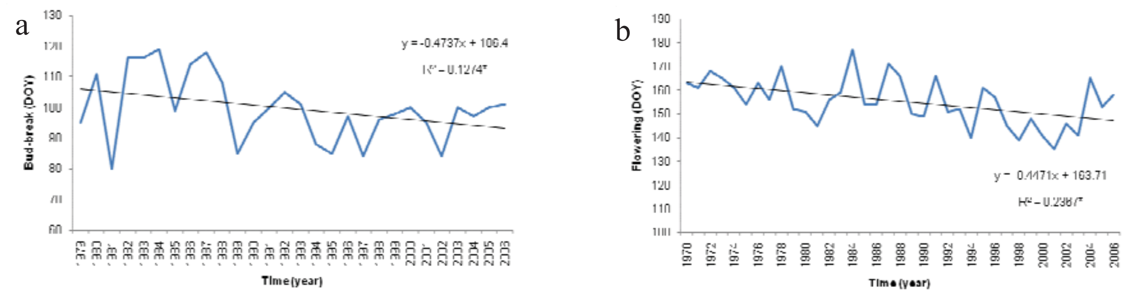

Figure 3 – Bud-break (a) and flowering (b) onset trends from 1948 to 2006. Legend: R^2=determination coefficient; *=p<0.05; DOY=day of the year.

The results demonstrated that a correlation exists between the value of meteorological indices and the onset and duration of Sangiovese phenological stages of following periods. This can represent crucial information in order to forecast the most suitable field and marketing operations. In fact, the analysis of these aspects on the basis of current meteo-climatic variability and change has a high importance, also in order to provide the growers with operational and forecasting tools to improve the management and planning of their production.
Keywords: agroclimatology, large scale meteorological information, climate change impact, viticulture

APPLICATION OF NUMERICAL WEATHER PRODUCTS AND SEASONAL FORECASTS IN AGROMETEOROLOGY

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Abstract

The use of numerical weather products in agricultural decision problems has a long history (Wilks, 1997) and it is nowadays recognized that short- to medium-range and seasonal weather forecasts can provide essential information to farmers and stakeholders (Stigter et al., 2000). Agrometeorological applications such as frost protection, irrigation, fertilization or harvest scheduling, rely on decision processes that take place on a time scale of the order of days and are on the whole well supported by traditional agrometeorological bulletins. But other activities, including the choice of crops and crop sequences, land management (land allocation), the management of fertilizers, or the management of harvest products (forage preservation), would actually profit from targeted information on time scales extending beyond the weekly, the monthly and even the seasonal (Meinke and Stone, 2005).

Over the past, the availability of numerical weather products has markedly increased in parallel to developments in the field of weather forecasting. These embrace for instance the possibility to issue limited-area deterministic forecasts at a horizontal resolution of 1 to 3 km, or high-resolution ensemble forecasts out to the week, or monthly forecasts and global multi-model ensemble predictions. While the use of high-resolution limited-area models is thought to have an enormous potential for improving forecasts of extreme weather events (Marsigli et al., 2005), multi-model ensemble is essential to tackle the problem of representing model uncertainty in seasonal predictions (Palmer et al., 2004).

Regardless of undeniable advances, the application of seasonal forecasts to agrometeorological decision problems remains difficult and has not yet found widespread application (Gabrecht et al., 2005; McCrea et al., 2005). From a technical point of view, there are at least two main reasons.

On the one hand, over most continental areas ensemble predictions systems essentially loose their skill after about two weeks of integration (Weigel et al., 2008). This is true for temperature and even more so for precipitation, which additionally suffers from an inherent inability of forecasting models to reproduce occurrence of wet days and rainfall intensity. The problem appears to be related to the failure of operational global circulation models to simulate processes with pronounced variability on the intra-seasonal time scale, such as the Madden-Julian oscillation and stratosphere-troposphere interactions, and their influence on the atmospheric circulation patterns (Vitart et al. 2007). For Europe, difficulties are evident in relation to the prediction of the North Atlantic Oscillation (Bojariu and Gimeno, 2003), which is the dominant mode of atmospheric variability and has been shown to affect not only the phenological development of crops but in some areas also such important aspects of agricultural production as yield quality (Atkinson et al., 2005).

On the other hand, there still exists a mismatch of spatial scales between the resolution of seasonal forecasts and the requirements of agrometeorological applications. Statistical downscaling techniques are therefore employed to close the gap (Hansen et al., 2006). Different approaches are to hand, including analogue techniques, multiple linear regression, singular value decomposition (Feddersen and Andersen, 2005), canonical correlation analysis, empirical orthogonal functions, non-linear statistical methods such as artificial neural networks (Huth et al., 2008) as well as the application of weather generators (Semenov and Doblas-Reyes, 2007).

Potential and limits of seasonal forecasts for agrometeorological applications have been examined in the framework of the project DEMETER (Palmer et al., 2004). For instance, using the operational system of the Joint Research Centre (JRC) Cantelaube and Terres (2005) considered the impact of replacing climatological data with seasonal forecasts on the reliability of yield predictions for Europe. Utilization of seasonal forecasts was found to have beneficial effects, but only for central and northern Europe. Potential advantages of seasonal forecasts were also exposed in applications of crop simulation models to the regional scale by Marletto et al. (2005, 2007). However, studies by Lawless and Semenov (2005) and Semenov and Doblas-Reyes (2007) suggest that at the operational level the benefits are less clear, with considerable variation in lead-time of predictions depending on crop characteristics and location.

In conclusion it can be said that efforts should be undertaken in the coming years to foster the application of monthly to seasonal forecasts to agricultural decision-making problems. This calls for targeted research programs supported not only by universities, but also weather services and agrometeorological agencies (Fraisse et al., 2006). But advancing the frontiers of knowledge should not be the only criterion for future research, for what is really needed by farmers and stakeholders are choices, options and recommendations to solve practical problems.

Key words: Agriculture, agrometeorology, weather forecasts, seasonal forecasts.

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SENSOR TECHNOLOGY TO ENHANCE WATER EFFICIENCY IN AGRICULTURE – AND THE MOST COMMON MISTAKES MADE IN THEIR APPLICATION

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Abstract

Irrigation practice is very slowly moving from inefficient flood irrigation to more sophisticated methods like pivots and drip systems, lagely reducing the amount of water being applied. In order to carry the criteria for the application of water beyond "observation and experience", modern sensor technology has evolved to assist farmers in their daily decision making process.

A closer look at these technologies is the subject of this paper, while it will not address the need for accurate and detailed soil maps, and the need have good knowledge about a crops water needs during its growth cycle.

The currently most common technologies to enhance water efficiency are Weather stations and soil sensors. Other technologies, like plant sensors, are only slowly evolving.

1) Weather stations

The data delivered by a weather station can be used in a variety of ways. The simplest application is the operation of overhead irrigation systems in correlation with certain environmental parameters.

a) Wind Speed: it is obvious that sprinklers and rain guns should not be in operation with wind speeds beyond a certain threshold. The literature doesn't name a uniform speed, but usually talks of "too strong" winds, sometimes naming thresholds of 16, sometimes 20 km/h.
b) Temperature: particularly in conjunction with wind temperatures too high can lead to excessive evaporation of irrigation water before it can penetrate into the soil.
c) Rain Gauge: since most irrigation systems still work based on time, a rain gauge will help to shut a system off once it starts to rain beyond a certain quantity.

What is of even higher significance is the option to calculate ETo, reference Evapotranspiration. With the help of this number and the addition of the crop-specific multiplication factor K_c an irrigator can determine how many millimeters of water need to be added through irrigation.

There is a large number of formulas to calculate Evapotranspiration, such as FAO-56, better know as "modified Penman-Monteith", Shuttleworth-Wallace, Priestley-Taylor, Hargreaves, and others. Most of these formulas calculate ETo based on air temperature and rel. humidity, wind speed and radiation.

2) Soil sensors

Soil sensors in turn are installed next or near the plant and it's root zone. There is a variety of soil sensors that can help determine the right amount of water during the irrigation process:

a) Soil Moisture
b) Soil Conductivity
c) Soil Salinity
d) Soil Temperature

In particular the direct monitoring of soil moisture is becoming increasingly popular. There is a number of sensors, using all different kinds of technologies to determine soil moisture status, either measuring suction or volumetric water content.

Since the one and only super sensor that does it all doesn't exist it will depend of a number of factors which sensor technology will be used. Such factors are soil type, crop type, annual or permanent installation, root depth, the desired usage of the information, and last not least the price of the sensor.

The most important suction sensors are tensiometers, gypsum blocks and watermarks. While these sensors are most likely better to indicate the plants efforts to extract water, they suffer two distinct disadvantages: their reaction to changing water contents is rather slow, and once the soil reaches saturation it is impossible to see how much the water content of the soil exceeds saturation.

The most important volumetric sensors are FDR sensors like the Sentek EnviroSMART's, the Delta-T Theta Probe and the Echo2 and TDR sensors like the AquaFlex and the Campbell TDR100. While most of these sensors are rather difficult to install their major advantage is a very fast reaction to changing moisture contents and a much wider measuring range.

Most capacitance based FDR sensors use access tubes to bring the sensor elements into the root zone. Therefore this type of sensor is well suited to measure soil moisture on several levels without causing excessive disturbance of the root zone upon installation or when adding more sensors. Sensors like the EnviroSMART offer the possibility to install a sensor every 10cm, and move them down the column as the crop develops deeper roots. It is vital to properly install the access tube.

Many volumetric sensorsare also capable of determining soil salinity and soil conductivity, like the TriSCAN version of the Sentek EnviroSMART and the Stevens HydraProbe.

3) Plant sensors:

Plant sensors are the most recent development, and are only slowly finding their way out of the scientific community into day to day applications. This is not only caused by their still fairly high cost, but also by the difficulty in interpreting their data.

The most common plant sensors are Dendrometers, which allow the measurement of a plants daily expansion and contraction. They come in a variety of sizes, large enough to measure the expansion of a trunk, small enough to measure the size variations on a single grape. Since these instruments measure variation in micrometers, extreme care and precision upon installation are required.

Data logging – data transmission - Telemetry:

Common to all of the above, from weather stations to soil sensors, is the requirement to somehow store and collect the data. The simplest option is a hand held reader that offers nothing else but a display of the current value. Such systems are of little value, since management decisions can hardly be based on a single reading. To create time series of changes a permanently installed data logger is required, ideally equipped with some form of telemetry, radio, GSM or satellite, that automatically transmits data in near real time back to base, and saves the effort of having to go to the field every day to collect the data with a notebook.

The major mistakes made when selecting and installing sensors:

However, no matter how simple or sophisticated the equipment, there are a number of mistakes users make. And these mistakes start long before the installation - they start with the decision what to buy and what to use it for, and they end with no or an insufficient maintenance plan. We should therefore take a closer look at the recommended 7 step process:

Step 1: Define the purpose of the equipment
Step 2: Make a thorough Risk Assessment
Step 3: Select the equipment according to the results of Steps 1 and 2
Step 4: Select the proper site
Step 5: Perform a good Installation
Step 6: Make a plan for ongoing Maintenance
Step 7: Build accruals for replacement

Step 1: Definition of the purpose of the equipment

Equipment needs to be purchased to meet a certain application. Prior to buying a weather station or a soil sensor the user needs to inform himself about probably existing legal requirements, but also about informal requirements such as recommendations and standards.

It is particularly important to make sure that the equipment's capabilities and technical specifications match the application's requirements! Example: computing ETo requires most sensors to be installed at well defined locations, that differ from the requirements of a disease model. A compact, all-in-one station wont be able to match these requirements.

If a multi-purpose approach is required, using the weather station for agricultural, hydrographical and meteorological purposes, it will be the most demanding set of rules that determines which sensors need to be purchased.

Step 2: Risk Assessment

Very often price is the only selection criteria. Which is strange, because in most cases, particularly at larger farms, huge amounts of money are at risk if incorrect decisions are being taken. It therefore helps to take a look at the potential risk connected to the problem that needs to be solved. The farm manager not only needs to perform a cost – benefit/risk analysis, but he should also contact his insurance company to check if their policy contains certain requirements.

A simple example for a basic cost-benefit analysis is reflected in the savings that can be achieved by avoiding extra stress on a corn crop by avoiding late irrigation.

In a 1000ha farm of corn with an average yield per ha of 10mt@USD158/mt, 2 stress days due to late or low irrigation might result in an up to 10% lower yield, amounting to a loss of up to USD 158.000!

Step 3: Select the equipment according to the results of Steps 1 and 2

Steps 1 and 2 should deliver a fairly clear picture as to which equipment should be purchased, both in terms of quality and in technical specifications. The higher the risk, the more stringent legal and informal requirements, the better the quality of the selected equipment. And in compliance with the desired usage of the sensors and depending on the required installation methods and locations the sensors can be selected.

Step 4: Select the proper site

Selecting the proper site is a gravely underestimated step in the process. Choosing the wrong site can render all the efforts taken obsolete, because the site simply doesn't reflect the microclimate of the crop, the dominant soil characteristics, or simply because it is so inadequately installed that its readings are of little or now value. It is therefore of the utmost importance to write up a list with the requirements of the respective application and some general rules, and select the site accordingly.

If the ideal site cannot be found, and a compromise needs to be made it is highly recommended to consult an expert to determine which trade-offs will have the least impact on the desired outcome.

A well defined set of rules for general environmental monitoring was established by the WMO in Switzerland, targeted at making weather data comparable. For the calculation of ETo a definition of the ideal site can be found in rule FAO-56.

A frequently underestimated factor in site selection is its future development. An assessment needs to be made of the site's surroundings to avoid errors in the readings due to external influences. The major observation points for the installation of a weather station are:

- Bushes and trees surrounding the site and their expected growth
- Changes in the suns path during a year

- The crop cover at the installation site
- The expected appearance of water bodies nearby (rivers, lakes, flooded areas)
- The zoning of the area (building plans)

When it comes to the installation of soil sensors different criteria apply:
- Is the installation site typical for the predominant crop type?
- Is the crop stage at the site typical for the whole zone?
- Is the probe well placed under the irrigation system to reflect its performance?

Step 5: Perform a good Installation

An equally crucial step as site selection is the proper installation of the equipment.

Weather stations:
The pole needs to be well anchored in the ground and perfectly vertical. If the soil is soft and/or the area rather windy it is recommended to secure the station with guy wires.
In the Northern hemisphere the solar panel needs to face South, in the Southern hemisphere North.
Wind direction sensors always need to point North.
The orifice of the Rain gauge and the pyranometer sensor must be absolutely horizontal. Tilted instruments can and will show large errors.
Sensors should not influence each other, and need to be kept away from hot surfaces like asphalt and metal (espec. Temp., RH, Leaf wetness, pyranometers!) and from reflecting surfaces (pyranometer).

It is highly recommendable to take a picture of the installation from all four directions and to note down its GPS coordinates.

Soil sensors:
Check the manufacturers recommendations carefully, select a site representative for the predominant soils and avoid soil compaction around the sensors by distributing your weight on wooden boards.

Step 6: Make a plan for ongoing Maintenance

The best equipment will have a short lifetime and little reliability if no proper maintenance is being performed. Unfortunately today's budgeting regulations separate the purchasing budget from the operation and maintenance budget, which is not a very wise move. At the time of purchasing the total cost of ownership over a stations lifetime should be a major part of the decision making process.

Basic maintenance doesn't require any special tools or skills. It's focusing on maintaining the physical integrity of the equipment by cleaning sensors and solar panels, and checking for damage, like nicks and animal bites, and removing dirt and chemical residue.

Second level maintenance makes sure that the logger and the sensors still perform properly, deliver correct readings, and if this is not the case will be adjusted accordingly. This includes checking sensor readings with a reference sensor, replacing sensitive elements like humidity sensors, the recalibration of sensors, and the regular replacement of batteries, gaskets and silica gel packs.

Step 7: Build accruals for replacement

Electronic equipment subjected to ever changing environmental conditions doesn't live forever. Microchips, sensor elements, gaskets, bearings and all mechanical components are subject to aging and degradation, and will suffer in performance and stability over time. The older a sensor gets the quicker it will start to drift after having been recalibrated. For most sensors there is a break-even point, where replacement is the better alternative to ongoing maintenance and recalibration, because degrading parts require recalibration in shorter and shorter intervals, and their drift compromises the equipments accuracy. Most manufacturers specify a certain lifetime for their sensors within which they will remain accurate as to their original specification. This specification is a good guideline as to when the sensor should be replaced.

The more mechanical components a sensor has the longer its lifetime. Non-heated Rain Gauges with a pulse output can usually remain in operation for 20 years and more. They have only one consumable part subject to aging – the reed switch, which can easily be replaced and is very inexpensive.

Sensors like wind speed sensors, having rotating elements, are subject to mechanical wear and tear. Depending on their construction principle ball bearings can be changed, but at a certain point the overall construction will be worn out. Expect a lifetime of 10 to 15 years.

Solar radiation sensors have one very sensitive element: the lense that lets the sun's rays pass into the instrument. Particularly in sandy, dusty and windy environments this lense is subject to wear, with scratches dispersing sun light away from the sensor element and reducing the output. Depending on the condition of this lense the sensor needs replacement. Expect a lifetime of 10 – 15 years or longer in clean environments.

The most robust element usually is the temperature sensor, commonly a platinum element converting temperature change in a change of electrical resistance. These sensors are very robust and hardly subject to wear and drift. They are also rather inexpensive, and usually come in combination with the relative humidity sensor, using the same amplifier. To avoid the hassle and cost of recalibrating resp. replacing the RH element it is recommendable to replace the whole sensor every 5 years.

Soil sensors: all sensors that are in direct contact with the media (=the soil) will need frequent replacement. This is particularly true for suction sensors such as gypsum blocks and Watermarks. Their substrates tend to disintegrate and to fall apart over time, being subjected to continuous wetting and drying cycles, and absorbing all kinds of other substances than water – nutrients, salts, micro-organisms, soil particles, etc. Expect a lifetime of no longer than 2 – 3 years.

More robust soil sensors like capacitance probes (type Sentek EnviroSMART) or AquaFlexes are hermetically sealed and enjoy the privilege of little temperature fluctuations and no UV radiation, thus eliminating the two main sources of aging and failure. If they are installed properly and protected from mechanical damage there lifetime should well reach 20 years.
***

This guide shall raise the awareness for a meteorological system as being part of a complex solution. The performance of this solution not only consists of the instruments you buy, but also on the where and how of its usage and operation. Everyone understands that the performance of his car will suffer if it never has its oil changed or its tyre pressure adjusted, or if it's continuously being overloaded. A weather station is no different! But if chosen carefully, if installed and maintained well it will pay back its purchase price in very little time and assist the farmer in taking better decisions every single day.

Keywords: irrigation, weather stations, soil sensors, soil moisture, evapotranspiration, agriculture

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LAND-USE CHANGE AND ADAPTATION IN THE NILE DELTA REGION

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Abstract

Irrigated agriculture is the dominated land-use type in the Nile Delta region. The Nile Delta is the most important agricultural region in Egypt has about 1.8 million ha of the total cultivated area of about 3.36 million ha, and about 93 % of the total Nile Delta land is old fertile land. The overall agricultural system in the Nile Delta is considered as one of the highest intensive and complicated agricultural systems in the world. The percentage of the total annual cropped area is averaged from 150 to 180 % from the total cultivated land area, and contributed 65% of the total national agricultural production. The size of land ownership of more than 50% if the agriculture land in the Nile Delta region is less than 2.1 ha (CAPMS, 2001).

Three agroecosystems were identified in the Nile Delta region of field crops, vegetable crops, orchards and palms (Medany and Attaher, 2008). Whereas, the majority of the farms in the Nile Delta follow mixed crop pattern of field crops, vegetable crops and fruits. The farms of the old land in the Nile Delta region have a full access to Nile water for irrigation. Aquaculture is one of the common agricultural practices in the Northern Nile Delta. The domination of this activity is mainly attributed to the high levels of the soil salinity in this region, besides it has high economical feasibility.

Climate is one of the factors that affect land-use change trends. Moreover, land –use type and trends of change are affecting both the vulnerability and the adaptation of the agricultural systems to climate change. The Nile Delta region is considered under many studies as a homogenous agriculture region in Egypt. Whereas, the Northern Nile Delta could be the highest vulnerable sub-region in the Nile Delta due to the combination effect of natural, human, agriculture management, and economical and political conditions (Medany and Attaher, 2008). The increased soil salinity, sea level rise and urbanization are the most important problems affecting land-use types in the Nile Delta region at the current and future timelines. The most likely result of climate change is a rise in global average temperature, which would in turn cause sea-levels rise (SLR), and 12-15% of the existing agricultural land in the Nile Delta could be lost (Abd El-Wahab, 2005). Under the current situation, soil salinization problems in the Nile Delta region highly sever in the northern costal line, and the severity is becoming lower by moving towards the south. The farmers in the Northern Nile Delta believe that they will have a serious problems with soil degradation more than the Middle and southern Nile Delta farmers (Medany and Attaher, 2008). This is mainly attributed to the original properties of the soil, sea-water intrusion, low water quality, poor fertilization management, the high reliance on poor irrigation systems, poor drainage systems, the high extensive cultivation system, and unsustainable agriculture management.

The reduction in agriculture land due to urbanization is one of the critical sources of vulnerability of agricultural sector. From year 1990 to year 2003 the urban area percent increased from 5.7% to 12% (85.3 % increase) in the Nile Delta , this result announced increase in average air temperature of the urban regions by 4.5 °C over the normal values in the last decade. A recent study of Elsayed (2006) projected air temperature of the Nile Delta to continue increase by 6 °C over the normal values by 2010 (without climate change scenarios). The reduction in arable land area of the Nile Delta is coupled with the reduction on the average size of land ownership. Based on this situation, the integrated and sustainable management is not applicable and/or economically fruitful.

The objective of this study is to investigate the risks and opportunities of possible adaptation measures relevant to land–use changes in the Northern part of the Nile Delta region.

The proposed adaptation measures under assessment were based on the main key points affecting the vulnerability of the agriculture system under the projected climatic changes described in Medany and Attaher (2008). Community-based pilot assessment was performed using a preset questionnaire. The survey was conducted in 6 pilot locations in the Nile Delta, and covered 160 samples in the northern Nile Delta. The samples were taken randomly, and represent local farmers of

the sub-region. The results indicated by the farmers were objective to experts' evaluation in terms of cost/benefit, opportunities, limitations and risks.

Table (1) presents the most efficient justifications, according to farmers' perceptions, of the possible adaption actions to face land loss due to SLR and salinity buildup in the Northern Nile Delta. More than 60% of surveyed farmers summarized the SLR impacts as salinity buildup, and they believe that the soil maintenance techniques could handle the problem. Whereas the previous adaptation measure will have a limited effect in facing SLR negative impacts, compared to gradual switching of the current old land under risk by reclaimed land in Upper Egypt. Land reclamation measure could be limited by many biophysical and socio-economical limitations and uncertainties, but it may sustain the national agricultural production at the secure level of production.

Table (1): Farmers perception for the possible adaptation measures to face land loss due to SLR and salinity buildup in Northern Delta.

	Adaptation measure	Farmers' perception (%)
1	Continues supply by extra amounts of agricultural gypsum and compost, to improve soil characteristics.	69%
2	Gradual increase in cultivating salinity tolerant crops.	64%
3	Adding soil layers to land in order to increase its elevation.	43%
4	Establish a new drainage system in field, equipped with suction pump unit, to control the excessive water table at constant level.	29%
5	Gradual decrease in the current cultivating area to obtain a higher level of crop management with a constant level of production cost.	9%
6	Switch cropping activates to aquaculture	5%
7	Leave the current cultivated land, and move to other land located away from the sea.	2%
8	Leave the agri-business and find other carrier.	1%

Furthermore, about three quarters of the surveyed farmers refuse to replace their current old land by reclaimed land (table 2). This high percent of refusal is attributed to the low productivity of the reclaimed lands compared to the productivity of the old lands, the high cost of agricultural management and production in reclamation regions, and the difficulties and complications related to marketing and governmental programs of land reclamation. For the same reason of productivity reduction in reclaimed land, most of the farmers, which accept land-replacement, believe that accepted area of reclaimed land should be twice the area of the old land. Moreover, they indicate the "Subsidies on production inputs" as the most important governmental stimulations actions, which should be addressed under the governmental program of land replacement.

Table (2): Farmers perception for alternative land area and governmental stimulations required to replace their current farms of old land in the Nile Delta by new farms of new reclaimed land in the Upper Egypt.

	Northern Nile Delta	Middle Nile Delta	Southern Nile Delta	Total
Acceptance of land replacement				
- No	83%	85%	73%	82%
- Yes	17%	15%	27%	18%
Alternative land area				
- Same old land area	0%	0%	14%	4%
- 1.5 of the old land area	6%	0%	7%	4%
- Twice of old land area	94%	100%	57%	85%
Governmental stimulations				
- Subsidies on production inputs	65%	81%	64%	70%
- Long term loan for land reclamation	24%	13%	21%	19%
- Marketing contracts with private sector, under governmental supervision	12%	6%	14%	11%

On the other hand, about 5% of the questioned farmers confirmed switching current agriculture system by aquaculture as a progressive adaptation measure to SLR. This small trend is contradicting with the observed actual perception of the farmers in the north-western Nile Delta, to change from vegetables and orchards production systems to aquaculture, in order to face the increasing negative impacts of the increasing environmental pressures. Switch cropping activates to aquaculture could imply good impacts on the national food security, while it may induce new environmental pressure on the natural resources on the region. Moreover it remarked by high degree of uncertainty in terms of farmers acceptance for carrier change, the national capacity of fishing industry, and the availability of financial resources.

Based on the indicated results it could be concluded that the farmers in the northern Nile Delta have a high capacity to change the agriculture production systems and activities, in order to interact with the environmental pressures. Although they are initiative in adaptation to environmental pressures, they applied some procedures that have negative effects at the long run. Improving the knowledge and adaptive capacity is essential point adaptation to the agriculture community in the Nile Delta.

Keywords:

Agricultural systems, the Nile Delta, Sea Level rise, Land reclamation, Climate change.

Acknowledgment:

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METHODS AND SPATIAL ANALYSIS FOR THE ADAGIO AGRICULTURAL ADAPTATION ASSESSMENT IN GREECE

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Abstract

The ADAGIO assessment in Greece was developed based on three major appraisal methods, by utilizing regional climate model downscaling and agrometeorological indexing/agroclimatological modeling, by contacting local experts and as much as possible by direct interactions with the practicing stakeholders, the farmers. More specifically, both quantitative computing methodology was used and also bottom up approaches and questionnaires, focusing at communications with farmers and local agricultural experts, to collect their views and opinions and then integrate those into the working documents and analysis of the project. GIS was used as means to collect, overlay and concentrate all the data and analysis made for the ADAGIO project, carry out additional investigations and deliver visual communication material (maps) for stakeholders.

Regional climate scenarios were used, since their higher resolution is applicable to describe with greater spatial detail the climatological conditions of current and future periods. The climate change scenario and model used was the ECHAM5 A1B RACMO2 KNMI from the ENSEMBLES Project (ENSEMBLES, 2009). The time periods used were 1971-1990, 2031-2050 and 2071-2090, covering all Greece.

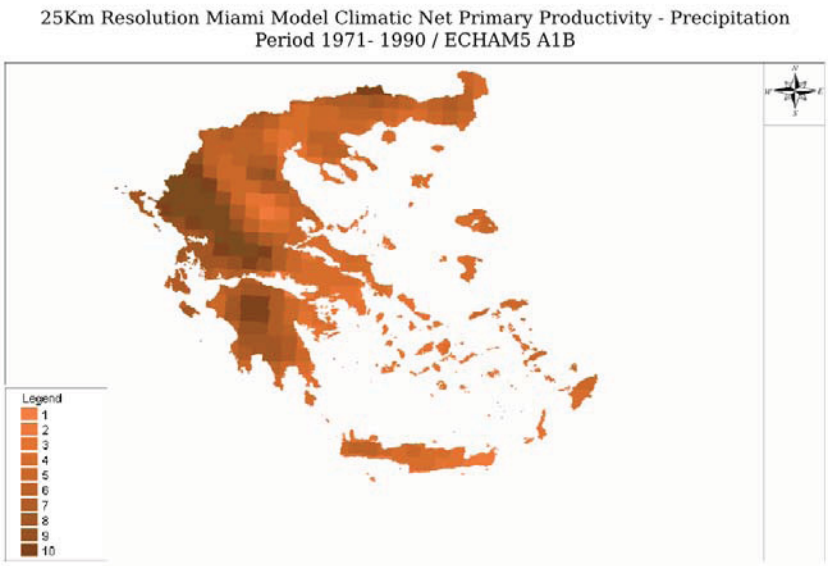

Fig. 1. Miami Climatic Net Primary Productivity, as the NPP is inluenced by precipitation (NPP,P). Spatial averages for the periods of 1971-1990. The 25 Km RCM is the ECHAM5 A1B KNMI RACMO2.

The creation of spatial indices in the form of maps for the whole country was preferred, to easily communicate the results. Precipitation sums and means, and temperature/precipitation statistics were derived also for the whole country area. The indicators developed include the Ombrothermic Index, the De Martonne Aridity Index, and the P/ET yearly ratio. Also, based on a methodology of FAO CLIMPAG website the Length of Growing Period was computed, which is defined as the months of the year that P/ET is larger than 0,50 (in our application was defined as P/ET>0.49). The way primary productivity of ecosystems is influenced by the climatic scenarios used was also examined. For that propose, the Miami Model Climatic Net Primary Productivity for Temperature and Precipitation was caclulated for each analysis grid cell and all temporal periods (FAO CLIMPAG, 2009). To assess the differentiation between each 25Km grid cell for all all spatial indices and analysis, additional spatial per pixel dissimilarity maps were developed for the classified variation between the 20 year periods of 1971-1990 comparing to 2031-2050, and, between the periods of 2031-2050 and 2071-2090.

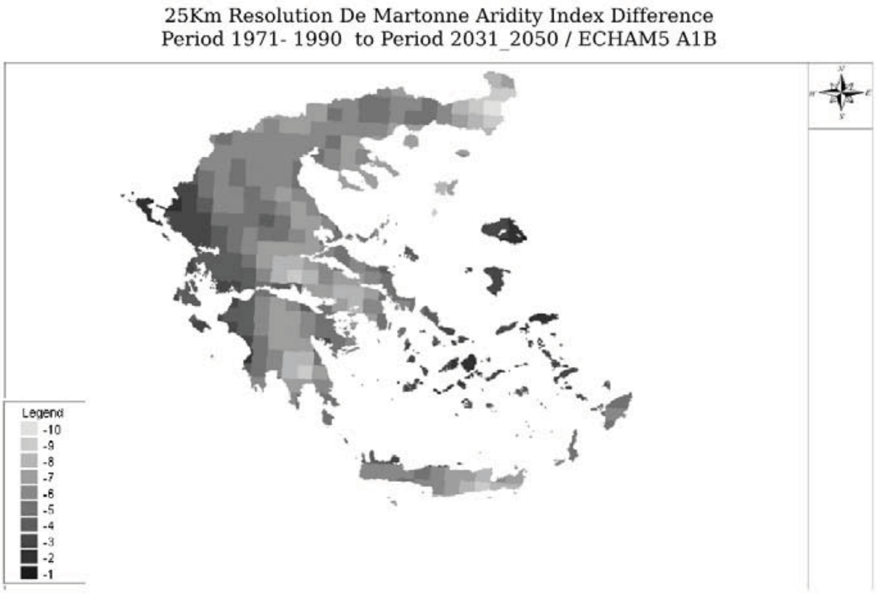

Fig. 2. Diffrences between time period averages for De Martonne Aridity Index. Differences are for periods of 1971-1990 to 2031-2050. The 25 Km RCM is the ECHAM5 A1B KNMI RACMO2.

One of the assessment goals was to address the landscape biodiversity with an experimental quantitative manner within the spatial analysis applied for the Greek territory. The rationale for such an analysis was based on the landscape diversity already observed especially in hilly and mountainous rural areas of Greece, and also in low land, more intensive agricultural areas, where for example farming areas, irrigated lands, rainfed crops, tree orchards, neighbor with natural and semi natural vegetated areas, forest patches, riparian areas and others. The response to major or minor disturbances of diverse land use mosaics, and their bioclimatic characteristics may differ under certain conditions from more homogeneous environments and extended mono cultures - as also their productivity, yield and economics differ too-. To represent such a field variability the CORINE Land Cover dataset (EEA, 2009) was used to derive spatial intra-specific biodiversity indices for the Level 3 CLC classification. The assumption and rationale behind it is, that agricultural and ecosystem land diversity, could create various responses to major or minor natural disturbances such as pest outbreaks, diseases, forest and wildfires, which are associated with climatological conditions. And, the nature and intensity of the impacts that a natural disturbance can have on a diversified agricultural ecosystem may vary, so there may be potential adaptation and mitigation options to examine. These diverse land use mosaics were created by a long history of land use and land use change, and long term risk aware adaptive regime practiced by farmers and rural people in general; by analyzing the farmers' practices the scientific community may identify new ecosystem management options. The integration of this analysis into the GIS platform permitted the incorporation of these results with the other assessment derivatives.

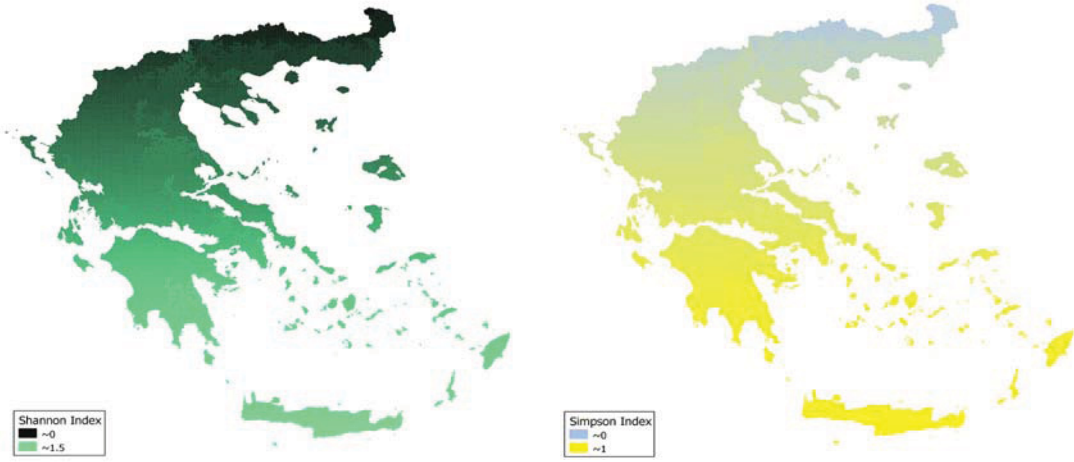

Fig. 3. Spatial Intra-Specific Biodiversity Indices based on CORINE Level 3 Code classification (first upeer left map image). Reference unit resolution is 250 meters for CLCand each index map. 5 indices were developed to present land cover spatial diversity: Menhinick's, Shannon, Brillouin, Simpson's and Margalef (Nelson et al, 1997; DIVA GIS, 2005). Above the Simpson's and Shannon spatial indices are available.

The 27 STARDEX indicators were analyzed for the daily (24h) time step of the climate change scenarios, and for the time periods of 1971-2000, 2021-2050 and 2071-2100. Also, frost occurrence, using the daily data available by the above mentioned scenario for reference and future time periods.
To further analyze the study area (Country of Greece) in the highest spatial resolution possible, analysis of the coastal areas with altitude equal to or less than 5 meters was realized. Catchments and watersheds that have part of, or total of their area below the above mentioned altitude threshold were identified in a map series and visual communication documents.
In addition to the climate change scenario and quantitative analysis, part of the ADAGIO goals was also to interact with farmers as much as possible. The bottom up approach of the analysis carried out was based in a "questionnaire for farmers" created by the project partner ITACYL (Dr. Angel Utset), after translation into Greek and distribution to farmers through frequent informal small meetings. This action was applied at a small sample size and it is not applicable for the whole area of the country, but representative at the local level only. The goal of this small sample size assessment was to collect at a chosen pilot area of Greece the local farmer views and opinions and their adaptation practices to local climate variability. Several variables of interest were questioned, such as the current adaptation practices of farmers, their evaluation of any climatic extremes and their impacts to crop species, their willingness to adapt their practices (ex. change of seeding dates, crop cultivars, new crops). The long term hands on experience of farmers is appreciated, since they carry out a profession in which continuous adaptation to local climatic variability, environmental and socioeconomic conditions is needed. Adaptation options and practices already commented by farmers were monitored and presented in project deliverables, presentations and annexes.
To complement with the ADAGIO analysis described, small scale field trials were also carried out to rapidly field test the suitability of some adaptation options and practices proposed from farmers or experts, while when and where possible, observations were collected directly from the field. These were not long term multi annual, large field surface scientific experiments; rather, these were rapid assessments carried out at private agricultural land for just one or two seasons to preliminary test some experimental adaptation options such as: early seeding dates of maize and its biomass growth and water needs, comparison with later seeded maize; or test the "no tillage" or "reduced tillage" options for the same crop, test of the establishment of ground cover crops to tree orchards and others (FAO Paper 56). Also, field visits were carried out to picture the spatial variability and landscape patterns of working lands. Please note that these field experiments served as rapid way to assess if the methods already observed or proposed are applicable at least once in specific sites: more field data and longer term field work is required for any general conclusions, while in our case only site conclusions were derived.
Comments collected from consultation and interview with farmers and local expert stakeholders were documented in various documents of the project. Final integration of quantitative results was made by creating tables and maps of all indices and analysis developed, either per land use class (CLC),

and/or per administrative unit. Such an analysis serves for a suitable dissemination to the public, or communication with stakeholders since tables and maps developed (or which can be custom developed to fit stakeholder needs) provide an easily and accurately interpreted picture of the project results.

Keywords: agroclimatic index, spatial biodiversity, climate change impact, agriculture

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RETARDATION OF WATER INFILTRATION INTO THE SOIL INDUCED BY ARIDISATION

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Abstract

The infiltration separates rain into two parts. One part stored within the soil supplies water to the soil organisms and roots of vegetation, and recharges groundwater (Kutilek & Nielsen, 1994). The other part evaporates or creates the surface runoff, and possibly soil erosion. Sands devoid of vegetation are able to absorb all rainwater up to the rainfall intensity of 300 mm/h (Yair, 2003).
However, vegetation and soil animals can produce amphiphilic organic compounds, which coat soil particles with films that alter surface properties considerably (CZARNES *et al.* 2000). These compounds are hydrophilic when wet, but below a critical moisture threshold, they start to behave as water repellent and retard the infiltration of water into the soil. Different affinities of soil-particle surfaces to water have crucial impact on hydrophysical characteristics (sorptivity and hydraulic conductivity) of otherwise texturally homogeneous soil with uniform structure. Last researches show that water repellency can evolve in soils of all textures and in the wide range of different land uses.
The objective of this study was to assess the impact of prolonged hot and dry periods on retardation of infiltration process into sandy Regosol formed from windblown material, mostly the sand (WRB, 1994) under different land use at locality Mláky II near Sekule (SW Slovakia).
Three sites were demarcated at the locality, with prevailing grass species on site 1 (“Meadow”), 30 years old pine forest on site 2 (“Forest”), and mainly moss species growing in a patchy pattern, on site 3 (“Glade”). The infiltration estimated in 50 cm depth on site 3 was taken as reference, since no influence of amphiphilic compounds could be expected there. The hot and dry spells were determined from the daily temperature maximums and daily precipitation amounts.
Five classes of water repellency (WR) persistence were distinguished at locality after the hot and dry spell by water drop penetration time (WDPT) test: wettable or non-water-repellent soil (WDPT < 5 s); slightly (5–60 s), strongly (60–600 s), severely (600–3600 s), and extremely (> 3600 s) water repellent soil (Dekker et al., 2001).
On all three sites, the infiltration tests were performed with both a small positive pressure head h_0 = +2 cm (double-ring infiltrometer) which simulates boundary condition by ongoing heavy rainfall, and with the negative pressure head h_0 = –2 cm (mini disk infiltrometer of Decagon Devices, Inc.) simulating the initial stage of the rainfall events, when the infiltration process is mostly influenced by sorptivity of soil.
Different land use on sandy regosol at locality Mlaky II has influenced the sorptivity of soil for water (S_W) considerably. It decreased in order: Glade-reference (mean = 9.43 x 10^{-3} m.$s^{-1/2}$) >> Glade (mean = 1.18 x 10^{-3} m.$s^{-1/2}$) >> Meadow (mean = 3.85 x 10^{-4} m.$s^{-1/2}$) >> Forest (mean = 4.85 x 10^{-5} m.$s^{-1/2}$) after hot and dry spells (table 1). Notice that the sorptivity for non-polar ethanol S_e(–2 cm) does not change significantly for the three sites.
Another important finding is that unlike the wettable soils where the sorptivity generally decreases with increasing soil moisture, at locality Mlaky II we measured the inverse trend under all respective land uses (for meadow site see fig. 1).

Table 1 The impact of plant cover on water drop penetration time WDPT, sorptivity S_W(–2 cm) for water and S_e(–2 cm) for ethanol, hydraulic conductivity k(h_0–2 cm) and saturated hydraulic conductivity K_S of the soil from locality Mláky II. The results are presented in the form: mean ± standard deviation.

Site	***θ*** **(%)**	***WDPT*** **(s)**	**S_w(–2 cm) (m s$^{-1/2}$)**	**S_e(–2 cm) (m s$^{-1/2}$)**	**k(–2 cm) (m s^{-1})**	**K_s (m s^{-1})**
Meadow	0.57 ± 0.44	1398 ± 2714	(3,85 ± 2,54).10^{-4}	(4,34 ± 0,87).10^{-3}	(2,45 ± 2,88).10^{-5}	(8,98 ± 5,66).10^{-5}
Forest	0.16 ± 0.10	3020 ± 2788	(4,85 ± 2,66).10^{-5}	(3,16 ± 1,56).10^{-3}	(0,67 ± 1,12).10^{-6}	(1,97 ± 0,43).10^{-4}
Glade	0.55 ± 0.65	1885 ± 3544	(1,18 ± 1,19).10^{-3}	(5,21 ± 1,73).10^{-3}	(5,83 ± 4,26).10^{-5}	(1,82 ± 0,33).10^{-4}
Pure sand (glade-reference)	4.98 ± 0.05	1 ± 0	(9.43 ± 2.29).10^{-3}	(3,17 ± 0,26).10^{-3}	(4,60 ± 1,08).10^{-4}	(5,29 ± 1,68).10^{-4}

Saturated conductivity K_S values were very similar on the the 'Glade' and the 'Forest' sites (1.82 x 10^{-4} m.s^{-1} and 1.97 x 10^{-4} m.s^{-1}, respectively) and were only slightly higher then on the 'Meadow' site (8.98 x 10^{-5} m.s^{-1}). The highest K_S values were estimated on the 'Glade-reference' site (5.29 x 10^{-4} m.s^{-1}).
In soils where water repellency evolves after hot and dry spells, K_S is not a constant characteristics but exhibits significant temporal variability. In the Fig. 1 there are two infiltration runs carried out at the same place on the meadow site, once after the hot and dry spell (20 June, 2005) and second time after the wet spell (15 July 2005). After hot and dry spell the sorptivity was low and the infiltration started gradually. The steady-state infiltration rate and K_S were also very small. On the contrary, higher S_W and K_S are typical for infiltration after wet spell.

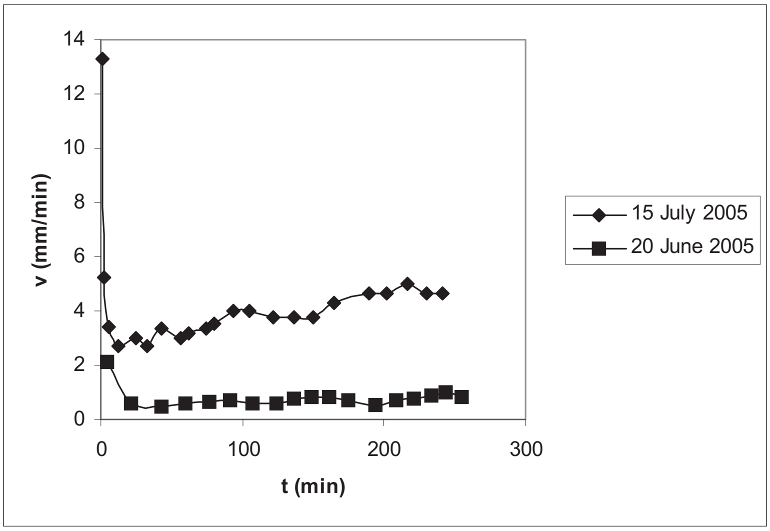

Fig. 1 The infiltration rate v vs. time t relationships measured with the double-ring infiltrometer at pressure head h_0 = +2 cm at the Meadow site on 20 June, 2005 (*WDPT* = 1800 s, θ = 0.93%), and 15 July, 2005 (*WDPT* = 24 s, θ = 3.1%).

The hydraulic conductivity estimated under negative pressure -2cm (k_{-2cm}) at particular sites increased in order: 'Forest' site (0.67 x 10^{-6}) << 'Meadow' site (2.45 x 10^{-5}) < 'Glade' site (5.83 x 10^{-5}) << and 'Glade-reference' site (4.60 x 10^{-4}). The S_W and (k_{-2cm}) do correlate with the class of WR persistence well (Fig. 2).

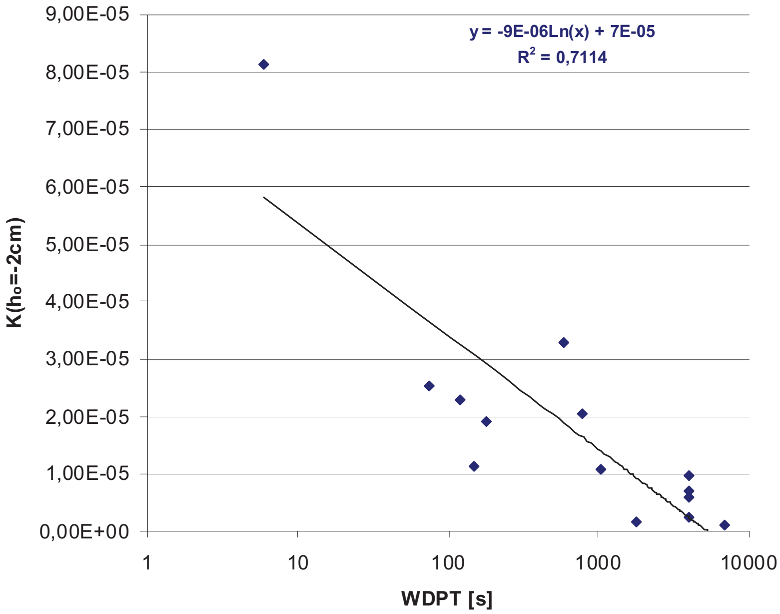

Fig. 2 Hydraulic conductivity under small negative pressure correlates well with the water drop penetration time test, which quantifies water repellency persistence.

It is concluded that the infiltration progresses very differently in water repellent soils then in the wettable soil with the same texture. Although the differences in K_S are not very high (it moves in a range of natural variability for a specific textural class), severely reduced sorptivities and hydraulic conductivities k_{-2cm} under all three vegetation covers indicate that after hot and dry spells the infiltration process can be significantly retarded not only in forests but also in grasslands used for agricultural purposes. Water balance in areas affected by WR can switch to higher evaporation / transpiration ratios and, on sloppy areas, to runoff generation with possible erosive effect on soil.
The water repellency of soil can be alleviated by cultural practices like claying with kaolinite clays (Lichner *et al.* 2006), core aerification followed by sand topdressing and application of a wetting agent (Mitra *et al.* 2006), liming (to enhance pH) and inoculation of wax-degrading bacteria *Rhodococcus* sp. and *Roseomonas* sp. (Roper 2006).

Key words: infiltration, water repellency, meadow, forest, glade, sorptivity, hydraulic conductivity

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ASSESSING CLIMATE CHANGE IMPACTS TO WHEAT YIELD USING AGROCLIMATIC INDICES

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Abstract

Rainfall contributes to an estimated 65% of global food production (Mavi and Tupper, 2004). In rainfed agriculture, production is often constrained by water limitations during the growing season. Thus, the quantity, variability and seasonal distribution of rainfall, along with soil characteristics and evapotranspiration losses, determine the final yield of non-irrigated crops (Arora and Gajri, 1998).

In Greece, winter wheat is a rainfed crop of great importance. The growing season of winter wheat starts in mid November with small variations depending on climatic conditions and ends in late June. Agroclimatic indices are used to describe the "crop potential", in terms of crop suitability and crop productivity. One way to estimate productivity is to incorporate agroclimatic indices in statistical models. Statistical models do not require details regarding the physiology of the plant involved but are based on correlation and regression analysis, relating to the plant under investigation and environmental variables (Norman, 1979). Previous studies in Greece (Tzanetopoulou, 1998) noted the importance of abiotic factors such as meteorological and climatic conditions. Tzanetopoulou (1998), included factor analysis of several agroclimatic indices computed via ten-day time step and wheat yield, and noted the significance of cumulative rainfall (CR) as the primary factor affecting wheat yield. Thus, in this paper, monthly cumulative rainfall (MCR) and growing season cumulative rainfall (GSCR) are used in order to identify the critical month for wheat yield regarding precipitation and estimate the final yield with the use of a statistical model.

The regions under consideration are two wheat productive Prefectures, Larisa and Alexandroupoli, located in Central and North-east Greece, respectively. Daily rainfall data from Larisa and Alexandroupoli meteorological stations are used for computing MCR and GSCR for the period 1980-2006. MCR values are obtained for the period from March until June. The rainfall and yield data are provided by National Meteorological Service of Greece and the National Statistical Service of Greece, respectively. Furthermore, MCR and GSCR are correlated with yield data. The correlation coefficients derived by correlating MCRs and GSCR for the period under consideration are illustrated in Table 1. The critical month is the one which has the highest correlation coefficient with yield data. The results present that the critical month for wheat yield is April. Previous studies in Greece have noted the significance of rainfall during April in yield variations (Danalatos, 2005).

Table 1. Correlation coefficients between cumulative rainfall (CR) per month and growing season and final yield for the period 1980-2006. Marked correlation are significant at $p<0.05$.

CR / Area	March	April	May	June	Growing Season
Larisa	0.0549	0.3716	-0.1060	-0.1460	0.2338
Alexandroupoli	0.0272	0.3143	-0.0570	0.0394	-0.2433

During the next step of the proposed methodology, MCR values of the critical month are used in order to derive the regression model for estimating wheat yield. The period 1980-2003 is used for developing the model, whereas the years 2004-2006 are used for validation. Linear regression analysis was selected, since it provided more accurate estimations of the final yields in comparison with other models (e.g quadratic). Indicatively, the regression model for Larisa region is depicted in figure 1. The linear equations derived from the regression analysis for Larisa and Alexandroupoli are:

$$Yield_{Larisa} = 6.6184 * Rapr_{Larisa} + 3041.7 \quad (1)$$

$$Yield_{Alexandroupoli} = 12.542 * Rapr_{Alexandroupoli} + 2013.1 \quad (2)$$

where Rapr is the cumulative rainfall for April, of the year and the area under investigation. The coefficient of determination (R^2) for Larisa (0.327) was higher than the one for Alexandroupoli (0.286).

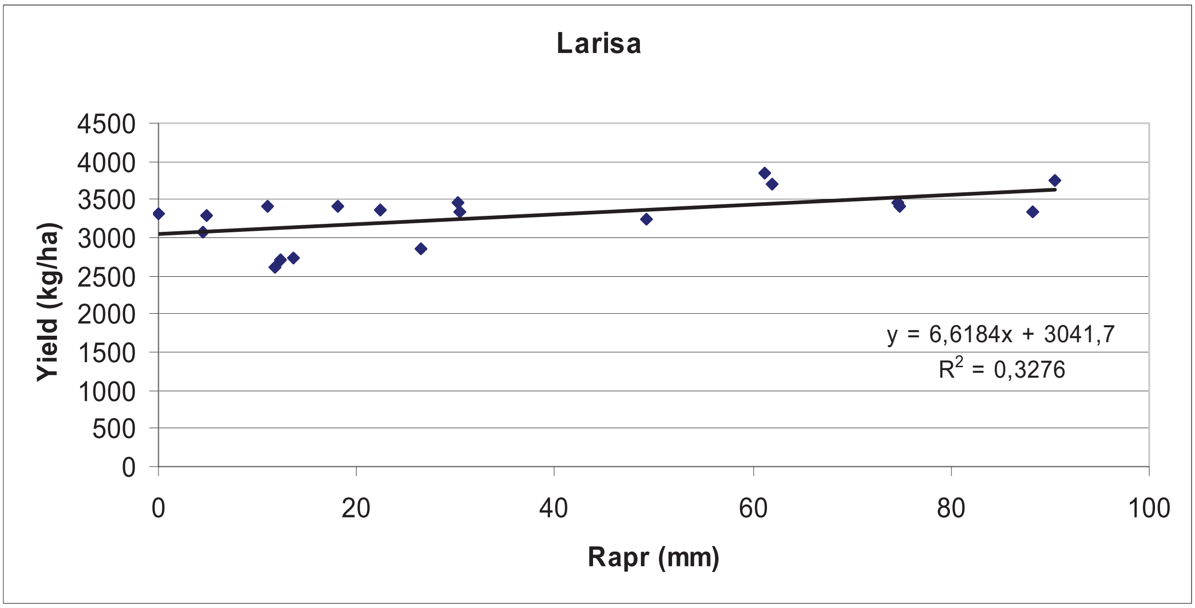

Fig. 1. Linear regression analysis of the April cumulative rainfall values and final yield for the period 1980-2003, for Larisa.

Using the equation (1) and (2), the yield is estimated for Larisa and Alexandroupoli Prefectures. The results of the estimated yield in comparison with the official values are presented in Table 2. The mean absolute percentage difference for the three validation years is 7.3% for Larisa and 12% for Alexandroupoli, which is considered satisfactory. Future work will examine if more satisfactory results can be obtained by using the rainfall gradient method for the reduction of the meteorological station value to the average height or the mean centroid weight of the Prefecture.

Table 2. Estimated yield values in comparison with the official yield, for the period 2004-2005 for Larisa and Alexandroupoli.

Area	Larisa			Alexandroupoli		
Yields / Year	Real Yield (kg/ha)	Estimated Yield (kg/ha)	Absolute Difference (%)	Real Yield (kg/ha)	Estimated Yield (kg/ha)	Absolute Difference (%)
2004	3326	3329	0,10	1935	2319	19,85
2005	2886	3079	6,70	2372	2146	9,52
2006	2841	3275	15,31	1997	2130	6,70

In general, most of the global and regional climate change studies on agroclimatic indicators are temperature based. In rainfed agriculture, rainfall is the most limiting factor for crop production. Thus, regarding rainfed crops such as winter wheat in Greece, the impact of climate change on rainfall associated agroclimatic indicators must be examined. Kosmas and Danalatos (1994) projected wheat yields in Greece (Mediterranean-type climate) to decrease by 90, 72, and 53% with reductions in rainfall of 65, 50 and 30% in 2050, respectively.

As noted, rainfall in April is crucial for the upcoming production. In equations (1) and (2), a probable increase of April rainfall will lead to increase of the final yield. The exact opposite will occur for a possible decrease. Analysis of the trend of April rainfall for the period 1980-2006, for Larisa and Alexandroupoli (Fig. 2), indicates reduction in wheat yields. The results of the current study contribute to the fact that variability in wheat production in Greece due to future climate change will be probably governed by rainfall. Nevertheless, further work must also examine the impacts of climate change on temperature based agroclimatic indicators and the wheat yield.

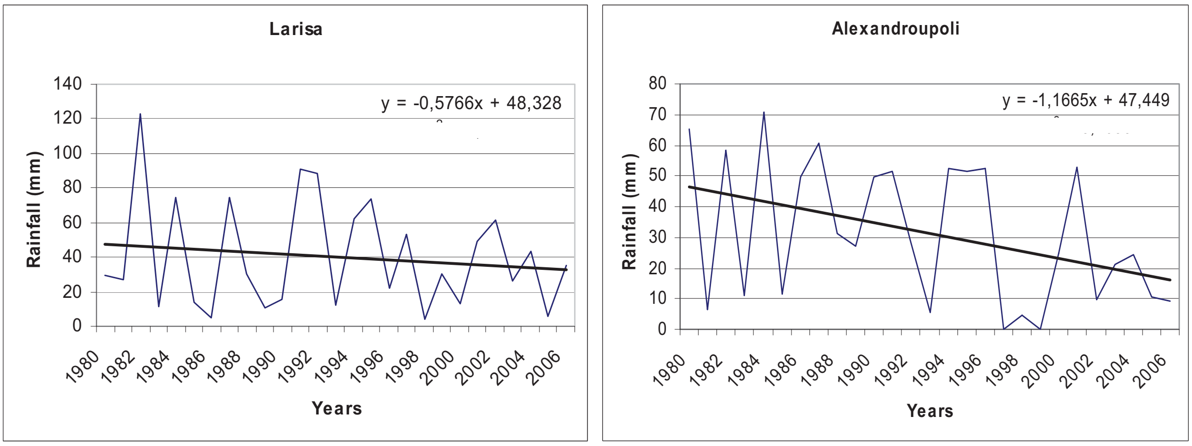

Fig. 2. Trend analysis of April rainfall for the period 1980-2006, for Larisa and Alexandroupoli.

Keywords: Winter wheat, cumulative rainfall, statistical models, yield, climate change.

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ASSESSING DIFFERENCES IN THE FARM LEVEL VULNERABILITY OF THE CEREAL PRODUCTION IN THE CENTRAL EUROPE – CONSEQUENCES, UNCERTAINTIES AND ADAPTATION OPTIONS

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Abstract

Central Europe is located between East and South European climate change hot-spots where its impact is thought to become visible sooner or will be more pronounced (or both). Despite the fact that agriculture is by no means a dominant activity in the region it remains an essential part of economy (and landscape) and in most cases it is based on the performance of few crops as it is case of spring barley and winter wheat within the Central Europe. It is obvious that production stability and quality would be influenced under changed climatic conditions and that these changes will differ between regions and farms. However the magnitude of the change in crop production (both positive and negative) is not fully known due to the large differences between individual global circulation models (GCM) and SRES scenarios. In order to assess trends and magnitude of crop yields (and other production characteristics of two selected crops) we applied dynamic crop models CERES-Barley and CERES-Wheat. Both models were evaluated using data from 17 (7) experimental sites with 230 (87) experimental years as well as compared with statistical yield levels at the NUTS4 level (Fig. 1). The extensive experimental database was also used to verify whether the model correctly simulates differences in crop growth processes caused by varying farming techniques, climatic and soil conditions. In order to carry out spatial analysis, the model was run for all combinations of 125 weather stations using 400 soil pits using special software package: Marwin. The results were then interpolated into a 1x1 km grid matrix using ArcInfo GIS software and only grids covered by arable land were analyzed further. The selection of the model crops made possible to distinguish between climate change impact on the winter and summer crops. The resolution used in the study allowed to evaluate changes on the scale of large farm units (NUTS 4) for which the models were also validated and thus assess their vulnerability to the climate changes.

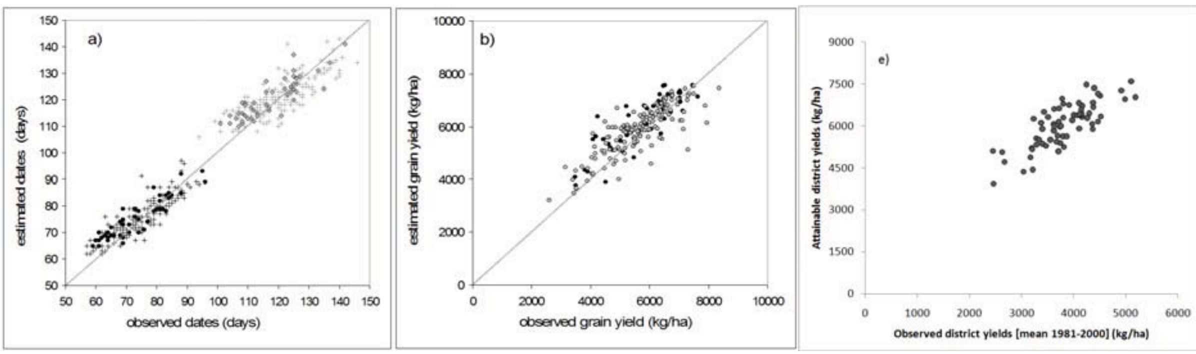

Fig. 1. Results of the calibration (a,b – darker color) and verification (a,b,c) of the anthesis and maturity (a); grain yield at individual experimental sites (b) and spatially integrated yields at NUTS4 level (c) of spring Barley.

In order to estimate the uncertainty in the future cereal production at this spatial scale number of GCMs provided for the Fourth Assessment Report (4AR) was used, namely ECHAM, HadCM and NCAR-PCM. The GCM based projections were based on the three SRES scenarios (i.e. A2, A1B and B1) taking into account three levels of climate system sensitivity (CS). The scenario values were used to set up boundary parameters of the future climate over the Czech Republic and part of Austria (including CO_2 levels required as an input for the crop model). In the next step synthetic weather series of 99 years were generated for each of 125 weather stations and centered for time periods centered on years 2020, 2030, 2040, 2050 and 2100. In order to estimate future yields more realistically both long-term trends in grain production yields between 1918-2005 (accredited to technological advance) and effects of simple adaptation strategies were taken into account. The latter included optimization of fertilization and sowing dates, changing basic parameters of the cultivar and finally measures to increase soil water accumulation during winter that precede to sowing.

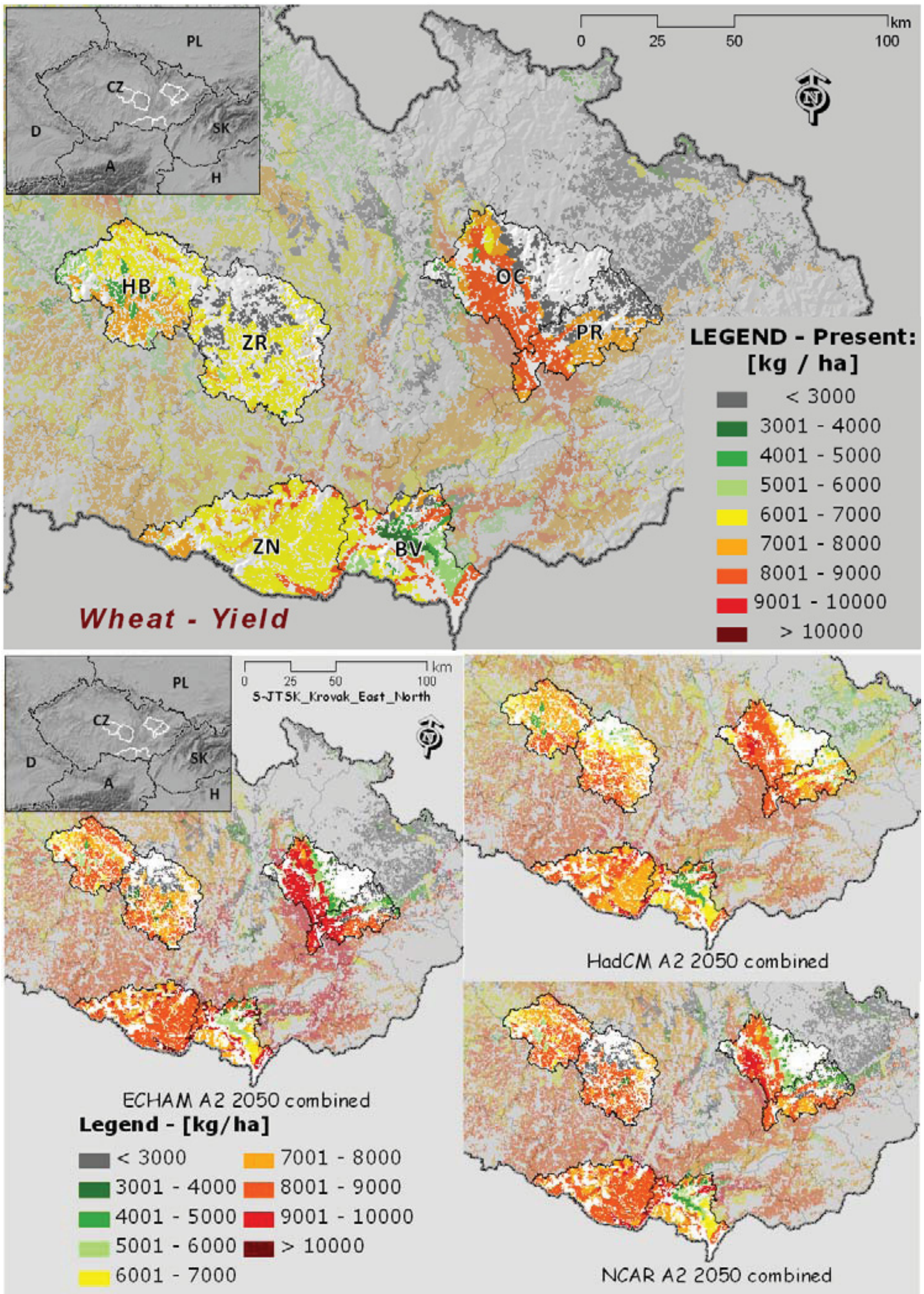

Fig. 2. Levels of the mean yield under present 1961-2000 climatic conditions (upper) and change of absolute mean yield (kg/ha) of winter wheat in 6 selected NUTS4 regions (bottom). The latter figure represents difference between present and expected yield levels according to three GCMs (as indicated in the legend) assuming high sensitivity of climate system and SRES A2 emission scenarios. Effects of both changed climate and increased CO2 levels are taken into account.

The result confirmed that both CERES-Barley and CERES-Wheat depicts well interannual variability of Central European spring barley and winter wheat production as e.g. the coefficient of determination between the simulated and experimental grain yields was higher than 0.70 at most sites and the systematic bias was acceptable (Fig. 1). The range of uncertainty caused by the different projections within the set of used GCM is relatively large and is most pronounced in case of A2 SRES scenario in

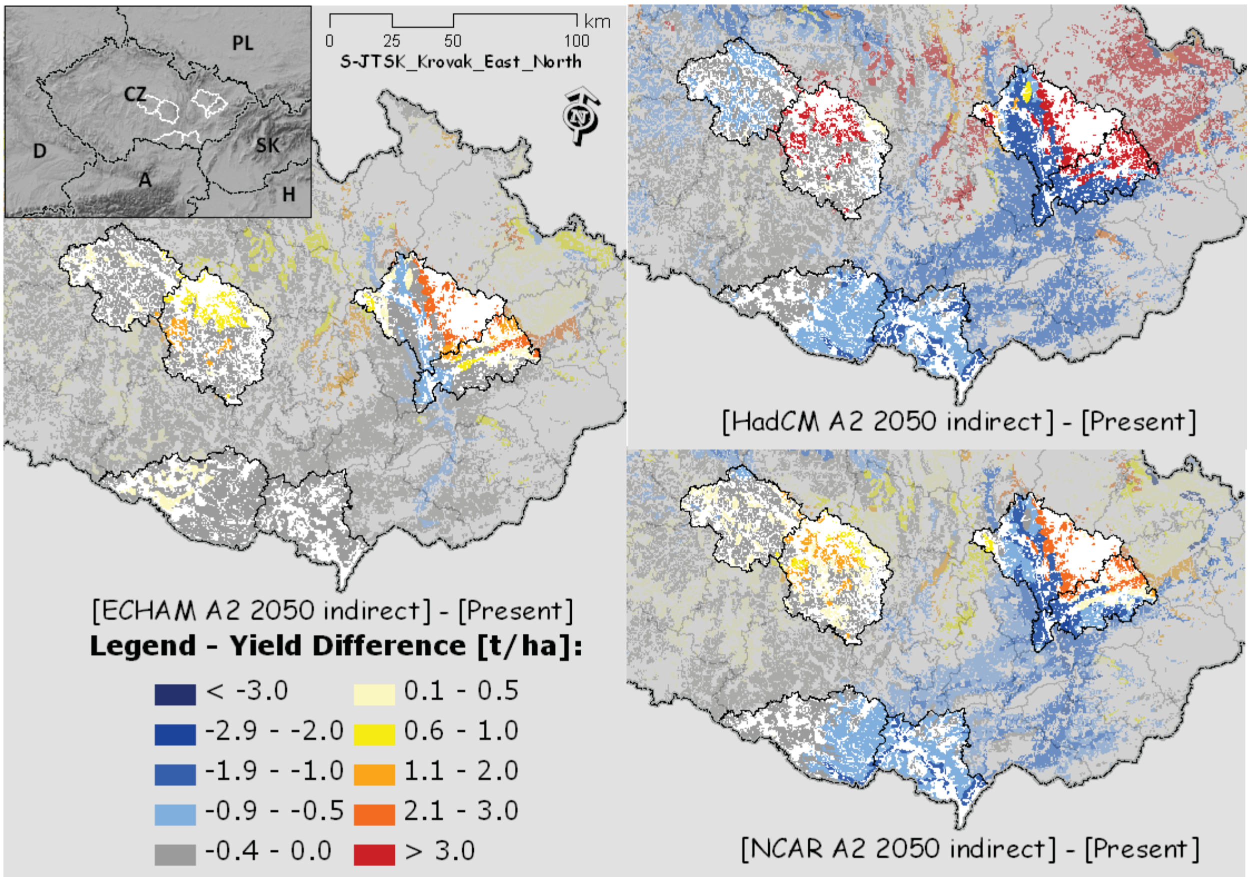

Fig. 3. Change of absolute mean yield (kg/ha) of winter wheat in 6 selected NUTS4 regions as a difference between present and expected yield levels according to three GCMs (as indicated in the legend) assuming high sensitivity of climate system and SRES A2 emission scenarios. Only change of climate conditions is considered.

combination with the high climate system sensitivity (Fig. 2, 3). In general yields are expected to increase across most productive areas in the target regions especially when positive CO2 effect as estimated by CERES model is included (Fig. 2). However so called indirect effect of climate change (i.e. change of climate conditions without considering fertilization effect of CO2) is mostly negative especially due to increased water stress and reduced duration of growing season (Fig. 3). Overall uncertainty of the future crop productivity is rather high (larger than 20% between individual GCM for 2050) and becomes even higher in case of spring cereals (compared to winter cereals) as it is indicated at Fig. 2-3. The results suggest that the effect of GCM driven boundary conditions are dominant on the national level, whereas the future regional and farm level productivity is significantly influenced by relatively subtle differences in the abiotic conditions (e.g. present climate or soil conditions). However the effect of uncertainty within the available set of GCM-SRES-CS on the future national production levels is one order higher than then the effect of sub-regional differences.

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Keywords: climate change impact, agriculture, CERES-Barley, CERES-wheat

MODELLING OF MAIZE PRODUCTION AND ADAPTATION TO CLIMATE CHANGE IN CROATIA

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Abstract

Analyzing agricultural systems and modelling the potential impact of climate change on crop production is a very important topic, particularly now as food supplies are becoming scarcer in many parts of the world and the need for all people to have sufficient food. As climate changes of different intensity in particular regions were detected there is a need for researching them at national and regional levels. The main application of the crop models is in climate change impact research on agriculture. Maize, winter wheat and spring barley are very often used for scientific investigations in the central and southeastrern Europe using the different crop models (Kajfež-Bogataj, 1993 and 1996; Bacsi and Hunkar, 1994, Alexandrov et al, 2002; Žalud and Dubrovský, 2002; Zebisch, 2005; Vučetić, 2008). These results help for optimizing agricultural management in order to adapt for current and changing climate and weather conditions.

As the maize is one of the most important agricultural crops in Croatia and its vegetation period is coincided with the warm season, from May to October, it was the decisive factor in the choice of the crop type for the research of the impact of climatic changes on maize yield in the central Croatia. Last decades in this region the linear trends of meteorological elements and observed maize phenological phases, and the non-parametric Mann-Kendall test indicated a significant increase in mean annual temperature (particularly in spring, winter and summer, Vučetić, 2009a; Vučetić and Cesarec, 2009) and significantly earlier beginning of silk emerged (4 days/10 years), milk ripe (6 days/10 years), wax ripe (9 days/10 years) and harvest (6 days/10 years) which is started in early 1990s.

The meteorological data of the Zagreb-Maksimir station (1949-2004), which is situated in the central Croatia, pedological, physiological and genetic data obtained in the field maize experiment in Zagreb 1999 and the DSSAT model, as one of the most applied crop model in the world (Jones and Kiniry, 1986; Hoogenboom,et al., 1995), have been used for the investigation of maize production in the present climate. The DSSAT 4.0 simulation underestimated the 1999 yield and biomass per hectare by 10% which is a good assessment. The reason for deviation between predicted and observed values is the model sensitivity to extremely warm condition in 1999 during the vegetation period. For the research of the impact of weather conditions on maize yield in the period 1949-2004, the same pedological, crop and soil data were presumed as in the 1999 field experiment. The linear trends of model outputs indicated a earlier onset of anthensis by 1.4 days/10 years and significantly earlier onset of maturity by 4.4 days/10 years (Fig. 1) which started in mid-1990s. It is also showed a decrease in maize yield by 212 kgha^{-1}/10 years and in biomass by 120 kgha^{-1}/10 years.

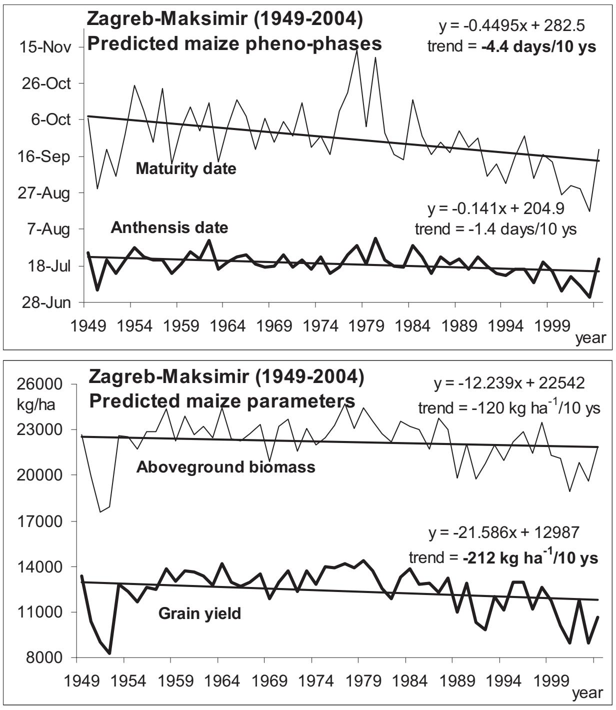

Fig. 1. Predicted time series and linear trends of the beginning of anthensis and maize maturity (days), aboveground biomass (kg/ha) and grain yield (kg/ha) according to the DSSAT model for Zagreb-Maksimir in the period 1949–2004. Linear trends significant at the 0.05 level are bolded.

In order to investigate the sensitivity of the DSSAT model at the initial weather and CO_2 conditions, the global solar radiation was increased by 7%, minimum temperature by 2°C, maximum temperature by 4°C and CO_2 by 330 ppm but precipitation amount was decreased by 8% according to the climatic scenarios which were prepared by the global climatic models: ECHAM, HadCM and CSIRO (Vučetić, 2008, 2009b). An increase in minimum and maximum temperature and a decrease in precipitation amount reduce maize yield by 6%, 12% and 3% respectively (Fig.2). A double increase in CO_2 stimulates the leaf assimilation and maize yield growth by 1%, while a solar radiation growth increases an evapotranspiration by 3%. By applying all above mentioned modifications simultaneously it is shown that the maize vegetation period shortens around a month and the maize yield is less than a normal value by 9%.

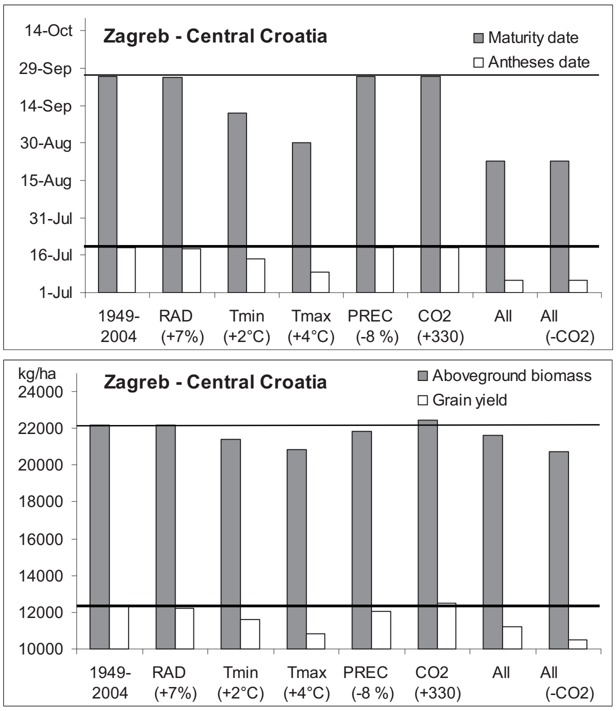

Fig.2. Sensitivity of antheses and maturity dates as well as aboveground biomass and grain yield of maize at the initial weather and CO_2 conditions using the DSSAT model for the Zagreb region.

One of the potential adaptation measures in agriculture is a changing planting date. In the 1999 field experiment the maize planting date was on 3 May. Using the DSSAT model, modified 56-years time series of weather date and double CO_2 concentration, the optimal time of planting date for increase in maize yield has been searched to shift its beginning by seven-day steps backward. In average the best result in improving maize yield (increase by 50 kg/ha) was obtained when the planting date is four weeks earlier (on 6 April, Tab. 1). In fact, yields dropped around 9% related to present climate and shifting planting date did not significantly increase maize yields.

Table 1. Shifting sowing date by seven-day backward from 3 May using the modification initial weather conditions and double CO_2 concentration for the Zagreb region according to the DSSAT model

Sowing date	Antheses date	Maturity date	Grain yield kg/ha	Aboveground biomass kg/ha
Present climate				
3-May	18-Jul	25-Sep	12372	22194
Changed climate				
3-May	6-Jul	22-Aug	11223	21622
27-Apr	2-Jul	19-Aug	11143	21416
20-Apr	30-Jun	17-Aug	11264	21469
13-Apr	29-Jun	15-Aug	11238	21451
6-Apr	27-Jun	14-Aug	11272	21481

Keywords: maize phenology, DSSAT model, shifting sowing data, climate change impact and adaptation
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ASSESSMENT OF POSSIBLE RELATION BETWEEN TRENDS IN AGROCLIMATIC INDICES AND CROP MODEL OUTPUTS

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Abstract

The crop models are indispensable dynamical tools for crop phenology dynamic and yield forecasting. Even the most physiologically-based crop models contain empirical relationships (e.g. growing degree-days to simulate phenology) based on broad range of observed data from which the relationships were inductively or deductively derived (Easterling et al., 1996). Therefore, crop model outputs can significantly deviate from observations if magnitude of anticipated meteorological element, relationships were estimated in the first place (Easterling et al., 1992). Therefore, model sensitivity and magnitude of deviation is a feature of the model itself. This problem can, on the whole, be approached two ways. The first approach completely relies on model developers and their capabilities to correct empirical coefficients and make them more realistic. A second approach is based on establishing a relation between crop model deviations and agrometeorological indices (or some other parameters) describing extreme weather event. This relation is expected to be in the form of linear regression function introducing indices which mostly affect crop growth dynamic and yield. The main advantage of this approach is possibility to estimate in advance, crop model outputs deviation. However, this estimation is applicable only at certain environmental conditions (soil, variety, management) and for selected crop model.

In order to access climate change impact on crop production in Vojvodina region (Northern Serbia), crop model SIRIUS has been calibrated and validated (Lalic, 2006; Lalic et al., 2008). Results obtained for timing of phonological phases were very accurate for whole period of interest (2000-2005) including some very dry years, while calculated yield, sometimes significantly, deviates from observations. Comparing calculated and observed yields of winter wheat variety Balkan for the 1986-2007 period (Fig. 1), it was concluded that the highest deviation is related to seasons with unfavorable amount and distribution of precipitation during the spring (remembered as a “dry years” for producers). An attempt to minimize deviations of yield calculated using SIRIUS model under extreme weather conditions was made using agrometeorological indices calculated over the period of observation (Lalic et al, 2007). To explore the relationship between various indices and the crop model deviation correlation coefficients were calculated. In order to describe “dryness“of period of interest a following indices and parameters were selected: (a) sum of temperature

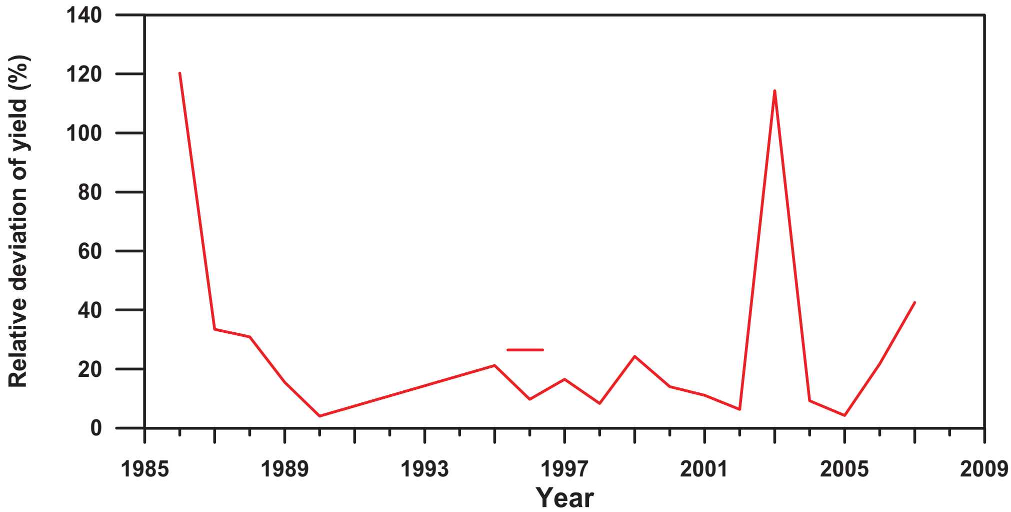

Fig.1. Relative deviation of yield calculated using SIRIUS crop model from observed values.

above 0 ^{o}C (Σt), (b) potential evapotranspiration (Wto), (c) soil water surplus (sws), (d) amount of precipitation during vegetation period (H), (e-f) crop drying days (c1, c2), (g) photothermal units (PTU), (h) thermal units (TU), (i) precipitation deficit (D_p), (j) duration of longest dry period (LDP), (k) number of rainy episodes (zh), (l) number of rainy days (z), (m) intensity of precipitation (I), (n) number of days with amount of precipitation less than 5 mm (z_{0-5}). Statistical significance of the correlation coefficients obtained was calculated by means of the t-test.

Indices	Correlation coefficient*	t - value	Indices	Correlation coefficient*	t- value
Σt (^{o}C)	0.37	1.61	April: H	-0.23	-0.96
Wto (mm)	0.33	1.41	April: zh	-0.16	-0.64
sws (mm)	-0.11	-0.46	April: z	-0.14	-0.55
H (mm)	-0.36	-1.54	April: I	-0.23	-0.94
c1 (day)	0.32	1.37	April: z_{0-5}	-0.01	-0.06
c2 (day)	0.34	1.46			
PTU (oC hour)	0.38	1.65	May: H	-0.13	-0.54
TU (oC)	0.39	1.68	May: zh	0.01	0.02
D_p (mm)	-0.39	-1.71	May: z	-0.51	-2.37
LDP	0.11	0.43	May: I	0.03	0.12
			May: z_{0-5}	-0.34	-1.45
March: H	-0.05	-0.21			
March: zh	-0.25	-1.04	June: H	-0.37	-1.59
March: z	0.04	0.15	June: zh	-0.04	-0.16
March: I	-0.17	-0.68	June: z	-0.16	-0.67
March: z_{0-5}	0.04	0.16	June: I	-0.42	-1.84
			June: z_{0-5}	-0.15	-0.59

* - none of the correlation coefficients reached the statistical significance of 0,05

Tab. 2. Correlation coefficient and t-parameter values between winter wheat yield calculated using SIRIUS crop model and selected agroclimatic indices for 1986-2007 period.

Obtained results indicate that, using the SIRIUS crop model, in agroecological conditions in Vojvodina, it was not possible to select indices that are significantly correlated to yield deviation under extreme weather conditions. Several circumstances could have influenced the obtained results. Extreme weather conditions appear infrequently. Furthermore, all selected indices were already introduced into the model; therefore the problem of circularity is expected to appear.

Keywords: agroclimatic indices, crop models, extreme weather conditions

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AGRICULTURE IN RUSSIA AND CLIMATE CHANGE

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Abstract

Agriculture has always been dependent on climate and weather, therefore most agronomic and agro-technological measures are attempted to overcome the adverse effects of climatic conditions and optimally use the conditions that are favorable for crop cultivation. The most advanced agro-technological methods, modern machinery and newest scientific approaches combined are unable to overcome the unfavorable weather consequences in spacious crop fields of Russia. Even the countries of the European Union applying the most advanced methods and technology in agriculture as to land and crop cultivation have been very anxious about the frequent adverse weather conditions.
The cause of this is the present-day climatic changes interpreted by climatologists as global warming. Frequently the publications on climate change exaggerate the danger of global warming. Yet no changes have been documented in precipitation, drought occurrence and other extreme hydrometeorological phenomena that could have definitely showed their dramatic increase or any trend due to the global warming. However, an increase in air temperature, changes in maximum and minimum temperatures, in the dates of a persistent transition of air temperature through 0, 5 and 10^{0}C in spring and autumn as well as in occurrence of phenological events is already a reality confirmed by observation data.
The northern location of Russia results in its natural environment being very sensitive to climate change, which affects the agricultural production, especially in the south mainly because of higher temperatures and lower water supply.
Since the late 19th century the mean annual air temperature has increased by about 1.29ºC for the Russian territory, which is above the global annual air temperature increase. On average, the warming of 1.33ºC in Russia for 1976-2006 was more pronounced in the winter-spring period. In the autumn period, on contrary, some cooling has taken place in western European Russia up to 2000. Changes in precipitation totals have not any clear tendency over the area under study for last decades. The decade 1981-1990 appears to be the most humid for the European part of Russia (ETR), which corresponds to the 1920s conditions (Lemeshko & Speranskaya, 2006). Decrease of annual precipitation by 5-10% is characteristic for the 1975-2006 in the central area of European Russia; upward tendencies in precipitation prevail for spring and autumn periods. Since 1995 annual precipitation has been less only in the years of 1996, 1999, 2003, and 2005 as compared to the average annual precipitation for 1961-1990.

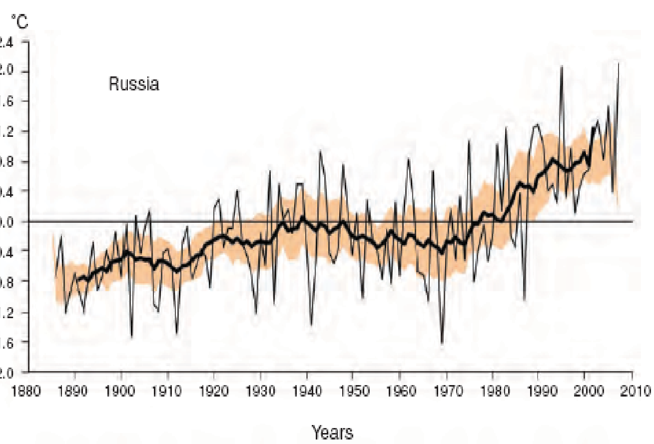


Fig. 1. Changes in annual surface air temperature (°C) averaged over Russia relative to its mean value for the period 1961–1990. The thin line shows observed temperature. The thick line implies a smoothed air temperature trend derived from 11-year moving averages. Considerable interannual variation of temperature took place against the background of its persistent growth. (Assessment Report, 2008).

The number of days with heavy precipitation of more than 10mm/day has decreased for the larger part of ETR. At the same time, it has significantly increased in North Caucasus, Krasnodar and Rostov Region. For the last three decades dry periods have extended 2 to 4 days/10years (Neushkin et. al., 2008).

Climate change will have significant effects on agricultural production, which has been considered as the most weather-dependent among all the human activities. In spite of the fact that there is an evident relationship between climate and agricultural production, climate change is not still taken into account in agricultural practice in Russia, but it is especially actually for Russia with its vast territory and diversity of climate and natural conditions.

In the Report of Federal Service for Hydrometeorology and Environmental Monitoring (Roshydromet) "Strategic Prediction for the period of up to 2010-2015 of Climate Change Expected in Russia" (2005) have been assessed the impacts of climate change on some economy sectors, special emphasis was made on the prediction of abrupt adverse weather changes and hazardous hydrometeorological events. The recommendations on the priority adaptation measures aimed at preventing losses from negative and increasing benefits from positive climate change impacts was formulated. These adaptation measures aimed at governmental authorities and other organizations in policy-making as well as in planning of specific measures to develop economy sectors and draw out sustainable development programs for the territories and regions.

Natural and anthropogenic climate and environment changes can have both positive and negative consequences for crop yield.

Negative effects are exhibited by higher probabilities of the extreme hydrometeorological events that can prove to be harmful to farming. Heavy rainfalls and droughts affect crop production sporadically in many semi-arid regions of European part of Russia, but upward trends in drought events during last 50 years were not discovered, while the drought periods were concentrated through in the 1990s. Such negative processes as soil degradation, aridization and flooding became real in the wide regions.

Positive effects are primarily connected with the expected increase of winter temperature, decrease in number of days with extremely low temperature. Minimal winter temperature increased by 3-4^{o}C in last two decades and coldest month moves from January to February, December and even to November (Fig. 2) (Lemeshko et. al., 2009). Positive effects result also in increase in warm season duration, which contributes to earlier start of farm operations in the North-West and Central Russia Regions.

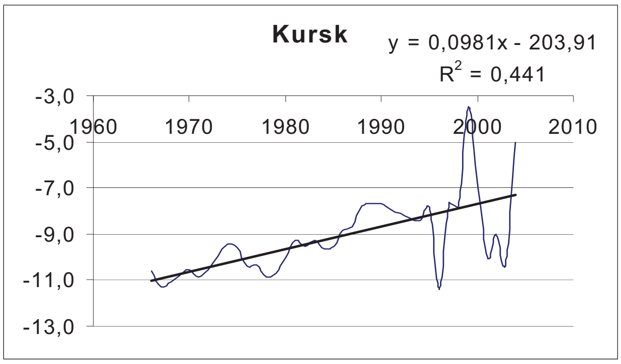
One of the most important positive effects of climate warming is a decrease in frequency of winters with minimum soil temperatures hazardous to winter crops. In the Chernozem zone the frequency of these winters has been reduced from 18-22% to 8-10% and in the Northern Caucasus - from 10% to 4%. The largest increase in minimum and maximum daily temperature occurred in the cold season (Assessment Report, 2008).

The number of frosty days decreased on 4-5 days per 10 years for 1976-2006. Decreased frost killing risk in the two last decades moderated the danger of winter crops perish in the Lower Volga and Southern Pre-Ural Regions and in some areas of Northern Caucasus Region. The example of such positive influence of warming for crop production in the cultivation zone of southern part of European Russia was 2008. Optimal moisture and temperature conditions in 2008 had ensured the increase in productivity of cereal and leguminous crops on 30-40% compare with 2007.

Further warming can create favourable conditions for expansion of heat-loving agricultural plants northward and winter crop acres to the Northern Caucasus, steppe regions of the Volga area, the Southern Urals, and Western Siberia.

However, increase in vegetation period duration can be not only a positive factor. According to the estimate by Verigo and Razumova (1973), total water requirement of plants increases with vegetation period prolongation. For example, buckwheat during its vegetation period of 93 days consumes 12 cm of water, while corn over 131 days of its vegetation period consumes 32 cm of water. Thus, in spite of longer vegetation period growing of more heat-loving crops would be difficult because of insufficient moisture in some region.

The water supply is one of the most significant resources for agriculture in the arid and semi-arid zones (Middle and Low Volga, Northern Caucasus), where there is a tendency to decrease in water use for irrigation from 1990 because of destroyed irrigation systems (canals, ponds and small reservoirs). The costs for water used increased in 3-5 times over last decade. These processes come on the background of increasing water resources of Volga and Kuban River basins. About 7 mln sq. km of agricultural lands is subjected to floods (Taratunin, 2000).



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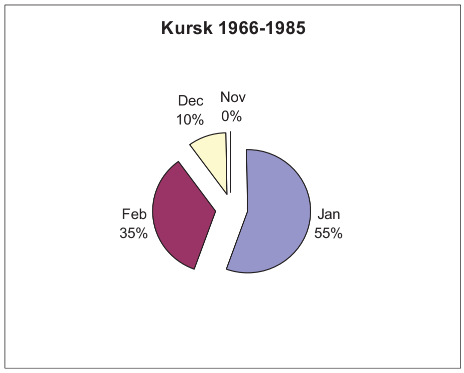

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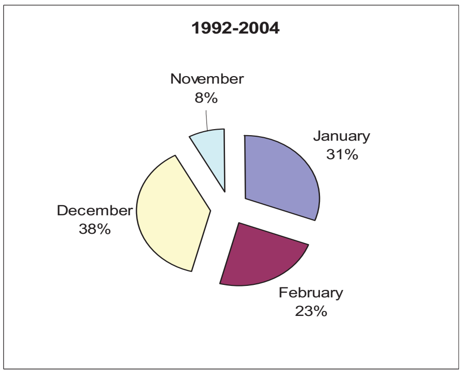

Fig. 2. Minimal winter temperature for the meteorological station Kursk (Central Chernozem Region)

a) 1960-2005; b) frequency of coldest months for the 1966-1985 (%); c) frequency of coldest months for the 1992-2000 (%).

Climate change coincides with changes in political and economic changes in Russia for last two decades. These economic changes affected agriculture as well. During last 15 years large state collective farms transfer to smaller private farms with mean size from 50-120 ha in the North-West ETR, 70-150 ha in the central ETR to 150-300 ha in the southern regions. Prevailing size is still lower in 3-5 times than mean ones. It leads to changes in structure of agricultural output. Main producers of grains are as before large agricultural organizations but main output of potatoes and vegetables gives by household farms (Fig.3).

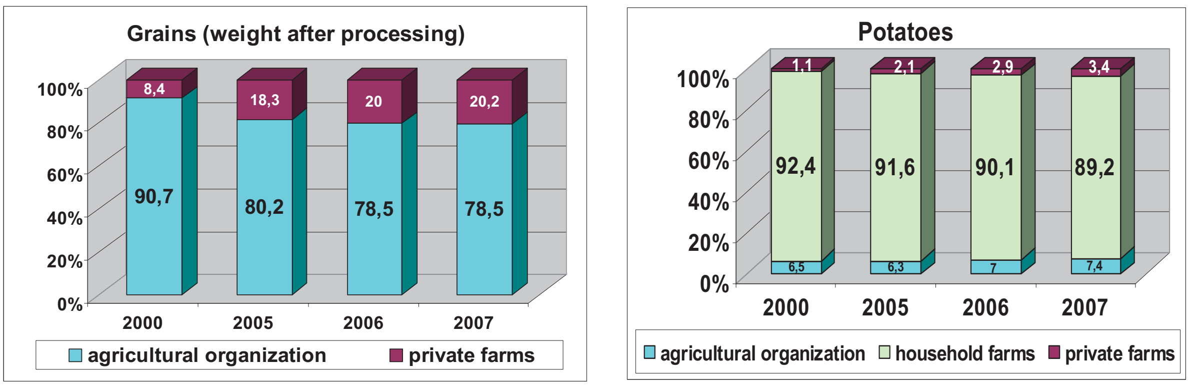

Fig.3. Output of main agricultural products by types of farms (percent of total volume of production of all farms).

In addition poverty dimensions of rural people are much larger than that of urban dwellers. ¾ of rural people have average income below minimal living wage and 61% rural families have all resources at their disposal (including all kinds of income) below poverty line. Large poverty in Russia rural areas and rational natural resources management are incompatible (Sdasyuk, 2005). Rural people, especially young people prefer emigrate abroad from the western regions (Kaliningrad) and to the cities from Pskov, Vologda regions. Common problem for rural people – their mean age are more than 55 years old, as this work is not attractive for young people.

Keywords: climate change impact, agriculture, water supply, frost, vegetation period, structure of agricultural output

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ADAPTATION OF AGRICULTURE SECTOR IN THE NILE DELTA REGION TO CLIMATE CHANGE AT FARM LEVEL

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Abstract

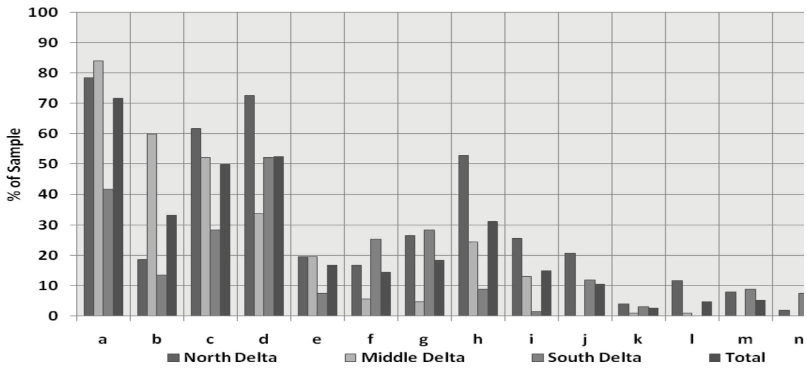
The overall agricultural system in the Nile Delta region is considered as one of the highest intensive and complicated agricultural systems in the world. According to recent study (Medany and Attaher, 2008), the Nile Delta region is one of the highly vulnerable regions in the world to climate change. Sea level rise, soil and water degradation, undiversified crop-pattern, yield reduction, pests and disease severity, and irrigation and drainage management were the main key factors that increased vulnerability of the agriculture sector in that region. The main objective of this study is to evaluate some feasible adaptation measures at the farm level.

A list of possible adaptation measures for agriculture production at farm level was proposed based on community assessment. The proposed adaptation measures under assessment were based on the main key factors affecting the vulnerability of the agricultural systems under the projected climatic changes described in Medany and Attaher (2008). Community-based pilot assessment was performed using a preset questionnaire. The survey was conducted in 18 pilot locations in the Nile Delta, and covered 160 samples in the northern Nile Delta, 142 samples in the middle Nile Delta, and 77 samples in the southern Nile Delta, by overall samples of 379. The samples were taken randomly, and represent local farmers of each sub-region. The results indicated by the farmers were objective to experts' evaluation in terms of cost/benefit, opportunities, limitations and risks.

The results indicated that the Nile Delta growers have strong perceptions to act positively to reduce the impacts of climate change. They reflected the need to improve their adaptive capacity based on clear scientific message with adequate governmental support to coop with the negative impacts of climate change.

Figure (1) presents the most efficient adaptation measures, according to farmers' perceptions, to reduce the negative impacts of climate change (warmer and dryer climate) over cultivation systems in the Nile Delta. More than 70% of the total sample considered that "changing cultivars" and "changing crop pattern" are the most important adaptation measures for agricultural systems in the Nile Delta region could be applied at the national level. Whereas, "increasing irrigation requirements" and "changing sowing dates" came in the next level of adaptation priorities, and both adaptation measures could be applied at farm level. Improve the current irrigation and drainage systems are addressed as an efficient adaptation measures at regional level of implementation. Changing sowing dates could increase the flexibility of the farming system to face temperature and water requirements increase due to climate change. Whereas, it may be limited by the marketing opportunities, which may not match the new harvesting dates, especially for cash crops.

Using environmental controlled production techniques for orchards production is one of the recommendations of the evaluation analysis that could be applied in the three sub-regions of the Nile Delta. This measure will require high financial investments and technology level, which may led to a general increase in the total price of fruits. While it may increase the flexibility of the production system to face temperature and water requirements increase.



Figuer (1): The proposed adaptation measures by the questioned farmers, and its representation values %, over the Nile Delta sub-regions (a= changing cultivars, b= changing crop pattern, c=changing sowing dates, d=increasing irrigation requirements, e= changing the current irrigation system, f=changing fertilization requirements, g=modifying plant protection programs, h=improving drainage systems, i=recycling agricultural drainage water in irrigation, j=using compost, k=cultivate the land one season and left it to rest in the second season , l=replace the current fertilizers by soil conditioners, m=leave the current cultivated land and move to reclaim new land, n=leave the agri-business and find other carrier).

Generally, the agricultural sector in the Nile Delta is suffering from the absence of financial and supporting systems. At the current conditions most of the Egyptian farmers prefer the self-financing more than the governmental systems. The current ability of the farmers for self-financing is projected to decrease under continues increase in agricultural inputs prices, and the projected incoming pressures on crop yields production. The current problems related to agricultural products marketing systems, are decreasing the income of the agricultural products, and add more pressures on the agricultural system, especially in the Northern and Middle Nile Delta.

Establishing insurance and financial systems to overcome the unfavorable weather conditions impacts on agriculture production, and/ or sustain the required resources for adaptation of the agriculture sector, is important emerging issue in adaptation planning. Average results for the Nile Delta reflect the high dependency of about one half of the farmers on the government in handling the insurance and the financial loads under current and future conditions. Whereas, the other half of the sample believe that they have to find suitable solutions for this critical problem, through farmers' cooperative funds, special taxies, and private sector cooperation. The experts encouraging establishing adaptation tax on crops prices (less than 2% of the price) as one of the imitative answers to the required adaptation fund. Whereas, this measure may likely face consumers and farmers refuse, because it will increase the prices of the agricultural products.

Regarding the field assessment, the farmers in the Nile Delta region have real strong and initiative perceptions to act positively in terms of climate change adaptation. Generally, farmers and the other agricultural stakeholders recommended the adaptation measures that have low total costs proportional to the total income. Moreover the political support in terms of agricultural stimulations policies and programs, capacity building programs, and knowledge and technology transfer, are essential driving forces for adaptation plans oriented to agricultural sector in the Nile Delta region.

Keywords: Agricultural systems, the Nile Delta, Climate change, changing sowing dates, adaptation insurance and financial systems.

Acknowledgment:

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CLIMATE CHANGE IMPACTS AND ADAPTATION OPTIONS IN SERBIA – RESULTS FROM THE ADAGIO PROJECT

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Abstract

The ADAGIO project (adagio-eu.org) was designed to focus on regional studies in order to uncover region-specific problems. In this context, a bottom-up approach is used (along with the top-down one) that employs scientific studies involving regional experts and farmers in the evaluation of potential regional vulnerabilities and adaptation options. Results of the regional studies and gathered feedback from experts and farmers show in general that (increasing) drought and heat are the main factors of agricultural vulnerability not only in the Mediterranean region but also in Central and Eastern Europe. Another important aspect is that the increasing risk of pest and diseases may play a more important role for agricultural vulnerability than assumed before; however, till now this field has been investigated in Europe only sporadically. Another important aspect is that there are increasing regional differences in the crop production potential in Europe due to climate change and that positively or negatively impacted agricultural systems can vary in a relatively small spatial scale depending on the specific limiting environmental conditions such as climate or soil conditions (Eitzinger at al., 2008).

As a partner in the ADAGIO project, the Center for Meteorology and Environmental Predictions at the Department for Physics of the Faculty of Sciences of the University of Novi Sad (Serbia) had the following responsibilities: (a) to suggest measures of adaptation based on the "observed" indicators about climate change in selected regions with intensive agricultural production (Subotica, Novi Sad, Arilje and Slankamen) and (b) to lead the thematic ADAGIO group "Adaptation on occurrence of pests and diseases determined by climate change". We also had the task to provide dissemination of the results obtained in order to raise the level of awareness about potential climate change and its impact on agricultural production. However, the drawback of scientifically based agricultural policy and a low level of agricultural inputs make agricultural production in Serbia particularly vulnerable to climate change and extreme weather events. Unfortunately, awareness about impact of global climate change on the national economy and particularly on agricultural production as its most sensitive part is at the lowest possible level among Serbian politicians and decision-makers. That produces a non-affirmative atmosphere within the scientific community concerning climate change impact research. Therefore, the implementation of the ADAGIO project in Serbia was a hard task with ambiguous results and effects.

During the first project year, a collaborative network was first established including agricultural engineers of different specialties from the University but also from scientific institutes, agricultural advisory services and private companies. We have to emphasise that the selected institutions for the collaborative network are broadly recognized in the agricultural community on the state as well as regional level (Subotica, Novi Sad, Arilje and Slankamen). Secondly, in order to properly address some socio-economic aspects of climate change issue, specialists for rural sociology and sociology of science were involved in the realisation of the second step of the first project year. On the basis of the corresponding methodology we designed a questionnaire for gathering data about the attitudes of experts and farmers towards climate change impact on agriculture production. There were three kinds of questionnaires, those for plant protection, fruit production and agronomy experts and farmers. The questionnaires were sent by regular mail to 921 addresses (experts and farmers) in various places throughout the Vojvodina region. Upon completion, they were returned to be analyzed. Unfortunately, as is common with the sending of questionnaires by regular mail, a relatively small number of addressees actually responded to the survey (73 out of the 375 experts (19.4%) and 195 out of 546 the farmers (36%)). Let us note that this kind of research was the first of its kind in Serbia and that analysis of answers from the questionnaires in some segments had a slightly limited specific weight in the sense of scientific conclusion. However, there was enough evidence to underline some conclusions regarding climate change impact on agriculture in Serbia. Based on the results obtained from the questionnaires, we have concluded that in the last 15 years the following diseases have occurred frequently in the region as a result of climate change impact: powdery mildew of cereals (*Erisiphe graminis*), *Fusarium* head blight, Cercospora leaf spot (*Cercospora beticola)*, sunflower blight (*Plasmopara halstedii*) and potato and tomato Alternaria leaf spots (*Alternari solani*), particularly because of dry and warm springs and dry summers with occasional showers. Additionally, a paper by

Jevtic et al. (2009) disusses the appearance of small grains diseases in Vojvodina as a product of climate change.

During the second project year, two project tasks were accomplished (1) climate simulation using a regional climate model (Mihailovic and Lalic, 2009a; Mihailovic and Lalic, 2009b) in order to get a picture of potential climate changes through experiments for the selected time-slice and (2) eight pilot assessments were conducted in order to (i) quantify past, present and future effects of climate change in the north of Serbia (the Vojvodina region) based on the trend of agroclimatic indices (Lalic et al., 2007; Lalic et al., 2008a; Lalic et al., 2008b; Lalic et al., 2009); and (ii) identify feasible potential adaptation measures for the selected regional agricultural systems based on the identified problems. For the climate simulation, we used EBU-POM, a two-way regional coupled model, with the Eta/NCEP limited area model as the atmospheric part and the Princeton Ocean Model as the ocean part (Djurdjevic and Rajkovic, 2009). Both models are well known and have been extensively verified. Eta was the operational model at NCEP for many years and POM is one of the most commonly used models for scientific investigations as well as for operational ocean forecasts. Exchanges of atmosphere fluxes and sea surface temperature (SST) between the two components are done interactively, during integration, using specially designed coupler software. In every physical time step of the atmospheric model (360 seconds), surface atmosphere fluxes needed for the ocean forcing are transferred to the ocean model grid. After that, SST is transferred back onto the atmosphere model grid, serving as the new bottom boundary condition. In this study the simulation domain selected covered the region of Europe. The horizontal resolution was 0.25° in the atmospheric model and 0.2° in the ocean model. The two-way coupled scheme was only applied over the Mediterranean Sea. For the other water bodies (Atlantic Ocean and the Black sea), we used SST from the global model integrations. Here, we present the verification of the present climate integration for the 1961-1990 base period and an analysis of the A1B climate change scenario experiment. CRCM was nested within integrations of the atmospheric ocean global circulation model SX-G.

In the last project year, we considered based on our results some urgent local adaptation measures that could be used immediately in crop production in Serbia, particularly in its northern part (Vojvodina): (a) a more reliable weather forecast before or during the growing season help farmers and the extension service staff to take appropriate measures and (b) preventive measures, such as determining the planting rate on the basis of available soil moisture, successful control of diseases, pests or weeds, nitrogen dose used for top dressing, etc.. Proposed measures to be used in fruit growing in the same region are: (a) to grow tolerant cultivars and to avoid growing fruits in regions with significant environmental risks; for example, growing peaches at higher altitudes and not in the lowlands of Vojvodina. It has been noticed that in years with frost damage the peach orchards affected the most were those bellow 170 m altitude. Advantage should be given to cultivars that have been locally selected or have been introduced a long time ago, because they are supposed to be more adapted to the environmental conditions. It is also of great importance for fruit trees to enter dormancy well prepared, as this provides assurance that they will be able to withstand low winter temperatures. Anti-frost sprinklers can also be installed, while small fruits growers can use agrotextiles or can grow plants in protected spaces such as small and large polytunnels, glasshouses etc. The list of adaptation measures will be extended after analysis of all the results of the project.

Identification and demonstration of dissemination strategies were foreseen as the last activities of the project. During the whole project, a lot of time was spent on consideration and planning of this segment. Unfortunately, several attempts to organise meetings with farmers and decision-makers had no success. Obviously, implementation should go through the media and teaching curricula in order to improve the knowledge of future producers and decision-makers about climate change impact on agricultural production. After 30 months of step-by-step project realisation, we can conclude that all research and assessment goals have been achieved, while their implementation in agricultural practice and policy is the hardest task, which requires more time than was anticipated by the project.

Keywords: climate change, impact, agriculture

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WHEAT RESPONSE TO CLIMATE IN DENMARK BETWEEN 1992 AND 2007

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Abstract

It is well known that production of agricultural crops to a large extent depends on weather conditions. However, the importance of the different climate variables and when (which months) the variables are most important is not fully known. We set up an empirical statistical model to evaluate this further.

This work was based on data from the national database of field trial data, held at the Danish Agricultural Advisory Service at Skejby, Aarhus. From the database we extracted trials carried out in Denmark between 1992 and 2007 with winter wheat under conventional treatment. Treatments typically had 3-5 replicates and we used the mean yield (hkg grains per ha with 85% dry matter). In total 5872 observations were extracted from variety trials, fertilizer trials and pesticide trials. The trials were mainly located at private farms spread over the country. Of the 5872 observations, 1857 were located on sandy loam soils and were used here as basis for the reported results. The yield data was combined with climate data available for each of the 44 grids of 40 km x 40 km covering Denmark (figure 1). For each grid we retrieved weather variables and calculated derived variables (table 1).

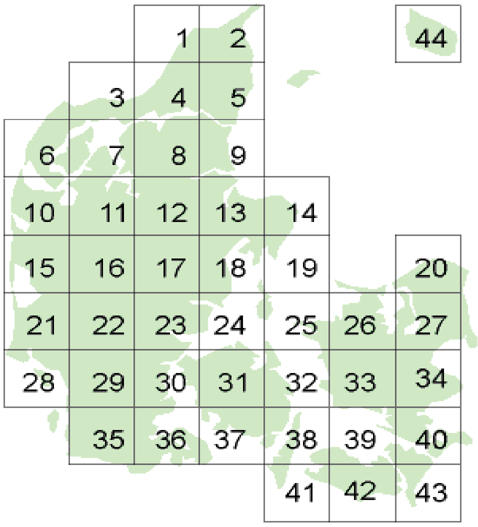


Figure 1. Location of the 44 grids from which daily weather variables were collected.

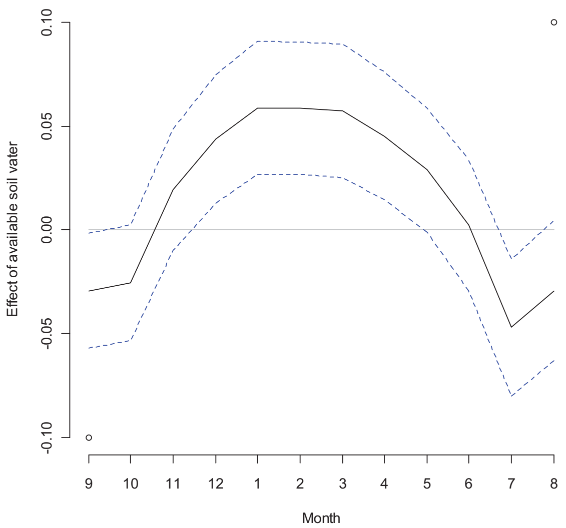
Table 1. Retrieved and derived daily weather variables

Retrieved variables
Mean temperature, °C
Minimum temperature, °C
Maximum temperature, °C
Global radiation, MJ m^{-2}
Precipitation, mm
Derived variables
Reference evapotranspiration, mm
Available soil water, mm
Low and medium intensive precipitation, mm

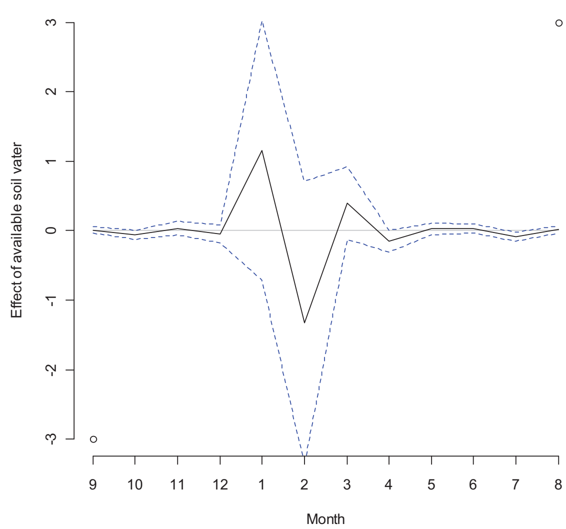
Reference evapotranspiration was calculated following de Bruin and Lablans (1998). The amount of available soil water was calculated by setting the amount of soil water at January 1st, 1991, equal to the maximum available soil water for the actual soil type (Olesen, 1995) and adding daily precipitation and subtracting daily reference evapotranspiration, with the restrictions that values could not exceed maximum available soil water or go below 0 mm. The 'low and medium intensive precipitation' was defined as accumulated precipitation on days with 20 mm or less.

One of the problems when evaluating the importance of weather variables on yield is the correlation between some of the weather variables, and correlations between values of the same variable that are close in time. This can be illustrated by the two graphs, A and B in figure 2. In 2A the effect of available soil water on yield was estimated by simple linear regression using one month at a time, while in 2B the effect of all months was estimated simultaneously using multiple regression (based on ordinary least squares). Most probably neither of the estimates in figures 2A or 2B give a good estimate of the effect of the month. In 2A it must be expected that the effects of neighbouring months are (partly) included in the effect, e.g. the estimated effect for January (approximately 0.07 hkg ha^{-1} mm^{-1}) partly includes effects of December and February soil water conditions and thus the estimate is most probably too high. The estimates in 2B seem to be unstable because of the high correlations between values in neighbouring months.

A



B



C

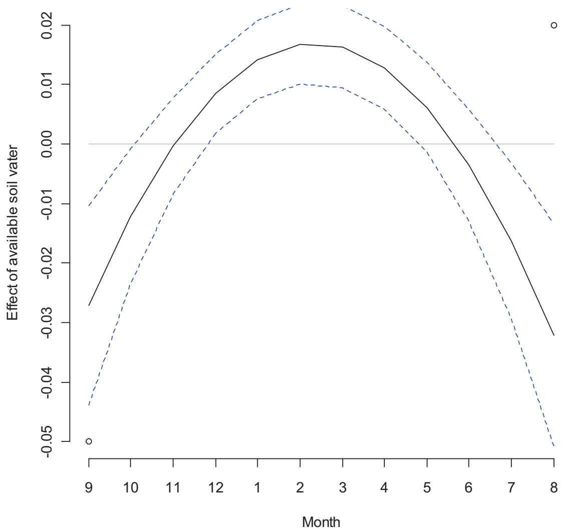


Figure 2. Monthly yield effect of available soil water (hkg ha^{-1} mm^{-1}) using three different methods. A: estimated separately for each month. B: estimated simultaneously for each month using ordinary least square. C: estimated simultaneously for each month using penalised regression. Dashed lines show the 95 percent confidence intervals for each of the 12 estimates.

In order to stabilise the simultaneously estimated regression coefficients, penalised regression was used (figure 2C). Since the effect of consecutive months should not be too different, we penalised for differences between consecutive months. Instead of minimizing the residual sum of square, the residual sum of square plus a constant times the squared difference between consecutive months was minimised, i.e., minimising $SS_{residual}+\theta\Sigma(\gamma_{i-1}-\gamma_i)^2$ with *i* running from October to August. The method described by Sims et al. (2007) was extended to accommodate more than one climate variable and applied for estimating the effect of variables for which monthly values were used.

A preliminary yield model included three predefined agroclimatic indices (x), three monthly climate variables (z) and a residual effect of year (δ_y). Mathematically the model may be written as:

$$Y_i = \mu + \alpha_1 x_{1i} + \beta_1 x_{1i}^2 + \alpha_2 x_{2i} + \beta_2 x_{2i}^2 + \alpha_3 x_{3i} + \sum_{j=September}^{August} \left\{ \gamma_{1j} z_{1ji} + \gamma_{2j} z_{2ji} + \gamma_{3j} z_{3ji} \right\} + \delta_{y(i)} + E_i$$

where

Y_i is the yield of observation i

x_{1i} is the average minimum temperature during October to March for observation i

x_{2i} is the accumulated global radiation during October to March for observation i

x_{3i} is the accumulated global radiation in July and August for observation i

z_{1ji} is the average amount of available soil water in month j for observation i

z_{2ji} is the average minimum temperature in month j for observation i (0.1)

z_{3ji} is the average amount of low and medium precipitation (< 20 mm day^{-1}) in month j for observation i

α_1, α_2, α_3, β_1 and β_2 are parameters to be estimated using ordinary regression

γ_{1j}, γ_{2j} and γ_{3j} are parameters estimated using penalised regression

$\delta_{y(i)}$ is effect of the year (not explained by climate variables) for observation i

E_i is the unexplained effect, which is assumed to be normally distributed with constant variance

The parameters α_i and β_i were estimated using ordinary regressions while γ_{ij}, and $\delta_{y(i)}$ were estimated using penalised regression. All parameters were estimated simultaneously. The estimates of the preliminary wheat yield model are shown in table 2 and figure 3.

Table 2. Estimates and standard errors for parameters quantifying the effects of indices based on minimum temperature and global radiation

Parameter name	Associated index	Estimate	Std. Err
α_1	$[T_{min\_Oct\text{-}Mar}]$	-7.4	5.0
α_2	$[Rad_{Oct\text{-}Mar}]$	13.5	4.7
α_3	$[Rad_{Jul\text{-}Aug}]$	0.160	0.210
β_1	$[T_{min\_Oct\text{-}Mar}]^2$	-0.246	0.219
β_2	$[Rad_{Oct\text{-}Mar}]^2$	-0.286	0.106

Available soil water had a significantly positive effect on winter wheat yield during the period from about January to May, whereas increasing soil water had a negative yield effect around sowing time and harvest time (Fig 3A). High minimum temperatures during autumn and especially winter had a positive effect on yield (Fig 3B). Ample precipitation in low or medium doses (< 20 mm day^{-1}) seemed to decrease yield; especially during winter and spring (Fig 3C). This is probably because the positive effect of water is modelled through available soil water. The yield of winter wheat (not explained by climate) increased during the period until about 1997 and decreased after 2003 (Fig 3D). However, non-climate effects were small compared to yields on sandy soils of approximately 60 hkg ha^{-1}.

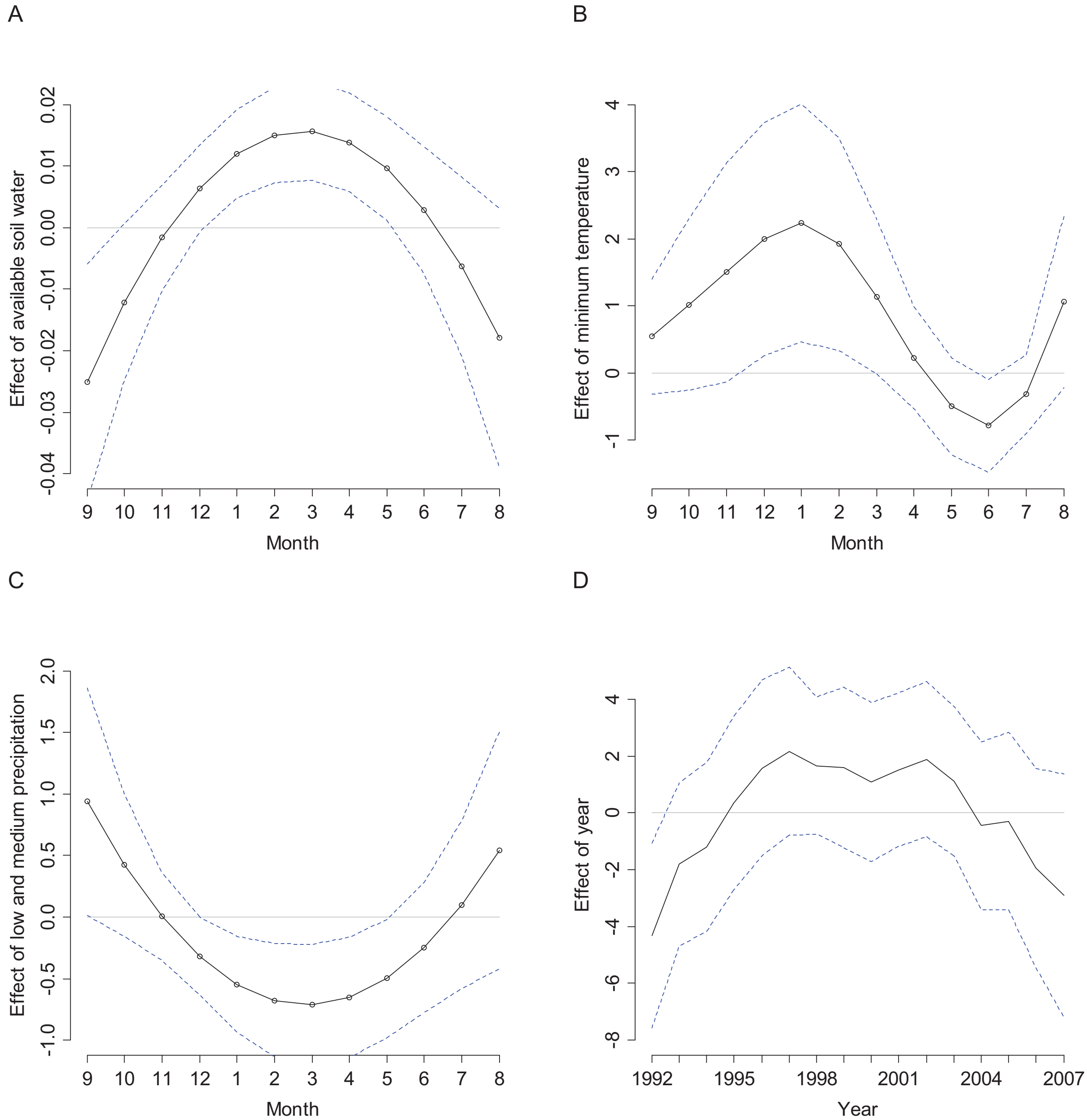


Figure 3. Modelled annual effect on yield of winter wheat (sandy soils), using penalised regression, of A: available soil water (hkg ha^{-1} mm^{-1}), B: minimum temperature (hkg ha^{-1} $°C^{-1}$), and C: low and medium precipitation, < 20 mm day^{-1} (hkg ha^{-1} mm^{-1}). D: The residual effect of year (hkg ha^{-1}). Dashed lines show the 95 percent confidence intervals for each of the estimates.

Keywords: Temporal and spatial climate variability, agriculture, winter wheat, water balance, statistical model, penalised regression

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ADAPTATION OF CROP MANAGEMENT PRACTICE TO CLIMATE CHANGE IN RUSSIA

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Abstract

As known, agriculture is very sensitive and vulnerable to weather and climate impacts, especially in conditions of changing climate. Therefore, it is necessary to identify limitations and vulnerabilities under climate change in order to outline the ways for 1) mitigating their possible adverse effects on crop production or 2) realizing the opportunities for cultivation of new crops in certain agricultural zones and regions.
In this research, the emphasis is placed on cereal crops are widely cultivated in the European Territory of Russia. Spatial distribution of main climatic limitations and vulnerabilities for cultivation of cereal crops is shown in Fig.1.

• zone where heat resources are limited for crop diversity (Boreal and Subboreal belts)

• zone where crops are subject to soil water shortage (Dry Agriculture zone)

Fig.1. Spatial distribution of main climatic limitations and vulnerabilities in the ET Russia.

Obviously, under climate change the distributions of these limitations and vulnerabilities will be subject to considerable spatial shift, thereby leading to the unavoidance of applying a whole set of adaptation methods for maintaining sustainable crop management in different agroecological regions.
To assess the effects of climate change on cropping systems in forthcoming decades, the Last Interglacial climatic optimum is considered as a paleoanalog scenario of global warming by 2020-2030, these conditions have been compared with simulation results obtained from transient GCMs for same "time slice". This scenario is based on proxy data, and scenario estimates show a good agreement with the observed trends in changing climatic conditions during the five last decades.
Thus, the scenario estimates indicate an increment of $\sum$ T> 10 °C up to 300-400 °C in the northern parts of ET Russia, and up to 100-200 °C in the central and southern parts. Such changes result in the opportunities to switch to more later season cultivars and also to grow new crops (e.g., buckwheat, sugar beet and maize hybrids) in Humid zone, including Boreal and Subboreal belts. In fact, we observe a potential shift in distribution of crops and cultivars northward, under reducing the area where heat shortage limit cropping systems diversity at present (see Fig.1).
In semiarid regions of ET Russia (Dry Agriculture zone and surrounding territories), the conditions are predicted also favorable to enlarging the areas under several crops. So, there is an opportunity to enlarging areas under winter wheat and winter barley due to decreasing frost killing risk (as an indicator of winter severity the value of mean monthly temperature in coldest month is used). Moreover, an increase in temperature sums may have resulted positively for maize and wheat durum cultivation (Nikolaev, 2008).
The simulation results from GCMs such as ECHAM4A, ECHAM5, HadCM3 and GFDL give close estimates of potential changes in thermal conditions, while the HadCM3 scenario simulates temperature increases under more arid climate.
In conditions of more earlier dates of sowing, cultivation of new crops is expected against changing background of mineral nutrient consumption by plants. According to paleoanalog scenario, the largest yield growth is to be expected in the Lower Volga sub-region on chestnut soils as on these the

efficiency of fertilizers sharply increases with additional natural soil wetting. Spatial analysis of changes in irrigation rates indicates that they should be increased in the semiarid regions north of 52° n.l., and they also should be decreased in more southern regions, excluding North Caucasus (Nikolaev, 2007a).
However, forthcoming climate change may result in a number of adverse effects on crop production.
It is expected that will be a significant increase in rotting- and wetting out risks for winter rye and winter wheat due to predicted more mild and damp winters. On average, the losses of winter cereals may increase by 13-15 % by 2020-2030. At the same time, such climatic extremes as droughts may occur sporadically over the ET Russia's territory.
To assess the drought recurrence, the G.T.Selianinov's Hydro-Thermal Coefficient for May-July ($HTC_{V\text{-}VII}$) and time interval between subsequent droughts τ (in years) statistically determined by Yu.L. Rauner were compared (Rauner, 1981). There is a strong correlation (r = 0,953±0,045) between spatial distribution of $HTC_{V\text{-}VII}$ values and spatial distribution of τ values. Based on this relationship, the maps are composed, which reflect geographic distributions of τ values at current and future climatic conditions (Fig. 2).

present-day conditions | by 2020-2030 (HadCM3 scenario) | by 2020-2030 (Paleoanalog scenario)

Fig. 2. Distribution of time intervals between subsequent droughts τ (years).

As seen, over the ET Russia's territory drought recurrence is expected to increase by 1.5 times in case of implementing the scenario of more arid climatic conditions by 2020-2030. In case of implementing the scenario of more humid climatic conditions by 2020-2030, drought recurrence is expected to decrease, also by 1.5 times. Of course, under change in drought climatology also climatology of drought accompanying phenomena such as dry winds and dust storms and producing water- and wind erosions will be changed.
It should be noted also that isoline of $HTC_{V\text{-}VII}$= 1 corresponds to the northern boundary of Dry Agriculture zone at present. Fig. 3 shows possible shifts in boundary of Dry Agriculture zone under different climatic scenarios.

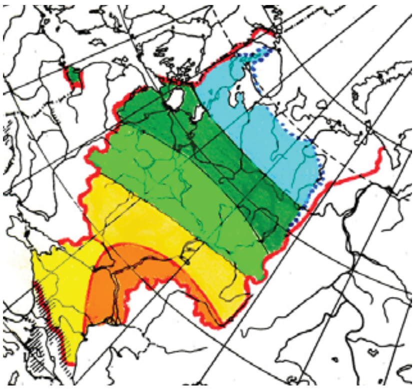
— implementing the scenario of more arid climatic conditions by 2020-2030

— implementing the scenario of more humid climatic conditions by 2020-2030

Fig. 3. Possible shifts in the boundary of Dry Agriculture zone (middle line).

Thus, we may observe a certain shift of crop management practice to more humid or more arid zones, respectively.

Meanwhile, the expected shift in distribution of crops and cultivars will cause the penetration of pests, pathogens and weed flora into new areas and also potential acclimatization of several insect pest species in more northern parts of ET Russia. In this connection, the spatial analogue method has been developed for defining the areas vulnerable to potential risk of crop damage by insect pests, diseases and weeds with warming process.
This approach is based on an analysis of analog regions under current and future climate regimes according to the following criteria: (1) similarity in annual course of daily temperatures; (2) similarity in annual precipitation amounts; (3) similarity in soil type and fractional composition (wide range of field crops adaptation to light factor taken into consideration). In this approach the Last Interglacial climatic optimum is considered as a paleoanalog scenario of global warming by 2020-2030 (Nikolaev, 2007b). Then, comparison was made of spatial analogs with those by O.D. Sirotenko and V.N. Pavlova, determined for more southern regions within ET Russia (Sirotenko & Pavlova, 2003). Their approach is based on HadCM3 and GFDL simulation results for 'time slice' 2020-2030,and the following criteria is used: 1)similarity in values of accumulated temperatures above 10º C; (2) similarity in values of evaporation deficit during the period with temperature above 10 º C; (3) similarity in values of mean monthly temperature in coldest month. Despite discrepancies between analogue criteria and climate prediction options, the vector directions are from south-west to north-east, i.e. from warmer regions to cooler regions (Nikolaev, 2007c).
All the above mentioned testifies about the necessity of search for adaptation options in order to realize sustainable crop management in a changing climate (Nikolaev & Yakushev, 2004).
Although there is a number of common adaptation options, including similar adaptation measures which could be applicable to all agroecological regions (e.g., adjustments in timing of farm operations, fertilization optimum, doses of chemicals and irrigation rates, etc.), yet regional agro-technologies are considerably differentiated due to existing differences in regional climates (Eitzinger et al., 2007). Therefore, the agroclimatological design for regionalization of feasible adaptation measures in agricultural sector of economy within ET Russia is created (Fig. 4).



- **ET Russia north 61° n.l.**
  (Type of climate: cool temperate, humid)
- **North-West Russia**
  (Type of climate: temperate, humid)
- **Central Russia**
  (Type of climate: temperate, humid/subhumid)
- **Chernozem Centre and Middle Volga**
  (Type of climate: temperate, semiarid)
- **Lower Volga and Southern Pre-Ural**
  (Type of climate: temperate, semiarid/arid)
- **North Caucasus**
  (Type of climate: warm temperate, semiarid/subhumid)

Fig. 4. Agroclimatological design for regionalization of feasible adaptation measures.

This map is made on the basis of integrated analysis of spatial distributions in agroclimatic resources, environmental risks, soil types and agricultural specialization. Proceeding from this map we further focus on feasible adaptation measures allowing for specific agroecological conditions in every region separately.
For **North-West Russia (including European part of Russia north 61° n.l.)**, specific feasible adaptation measures may include the following: • adjusting soil liming standards under acid soils; • applying furrow- and pumped-well drainage to eliminate surplus runoff in autumn and spring as well as wetting-out resistant cultivars; • snow rolling to reduce soil temperature in the depth of tillering node and also application of snow mold resistant cultivars; • improving weed control; • effective application of aboriginal and introduced entomophages and useful insects; • introduction of useful flora species from more southern regions to more northern regions for establishing reservations for acclimatization of new entomophages and useful insects
For **Central Russia**: • full fallowing; • applying lea- and grass arable rotation by enlarging generic composition of seed grasses; • improving crop rotation systems by introduction of alternative crops; • application of more rot- and lodging resistant cultivars in the extra-humid districts; • intensification of surface runoff in northern portions of the Region; • improving practice for water infiltration into soil in southern portions of the Region.

For **Chernozem Centre and Middle Volga** Regions: • bare fallowing; • snow melt water retention; • plowing application for water uptake from melt snow into soil; • application of harrowing to reduce evaporation losses; • improving sugar beet irrigation; • snow piling for snow accumulation; • applying different kinds of afforestation (more effective application of protective belts and agroforestry for snow accumulation, regulation of soil moisture and water erosion protection by conversion- , slope- and gully afforestation as well as enlarging generic composition of forest belts - in this consequence the opportunities for reservation and acclimatization of new entomophages are enlarged in these belts).
For **Lower Volga and Southern Pre-Ural** Regions: • adjusting soil gypsuming standards under alkali-affected soils; • stubble mulching; • soil loosening in autumn; • deep plowing to improve water uptake; • subsurface tillage due to existing wind erosion; • improving wheat irrigation; • snow retention (e.g., by using snow plowing); • application of windbreaks and vegetable fences (more effective application of windbreaks and afforestation of sands for protection against wind erosion and dust storms as well as snow hedges by improving their wind protection, soil protection and snow regulation effects under climate change).
For **North Caucasus**: • bare- and legume fallowing; • improving fall tillage and deep plowing; • enlarging grass diversity in crop rotation systems; • flood control; • improving computerized irrigation for rice; • slope terracing; • more effective techniques for protection of warm weather crops against frosts.
In this connection, a number of adaptation strategies for crop management practice can be considered.
Strategy for agricultural land use planning and crop selection may consist in:

- ✓ shift in the planted areas under more productive crops and cultivars to high latitudes;
- ✓ expansion the areas under cultivars high resistant to pests and diseases (in particular, extending areas under rot resistant cultivars: overwise switching from winter crops to summer crops in most vulnerable regions);
- ✓ switching from summer crops to winter crops in the regions with severe winters due to reducing frost killing risk;
- ✓ enlarging the areas under cultivars high tolerant to drought stress: otherwise switching to crops that use less water (e.g., millet and sorghum);
- ✓ widening areas under salt tolerant cultivars;
- ✓ shift in the planted areas under winter barley and vineyards towards elevations.

Of course, changing land use will require: (1) supply of the regions where conditions are expected to be favorable for new fertilizer-respondent crops by additional amounts of mineral fertilizers; (2) diversification of pesticides, fungicides and herbicides for further applying in the regions potentially vulnerable to new insect pests, viruses and weeds.
Strategy for effective water use in agriculture may consist in:

- ✓ improving different kinds of irrigation including surface, subsurface, drop and mist irrigation;
- ✓ concentration of irrigation water during peak growth period for best crop response, taking into account a possible shift in peak growth period under climate change;
- ✓ optimizing sprinkler irrigation including fertilizer- and frost control sprinkling in different agroecological regions;
- ✓ improving basin and bench border irrigation in the costal lands and foothills;
- ✓ installation of more efficient irrigation systems (by improving system of canals) in drylands;
- ✓ installation of more efficient drainage systems (by improving water regulating drainage) in wetlands;
- ✓ conjunctive water use.

Strategy for effective application of crop protection system basing on sustainable agriculture criteria may consists in:

- ✓ intensification of pest-, disease-, and weed control by monitoring of harmful organisms in time and space (e.g., by using GIS);
- ✓ improving agricultural practice including tillage practice to suppression of pest populations and pathogens survivability;
- ✓ breeding of new cultivars and varieties with high resistantability to pest-, virus-, and weed stresses;
- ✓ improving biological methods for crop protection including application of new entomophages and useful insects, and also new entopathogens;
- ✓ improving genetic methods for crop protection;
- ✓ improving chemical methods for crop protection by switching to ecologically friendly bio-preparations

In conclusion, it should be noted that assessing the agroclimatic conditions in forthcoming decades shows that distribution of climatic resources for crop management practice will be subject to significant spatial shift under climate change. Meantime, the boundaries of agricultural areas vulnerable to unfavorable factors will also significantly be shifted.

For this reason, the conditions for crop management practice in certain regions in the future are expected to be similar to present-day conditions for this practice in certain climatic zones and provinces. Respectively, application of spatial analogue method to a changing climate for analyzing feasible adaptation measures and strategies is highly prospective.

Seemingly, choosing spatial analogs should not be restricted only to the surrounding territories, since the similar natural zones (landscapes) may be located at a great distance from each other. Therefore, a development of international cooperation in the aspects of crop management adaptation to climate change appears to be actual, taken into consideration national experiences.

Keywords: climate change impact, agriculture, adaptation measures and strategies

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SIMULATED IMPACTS OF CLIMATE CHANGE AND ELEVATED CO_2 ON CROP PRODUCTION AND MANAGEMENT IN DIFFERENT REGIONS OF GERMANY

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Abstract

Based on simulations with the agro-ecosystem model HERMES, the impact of climate change on crop growth and water and nutrient management was assessed using a downscaled climate change scenario A1B from the GCM ECHAM5 from the WETTREG model. The suitability of different algorithms describing CO_2 response on crop growth and crop water use efficiency were tested within the framework of the HERMES model using data of a six year agricultural crop rotation in a FACE experiment under ambient and elevated atmospheric CO_2 level. A combination of a semi-empirical Michaelis-Menten approach and a Penman–Monteith approach with a simple stomata conduction model for evapotranspiration yielded the best simulation result expressed by model performance indicators. Simulation case studies at 10 different locations in Germany show the potential effects of climate change and variability on wheat production and its management regarding water and nitrogen supply. Results indicate that the effects of climate change on wheat production and management will vary across Germany depending on the specific regional projection and site properties. including the direct and indirect effect of elevated CO2 in the simulation showed an increase in crop yields in many cases. Only the regions of East-Germany may suffer from more frequently occurring dry spells.

Key-words: climate change, CO_2 effect, FACE experiment, crop yield, water use

Introduction

Climate change including increasing CO_2 concentration of the atmosphere will affect crop growth as well as soil water and nutrient dynamics in Germany very differently due to different regional changes of climate and site specific boundary conditions. This will require an adaptation of crop management regarding cultivation, water and nutrient management. Describing the interactions of crop growth, soil processes, and weather variables in a simulation model is current state-of-art methodology to interpret downscaled GCM outputs for yield predictions. The effect of CO_2 on crop growth was recently implemented in agro-ecosystem models using approaches of different complexity. Mainly two processes are affected: (i) in C3 plants, an increasing CO_2 would directly increase the photosynthesis rate (Gaastra, 1959) and (ii) a higher CO_2 would also lead to a decrease in stomatal conductance and thus to a higher water use efficiency (Manderscheid and Weigel, 2007).

In this study, we integrated a number of selected algorithms into the soil-crop model HERMES to test their suitability to describe CO_2 impact on crop growth against data of a Free Air Carbon Enrichment (FACE) experiment (Weigel and Dämmgen, 2000). The best algorithm was then used in combination with downscaled climate change scenarios for simulations at different sites in Germany under the SRES-A1B scenario. Selection of regions considered locations with different climatic situations to demonstrate the combined climate change and CO_2 effect on crop yields of winter wheat.

Material and Methods

Applied model

CO_2 response algorithms were integrated within the HERMES model, which was designed to simulate crop growth, water and nitrogen uptake, and the nitrogen dynamics in the soil for applied purposes. This implies simple and robust model approaches, which are able to operate under restricted data availability. A more detailed description of the model is provided by Kersebaum (2007). To consider CO_2 effect on stomatal reseistance we recently extended the model approaches for calculating reference evapotranspiration by the Penman-Monteith method according to Allen et al. (1998). Crop specific potential evapotranspiration is calculated using crop specific factors (kc) during the growing season linked to the developmental stages of the crops, and bare soil factors between harvest and crop emergence. The HERMES model was calibrated to the data of the control treatment of the FACE experiment, using the output variables soil moisture (sum of 0 – 60 cm soil depth), above-ground crop dry matter, and yield. Willmott's index of agreement (IoA) was used as a goodness-of-fit criterion (Willmott, 1981). The algorithms tested in the framework of the HERMES model were:

(I) The Mitchell approach (Mitchell et al., 1995) used a set of algorithms based on the ideas of Farquhar and von Caemmerer (1982) and Long (1991), calculating the maximum photosynthesis rate
(II) The Nonhebel approach is a much simpler approach extracted from the SUCROS87 model (Nonhebel, 1996), where radiation use efficiency is directly affected by CO_2.
(III) The Hoffmann approach (Hoffmann, 1995) where the maximum assimilation rate Amax is adjusted depending on CO_2 concentration and incomming radiation.
These three approaches were combined with a mixed Allen/Yu approach describing the CO_2 impact on crop transpiration. Evapotranspiration was calculated using the Penman and Monteith formula according to Allen et al. (1998) using the stomata resistance calculated as suggested by Yu et al. (2001) which considers CO_2 concentration at leaf surface, gross photosynthesis rate and vapour pressure deficit. A more detailed description of the algorithms can be found in Kersebaum et al. (2009).
The algorithms were tested comparing model outputs with 6 years measured data of a three-year crop rotation (winter barley, sugar beet, winter wheat) from a FACE experiment located at the experimental station of the von Thünen-Institute (vTI) at Braunschweig, Germany (52°18'N; 10°26'E). Crops were grown under optimum nutritional and moisture conditions over two cycles at normal (~374 ppm) and elevated (~550 ppm) CO_2 levels. Subplots within the rings with 50% (N50) of the adequate nitrogen supply (N100) were established to study interactions between C and N. A detailed description is given by Weigel and Dämmgen (2000). Willmott's index of agreement (IoA) was used as a goodness-of-fit criterion (Willmott, 1981).
Scenario simulations with CO_2 effect were carried out for 9 different regions in Germany for the present and future situation of the A1B scenario using 3 realisations of statistically downscaled climate change scenarios from the WETTREG model (Enke et al. 2005) and a small scale soil map (1:1.000.000). For this the best combination of the best performing algorithms from the test were used.

Results

Two important results were observed in the Face experiment: increased CO_2 (i) enhanced crop growth for all investigated species and (ii) decreased evapotranspiration rate of the canopies resulting in higher soil moisture content (Weigel et al., 2006). All algorithms tested within the HERMES model framework were able to describe the observed crop growth and soil moisture dynamics sufficiently under ambient and elevated CO_2 levels. Table 1 shows the average index of agreement of above gound biomass, crop dry matter yield, leaf earea index and soil moisture (0-60 cm). Details can be found in Kersebaum et al. (2009).

Table 1: Average index of agreement (Willmott 1981) of above gound biomass, crop dry matter yield, leaf earea index and soil moisture (0-60 cm) across all CO_2 concentrations and nitrogen levels.

Algorithm	**single**	**combined with Allen/Yu**
Nonhebel	0.82	0.83
Mitchell	0.81	0.82
Hoffmann	0.83	0.84

On the basis on above ground dry matter, yield, and soil moisture simulation, the Hoffmann approach in combination with the Allen/Yu approach performed best. However, the differences were marginal. In all cases the combination with the Allen/Yu approach improved the results, especially for the comparison between the observed and simulated water contents. Elevated CO_2 concentration of 550 ppm yields in a reduction of about 20 mm year^{-1} on average during the simulation period using the combined Hoffmann/Allen/Yu approach. Therefore, we used the combined Hoffman/Allen/Yu approach for the simulations of regional climate change effects.
Results of the regional simulation indicate that the effects of climate change on wheat production and management will vary across Germany depending on the specific regional projection and site properties. In a preliminary study it was found that without consideration of the CO_2 effect the crop yield under climate change was mainly reduced compared to the reference time slice (Kersebaum et al. 2009). Only at one higher elevated site crop growth benefited from increasing temperature. However, including the direct effect of elevated CO_2 on photosynthesis and the indirect effect of reduced transpiration in the simulation yielded in an increase in crop yields in many cases. Only the regions of East-Germany may suffer from more frequently occurring dry spells, where the CO_2 effect was estimated to be not sufficient to level out the negative impact of water shortage on crop growth. However, in every region positive and negative effects can be found depending on the specific site conditions. Sandy sites with low water holding capacity and low available water were mostly exposed to increasing drought conditions while at sites with shallow groundwater, mainly river lowlands, crops

will benefit from climate change getting additional water from capillary rise. Nitrogen use efficiency was reduced under typical summer drought conditions. In wetter regions the elevated temperature led to an increase of nitrogen mineralisation. Therefore, in dryer regions the required nitrogen supply by fertilization for maximum yields was estimated to increase although the potential yield decreased compared to the reference period while in the more humid regions the nitrogen fertilization demand remained unchanged although higher yields were expected. Fig. 1 shows the area-weighted average of yield change for each region and the variation within the regions.

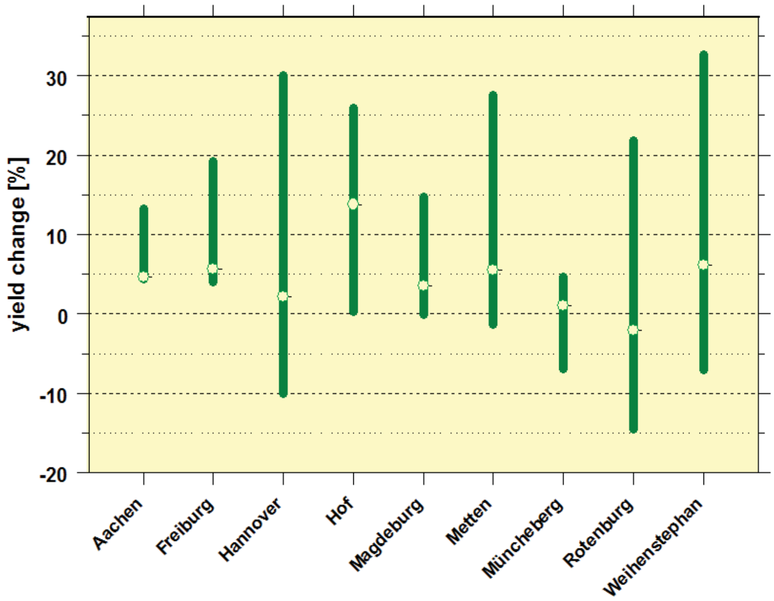

Figure 1: Area-weighted average and range of winter wheat yield change in different regions (scenario A1B 2031-2050 compared to reference period 1971- 1990)

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BIO-ECONOMIC IMPACTS OF CLIMATE CHANGE ON FLANDERS‘ FIELDS

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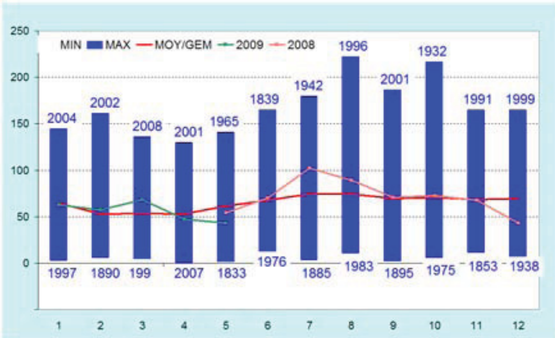
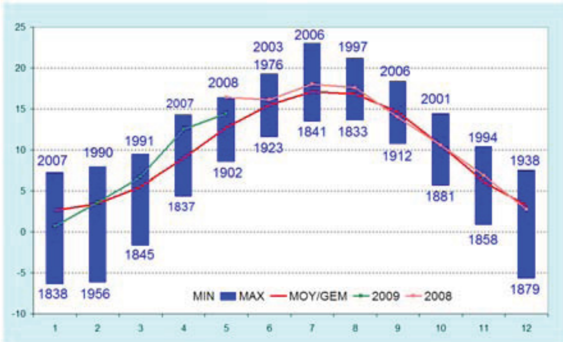
Abstract

The frequency and magnitude of extreme weather events are likely to increase with climate change. In Belgium the past decade has experienced more monthly extremes than any other decade before since the observations started in 1833 (Fig. 1).



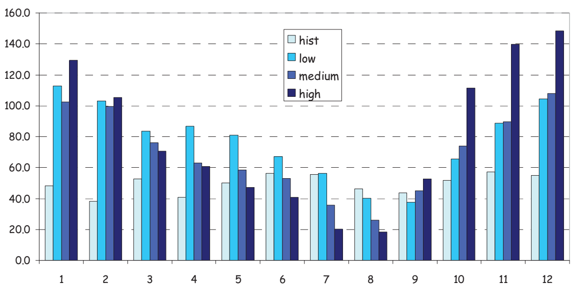
Monthly total rainfall at Ukkel (mean in red, extremes in blue) (*n* = 7)



Monthly mean temperature at Ukkel (mean in red, extremes in blue) (*n* = 8)

Fig. 1. Monthly extremes at Ukkel since 1833 (RMI, 2009)

According to Global Circulation Model predictions, Belgium is situated on a wedge between a wetter and drier climatic regime. Three climate change scenarios were selected on the basis of multi-criteria analysis of the PRUDENCE RCM runs (Christensen and Christensen, 2007) such that future climate variability was captured (Fig. 2).



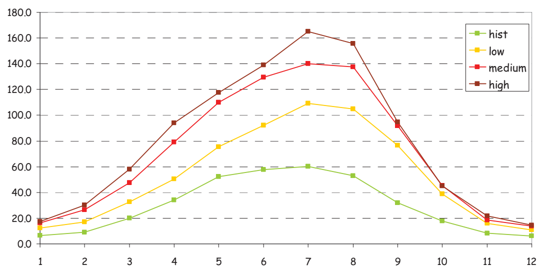


Fig.2. Rainfall (in mm, left) and Penman-Monteith evapotranspiration (in mm, right) for three climate change scenarios (low, medium, high) compared to 1960-1989 observations (hist)

Not only the frequency and magnitude of meteorological events but also their timing in relation to crop development and the physical environment will determine their impact. The cropping calendar for major agricultural regions in Flanders indicates an influence of the physical environment (agricultural region) on planting and harvesting dates (Fig.3 and Fig.4).

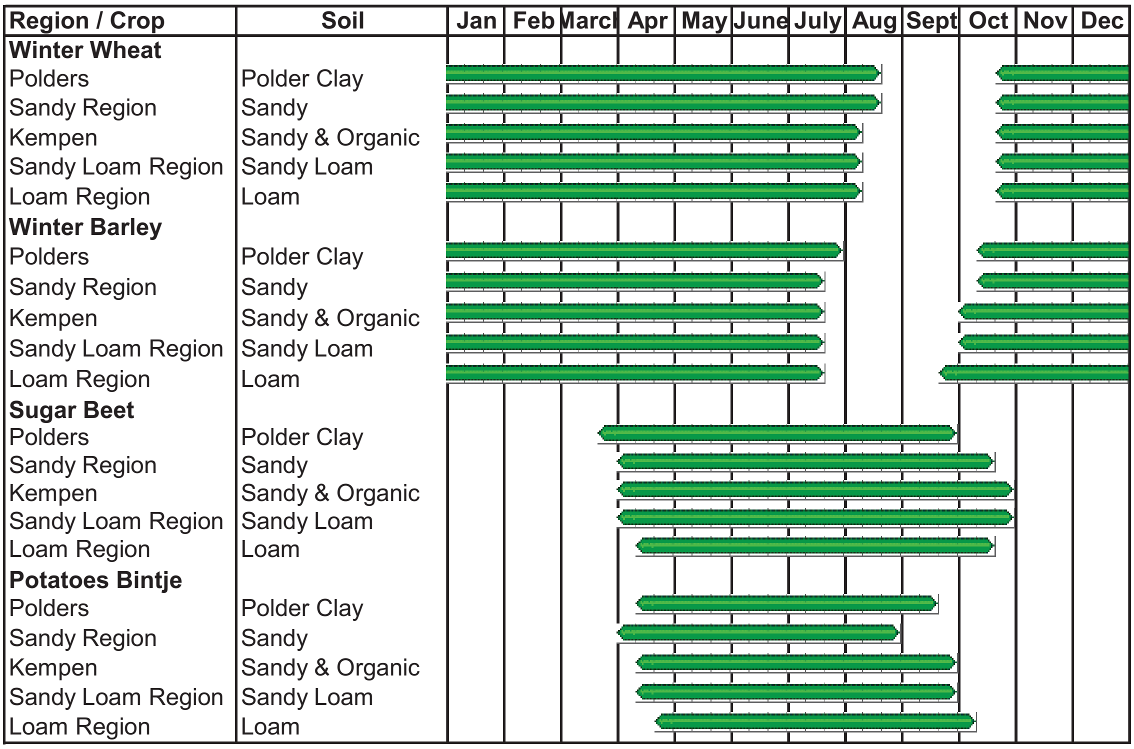


Fig. 3. Cropping Calendar for different arable crops in different regions of Flanders

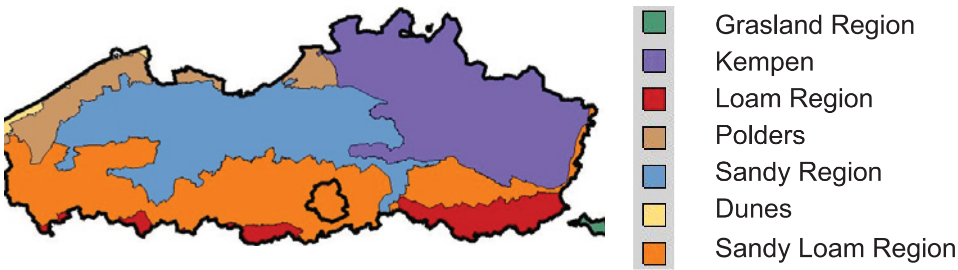
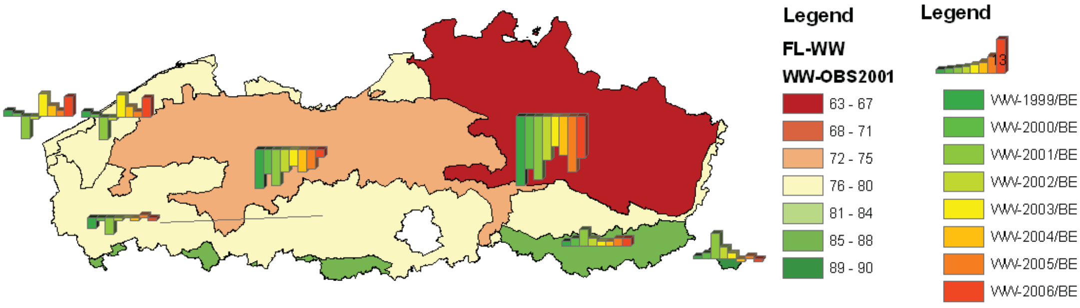


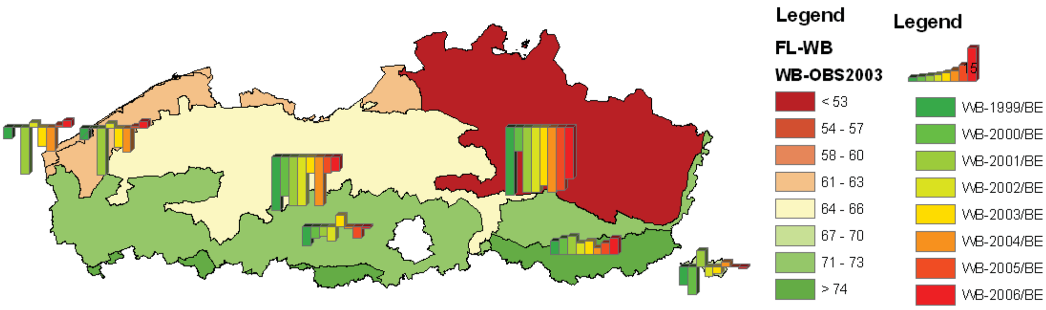
Fig. 4. Agricultural regions of Flanders

The implications of extreme weather events are demonstrated for the year with the lowest yields in the past decade for four arable crops in the agricultural regions of Flanders (Fig. 5). A very wet spring and a dry hot summer interrupted by hailstorms in July caused low yields for winter wheat in 2001. Frost in February, droughts during February-April and high temperatures in June 2003 resulted in the lowest yields during the past decade for winter barley. Late planting due to rains, low radiation during July, high rainfall during September-October followed by early frost in November caused low sugar beet yields in 1998. In 2006, low temperatures in April, high rainfall in May and a heat wave in July followed by a cold and rainy August created unfavourable growth conditions for potatoes. Water stress, both drought and flooding, and heat stress seem the major factors that influence arable yields in Flanders.

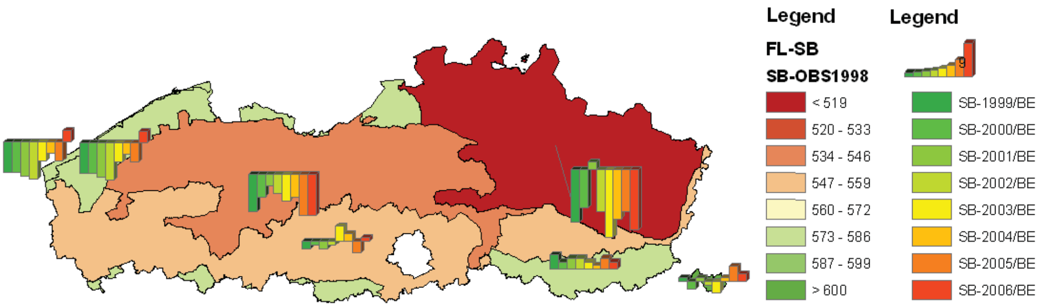
The unfavourable weather conditions during the growth season may be further enhanced by the physical environment. The effects of drought and heat stress are stronger in agricultural regions with sandy soils (Kempen, Sandy Region) as compared to the regions with heavier soil textures (Sandy Loam Region, Loam Region). The negative bar charts on the regions dominated by sandy soils (Fig.5) reflect a systematic lower yield as compared to the Belgian national average yield. A bad year for one arable crop is not necessarily a bad year for another arable crop such that diversification within one farm may be a good strategy of cooping with climate variability.



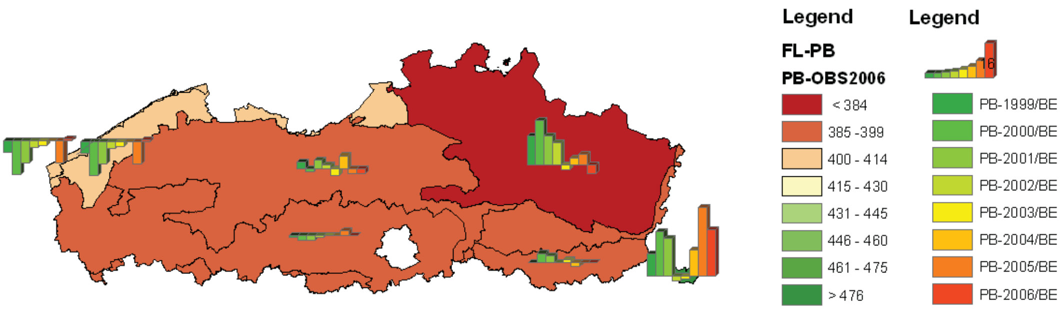
Winter wheat: lowest yields in 2001



Winter barley: lowest yields in 2003



Sugar beet: lowest yields in 1998



Potato Bintje: lowest yields in 2006

Fig. 5. Observed regional yields (in 100 kg/ha) for the worst year in Flanders (map), and percentage difference from the Belgian average yield (bar chart) during the past decade (Data from NIS).

Process-based dynamic vegetation models can integrate the effects of crop management, weather and soil on crop growth. A combination of historical analysis, climate scenarios, a dynamic vegetation model and economic evaluation was used to assess climate impacts on four arable crops in Flanders. The dynamic vegetation model consists of a water balance corrected for water use efficiency and reduced growth conditions due to water stress, and a biomass model on the basis of the Monteith equation corrected for temperature increases, vapour pressure deficit and changing CO_2 concentrations. Pronounced yield losses mainly due to water shortages and heat stress occur for all climate change scenarios, to a lesser extent in the case of winter cereals. In a high climate change scenario, yield losses of 16 to 40% are simulated for sugar beet and losses of 12 to 30% for potatoes (Fig.6), whereas winter cereal losses are only up to 8% as compared to current normal yields. Although yearly water balances fail to reflect seasonal dry spells, a general shortage of water during the growing season is simulated for sugar beet (Fig.7). Root crops such as potatoes and sugar beet will experience increased drought stress particularly when the probability rises that sensitive crop stages coincide with dry spells. This may be aggravated when wet springs cause water logging in the field and delay planting dates. Despite lower summer precipitation predictions for future climate in Belgium, winter cereal yield reductions due to drought stress will be smaller due to earlier maturity (Fig.7). On the contrary winter cereals may suffer from water logging on the field during early spring and from heat stress during flowering.

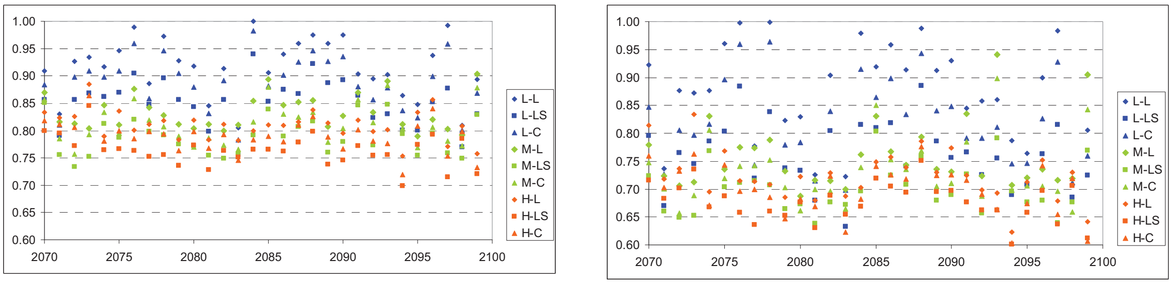


Fig. 6. Simulated yields relative to normal yield for potato (left) and sugar beet (right) under three climate change scenarios (Low, Mid, High) and three typical soils (Loam; Loamy Sand; Clay)

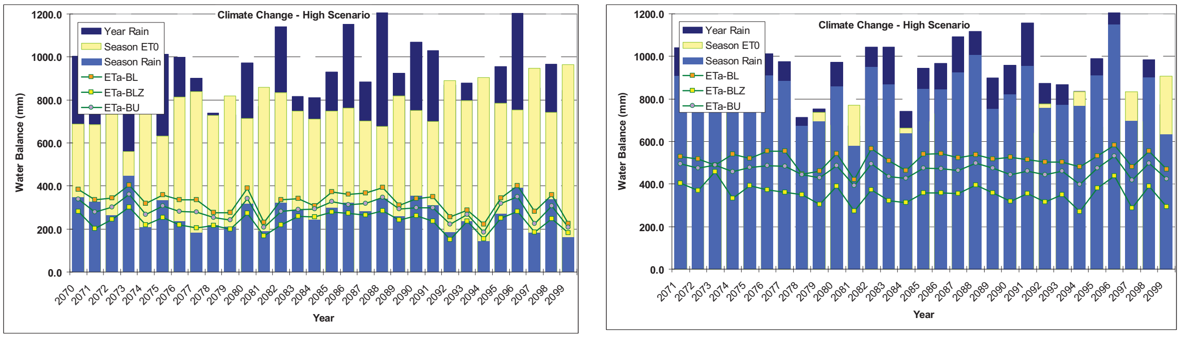


Fig. 7. Water balance for sugar beet (left) and winter wheat (right) on three typical soils (Loam, Loamy Sand, Clay) for a high climate change scenario

Maximum agricultural yield losses were combined with projected market prices keeping the total area constant. The total area of each arable crop was derived on the basis of LPIS (parcel information). Without adaptation and in a worst case scenario of high climate change, the agricultural sector will loose 105 m€ due to average yield losses in cereals, potatoes and sugar beet. This amount reflects the acceptable cost and efficiency of adaptation measures.

The results demonstrate that observed yield patterns contain substantial information on the impact of climate variability on yields. This knowledge was used to simulate yields and bio-economic impacts for four arable crops in Flanders under three scenarios of climate change.

Keywords: spatial variability, arable yield, climate change impact, dynamic vegetation model

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CROP RESPONSES TO TEMPERATURE AND PRECIPITATION IN PAST AT HIGH LATITUDES WITH REFERENCE TO CLIMATE CHANGE

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Abstract

Global surface temperatures have risen on average by 0.76°C during the last 100 years. The warming has accelerated in recent decades, 1995-2006 being the warmest period ever recorded. The last few decades have been warm also in Finland. Hence, the conditions during many of the growing seasons have reflected the future scenarios according to temperature and precipitation conditions, though neglecting the impact of elevating CO_2.

Typically an increase in temperature results in hastened developmental and growth rates of crops. This is especially critical under northern growing conditions where development progresses already rapidly due to long days (Peltonen-Sainio & Rajala, 2007; Peltonen-Sainio et al., 2009). Hence, we studied how current field crop cultivars adapted to cool northern growing conditions have responded to the warmer growing seasons. These comparisons were carried out with spring and winter wheat (*Triticum aestivum* L.), oats (*Avena sativa* L.), barley (*Hordeum vulgare* L.), winter rye (*Secale cereale* L.), pea (*Pisum sativum* L.) and rapeseed (turnip rape *Brassica rapa* L., oilseed rape *B. napus* L.). Long-term datasets of MTT Official Variety Trials and the Finnish Meteorological Institute were used to study crop responses to precipitation and elevated temperatures at different growth phases.

When studying the role of temperature and precipitation on yield formation by dividing the growth period of cereals, rapeseed and pea into four phases (according to °Cd), we noted the general trend that in all spring cereals increase in early summer precipitation increased yields by 45-75 kg per 10 mm increase in precipitation. The yield response to precipitation was, however, often opposite at later growth stages: yields were reduced especially during late grain-filling.

When monitoring the probabilities of having sufficient rains during the most critical phases of yield determination in barley with an additional case study, we noted that on average over three previous decades only about 40-50 % of the precipitation needed for undisturbed yield formation fell, the effect depending on region. Such constant water deficit resulted in yield losses averaging up to 17 % over a 30-year period, again depending on region. Yield losses were, however, most prominent in the areas where cereal production is presently concentrated. In contrast to cereals, rapeseed did not respond significantly to precipitation during any growth phase. For pea, yield losses followed increases in precipitation at late seed-filling. Presently rains are increasingly frequent in Finland during the late maturity phase and at harvest. The situation might worsen with climate change (Jylhä et al., 2004).

We did an additional exercise with long-term MTT datasets by grouping experiments according to temperature conditions typical for the past three decades, 1971-2000 (centred on 1985) and conditions estimated likely for 2010-2039 (centred on 2025), according to SRES scenario A2 of IPCC (IPCC, 2000). We found that growth of the current cultivars of studied crops was not favoured by elevated temperatures compared to present-day conditions. The response of pea was, however, different from the other spring crops as seed yield of pea was enhanced in '2025' compared with '1985' (Table 1). Winter cereals tended to benefit from higher temperature conditions, although the difference between '1985' and '2025' was not significant, nor was the tendency of negative yield response in rapeseed.

Under elevated temperature conditions, the typically early maturing spring barley was especially prone to yield losses. Barley has least time and capacity to compensate for the reduced floret number (yield potential) resulting from an increased pre-anthesis developmental rate (Peltonen-Sainio et al., 2009). Spring oat matures at about 60 °Cd and wheat at 100 °Cd later than barley in Finland (Peltonen-Sainio et al., 2009). Hence, yield losses of barley, despite the significant but small compensation in grain size (Table 1), were most severe. Ugarte et al. (2007) found that both of the yield components, grain number and grain weight, responded negatively to elevated temperatures. It is, however, possible that in the future, elevated CO_2 partly alleviate the high temperature induced yield losses that could not be studied here when using historical datasets. According to Hakala (1998) negative effects of elevated temperatures for spring wheat in long day conditions were compensated by elevated CO_2.

Crop and trait	1985	2025	Change	*p* value
Spring barley:				
Yield (kg ha^{-1})	4475	4222	-254	0.05
Grains m^{-2}	10 770	9780	-990	<0.01
Single grain weight (mg)	42.5	43.6	1.1	<0.01
Spring oat:				
Yield (kg ha^{-1})	4838	4589	-249	0.03
Grains m^{-2}	14 100	13560	-540	0.14
Single grain weight (mg)	34.5	34.0	-0.5	0.10
Dry pea:				
Yield (kg ha^{-1})	3150	3651	501	0.06
Seeds m^{-2}	1480	1570	90	0.44
Single seed weight (mg)	228	248	20	<0.01

Table 1. Yield and yield components of spring barley, oat and pea in MTT Official Variety Trial experiments grouped according to typical temperature conditions for the past three decades 1971-2000 (shown as '1985') and typical conditions estimated for 2010-2039 (shown as '2025'), according to SRES scenario A2 of IPCC. Temperature data is from the Finnish Meteorological Institute. No significant effects were found on spring and winter wheat, winter rye, spring rapeseed. Effect of elevating CO_2 was ignored, because historical datasets were used for comparisons.

In conclusion, Elevated temperatures caused yield penalties for spring barley and oat. This likely associated with reduced water availability. As elevated temperatures typically hastened development and growth, it is essential that cultivars are bred for adaptation to future prolonged growing seasons and elevated temperatures, as they need to be less sensitive (Gonzalez et al., 2005) to increases in developmental rate induced by long day conditions. They should also have improved water-use efficiency to cope with early summer drought (Lopez-Castaneda and Richards, 1994).

Keywords: Barley, dry pea, oat, oilseed rape, rye, turnip rape, wheat, yield, yield components, quality, temperature, precipitation, climate change, adaptation, cultivars

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CLIMATE CHANGE AND ADAPTATION OPTIONS IN IRISH AGRICULTURE

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Introduction

An increase in global temperatures of the magnitude projected by GCMs is likely to have a significant impact on climate processes operating at various scales, from global- and hemispherical-scale processes to the regional- and local-scale surface environmental variables. As a mid-latitude country, Ireland can expect its future temperature changes to mirror quite closely those of the globe as a whole. Best estimates of global temperature change by the end of the present century are currently in the region 1.8–4.0°C. Confidence in the simulations of these models is largely based on the assumptions and parameterizations used to develop them but also on their ability to reproduce observed climate (Karl *et al*., 1990). Despite the high degree of sophistication of GCMs, their output is generally too coarse to be useful for regional- or local-scale impact analysis, Therefore, the application of regional climate models (RCMs), which are dynamical in nature, to the downscaling problem has become more widespread in recent years. Their optimum resolution is in the tens of kilometres, which may still be too coarse for some impact analysis needs and so empirical statistical downscaling has become a viable alternative where high spatial and temporal resolution climate scenarios are required. This requires substantially less computational resources and produces results that are comparable to those outputs from RCMs. The methodologies employed are largely in common with those of synoptic climatology; however, the goal of downscaling is to adequately describe the relationship between atmospheric circulation and the surface environment, with attention being focused more on model parsimony and accuracy, rather than on understanding the relationship between them (Yarnal *et al*., 2001).

Methodology

Observed daily data for precipitation, temperature and sun hours were obtained from 14 synoptic stations from the Irish Meteorological Service, Met Éireann, for the period 1961–2000 for which baseline scenarios were derived. In order to derive the future climate scenarios based on the transfer functions, GCM data were obtained, from the UK SDSM archive, for three models, namely the HadCM3, the Canadian Centre for Climate Modelling and Analysis (CCCma) (CGCM2) and the Commonwealth Scientific and Industrial Research Organization (CSIRO Mark 2), for both the A2 and B2 emissions scenarios (Wilby and Dawson, 2004). The outcome of this downscaling was fed in to examine the impact of climate change on agriculture in Ireland driving crop models using monthly climatic data (low temporal resolution) with high spatial resolution (10 x 10 km grid over Ireland) for the baseline scenario. For the future scenarios the climate change data consisted largely of daily data (high temporal resolution) with low spatial resolution (i.e. for a limited number of sites). For each grid cell, a baseline climate (1961–1990), and 2055 and 2075 estimates of climate parameters were derived. From these values, a weather simulator was used to create 30 years' worth of daily data that could be used with the crop simulation models. For each grid cell, barley, maize, potato, soybean and grass production were simulated. The mean production for the 30-year simulation was then assessed with respect to baseline production. Using simulation models, we compared yield responses to N and water supply for baseline (1961–1990) and 2055 (2041– 2070). The models used were integrated into the Decision Support System for Agricultural Technology Transfer (DSSAT; http://www.icasa.net/dssat; Tsuji *et al*., 1994). We also simulated late a low-cost grass-based dairy production system with three main process models involving Animal nutrient demand, herbage production, and utilization combinedly called Dairy_sim which was parameterized by setting up the NDB system

Results and conclusions:

Mean annual temperatures in Ireland have risen by 0.7°C over the past century. Using a multi-model ensemble involving three different GCMs for downscaling to the Irish Synoptic Station Network, we conclude that mean temperatures in Ireland relative to the 1961–1990 averages are likely to rise by 1.4–1.8°C by the 2050s and by in excess of 2°C by the end of the century as shown in Table-1. Summer and autumn are projected to warm much faster than winter and spring, with a pronounced continental effect becoming apparent whereby the midlands and east warm more than coastal areas with temperature projections of this kind, a high degree of confidence exists.

Table-1 Mean temperature increases for each season and time period

Season	2020	2050	2080
December-February	0.7	1.4	2.1
March to May	0.8	1.4	2.0
June to August	0.7	1.5	2.4
September-November	1.0	1.8	2.7

Future precipitation changes in Ireland are subject to greater uncertainty with all modelling approaches as shown in Fig1. Nonetheless, these are suggested to be the most important aspect of future climate change for Ireland. Using an approach based on General Linear Modelling, winter rainfall in Ireland by the 2050s is projected to increase by approximately 10% while reductions in summer of 12–17% are projected by the same time. By the 2080s, winter rainfall will have increased by 11–17% and summer rainfall will have reduced by 14– 25%. Spatially, the largest percentage winter increases are expected to occur in the midlands. By the 2050s, summer reductions of 20–28% are projected for the southern and eastern coasts, increasing to 30–40% by the 2080s.

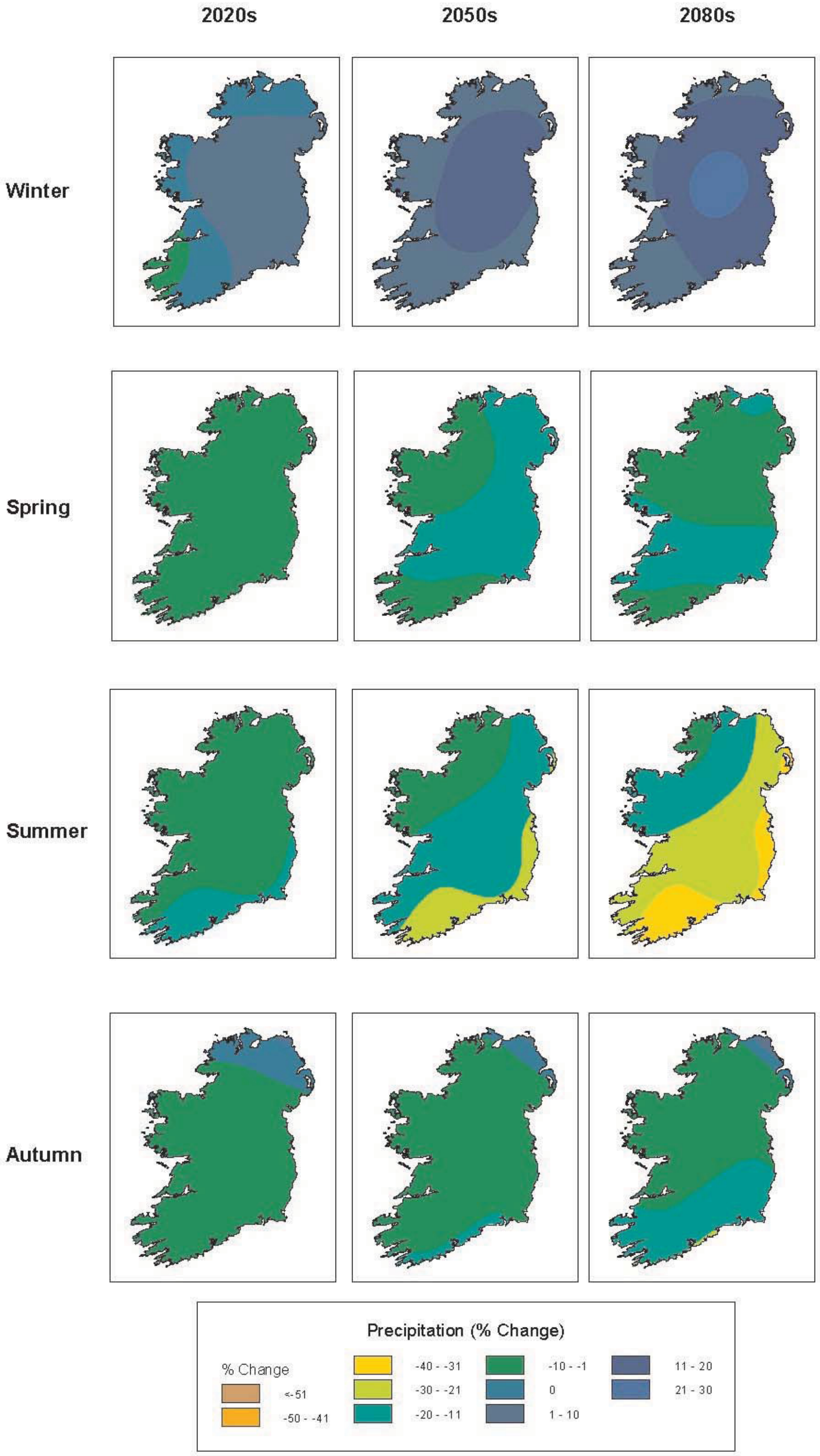

Fig.1 Ensemble means seasonal precipitation changes projected for the 2020s–2080s

Changes in the frequency of extreme events will accompany these climate changes. Lengthier heatwaves, a substantial reduction in the number of frost days, lengthier rainfall events in winter and more intense downpours in summer are projected. At the same time an increased summer drought propensity is indicated, especially for eastern and southern parts of Ireland.

With these projected climatic scenarios being fed into agriculture, the N response curves for spring barley under unirrigarted conditions indicate that where growing season rainfall is not too low, a reduction in recommended N rate may be possible without increasing the risk for yields, and elsewhere the N management guidelines will be unaffected by climate change. However, in these areas if small amounts of irrigation were used in the future then the amount of N needed could be significantly reduced. The reason why N application can be reduced with climate change and irrigation is related to elevated CO_2. There is more efficient assimilation of CO_2 to plant structures with elevated CO_2, which results in a lower relative leaf N content (Penuelas and Matamala, 1990). This response is simulated in the models as a growth rate change with elevated CO_2, and means that for a given amount of N uptake there will be a greater amount of carbon stored in the yield component of the plant. Site-specific evaluation of the simulated automatic irrigation of the potato crop indicated that even under baseline conditions the potato crop is not operating at best WUE. When compared with data presented by Miglietta *et al*.,(2000) the reduction in yield predicted for non-irrigated potato in Ireland is more marked than that predicted for elsewhere in Europe but the response to irrigation is broadly similar to that predicted for sites in northern Europe (as compared with southern Europe). It can be concluded that there will be no major changes
necessary in order to maintain spring barley production with similar spatial distribution as currently found. For the potato crop the simulations result in the conclusion that irrigation is going to be essential in most areas where potatoes are currently grown.

In a bigger picture, the main challenges for Irish agriculture will come from wetter winter and drier summer soils which has spatial contrasts. In east Ulster and east Leinster, water stress in grass, barley and potato and, to a lesser extent, maize will occur on a much-increased frequency. Summer soil moisture deficits will be problematical for dairying, losses from which may be partially compensated by reductions in fertilizer inputs. Late summer feed deficits may require supplementation or the introduction of a mid-season housing period. In much of Connaught and central Ulster, less stresses are apparent in summer and good yields of grass, barley, maize, potato and, later in the century, soybean can be expected. Scope for reduced fertilizer inputs will be greater in areas of poorly drained soils. In the extreme north-west, cool temperatures and relatively wet conditions will produce lower grass, maize and soybean yields, but good barley and potato yields. Dairying will not be heavily impacted. In south and south-west Munster, the combination of warmer and relatively moist conditions will suit most crops and enable dairying to continue much as at present. Potato yields will be limited and summer droughts will be more common, though not as severe as further east. Adaptation to climate change for Irish agriculture will centre either on maximizing outputs or minimizing inputs. Generally the potential for considerable reduction in nitrogen application rates will occur. For the key dairying sector, a range of response options exists for adapting to climate change that should mean the continuing viability and profitability of this sector.

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VALIDATING THE ADAPTATION OF PADDY RICE TO DIFFERENT SCENARIOS USING A CLIMATE CHANGE IMPACT MODEL IN NORTHWESTERN TURKEY

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Abstract

Rice (Oryza sativa L.) feeds nearly 50% of the global population. Estimated global growth rate of rice is 748240 ha/yr and the expected production by 2025 would reach 845099000 t with a growth rate of 9 790950 t/yr (Zhang et. al., 2004). With an average planting area of 70000-75000 ha and average yield of 500000-650000 t/year, the rice is grown on particular areas of Turkey, in which nearly 50% yield increase has been recorded during the last 10 years (Torun, M, 1995, www.ttae.gov.tr). Covering the northwestern Turkey, the Thrace Region represents about 45% of the total paddy rice planting area and 50% of total production of Turkey within only 3.1% of Turkey's total area. This means that the average production values obtained from the Thrace are much higher than those of the rest of Turkey as well as than those of the world. Most of the above mentioned production in the Thrace is acquired mainly from the Edirne city in the region. In addition to rice; wheat (Triticum aestivum L.) and sunflower (Helianthus annus L.) is widely grown in the region.
The importance of possible results of global warming increases seriously for semi-arid countries such as Turkey (Caldag and Saylan, 2005). Hence, having reliable and enough information on the possible yield reactions of crops to varying climate conditions is crucial for decisions makers as well as the farmers, especially when the recent and popular global warming phenomenon is in question. Like most of the crops, rice is very sensitive to variations in climatic factors by means of growth and yield. This is especially critical for the Thrace, in which the rice (paddy rice) agriculture is applied under rainfed conditions by applying basin irrigation.
According to many researchers, the Thrace is going to face with decreasing average precipitation that corresponds to higher average temperatures. Önol (2007) indicated that the average temperatures would increase between 3.5°C and 5°C for the summer, which includes almost the whole of the mean paddy rice growing season (Table 1).

Table 1. Phenological properties of the paddy rice (1975-2005).

Phenol.	Sowing	Emergen.	3. Leaf	5. Leaf	Germinat.	Anthesis	Flowering	Panicle	Harvest
Date	10 May	22 May	6 June	16 June	1 July	24 July	8 Aug.	24 Aug.	21 Sep.

In this study, an explanatory crop growth simulation model (CERES-Rice) in the DSSAT package was used to take a first step on the estimation of the adaptation abilities of paddy rice cultivar to varying climate conditions (Tsuji, 1994). To achieve this, the model was supplied with long term meteorological data together with the desired soil and plant parameters. No water stress was assumed during the simulations because traditional basin irrigation is applied on the field. After the calculations of the average values of soil-plant and atmospheric parameters for between 1975 and 2005, simulations have been applied to test the model sensitivity (Table 2).

Table 2. Sensitivity of CERES-Rice to paddy rice yield in Edirne.

Absolute Error kg/ha)	Relative Error (%)	Yield (Observed) (kg/ha)	Yield (Simulated) (kg/ha)
385	4.53	8500	8115

Table 2 indicated that the mean rice yield could be simulated quite satisfactorily by the model, with a relative error of 4.53%. After achieving this, a series of simulations have been applied to get reliable answers to some simple "what…if" questions (Table 3). The results showed that the paddy rice growth occurred under optimum temperature factors in Edirne. That's why an increase of only 1°C (T+1) in

daily average temperatures would cause a decrease of more than 7% in grain yield. Yield decrease reached up to 23.5% for the T+5 scenario. 30% increase in the global solar radiation (R_g+%30) indicated a yield increase of 21.1%. An extreme multiplicative increase in the average CO_2 concentration (CO_2x3) resulted in a corresponding grain yield increase as 48% (Table 3).

Table 3. Grain yield variations of paddy rice for possible climate change applications.

			Sensitivity Analysis																						
		T	T+1	T+2	T+3	T+4	T+5	P	P-%10	P-%20	P-%30	P-%40	Rg	Rg+%10	Rg+%20	Rg+%30	CO2	CO2x1.5	CO2x2	CO2x3	CO2x4
		0.0	-7.4	-13.9	-17.6	-21.4	-23.1	0.0	0.0	0.0	0.0	0.0	0.0	7.3	14.3	21.1	0.0	14.2	28.2	48.0	48.3
T	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.3	14.3	21.1	0.0	14.2	28.2	48.0	48.3
T+1	-7.4	0.0	0.0	0.0	0.0	0.0	0.0	-7.4	-7.4	-7.4	-7.4	-7.4	-7.4	2.0	8.6	15.0	-7.4	8.5	21.7	40.5	40.8
T+2	-13.9	0.0	0.0	0.0	0.0	0.0	0.0	-13.9	-13.9	-13.9	-13.9	-13.9	-13.9	-4.3	2.1	8.2	-13.9	2.0	14.6	32.2	32.5
T+3	-17.6	0.0	0.0	0.0	0.0	0.0	0.0	-17.6	-17.6	-17.6	-17.6	-17.6	-17.6	-9.1	-2.7	3.5	-17.6	-2.8	9.9	27.6	27.8
T+4	-21.4	0.0	0.0	0.0	0.0	0.0	0.0	-21.4	-21.4	-21.4	-21.4	-21.4	-21.4	-14.7	-6.2	-0.1	-21.4	-0.1	6.3	23.8	24.1
T+5	-23.1	0.0	0.0	0.0	0.0	0.0	0.0	**-23.1**	-23.1	-23.1	-23.1	-23.1	-23.1	-16.2	-8.1	-1.9	-23.1	-8.1	4.6	22.2	22.5
P	0.0	0.0	-7.4	-13.9	-17.6	-21.4	-23.1	0.0	0.0	0.0	0.0	0.0	0.0	7.3	14.3	21.1	0.0	14.2	28.2	48.0	48.3
P-%10	0.0	0.0	-7.4	-13.9	-17.6	-21.4	-23.1	0.0	0.0	0.0	0.0	0.0	0.0	7.3	14.3	21.1	0.0	14.2	28.2	48.0	48.3
P-%20	0.0	0.0	-7.4	-13.9	-17.6	-21.4	-23.1	0.0	0.0	0.0	0.0	0.0	0.0	7.3	14.3	21.1	0.0	14.2	28.2	48.0	48.3
P-%30	0.0	0.0	-7.4	-13.9	-17.6	-21.4	-23.1	0.0	0.0	0.0	0.0	0.0	0.0	7.3	14.3	21.1	0.0	14.2	28.2	48.0	48.3
P-%40	0.0	0.0	-7.4	-13.9	-17.6	-21.4	-23.1	0.0	0.0	0.0	0.0	0.0	0.0	7.3	14.3	21.1	0.0	14.2	28.2	48.0	48.3
Rg	0.0	0.0	-7.4	-13.9	-17.6	-21.4	-23.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.2	28.2	48.0	48.3
Rg+%10	7.3	7.3	2.0	-4.3	-9.1	-14.7	-16.2	7.3	7.3	7.3	7.3	7.3	0.0	0.0	0.0	0.0	7.3	22.8	37.0	58.0	58.3
Rg+%20	14.3	14.3	8.6	2.1	-2.7	-6.2	-8.1	14.3	14.3	14.3	14.3	14.3	0.0	0.0	0.0	0.0	14.3	30.0	45.5	67.7	68.0
Rg+%30	21.1	21.1	15.0	8.2	3.5	-0.1	-1.9	21.1	21.1	21.1	21.1	21.1	0.0	0.0	0.0	0.0	21.1	37.5	53.8	77.0	77.4
CO2	0.0	0.0	-7.4	-13.9	-17.6	-21.4	-23.1	0.0	0.0	0.0	0.0	0.0	0.0	7.3	14.3	21.1	0.0	0.0	0.0	0.0	0.0
CO2x1.5	14.2	14.2	8.5	2.0	-2.8	-0.1	-8.1	14.2	14.2	14.2	14.2	14.2	14.2	22.8	30.0	37.5	0.0	0.0	0.0	0.0	0.0
CO2x2	28.2	28.2	21.7	14.6	9.9	6.3	4.6	28.2	28.2	28.2	28.2	28.2	28.2	37.0	45.5	53.8	0.0	0.0	0.0	0.0	0.0
CO2x3	48.0	48.0	40.5	32.2	27.6	23.8	22.2	48.0	48.0	48.0	48.0	48.0	48.0	58.0	67.7	77.0	0.0	0.0	0.0	0.0	0.0
CO2x4	48.3	48.3	40.8	32.5	27.8	24.1	22.5	48.3	48.3	48.3	48.3	48.3	48.3	58.3	68.0	**77.4**	0.0	0.0	0.0	0.0	0.0

To make a more explanatory picture of the grain yield variation aspect, crosswise simulations have been also considered, in which more than one meteorological parameter changed (Table 3). Here, the T+5 application gave the worst result (23.1% yield decrease), where the opposite scenario appeared as the combination of R_g+30% with CO_2x4 (77.4% yield increase). It has been determined that the yield increases or decreases were generally associated with increasing scenario extremities and increasing number of meteorological parameters. This situation can be seen in the results of simulations including multiple (3 and 4) meteorological parameter variations in Figure 1 and Figure 2, respectively. It can easily be understood that especially CO_2 would have a positive feedback effect on grain yield until the CO_2x4 application (Fig. 2).

It is to be taken into account that no water stress was applied on the crop during the simulations, but there is no guarantee of having enough water to supply the crop in the future. In addition, changing soil conditions as well as the introduction of new cultivars can also avoid the exact evaluation of the results given here. It is hoped that developments in model studies together with the steps in fulfilling the lack of the desired databases can enable the model users to obtain more representative results.

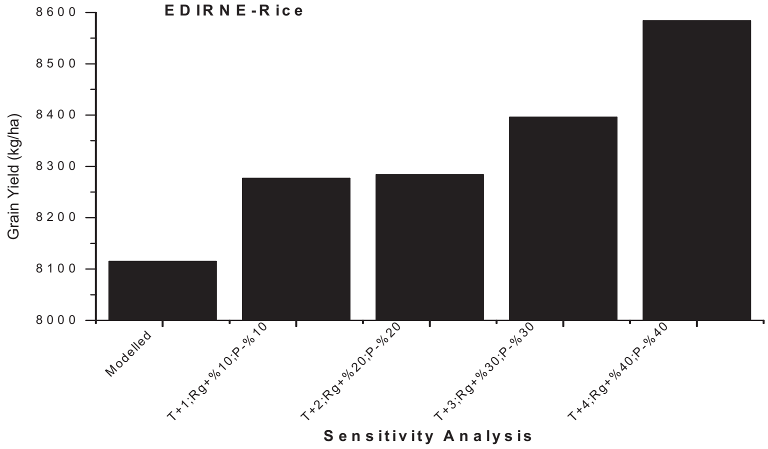

Fig. 1. Grain yield variations of paddy rice for 3 changing parameters.

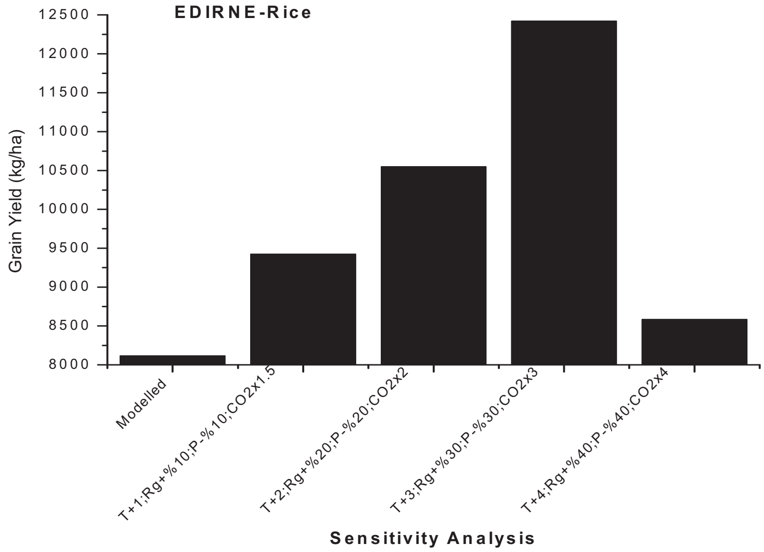

Fig. 2. Grain yield variations of paddy rice for 4 changing parameters.

Keywords: Rice, sensitivity analyses, climate change impact.

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TRENDS OF SELECTED CHARACTERISTICS OF PRECIPITATION IN THE NORTHERN CARPATHIANS IN THE LIGHT OF WATER SUPPLY FOR AGRICULTURE

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Abstract

Global warming resulting from antropogenic greenhouse gas emissions is projected to lead to substantial temperature increase over the most of continental Europe, including Slovakia. Changes in atmospheric CO_2 concentrations, temperature and rainfall will affect productivity of crops differently in different regions. Slovakia lies in Central Europe (the Northern Carpathians region) with a total area of 49,036 km^2. Agricultural soil covers 50%, forest soil 41%, water area 2%, and 3% is covered by built-up areas. It is a mountainous country, 60% of its surface is over 300 m. In the paper we deal with analysis of long-term changes in precipitation (including snow cover) regime as well as changes in precipitation extreme phenomena occurrence in the Northern Carpathians region within the most of 20^{th} century and the first decade of 21^{st} century. The Northern Carpathians represent the territory of the northern part of Hungarian lowland and the space of the foothills and the massif of Carpathian ridge. Both air temperature and precipitation are quite strongly correlated with elevation.

Air temperature increase by 1.41°C and annual precipitation decrease by 3.38% was registered in the 1901-2008 period. Significant increase in air temperature and changes in atmosphere circulation modified precipitation patterns nearly in whole Slovakia, mainly since 1980. Fig. 1a demonstrates deviations in the annual air temperature from 0,0 ro 1,2 °C between the periods 1988-2007 and 1961-1990 (more in the south), and Fig. 1b the same for April-September temperatures, from 0,0 to 1,6 °C (also more in the south). In spite of nearby periods the deviations in the mean temperature are relatively high and represent a very rushed change in climatic conditions. More detailed information are in Faško et al. (2008).
The precipitation trends show significant decrease of mean totals with the lowest values from the 80^{th} to early 90^{th} of the 20^{th} century. These trends were quite strongly expressed in the northern part of Hungarian lowland while the mountainous area showed rather steady trends. In can be seen (Fig. 1c) while annual precipitation totals decreased in southern Slovakia in 1988-2007 very significantly (up to 20 %), in northern Slovakia an increase in annual precipitation up to 10 % has been registered. On the other hand the seasonal (April-September; Fig. 1d) precipitation totals decreased in northwestern Slovakia (up to 20 %) and increased in many sites in southern and northeastern Slovakia (up to 20 %). The balance of annual regional precipitation totals showed their increase from the fifties and later slow decrease to the same level after middle of nineties. (Fig. 2a). It is interesting that the new increase of precipitation totals was registered mainly in winter, partly also in spring and autumn. Decrease of totals in summer is not regular and it is more remarkable in the southern Slovakia. A decrease of summer precipitation totals is balanced by its slight increase in winter and other two transition seasons. Generally, the annual totals are sufficient to support the agricultural production regarding the rain fed crops by water. There is also a tendency of change in the share of solid, mixed and liquid precipitation totals on the majority of the country.

On the other hand more important is a change of the precipitation regime – longer and more severe drought spells and short periods (several days) with heavy precipitation in the growing period. The new observed feature is the distribution of the precipitation during the years as well as the cumulation of heavy rains and precipitation deficit periods through the different seasons in recent two decades. Fig. 3a, b refers to long-term changes in 2- and 5-day precipitation totals in summer periods at selected meteorological stations. Also the distribution of heavy rains as well as the distribution of maximal daily precipitation has changed in many sites in Slovakia. These characteristics should be influenced by the changes in yearly totals which have not appeared. The most significant increase has been registered in eastern and southern regions of Slovakia.

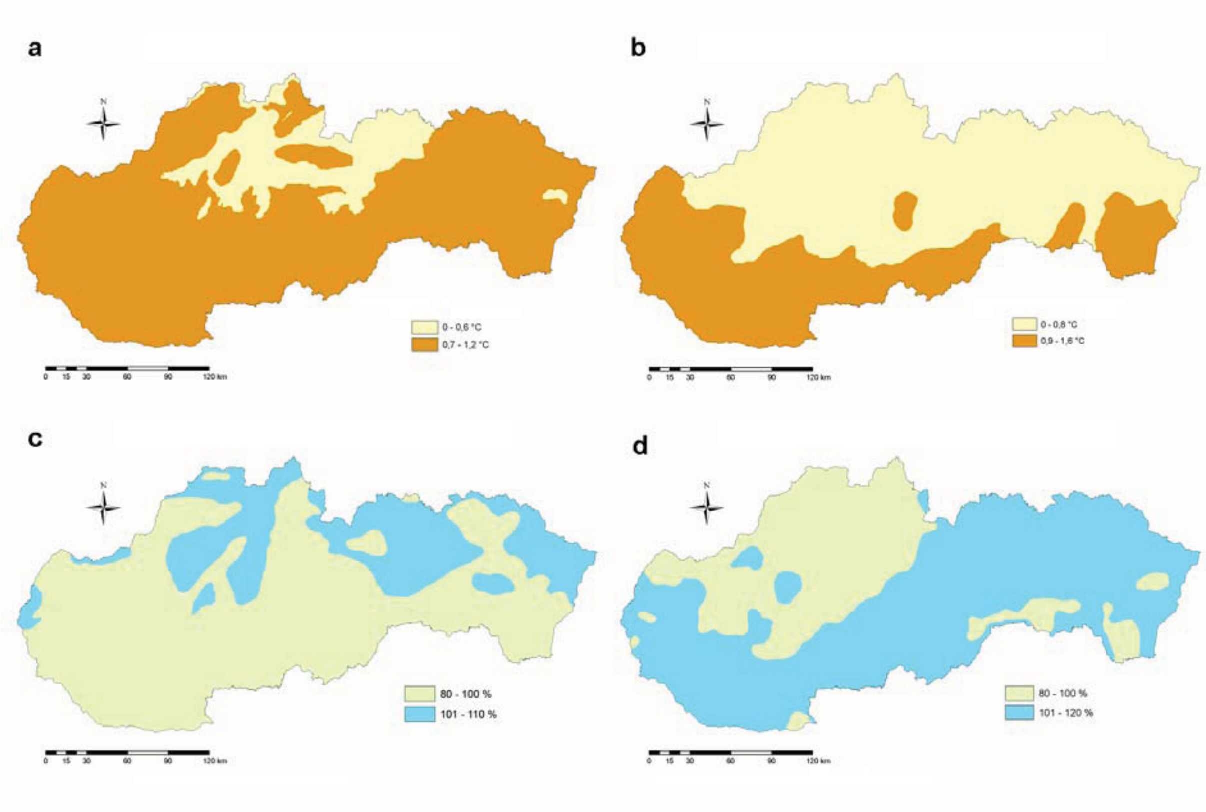

Fig.1. Deviations of annual (**a**) and seasonal (April-September; **b**) air temperature means in Slovakia between periods 1988-2007 and 1961-1990; deviations of annual (**c**) and seasonal (April-September; **d**) precipitations means in Slovakia between periods 1988-2007 and 1901-2000 expressed as % of 1988-2007 totals from 1901-2000 ones.

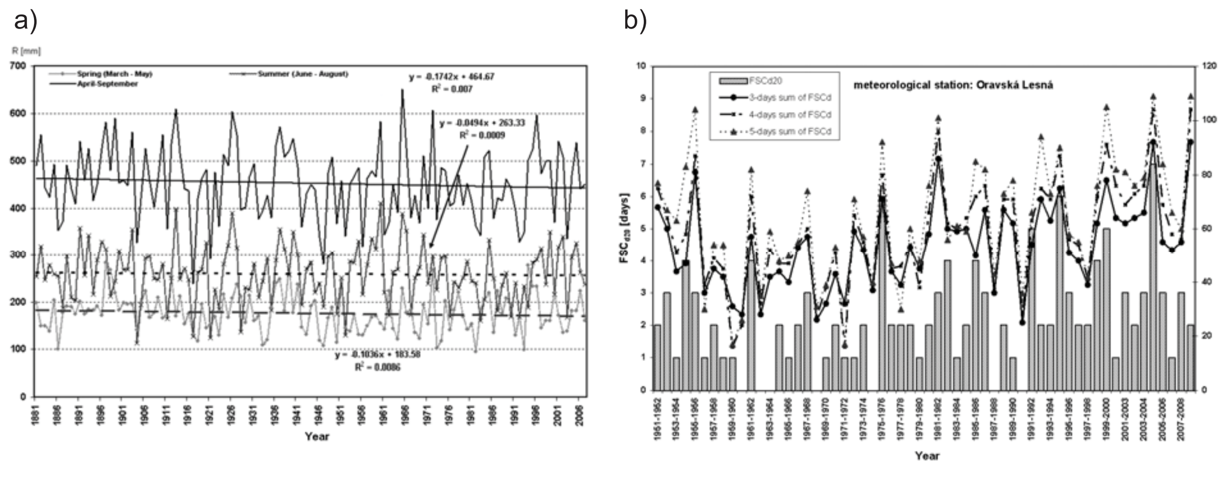

Fig. 2. Long-term changes of areal precipitation totals in spring, summer and April-September period (calculated using 203 rain gauge stations in Slovakia) within 1881-2007 period (**a**); number of days with fresh snow cover depth ≥ 20 cm (FSC_{d20}) and n-days sum of fresh snow cover depth (FSC_d) at mateorological station Oravská Lesná (780 m a.s.l.) in the 1951/1952-2008/2009 winter (**b**).

a) b)

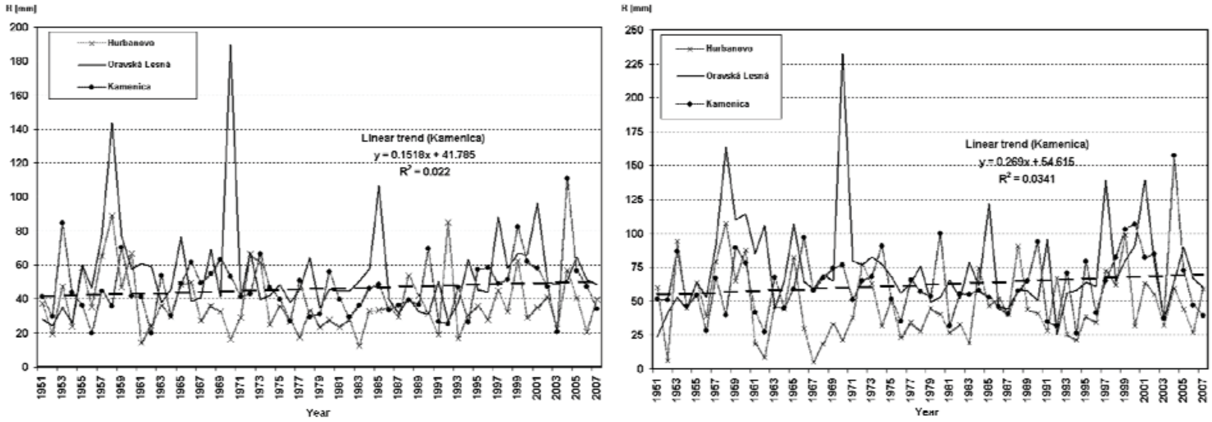

Fig. 3. 2-day (**a**) and 5-day (**b**) precipitation totals in summer period at selected meteorological stations (Hurbanovo, Oravská Lesná and Kamenica) within 1951-2007 period.

b) b)

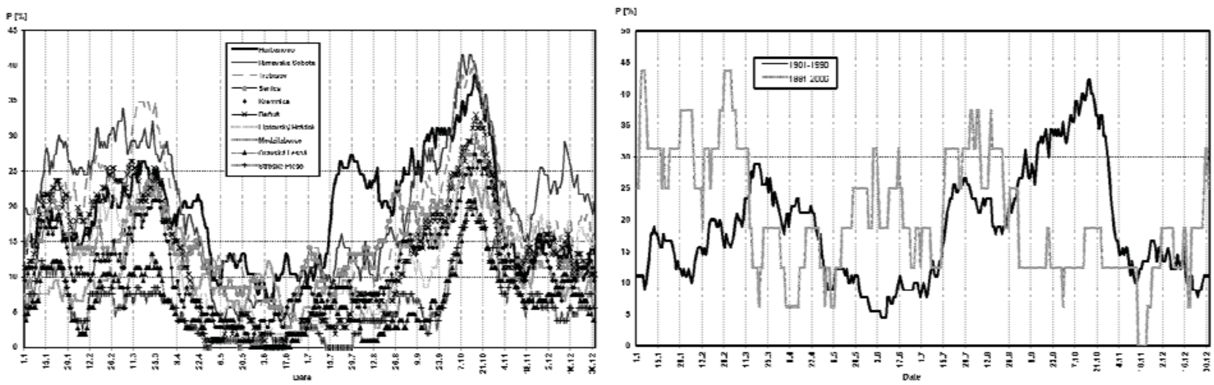

Fig. 4. Annual regime of probability of precipitation deficit period occurrence at selected meteorological stations (1901-2006) (**a**), annual regime of the probability of precipitation deficit period occurrence in the 1901-1990 and 1991-2006 periods in Hurbanovo (**b**).

The precipitation deficit periods are cumulated mainly in lowlands into the summer (Fig. 4a) months and there is a notable decrease of these periods in autumn (Fig. 4b).
The increase of precipitation deficit periods in summer brings in combination with heavy rains makes the use of such water useless for rainfed crops which represent the main crops of the region. This feature is stressed by the fact that the major part of the region of The Northern Carpathians represents a watershed and the precipitation is basically the only source of water for the most part of this territory.

Further strong characteristic of the water supply is the portion of snowfall on the precipitation totals. In the mountainous areas snowfall represents about 40 per cent of the annual precipitation totals. A decreasing trend of both daily fresh snow amounts and cumulative snow cover depth was observed in the lowlands and the foothills. The opposite trend has appeared in the mountains. The maximal annual depth of the snow cover have not been reached by step by step accumulation of daily portions of snowfall but they were rather connected with the extreme events bringing heavy snows. The results of fresh snow depth analysis have shown an expected increase at considered meteorological stations in Slovakia in the winter (e.g. Oravská Lesná, Fig. 2b). The fresh snow cover depth maxima raking and its temporal occurrence support an exceptional status of the values recorded in the last decade of the 20th century and in the first decade of the 21st century, as well. In the case of n-days sum maxima (particularly 3-, 4- and 5-days sum) of fresh snow cover depth as well as the number of days with higher values of fresh snow cover depth the statistical analysis have preliminarily detected a significant positive trend for the most of territory of Slovakia in the winter (Figure 1).

All these features indicate a tendency to the higher frequency of extreme events regarding the precipitation which makes the conversion of precipitation to the usable water for agricultural purposes more difficult.

Keywords: precipitation regime changes, precipitation deficit periods, snow cover changes, precipitation ratio changes, agroclimatological conditions, vegetation season of main crops, extreme precipitation analysis.

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CLIMATE CHANGE IMPACT ON RELATIONS AMONG CROP EVAPOTRANSPIRATION, WATER USE EFFICIENCY AND CROP YIELDS OF WINTER WHEAT AND MAIZE ON DANUBIAN LOWLAND

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Abstract

Climate change impacts on field crop yields of winter wheat and maize in conditions of Danubian lowland were evaluated by agroecological model DAISY (Abrahamsen, Hansen, 2000, Hansen, 2000). The model was calibrated and validated for the Slovak conditions (Takáč, Šiška, 2008). The selection of the crops included in the crop rotations (winter wheat, spring barley, sugar beet, maize, potato, winter rape, alfalfa, pea) was based on the areal coverage of crops dominating in the region of Danubian lowland. Top dry biomass (separately grain and leaves and stems) were related to evapotranspiration of cereals and consequently water use efficiencies were calculated. Evapotranspiration was calculated according to the Makkink method. CO_2 effect on photosynthesis rate was evaluated in simulations on 2 levels: with and without the effect of gradual increase of CO_2 concentration on photosynthesis on formation of yields (IPCC, 2007).
Hurbanovo (47°52’ N, 18°12‘ E) was considered as representative meteorological station. Meteorological data up to 2100 were generated according to GCM CGCM3.1 and emission scenarios SRES A2 and SRES B1 (Lapin et al., 2006) for this station (tab. 1).

Table 1 Annual and seasonal mean temperature T [°C] and precipitation totals [mm] in various slice periods according to the scenarios SRES A2 and SRES B1 in Hurbanovo

SRES	Period	1961-1990		2011-2040		2041-2070		2071-2100	
		T [°C]	R [mm]	T [°C]	R [mm]	T [°C]	R [mm]	T [°C]	R [mm]
A2	Year	10.0	523	11.6	603	12.6	665	14.2	712
	Apr-Sep	16.7	303	18.2	349	19.1	372	20.7	377
B1	Year	10.0	523	11.6	621	12.2	642	12.4	656
	Apr-Sep	16.7	303	18.0	380	18.5	364	18.9	369

Medium textured chernozem soil profile with 3.5 % humus content in topsoil was considered. It is expected rise of mean annual temperature about 2.4 °C and 4.2 °C and increase of mean annual precipitation total about 25 % and 36 % according to the scenarios SRES B1 and SRES A2, respectively in the period 2071-2100 compared to the period 1961-1990.
Various 10-year crop rotations as well as various management practices including irrigation were taken into account. The water regime was simulated in 2 variants: rainfed and water limited irrigation. The limit was setup because lack of water sources for irrigation is supposed in future. The beginning and end of irrigation season were defined by growing stages. The aim was not to settle the consumptive water requirements by the crops during the entire vegetation period, but in given important, economic yield forming stages only. Farming practice was taken into account to establish the fertilisation schedule.
Reference evapotranspiration ET_0 as well as crop potential evapotranspiration ET_c equal to crop water requirements will increase about 15 % (SRES B1) and 19 % (SRES A2) in the time slice 2071-2100 compared to the reference period of years 1961-1990. Actual evapotranspiration will rise about 4 % and 3 % according to the scenarios SRES B1 and A2, respectively.
Decrease of ET_c from the sowing to the harvest is calculated due to shortening of the growing period.
Rise of the temperature will accelerate the crop development (fig. 1). The harvest date of selected crops was simulated to be earlier about from 6 (winter wheat) to 17 days (maize) and about from 11 days (spring barley) to 27 days (winter wheat) according to the scenarios SRES B1 and SRES A2, respectively in the period 2071-2100 compared to the period 1961-1990.

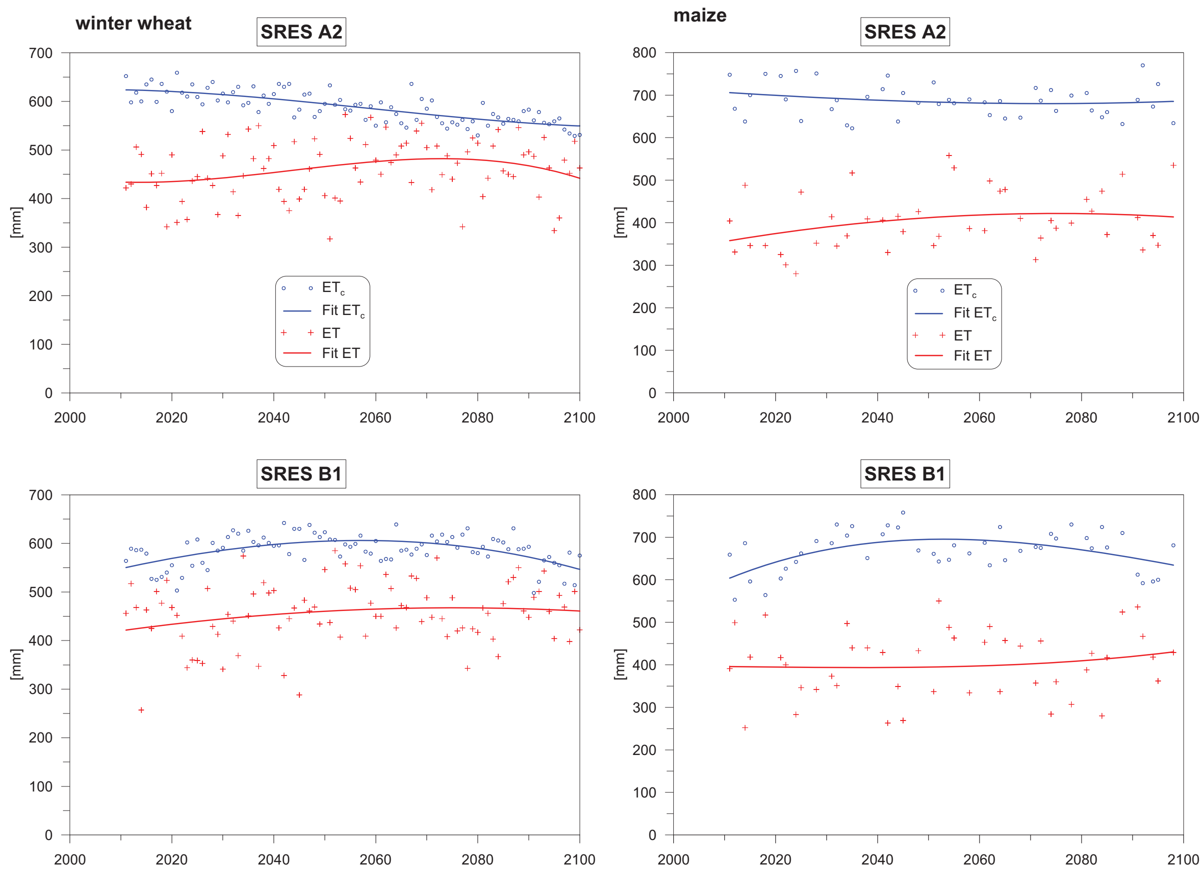

Fig. 1 Course of winter wheat and maize crop potential evapotranspiration ET_c and actual evapotranspiration ET [mm] from the sowing to the harvest according to SRES A2 and SRES B1.

Slightly increase of winter wheat yields and continual decrease of maize yields are significantly influenced by CO_2 concentration in the atmosphere. Wheat as C3 plant reacts positively on elevated CO_2 concentration in the atmosphere. This effect is more important then effect of extreme climatic conditions during ripening. At the end of the 21st century this trend will be stopped according to SRES A2 or small decrease of top dry matter as well as grain yield can be supposed. Maize response on CO_2 concentration is not so high compared to wheat and negative climatic conditions during its growing season will reduce the yield in future. Climatic conditions increase variability of grain yields winter both wheat and maize.

CO_2 effect on grain yields was calculated as a difference between simulated yields with and without CO_2 effect on photosynthesis. Based on the calculations the CO_2 effect on grain yields of cereals in the period 2071-2100 was up to 15 % and 20 % according to the scenarios B1 and SRES A2, respectively. Calculated CO_2 effect on grain yields of maize was only 4 %.

Increase of water use efficiency of cereals was found out. On the other hand, decreasing water use efficiency of maize was obtained.

Water use efficiency was influenced by complex effect both of elevated CO_2 concentration and available soil water content. While the winter wheat top dry matter yield is strongly affected by elevated CO_2 concentration, maize as C4 plant reacts on this effect less significantly. Except for it winter wheat can utilize higher amount of soil water from winter period. Result is that WUE of winter wheat increase according to both SRES while the decreasing tendency of WUE is observed on maize (fig. 3). More extreme differences of WUE between time slice 2071-2100 compared to reference period of years were calculated according to SRES A2 (winter wheat +15,9 %, maize -14,6 %) Those differences according to SRES B1 are relatively small (winter wheat +2,2 %, maize -5,6 %). This fact is related with the nature of climate change scenarios when high air temperatures reduce yields both of winter wheat and maize.

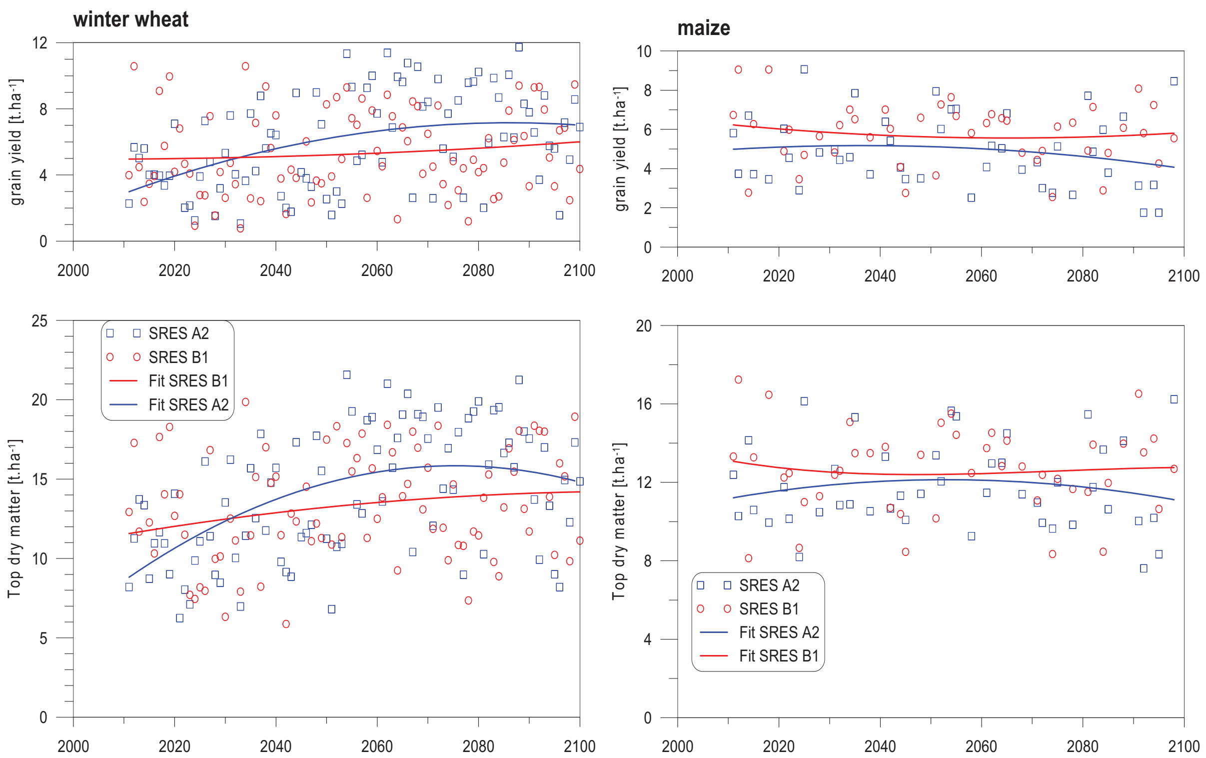

Fig. 2 Course of winter wheat and maize grain (top) and top dry matter yields (bottom) [t.ha^{-1}] according to SRES A2 and SRES B1.

Water use efficiency was influenced by complex effect both of elevated CO_2 concentration and available soil water content. While the winter wheat top dry matter yield is strongly affected by elevated CO_2 concentration, maize as C4 plant reacts on this effect less significantly. Except for it winter wheat can utilize higher amount of soil water from winter period. Result is that WUE of winter wheat increase according to both SRES while the decreasing tendency of WUE is observed on maize (fig. 3). More extreme differences of WUE between time slice 2071-2100 compared to reference period of years were calculated according to SRES A2 (winter wheat +15,9 %, maize -14,6 %) Those differences according to SRES B1 are relatively small (winter wheat +2,2 %, maize -5,6 %). This fact is related with the nature of climate change scenarios when high air temperatures reduce yields both of winter wheat and maize.

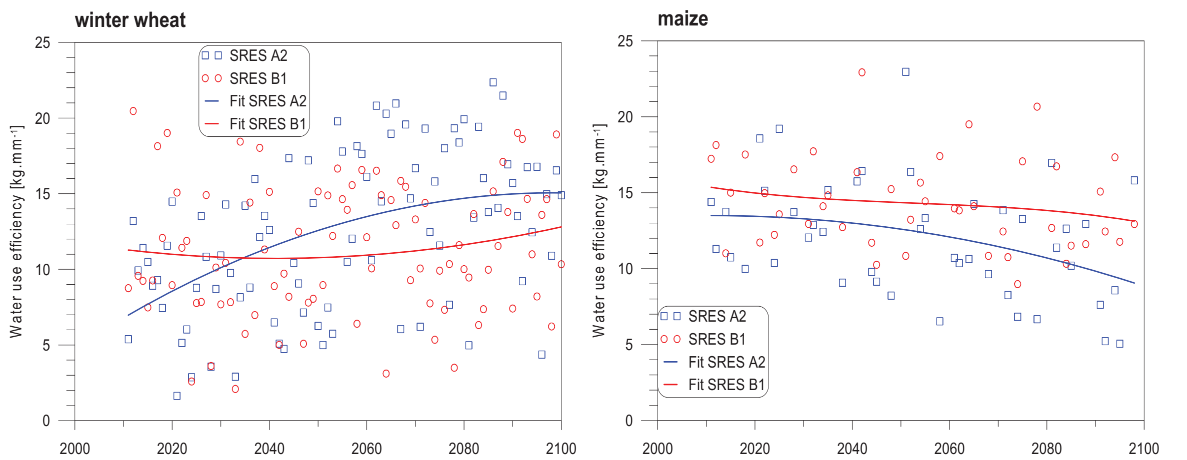

Fig. 3 Course of winter wheat and maize water use efficiency [kg.mm^{-1}] according to the SRES A2 and SRES B1.

Irrigation was confirmed as an effective adaptive measure reducing yield loss and significant factor stabilizing top dry matter and grain yields of winter wheat and maize (fig. 4). Harvest index of irrigated crops was higher than the harvest index of rainfed crops.

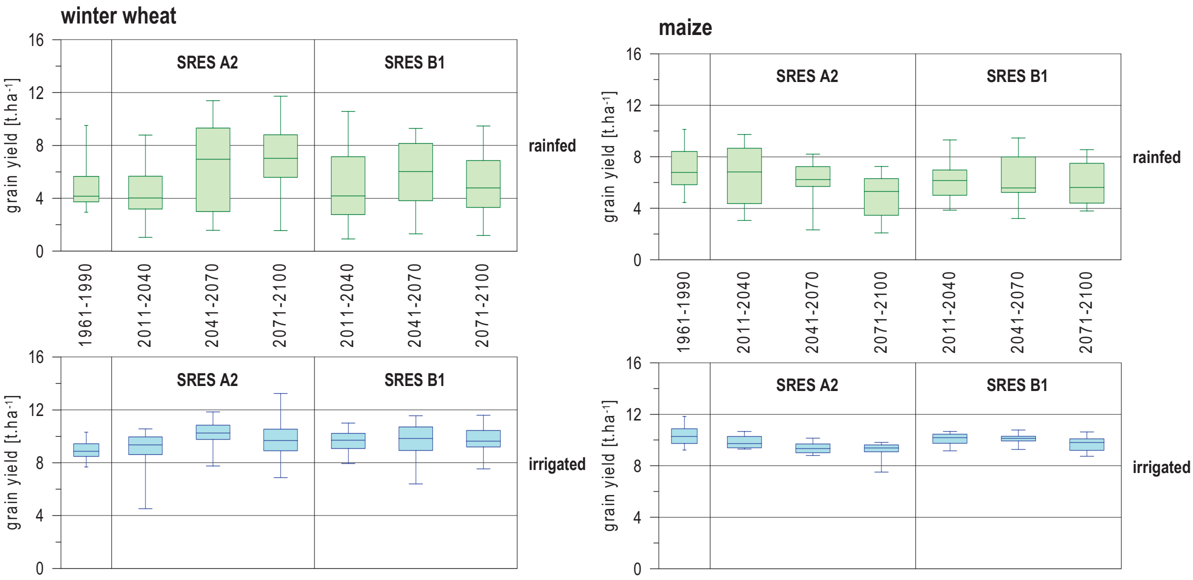

Fig. 4 Rainfed and irrigated grain yields of winter wheat and maize [t.ha^{-1}] according to the SRES A2 and SRES B1.

Key words: climate change, evapotranspiration, water use efficiency, yield modeling

Acknowledgement

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MODEL EVALUATION OF NITROUS OXIDE EMISSIONS FROM AGRICULTURAL LAND OF SLOVAK REPUBLIC AS INFLUENCED BY CLIMATE CHANGE CONDITIONS

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Abstract

Model DNDC was applied for evaluation of nitrous oxide (N_2O) emissions from arable soils of the Slovak Republic. During the past decade, DNDC has been tested by many researchers worldwide with promising results (Brown, 1995; Smith et al., 1997; Jagadeesh Babu et al., 2006; Smith et al., 2008).
N_2O emissions were estimated on regional scale for traditional agricultural regions of Slovak Republic that are represented with typical crop rotations, climatic and soil conditions. Maize agricultural region was divided into two climatic subregions, Sugar beet into 3 subregions. Potato and Mountainous agricultural regions were represented with one climatic station each. Each subregion represents one climatic station (Fig. 1). Required input data for DNDC model (climate, soil properties, farming management) were obtained or recalculated according to this classification.

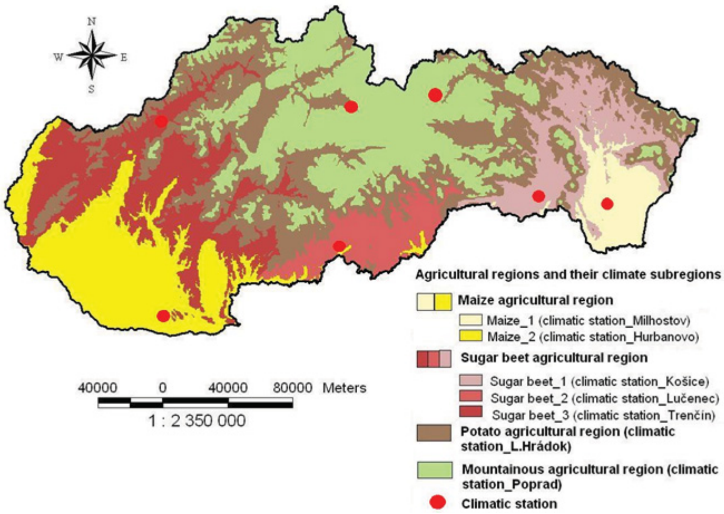

Fig 1. Agricultural regions of Slovakia and classification of subregions for this study

Soil data were obtained from GIS database of Soil Science and Conservation Research Institute (SSCRI). Soil texture classes were divided into 5 categories (light soils, medium heavy soils-lighter, medium heavy soils, heavy soils, very heavy soils). Average soil input values of bulk density, pH, Cox were calculated for each soil texture class for each agricultural region or subregion according to classification given in figure 1.
Representative agricultural practices and specific crop rotations for each agricultural region were applied according to information from Central Agricultural Supervisory and Testing Institute (CASTI). Crops with the biggest acreage according to the statistical yearbooks were included into these crop rotations (Tab. 1).

Tab 1. Specific crop rotations in agricultural regions and evaluated time periods according to number of crops in rotation

Agricultural regions (agroregions)	Crop rotation [*]	Conditions of present climate (years)	Conditions of climate change (years)
Maize	A, WW, S, WW, RS, C, C	2000-2007	2043-2050
Sugar beet	A, WW, RS, C, WW, S, C, C	1998-2007	2041-2050
Potato	A, WW, RS, WW, C, B	2002-2007	2045-2050
Mountainous	A, A, WW, RS, WW, C, R	2000-2007	2043-2050

[*] Crops in crop rotation: A-alfalfa, WW-winter wheat, S-sunflower, RS-rapeseed, C-corn, B-barley, R-rye

Nitrogen fertilization level for crops included into rotations was recalculated according to statistical yearbook (conventional system – CS). The sensitivity of the model was tested by increase and decrease of nitrogen application rate by 30 %. There was specified an expert guess of nitrogen inputs for conditions of climate change according to individual needs of crops recommended in terms of good agricultural practices (Karabínová et al., 2001; Fecenko and Ložek, 2000; Molnárová and Žembery, 1999). This level of nitrogen fertilization rate was higher by 5% on average for the whole Slovakia compared to nitrogen inputs in present conditions.
Daily climate data of maximum and minimum air temperature as well as precipitation were offered by Slovak Hydrometeorological Institute (SHMI). Data for conditions of climate change up to 2050 were generated from climatic model ALADIN with emission scenarios SRES A1B (Skalák et al., 2008). Annual mean air temperatures as well as annual precipitation have an increasing trend in all selected climatic stations during evaluated periods. Annual mean air temperature [ΔT] is going to increase by range of 0,2-up to 0,9 °C in conditions of climate change compared to the conditions of present climate. Also annual precipitations [ΔR] are going to increase by 39 –up to 156 mm (fig. 2).

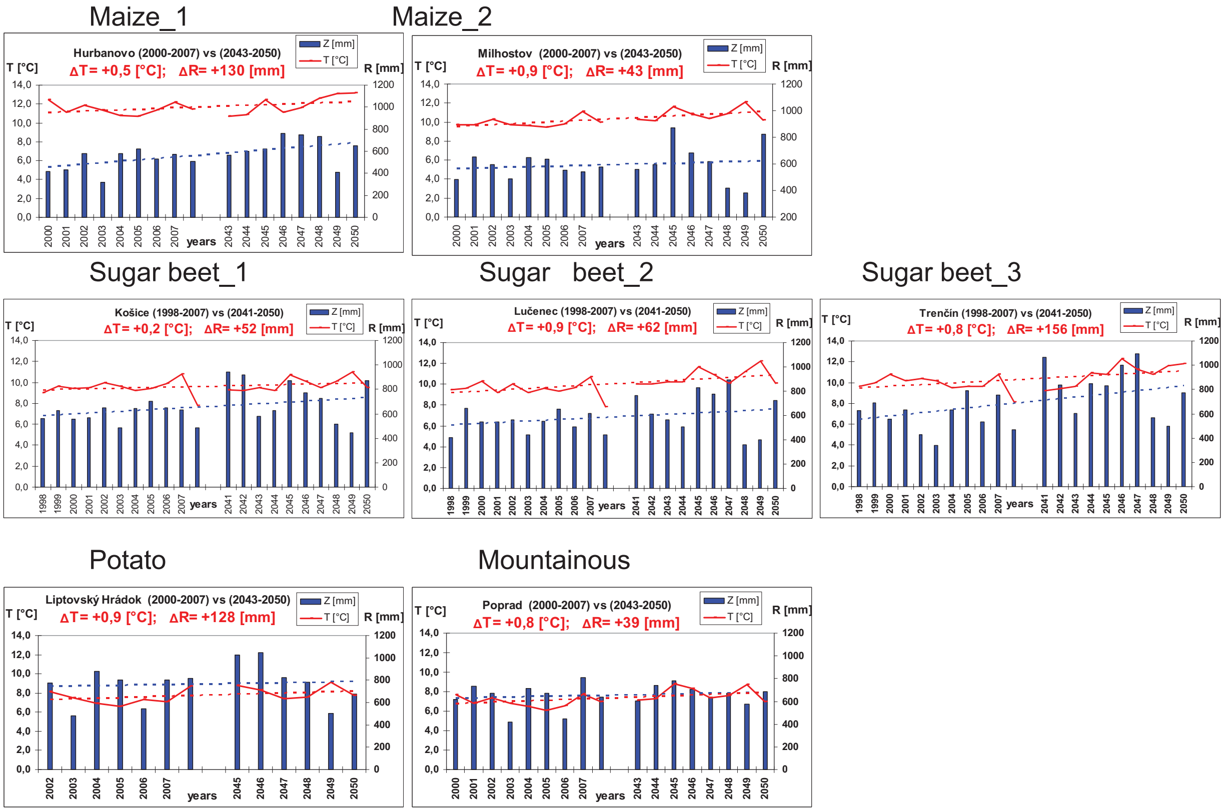

Fig. 2. Linear trends of annual mean air temperatures as well as annual precipitation in selected climatic stations during evaluated periods.

N_2O emissions were simulated for a different climatic condition, soil texture classes and crops included in rotations of subregions for evaluated periods as given in tab. 1. N_2O emissions rate for the whole agroregion were calculated as an average from each soil texture class for each year of evaluated time periods for the subregion or agroregion (Maize_1, Maize_2, Sugar beet_1, Sugar beet_2, Sugar beet_3, Potato agroregion and Mountainous agroregion) and also for the whole time period of years. N_2O emissions for each agricultural region for condition of present climate and for condition of climate change were compared.
According to DNDC model the highest N_2O emissions rate was found in Mountainous regions and the lowest was in Sugar beet agricultural region (fig. 3).

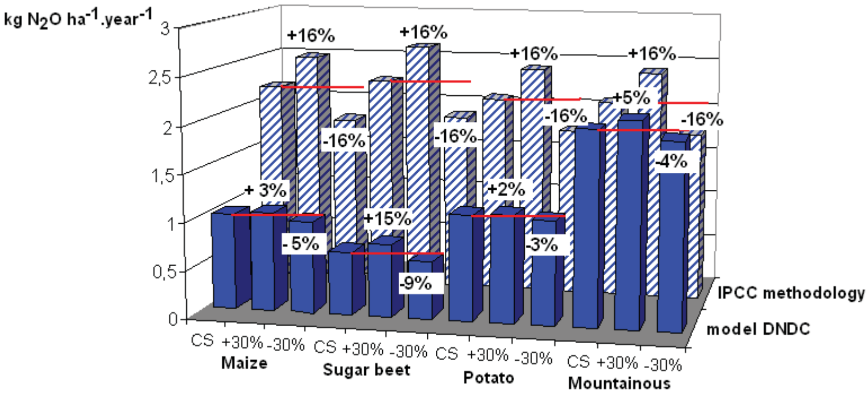

Fig. 3. Average rate of N_2O emissions from arable soils of agricultural regions in conditions of present climate.

There was found very close correlation (R^2 = 0,9948) between average N_2O emissions and average soil organic carbon content in agricultural regions. The highest soil organic carbon (Cox) content is in Mountainous agricultural region and the lowest in Sugar beet agricultural region. So N_2O emission is higher with higher soil organic carbon content and lower with lower soil organic carbon according to DNDC model (fig. 4).

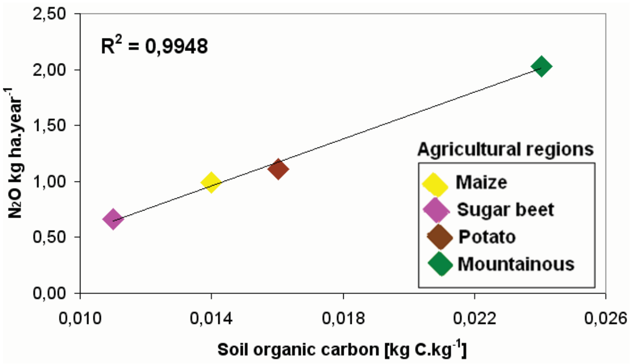

Fig. 4. Correlation between the average soil organic carbon content (Cox) and average N_2O emissions rate in agricultural regions of Slovakia

DNDC emissions and emissions according to IPCC methodology were compared in condition of present climate. A comparison of N_2O emissions according to IPCC methodology and according to DNDC model showed, that the emissions rate doesn't depend only on nitrogen fertilization inputs to the agroecosystem. According to DNDC model increase in nitrogen fertilization rate by 30 % caused increase of N_2O emissions ranging from 2 – 15 %. The decrease in nitrogen fertilization rate by 30 % caused decrease of N_2O emissions ranging from 3 – 9 %.
According to IPCC methodology the highest N_2O emissions were in Sugar beet agricultural region and the lowest in Mountainous region, which is on the contrary to DNDC model results. This is because IPCC methodology estimates N_2O emissions on the basis of amount of N-fertilizers applied to the soils. The highest average amount was applied in Sugar beet region and the lowest in Mountainous and Potato agroregion (fig. 6). Increase or decrease in nitrogen fertilization rate by 30 % caused increase or decrease of N_2O emissions equally by 16 %.
Fulfilling expert guess of nitrogen fertilization rate for future and fulfilling climate scenarios caused according to DNDC model increase in N_2O emissions rate from arable soils of all Slovak agricultural regions in climate change condition as compared with present climatic condition. N_2O emissions increased in Maize agricultural region by 18 %, in Sugar beet region by 20 %, in Potato region by 2 % and in Mountainous agricultural region by 0,5 % (fig. 5).
There was found most significant increase of N_2O emissions in Sugar beet region (20%) with increase of N-fertilizers application by only 3%. On the other hand there was found increase of N_2O emissions only by 2% with the highest increase of N-fertilizers application by 8% in Potato agroregion (fig. 5 and fig. 6).

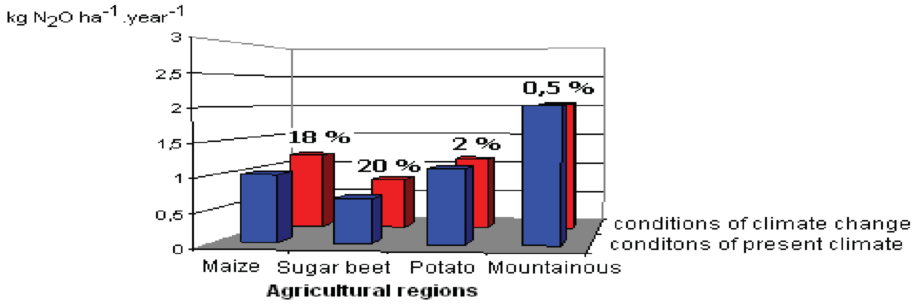

Fig. 5. Average N_2O emissions from arable soils of agricultural regions in conditions of present climate as compared with emissions in conditions of climate change

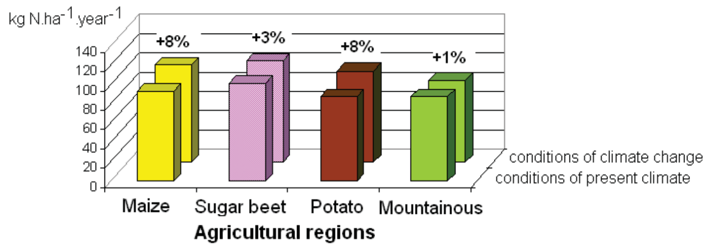

Fig. 6. Average N-fertilizers applied to the arable soils in agricultural regions of Slovakia

N-fertilization rate isn't the only one factor influencing N_2O emissions. There were changed two inputs into the DNDC model for conditions of climate change: rate of N-fertilizers application which increased by 5% on average for the whole Slovakia and climatic conditions represented by increase of temperature ΔT = in range of 0,2 up to 0,9 [°C] and by increase of precipitation ΔR = in range of +39 up to +156 [mm]. So it is expected that climate change will be one of the most significant environmental factor, influencing N_2O emissions in the future.
Using DNDC model for evaluating N_2O emissions in agroclimatic conditions of Slovakia showed, that not taking into account soil-climatic factors lead to significant differences in production of N_2O emissions from arable soils of Slovak Republic.

Key words: N_2O emissions, DNDC model, agricultural regions, climate change.

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CALIBRATION AND VALIDATION OF DSSAT MODEL FOR SERBIAN AGROECOLOGICAL CONDITIONS

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Abstract

The geographic distribution of plant species, vegetation types and agricultural cropping patterns demonstrate the very strong control that climate has on plant growth. Changes in weather conditions are one of the main reasons why agriculture needs advisory support systems. These systems have emerged in the form of crop simulation and they are now essential tools in the study of plant responses to climate change and in design of appropriate agricultural management practices. Crop simulation models can be used to predict crop yield expectancies under limited environmental resources and various management scenarios; nevertheless they can be used for prediction of climate change impact on crop.

This paper has a purpose to describe the phases in process and results of calibration and validation of DSSAT (Decision Support System for Agrotechnology Transfer) model for Serbian agroecological conditions and to confirm the possibility of applying DSSAT to predict the yield and climate change impact on winter wheat. DSSAT model was originally developed by an international network of scientists, cooperating in the International Benchmark Sites Network for Agrotechnology Transfer project (Hoogenboom et al., 2003). The model simulates the impact of the main environmental factors such as weather, soil type, and crop management on plant growth, development and yield.

Calibration of model was made for years 2003/2004 vegetation periods. Observed data, that was used for the model runs can be classified in three categories (i) site weather data for the duration of the growing season (latitude and longitude of the weather station, daily values of incoming solar radiation (MJ/m²-day), maximum and minimum air temperature (ºC) and rainfall (mm)); (ii) site soil data observed in year 2003 (percentage sand, silt, clay, organic compounds and pH in water, the other soil data were calculated by DSSAT); (iii) management and observed data from insitu experiment (planting date, planting density, row spacing, planting depth, crop variety and fertilizer practices) (Jones et al., 2003). Crop, soil and management data used for crop model runs are collected during the experiments curried out on Institute for field and vegetable crops (Novi Sad, Serbia) during 2001-2005 vegetation periods. Other required data, weather condition in that period, are from the agricultural experimental station Rimski Šančevi (Novi Sad) (45.20˚N, 19.51˚E). The chosen crop for model calibration was Anastasia winter wheat, the cultivar that was one of the most freaquent in the considered period.

The calibration of model was based on adjusteing the genetic coeficients of specific cultivar of winter wheat which are describing the phenology and grain yield. The first step was to calibrate the coefficients related to phenology and then the coefficients related to the grain filling characteristics (Rezzoug et al., 2008). The second one was the comparation between observed and simulated values of growth stage appereance for vegetation period of 2003/2004 (Table 1).

Table 1. Observed and simulated values of main growth stages and yield for vegetation period of Anastasia winter wheat, year 2003/2004.

	Observed, days after planting	Simulated, days after planting
Anthesis	212	213
Maturity	253	251
Yield kg/ha	6857	6854

The performance of the DSSAT model after calibration was validation. The variables tested included the key phenological dates (anthesis (Fig.1) and harvest maturity (Fig.2)) the final yield (Fig. 3) for period between 2001 and 2005 and for Anastasia winter wheat.

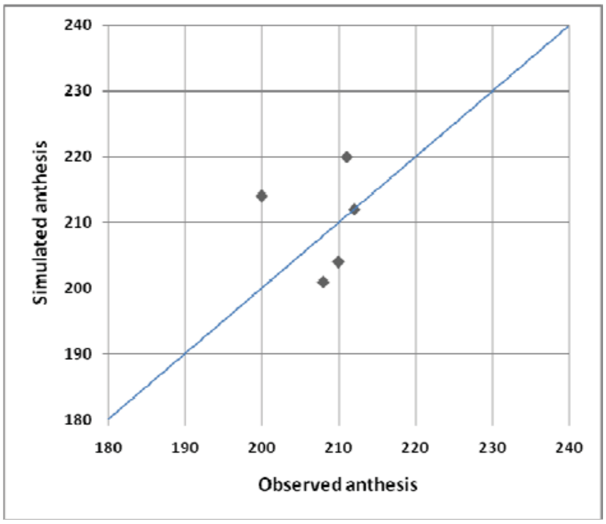

Fig.1.Comparison of anthesis appereance obtained using observed and simulated data expressed in days from sowing

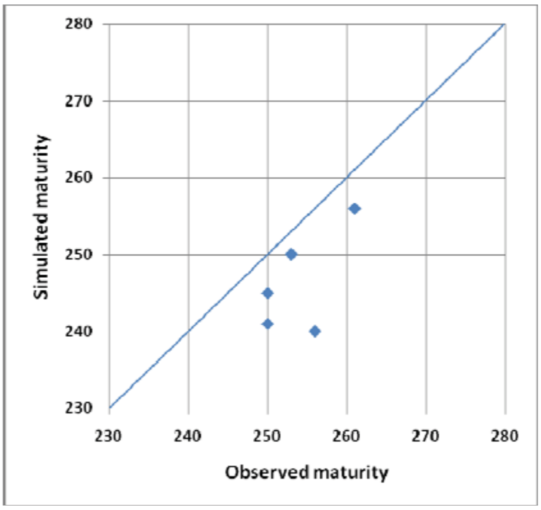

Fig.2. Comparison of maturity appereance obtained using observed and simulated data expressed in days from sowing

In general, the model gave good predictions of crop development and final grain yields. It predicted the anthesis and maturity dates with the mean absolute percenttage errors (MAPE) of 3.34 and 2.9%, respectively. The eror of yield simulation was larger, MAPE of 8.5%, but the trend of yield that simulation made was the same during the examined years (Fig. 3).

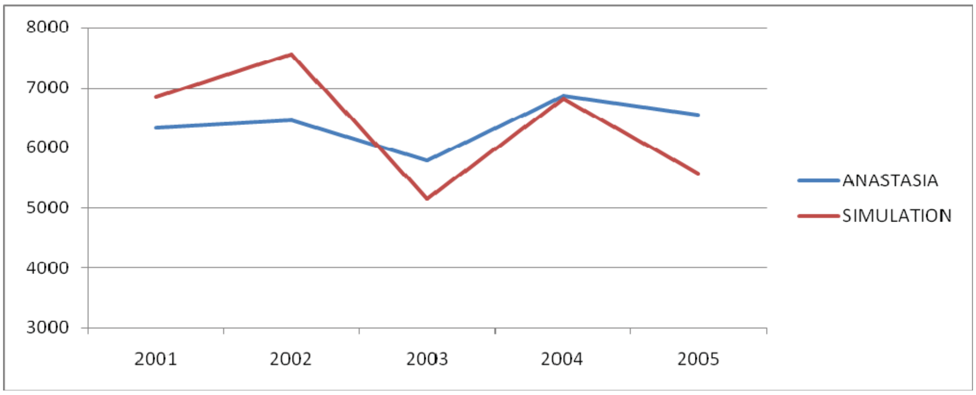

Fig.1. Observed vs.simulated Anastasia winter wheat yield

After the validation we have examined the sensitivity of DSSAT model on climate change impact. Climate change scenarios used in this study projected shorter vegetetation period for winther wheat in Novi Sad region. It is SRES-B1 scenario which assumes world with moderate population growth, intermediate levels of economic development, and less rapid and more diverse technological change. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels (Watson et al., 2001). If we only change concentration of CO_2 in atmosphere the duradion of vegetetation period is allmost the same, but if we introduce changes of key climate elements (temperature, solar radiation, precipitation) the differences between observed and simulated appearance of anthesis and maturity is near three weeks (Fig. 4).

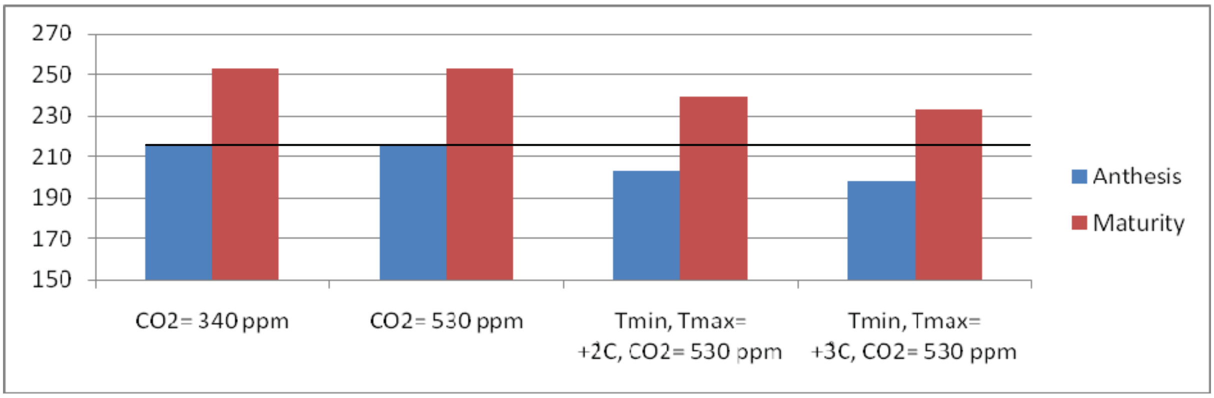

Fig. 4. Impact of changes of climate elements and CO_2 concentration on appearance of anthesis and maturity.

Sensitivity of model on climate change impact showed that it can be used for evaluation of crop production in future. That is important fact for producers as well as for decision makers, and we can expect that models like this are going to play a major role in that area.

Keywords: DSSAT, crop modelling, climate change impact, agriculture

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ADAPTATION TO DISEASES, PESTS AND WEEDS CAUSED BY CLIMATIC CHANGES AND EVALUATION OF ASSOCIATED RISKS IN EUROPEAN REGIONS – RESULTS FROM THE ADAGIO PROJECT

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Abstract

It is evident that certain climatic changes have taken place in recent years. Global warming is one of them. These climatic changes have exerted high effects on agriculture, especially when it comes to the occurrence of plant diseases, pests and weeds. The risk of plant disease, pest and weed damages to agricultural crops has increased significantly. Plant species that have been intensively attacked by harmful organisms are: wheat, barley, oat, maize, sunflower, sugar beet, potato, tomato, different fruits and grapevine in several European regions and olive trees in Greece, Italy and Egypt.

The occurrence of new diseases, pests and weeds is direct consequence of climate changes in: Austria, Italy, Greece, Egypt, Poland, NW Russia, and Serbia. In Bulgaria, occurrence of new harmful organisms has not been directly linked to climate changes but only indirectly. Certain harmful organisms adapted very fast their life histories to the changes and became prevalent in respect to other pests since the climate changes favored their large-scale multiplication and distribution.

If the predictions of global warming (which is often accompanied by drought) in the 21st century come true, frequent mass occurrences of the cotton bollworm and other xerothermophilous pests (grasshoppers, thrips, Sunn pests, weevils, flea beetles, etc.) may be expected as well as some new species, as a result of the expanding geographic distribution of some Mediterranean species. The western corn rootworm (which originated from North America) was observed in Serbia (Baca, 1993) and it is spreading fast in other European countries (Fig. 1). The red palm weevil (*Rhynchophorus ferrugineus*) comes from Egypt and it is spreading in several regions in Italy (found in 1994 in Campania, Toscana, Sicilia).

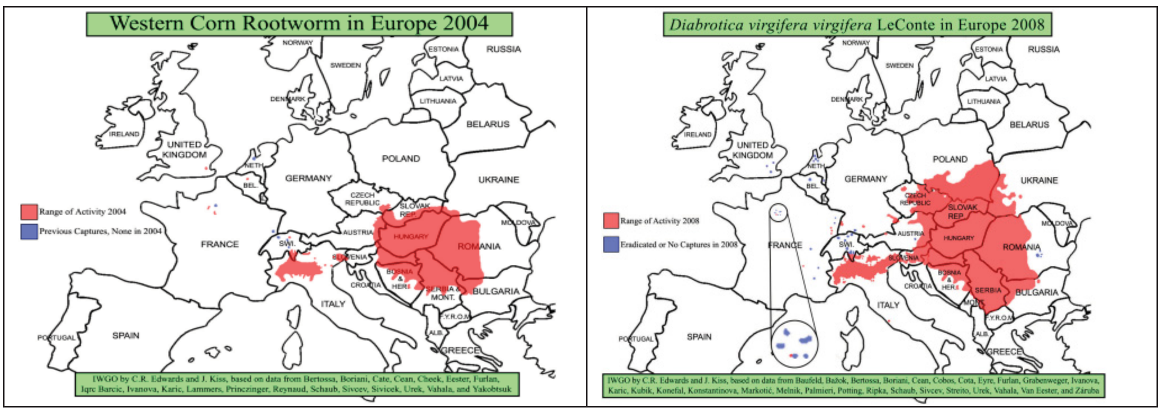

Fig. 1. The Western Corn Rootworm, which is spreading around in Europe, started from Serbia in the 1993 (originated from North America); Source: http://www.entm.purdue.edu/wcr/

New disease complexes may arise and some diseases may cease to be economically important if warming causes a poleward shift of agroclimatic zones and host plants migrate into new regions.

Pathogens would follow the migrating hosts and may infect remnant vegetation of natural plant communities not previously exposed to the often more aggressive strains from agricultural crops (Coakley, 1999). The occurrence of new harmful organisms is direct consequence of climate changes in the European regions and Egypt (Tab. 1).

Tab. 1. New diseases as direct consequence of climate changes in the European regions and Egypt

Country	New Diseases
Austria	Organisms from warmer to previous cooler regions is observed Main direction is from south east to west of Austria, north of the Alps.
Egypt	Downy Mildew in Grape Powdery Mildew Late Blight of Potatoes and Tomatoes Leaf and stripe rust on wheat
Italy	Citrus tristeza virus
Greece	Esca disease *Phytophtora* species (2) *Alternaria* species *Verticillium dahliae*
Russia, Northern Part	*Helminthosporium* spp. *Puccinia avenae* *Pyrenosporioses*
Serbia	Tan spot The reddish discoloration of corn SBFS complex on apple fruits

Physiological changes on plants are manifested as disorder of the vascular system, causing plant wilting and intensive occurrences of phytoplasmoses in certain crops. The reddish discoloration of corn leaves was registered in the region of south Bačka (Serbia). Its causal agent is stolbur phytoplasm (Duduk and Bertaccini, A., 2006), and its vector is a cycad *Reptalus panzeri* (Cixiinae, Auchenorrhyncha) (Milićević et al., 2006). Large problems on grapevine have been caused by the occurrence of yellow and red leaf discoloration. The vector of *flavescence dorée* (FD) phytoplasm is a cycad *Scaphoideus titanus* Ball., registered in Serbia in 2004 (Magud and Toševski, 2004). The occurrence of sooty blotch and fly speak (SBFS complex) on apple fruits was described for the first time in Serbia by Knežević et al. (2006).

Burns of apple leaves and fruits due to excessive insolation have become evident in recent years. A mechanical injury of fruits by hail or uncontrolled tree development that causes bark lesions allows a rapid pathogen development and a large production of spores.

In Austria on the wine increasing sun burn of grapes (white wine cultivars) was observed during past years, based on the current leaf reducing measures. Heat stress and damage, also water stress, especially on southern slopes were observed (in alpine grasslands) during past years. In 2008, Ministry of Agriculture and Land reclamation of Egypt declared that the cold wave hit Egypt From 29th January to 1st February 2008 caused physical losses in winter vegetable crop-yields by 20 to 40%. As well as, there were serious losses in mango, banana and citrus by 30 to 40% of the total crop-yield (NOAA, 2009). Diffuse burns on tomato and sweet pepper fruits was observed in Italy. Vegetables and other “cash” crop species have suffered from burns, especially on heat wave periods, as reported by farmers at the project study and data collection areas. Also, other crops such as grapevines and tree fruits have also been reported to be burned by radiation damage in Greece.

Several weeds are considered as increasingly harmful factors in Austria and Serbia in relation with climate warming (*Ambrosia artemisifolia, Datura stramonium, Solanum nigrum, Abutilon theophrasti*).

Adaptation to the occurrence of diseases caused by climatic changes can be viewed from several aspects in which a specific relationship exists between the plant (host) and the harmful organisms. Climatic changes alter plant physiological processes and resistance levels, while harmful organisms adapt their life cycles and aggressiveness.

In recent years, increased numbers of chemical treatments have been required in order to control harmful organisms in most field crops, vegetables, fruits and grapevine. The increase in the number of treatments builds up production costs and intensifies environmental pollution. Development of cultivars resistant to pathogens and insects is an important measure of their control. Other important measures include the planting of healthy seeds, crop rotation, irrigation, balanced fertilizer use and other cultural practices. In order for the adaptation measures to be implemented successfully, the breeding process must be adapted to the newly arisen climatic changes from the points of view of both, the plant and harmful organisms.

Keywords: disease, pest, weeds, climate change, Adagio project.

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ASSESSMENT OF GRAIN YIELD, CROP WATER PRODUCTIVITY AND WATER REQUIREMENT UNDER CLIMATE CHANGE SCENARIOS AGAINST DEFICIT IRRIGATION FOR IRRIGATED AUTUMN MAIZE AT FAISALABAD-PAKISTAN

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Abstract

CO_2

Agricultural is one of the crucial human sectors that might be significantly affected by changes in climate and rising atmospheric CO_2 concentrations, with the effect to world food production (Rosenzweig and Hillel., 1998). According to the IPCC Fourth Assessment Report (IPCC, 2007), global mean temperatures have risen approximately 0.74 ^{0}C in the last 100 years and increase in CO_2 direct result of human activities, primarily fossil fuel burning, cements production, and modified land-use patterns (IPCC, 1996). Due to change in land use pattern , cropping system or cropping intensity have numerious effects on weather elements (Raddaz, 2007) and the impact of GHG emission on climate is well documented (IPCC, 1996a).

This simulation study was carried out to evaluate the effect of climate change and elevated CO_2 on crop yield, water requirement and crop water productivity under two climate change scenario (A1B and A2) for present and future periods against different deficit irrigation scenarios. Climate change projections were obtained from General Circulation Model (GCM), ECHAM 5 developed at the Max Plank Institute of Meteorology, is the latest version in a series of ECHAM Models. Crop simulator CERES-Maize model was calibrated and validated with filed experiments and then was used to study the climate change impact. Baseline simulations were carried out for reference period (1978-2008), with average CO_2 concentration 360 ppm. Simulated results shows that highest grain yield (6760 kg/ha^{-1}) was observed in scenario 3 (S_3) with less irrigation(60 mm) as compared to other two scenarios and in scenario 3, two irrigation were skipped , one at crop establishment (25 DAS) stage and second at maturity stage (105 DAS). Lowest grain yield (6102 kg/ha^{-1}) was observed in scenario 2 (S_2), when irrigation was skipped at maturity stage. Second highest grain yield (6442 kg /ha^{-1}) was simulated in scenario1 (S_1), in this scenario irrigation was skipped at vegetative stage.

According to our simulated results for present conditions indicate that significantly highest grain yield and CWP was achieved with less irrigation. It means highest irrigation can normalized the CO_2 effects while less irrigation (255 mm) with CO_2 360 ppm will enhance grain yield and CWP for this region. Actually there is less information available for the mechanism to understand plant atmosphere to water fluxes against elevated CO_2 under water stressed condition but it is well documented growth stimulating effects of CO_2 than well watered conditions (Idso and Idso, 1994; Chaudhuri et al., 1990; Kimball et al., 1995). Generally when plants exposed to atmospheric CO_2, induced partial closure of their stomata, through which they take in CO_2 and loose water vapors, so in this way transpiration becomes reduced, and more water extracted from soil and consequently their ability to withstand in water stressed condition increased and also tend to increase crop water productivity (Rosenberg et al., 1990; Eamus, 1991; Dhakhwa et al., 1997).Our results are also agreed with the information provided in the literature for increasing yield and crop water productivity under water stressed conditions.

For scenario A1B (2015) highest grain yield (6629 kg /ha^{-1}) was observed in deficit irrigation scenarios 3 without CO_2, on the other hand with CO_2, 6878 kg/ha^{-1} was recorded. With CO_2 408 ppm, produced 249 kg/ha-1 more yield than without CO_2. For the year 2025, again highest grain yield was observed 6907 kg/ha^{-1}, with 443 ppm and yield difference was 303 kg/ha^{-1} than without CO_2. For the 2050, with CO_2 536 ppm, grain yield was 6396 kg/ ha^{-1}, while without CO_2 it remained 5825 kg/ha^{-1}. Here with increase in CO_2, grain was less as compared to 2015 and 2025. Climate change signal, for 2050, there was increase in temperature 2.9 ^{0}C per month and 0.2 MJ/m^{-2}/ month as compared to 2015, 2025.So here this can be a reason that with increase in temperature and solar radiation and increasing CO_2 concentration, can produced more drought and reduced the water availability to plants in less amount of water and ultimately less gain yield.

Crop water Productivity evapotranspiration (CWP_{ET}) also significantly higher with CO_2 fertilization as compared with out CO_2 fertilization (Table 3). Highest CWP was achieved in irrigation scenario 3 with less amount of irrigation as compared to without CO_2 . It is cleared that CO_2 increased carbon

assimilation, partial closure of stomata and decreased ET and increase in water use efficiency (Morison, 1998).

For scenario A2 (2015,) highest grain yield (6660 kg /ha^{-1}) was observed in deficit irrigation scenarios 3 without CO_2, on the other hand with CO_2, 6810 kg/ha^{-1} was recorded. With CO_2 403 ppm, produced 150 kg/ha^{-1} more yield than without CO_2. For the year 2025, again highest grain yield was observed 6872 kg/ha^{-1}; with 429 ppm and yield difference was 227 kg/ha^{-1} than without CO_2. For the 2050, with CO_2 507 ppm, grain yield was 6797 kg/ ha^{-1}, while without CO_2 it remained 6413 kg/ha^{-1}. Here with increase in CO_2, grain was less as compared to 2015 and 2025. Climate change signal, for 2050, there was increase in temperature 2.0 ^{0}C per month and -8.4 MJ/m^{-2}/ month as compared to 2015, 2025 .Here this can be a reason that with increase in temperature and decrease in solar radiation and further increase in CO_2 concentration, can produced more driest conditions and less favorable environment for optimum plant and consequently reduced grain yield in decreasing amount of water.

Crop water Productivity evapotranspiration (CWP_{ET}) also significantly higher with CO_2 fertilization as compared with out CO_2 fertilization.Highest CWP was achieved in irrigation scenario 3 with less amount of irrigation as compared to without CO_2 , again same trend was observed as in scenario A1B.

Keywords: Grain yield , Crop water productivity , climate change scenario, deficit irrigation, CERES-Maize model

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ANALYSIS OF SIMULATED TRENDS OF EXTREME CLIMATE INDICES WITH SPECIAL EMPHASIS ON AGRICULTURAL IMPACTS USING REGIONAL MODEL OUTPUTS FOR THE CARPATHIAN BASIN

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Abstract

Expected regional climate change in the Carpathian Basin is evaluated using simulations of the model RegCM (Torma et al., 2008) for 1961-1990 (as the reference period), 2021-2050 and 2071-2100 (as the target periods, A1B scenario). Model RegCM was originally developed by Giorgi et al. (1993a, 1993b) and then modified, improved and discussed by Giorgi and Mearns (1999) and Pal et al. (2000). The RegCM model (version 3.1) is available from the Abdus Salam International Centre for Theoretical Physics (ICTP). The dynamical core of the RegCM3 is fundamentally equivalent to the hydrostatic version of the NCAR/Pennsylvania State University mesoscale model MM5 (Grell et al., 1994). Surface processes are represented in the model using the Biosphere-Atmosphere Transfer Scheme, BATS (Dickinson et al., 1993). The non-local vertical diffusion scheme of Holtslag et al. (1990) is used to calculate the boundary layer physics. In addition, the physical parametrization is mostly based on the comprehensive radiative transfer package of the NCAR Community Climate Model, CCM3 (Kiehl et al., 1996). The mass flux cumulus cloud scheme of Grell (1993) is used to represent the convective precipitation with two possible closures: Arakawa and Schubert (1974) and Fristch and Chappell (1980). Model RegCM can use initial and lateral boundary conditions from global analysis dataset, the output of a GCM or the output of a previous RegCM simulation. In our experiments these driving datasets are compiled from the Centre for Medium-range Weather Forecasts (ECMWF) ERA-40 reanalysis database (Uppala et al., 2005) using 1° horizontal resolution, and in case of scenario runs (for 3 time slices: 1961-1990, 2021-2050, and 2071-2100) the ECHAM5 GCM using 1.25° spatial resolution (Roeckner et al., 2006). The selected model domain covers Central/Eastern Europe centering at 47.5°N, 18.5°E and contains 120x100 grid points with 10 km grid spacing and 18 vertical levels (Torma et al., 2008). The target region is the Carpathian Basin with the 45.15°N, 13.35°E southwestern corner and 49.75°N, 23.55°E northeastern corner.

Validation of RegCM for our domain is discussed by Bartholy et al. (2009). Precipitation is overestimated by 35% in winter, 25% in spring, 5% in summer, and 3% in autumn (on average for the whole domain). Persistent drying bias occured in the southern part of the Alps. For Hungary, the seasonal bias values are acceptable and less than 23% (except in spring, when it's 29%). The annual bias is +16% for the Hungarian grid points. Temperature is overestimated in winter (by 1.1 °C), and underestimated in the other seasons (by 0.3 °C, 0.2 °C, and 0.1°C in spring, summer, and autumn, respectively). The largest bias values are shown in the high mountainous regions (Alps, southern part of the Carpathians). For Hungary, the seasonal bias values are +1.3 °C, -0.5 C, -0.5 °C, and -0.2 °C for DJF, MAM, JJA, SON, respectively. The annual bias is less than 0.05 °C for the Hungarian grid points.

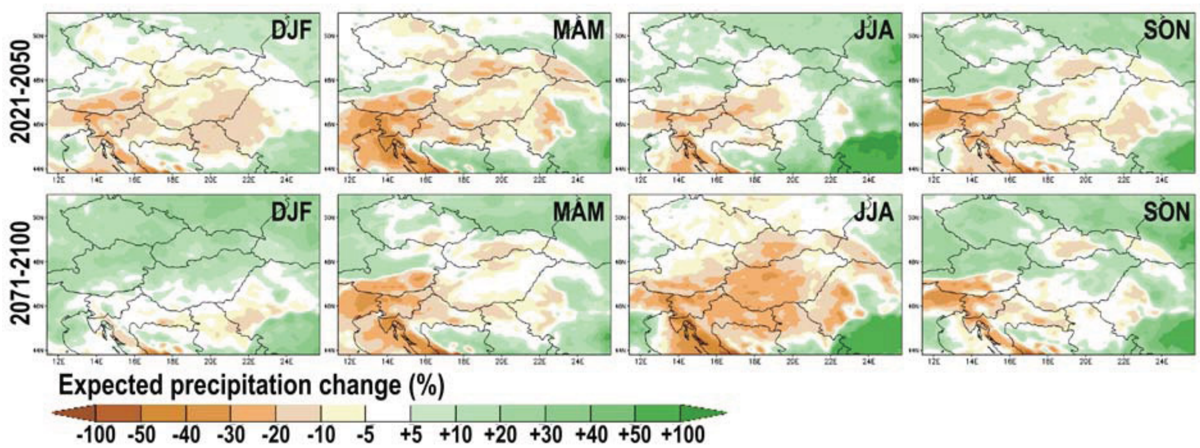

Fig.1. Seasonal expected precipitation change for the selected domain using A1B scenario (reference period: 1961-1990).

The simulation results suggest that temperature change in the simulated regional climate is evident in all season for both future time slices. Warming is expected in all regions, the spatially averaged seasonal changes (for the entire domain) are projected as follows: +1.8 °C in winter, +1.6 °C in spring, +0.6 °C in summer, and +0.8 °C in autumn by 2021-2050, and +1.8 °C in winter, +1.6 °C in spring, +0.6 °C in summer and +0.8 °C in autumn by 2071-2100 (relative to the 1961-1990 reference period).
Precipitation seasonal changes in the simulated climate are naturally far more variable in space than temperature. For Hungary, in general, drier climate is projected for 2021-2050, especially, in the eastern and southern parts of the country (upper panel of Fig. 1). The spatially averaged expected seasonal changes for Hungary are as follows: -9% in winter, -10% in spring, -2% in summer, and -4% in autumn. The largest precipitation decrease is expected close to southern edges of the Alps, which can be caused by the shadowing effect of the mountain, the weakening of the uplifting force. In the southeastern part of the domain (outside of Hungary) a large precipitation increase is expected in every season, which can be related to stronger low level easterlies in future climate. If we look at the end of the century (lower panel of Fig. 1), for Hungary, in general, winter and autumn are expected to become wetter than in the reference period (by 8% and 5% on spatial average), especially, in the northern part of the country. Drier summers (by 18%) and slightly drier springs (by 5%) are projected for 2071-2100 compared to 1961-1990. For the entire domain summer is expected to become drier in general, however, the southeastern part of the domain is projected to become wetter by 2071-2100 as well, as by 2021-2050.

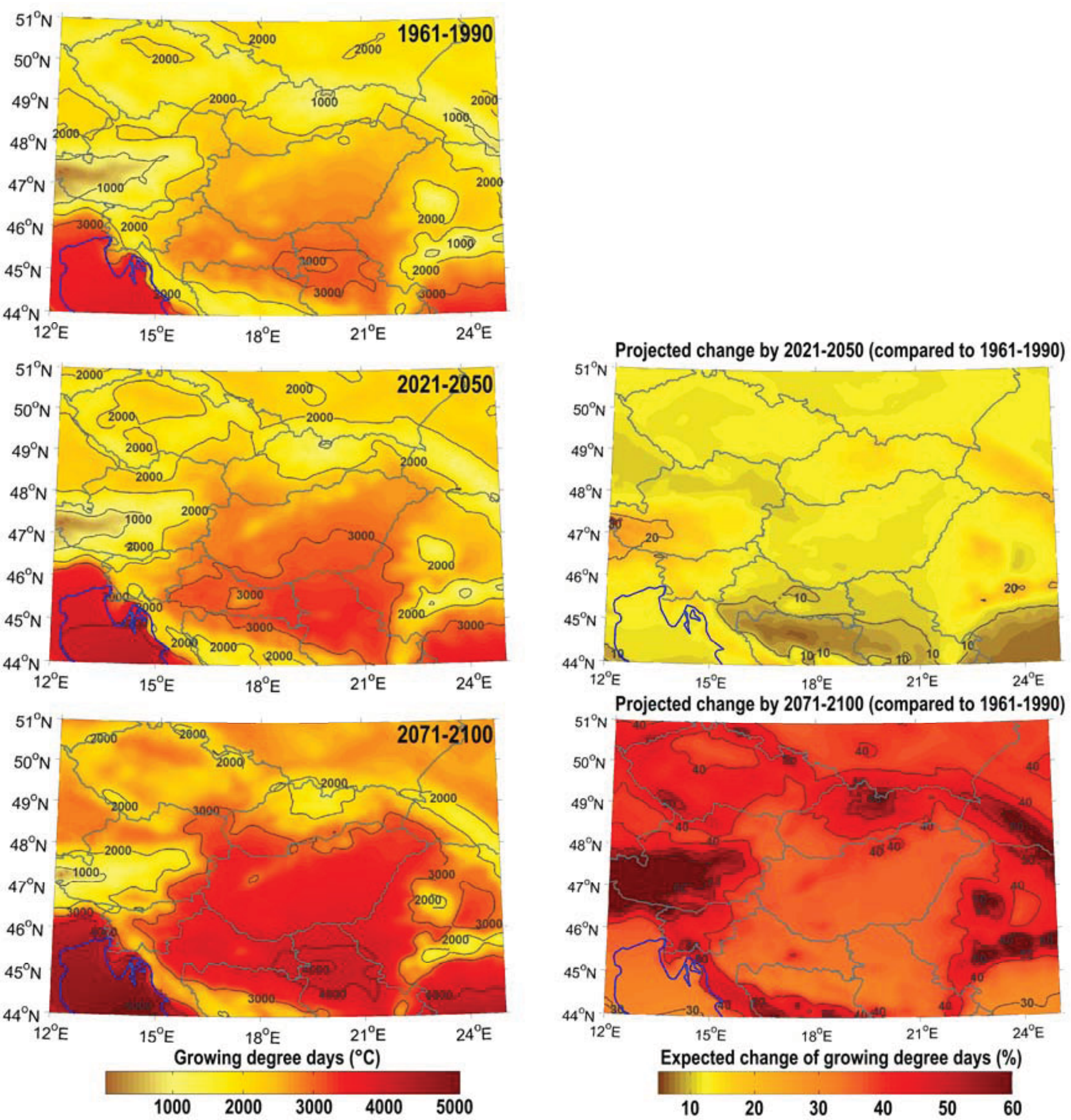

Fig. 2. Growing degree days (Sum of (T_{mean} – 4 °C) for all days with T_{mean} > 4 °C) based on simulated daily mean temperature.

Among the temperature related extreme indices, one example is selected, which has a strong influence on agriculture. Growing degree days (Fig. 2) are defined as the annual sum of the daily mean temperature values (T_{mean}) decreased by 4 °C when T_{mean} is larger than 4 °C. According to the simulated results, in the entire domain an evident increase of the growing degree days is expected for both future time slices compared to the reference period (1961-1990). Projected changes are larger for 2071-2100 than for 2021-2050 (in Hungary, the growing degree days are projected to increase by about 38% and 12% on average, respectively)

Among the precipitation related extreme indices, one example is selected, which reflects the drought conditions. Annual maximum number of consecutive dry days are shown in Fig. 3 calculated from the simulated daily precipitation amount time series. The results suggest that in general, an increase is projected for the southern part of the domain, and a decrease for the northern part. Expected changes in absolute value are larger for 2071-2100 than for 2021-2050. In Hungary for both periods, consecutive dry days are projected to increase, thus, resulting in more severe drought, especially by the end of the 21st century (in some places the projected increase may exceed 5 days, which means 25% of the current climatic conditions).

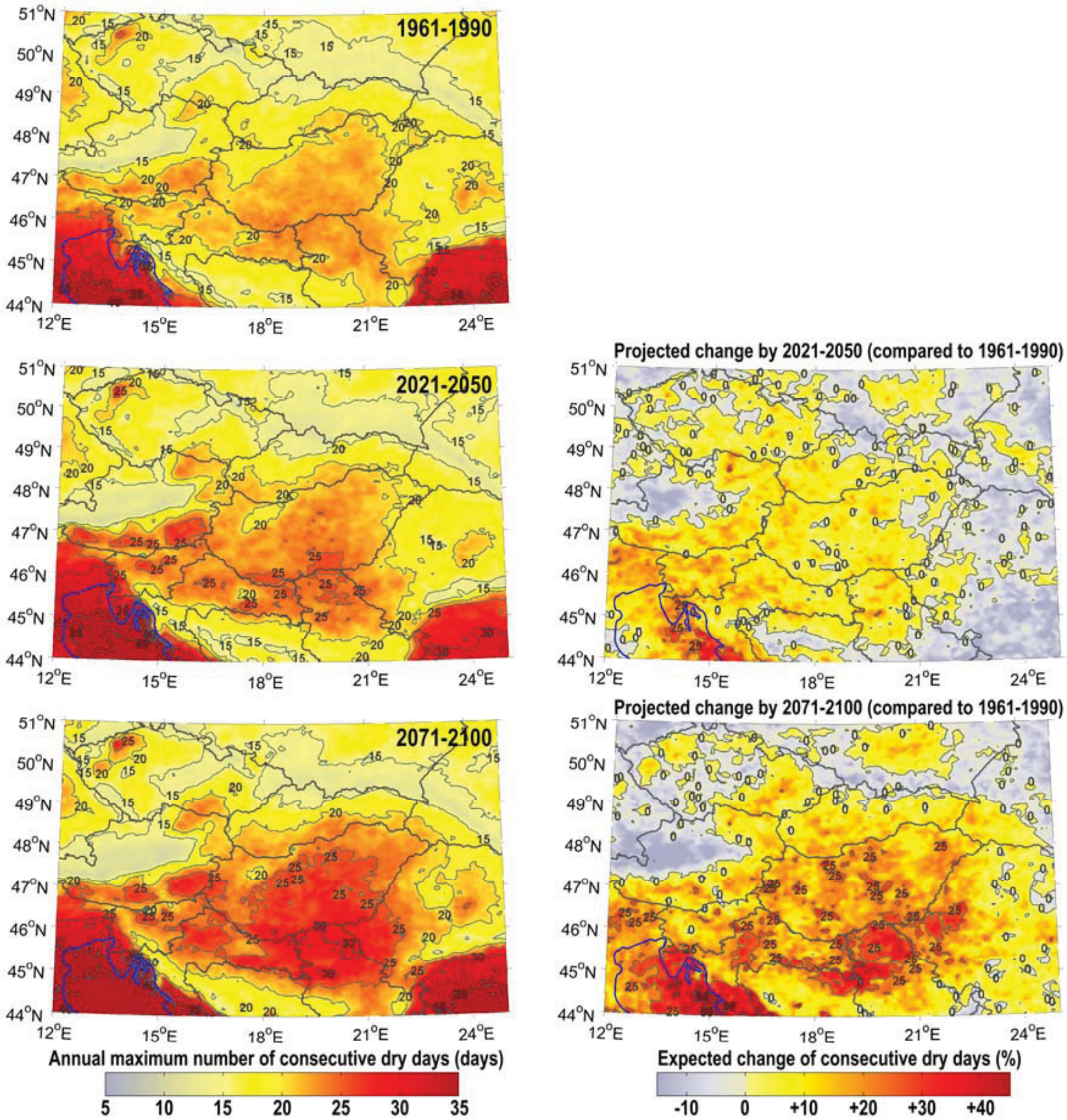

Fig. 3. Maximum number of consecutive dry days based on simulated daily precipitation amounts.

Keywords: regional climate modelling, extreme climate index, drought, Carpathian Basin

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LANDSCAPE STRUCTURES (HEDGEROWS) AS ADAPTATION MEASURE TO CLIMATE CHANGE IN SEMI-ARID REGIONS

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Abstract

Climate change associated with limited natural water supply hampers agriculture. Without adequate adaptation measures rainfed crop production may partially become impossible under climate scenarios in North-East of Austria that is characterized by semi-arid climate. Landscape structures, such as windbreak hedges, can change microclimate of crops by slowing down wind speed, promoting dew formation and reducing evapotranspiration and unproductive water loss. Furthermore they reduce wind erosion. In semi-arid regions the impact of landscape structures on evapotranspiration therefore is crucial and can have a significant effect on crop water balance, drought damage and crop yields. A landscape that is structured with hedgerows could have an average windbreak function of about 10 to 15 times the height of the hedge. This effect may increase yield considerable and means an economic benefit for the farm. The assessment of the economic opportunities and limitations of a landscape structure showed that there are not necessarily very high yield increases needed to get an economic benefit out of a structured landscape.

Introduction

Hedgerows play an important role for agricultural production as their impacts on field crops are manifold (Cleugh, 1998; Mayus et al., 1999). One of the important effects is the modification of the microclimate of neighbouring fields, especially caused by the well known function of wind speed reduction.

Already today water is one of the limiting factors of agricultural production in the eastern part of Austria. More and more the efficient use of this limited and in future scarce resource by adaptation measures gets an important role in relation to the maintenance of sustainable agricultural production.

A possible adaptation measure to face climate change in agricultural regions could be the implementation of landscape structures (e.g. hedgerows) with the aim to influence microclimate in an optimal way and thereby significantly improve the water use efficiency of their neighbouring fields.

Data and methods

Downscaled climate scenarios (Dubrovski et al., 2005) for the eastern part of Austria show a raise in temperature and nearly unchanged amounts in annual sums of precipitation. Compared to the period 1961-1990 the mean temperature will increase by about 1,9 °C for the period 2015-2035 and by about 2.5 °C for the period 2040-2060. Higher temperatures result in an increase of potential evapo-transpiration of 18% (2015-2035) and 25% (2040-2060) respectively (Eitzinger et al., 2005). As far as precipitation is concerned at least the annual distribution is expected to change (Fig. 1). Less rainfall during the summer months, more precipitation - but less snowfall - during winter and ambiguous conditions in spring are expected.

Since 2003 field studies and special measurements campaigns (transect measurements) were carried out within the framework of an interdisciplinary monitoring project called "MUBIL" (www.mubil.at) to define the total shere of influence of a hedgerow in the semi-arid NE of Austria. Additional literature research completes the state of our knowledge. First economic assessments at farm level were undertaken within a recently finished national project. These assessments concern the increased demand of crop yield in a structured landscape due to loss of arable land that is needed for hedges.

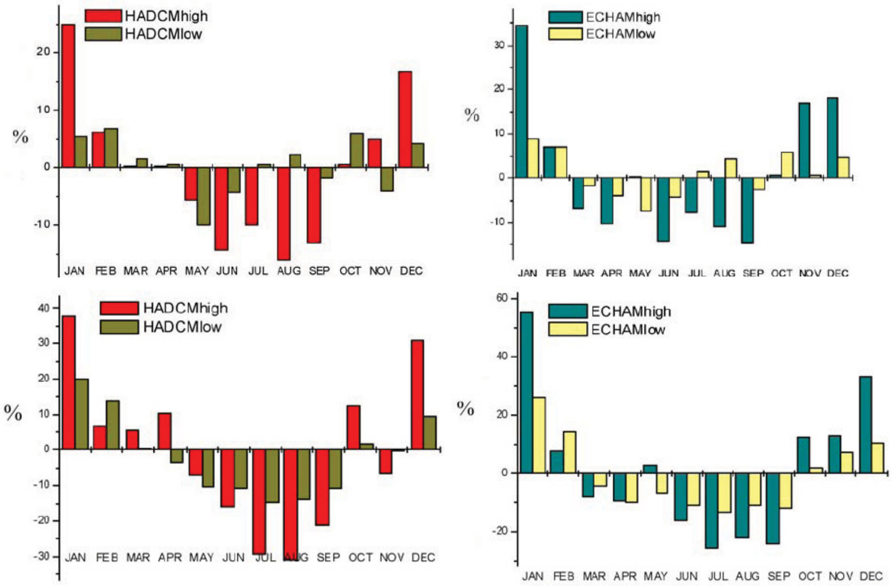


Fig. 1: Relative changes of monthly sums of precipitation for the periods 2015-2035 (above) and 2040-2060 (below) compared to the reference period 1971-2005 (in: Rischbeck 2007)

Results and discussion

Based on literature analysis, a wind protecting effect can be assumed on a width of 10 to 20 times of the height of the landscape structures (see, e.g. Mazek-Fialla, 1967). Hence a 5-meter-high hedge causes a potential windbreak function up to 100 m and thus has a positive influence on water supply of arable land. Literature research also shows that landscape structures should have a minimum width of 6 meters, so that a significant climate impact and thus a positive influence on water and soil erosion can take place (DVL, 2006; Meyerhoff, 2006).

An overview of effects of a hedgerow on micro-climate is given in Fig. 1. The analysed effect depends on the regarded parameter and on the structure of the hedge, which means height, width, wind permeability and orientation. For the sake of completeness it should be mentioned that there are also other factors such as abiotic site conditions (soil and subsoil of rock, water and nutrient budget) and the cultivated crop itself which influence yield.

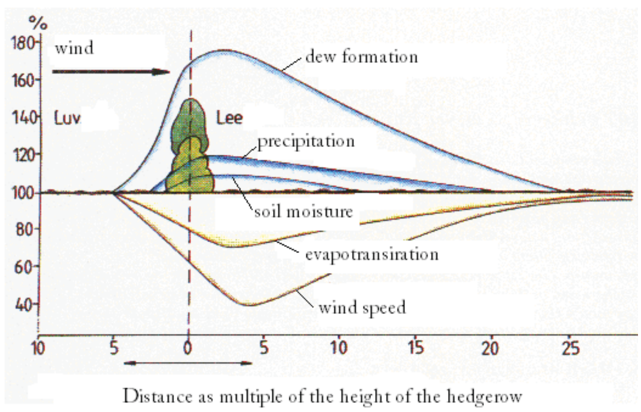


Fig.2: Effects on microclimate. Distances as multiple of the height of a hedgerow (Frielinghaus et al, 1997, modified).

Based on field measurement campaigns during the already mentioned monitoring project MUBIL and additional literature research the total sphere of influence of the hedgerow was investigated (Fig. 2). Parameters like precipitation, wind speed, potential evapotranspiration and others were measured in orthogonal transects at different distances. The shadowing effects of the hedgerow are remarkable and depend on the respective parameter and distance from the hedge (Fig. 3).

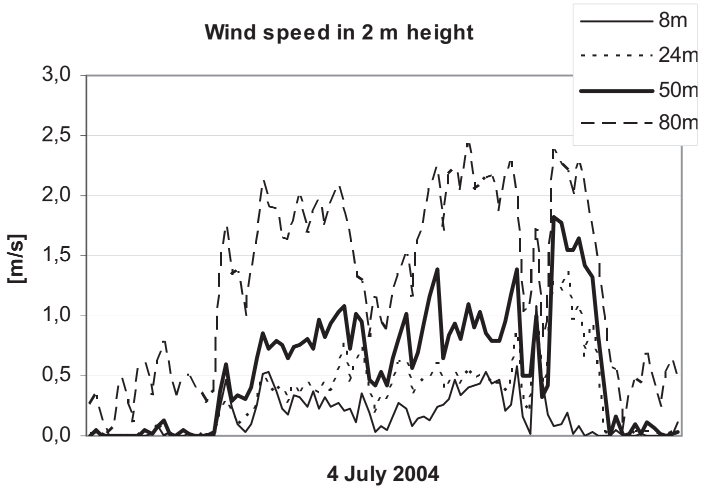
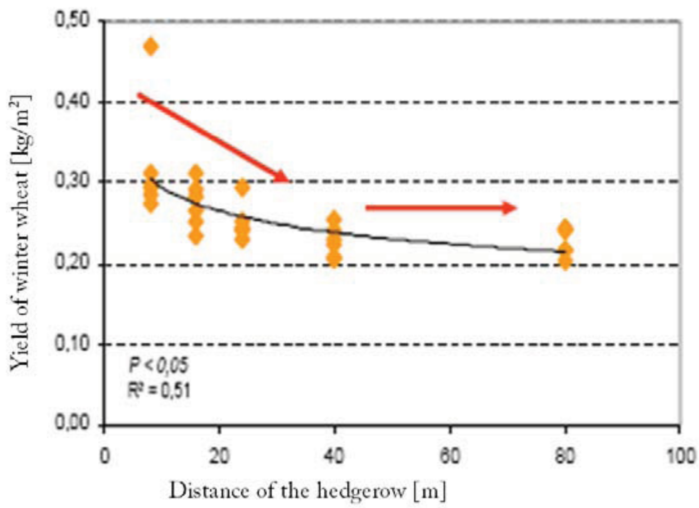


Fig. 3: Wind speed in 2m height in 8, 24, 50 and 80m distance to the east side of the hedgerow, leeward - wind from north-west.

Snow banks directly at the hedgerow and snow cover thickness play an important role for the soil water budget. A melting water equivalent of the snow banks of about 158 mm was measured in a single year in late winter (Fig. 4). It represents more than 30% of the average annual precipitation in this region. A simulation of the conditions in March 2005 showed a positive influence on soil water content for about 2 months nearby the hedgerow. Additionally, these snow banks affected yield of winter wheat in 2005 which was decreasing with increasing distance from the hedgerow (Fig. 5).

Fig. 4: High snow banks near the hedge in March 2005, left and middle: lee-ward, right: luv-ward.



distance [m]	yield dm [kg/ha] averaged
8 m	3220
16 m	2730
24 m	2500
40 m	2270
80 m	2270

Fig. 5: Inventory of yield. Multiple yield measurements in a transect at different distances from the hedgerow (Surböck et al, 2009).

For first economic assessments the local field crop rotation in conventional farming in the eastern part of Austria, local crop yields, price forecasts and the maintenance of income were assumed, despite

unfavourable climate conditions. The economic limitations and opportunities of a structured landscape in terms of direct economic impact and effects were estimated.
Assuming an increase of yield by about 10 % in relation to the open area which seems feasible (Fig. 5) a landscape structure with 5 m in height and 6 m in width and a windbreak function of 50m - applying 10 times the height of this structure - shows an economic advantage for the example farm in that region. If the average wind protection is 20 times the height of the hedge, an increase of approximately 5 % of the natural yield causes a positive effect of the landscape component (hedge) on the farm account (Brandenburg et al., 2009).

Conclusions
Hedgerows change the microclimate. They improve water use efficiency of crops by increasing dew formation and reducing wind speed, evaporation and furthermore wind erosion. Dislocation of snow (snow banks) near the hedge has a high positive impact on soil water budget in spring.
Under climatic conditions of today, this leads to an increase of crop yield. Considering ongoing climate change adaptation measures are therefore increasingly important. One possible adaptation measure is the implementation of landscape structures such as hedgerows.
A landscape structured with hedgerows could have an average windbreak function up to 20 times of the height of this structure. It may increase yields by about 10 % which means an economic benefit for the farm under the conditions in North-eastern Austria. Our first assessments of economic opportunities and limitations of a hedgerow showed that there are not necessarily very high yield increases needed to get an economic benefit out of a structured landscape.
Structuring arable land with hedgerows provides a meaningful adaptation measure – microclimatological and economically – to the changing climate in semi-arid regions of Austria.

Acknowledgements:
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Keywords: hedge, adaptation, windbreak, semi arid, climate change, microclimate, economic assessment

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CLIMATE CHANGE AND SOIL NITROGEN DYNAMICS IN WINTER WHEAT

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Abstract

With climate change, Europe becomes warmer (0.1-0.4 °C per decade) and the greatest increases are predicted over northern parts (IPCC 2001). Widespread changes in annual rainfall patterns; amount, distribution over time and intensity, are also predicted and northern Europe would get wetter (1-2% increase per decade) with regional variations (Matthies et al., 2007). As a main limiting factor for plant growth and net primary productivity, soil nitrogen (N) availability and its responses to global environmental change are critical for the projection of ecosystem and global C budgets (Hungate et al., 2003). Net N mineralization, the transformation process from organic N to inorganic N, primarily determines soil N availability and crop productivity. It is highly likely that if no major changes in rainfall pattern occur, CO_2 induced climate change will have no major changes in wheat production in Europe as negative effects of rise in temperature will be nullified by the positive effects of higher CO_2 levels (Nonhebel, 1996). Hence, a better understanding of the effects of soil temperature, soil water availability influenced by projected rainfall amount and patterns, and their interactions on net N mineralization in soils affecting the crop productivity will facilitate our predictions of soil N dynamics and net primary production in terrestrial ecosystems under global climate change. By warming the soil beyond the range of natural variability, soil warming experiments can explain the effects of soil warming on biogeochemical processes (e.g. decomposition, N cycling, and trace gas emission); and the feedback that changes in these processes may have on crop yields and quality, N leaching, and climate change besides providing a unique and valuable data set for calibrating and testing ecosystem models and help in better understanding how ecosystems respond to changing climate. Elevated soil temperatures stimulate net N mineralization rate in various biomass across the world (Rustad et al., 2001; Shaw and Harte, 2001; Melillo et al., 2002; Wang et al., 2006). However, most of these soil warming experiments have either focused on the summer months or carried out under controlled laboratory conditions, which do not truly represent field conditions at all times and location and very little work has been done on the winter period under elevated soil temperatures (Bauchhenss et al., 1982; Ineson and Benham 1991; Hillier et al., 1993; Jamieson et al., 1996).

In this background, a semi-field experiment on winter wheat is laid out in lysimeters with loamy sand soil using soil warming cables placed at 10 cm depth in heating plots, automatic rain shelter and watering system (Oct. 08– Sep. 09) to study the effect of soil warming (normal soil Vs up by 5°C) and future rainfall patterns; amount (reference period 1961-90 Vs projections for 2071-2100) & intensity (normal number of rainy days for the reference period Vs 50 % fewer rainy days), projected for Denmark (IPCC A2 Scenario; 2071-2100 AD) on soil N dynamics, N losses through leaching & emissions, incidence of pests, and yield and grain quality of winter wheat. A total of eight treatments (2 x 2 x 2) with four replications laid out in a completely randomised block design on 32 lysimeters of 1 x 1 x 1.5 m size. The experiment is still going on while writing this as the winter wheat crop is expected to be harvested by early August 2009. Hence, few initial results are presented here. For the rainfall amounts for Denmark, 1961-90 is taken as a reference period (control) against the projected one for 2071-2100 (IPCC A2 scenario). Mean annual rainfall for 1961-90 is 627 mm while for 2071-2100 it is projected to be around 658 mm, an increase of 31 mm on an annual basis. But, what is more important is the monthly distribution pattern of rainfall (Fig. 1). The projected monthly distribution of rainfall suggests that rainfall during the winter months would increase (Oct-Mar) creating too wet a conditions while in summer and early autumn it reduces (Jul-Sep). We hypothesised; this will have a significant influence on seasonal soil moisture availability to winter wheat crop, percolation losses during winter and N leaching.

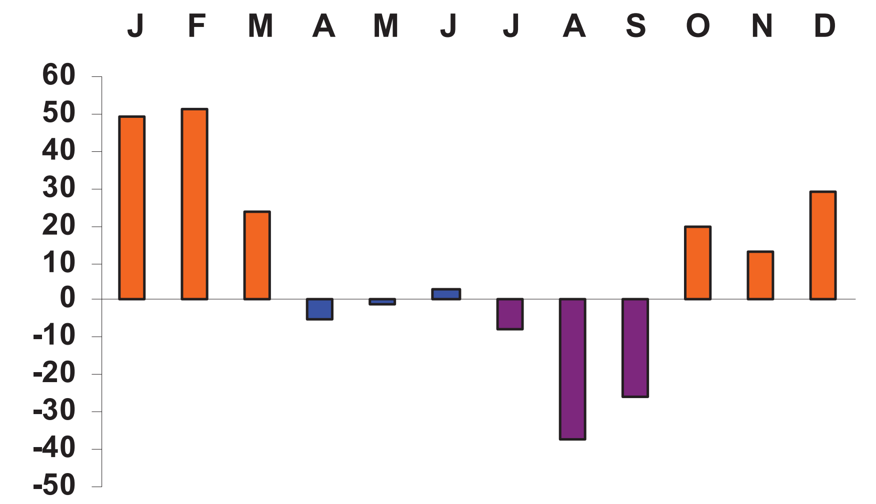

Fig. 1: Change in monthly rainfall (%) projected for 2071-2100 compared to base year 1961-90

In the figure 2, the columns with yellow shade (treatment 5, 6, 7 & 8) indicate soil warming plots while the one with blue shade (treatment 1, 2, 3 & 4) indicate control (un-heated) plots super-imposed with different rainfall pattern treatments. Soil freezing and thawing cycles during winter were greatly reduced in soil heating plots which lead to continuous evaporation losses and the wheat crop put on more biomass (foliage) and grew faster when compared to the crop in un-heated plots (Fig. 3). This in turn significantly reduced (> 50%) the amount of rain water lost through percolation (Fig.2).

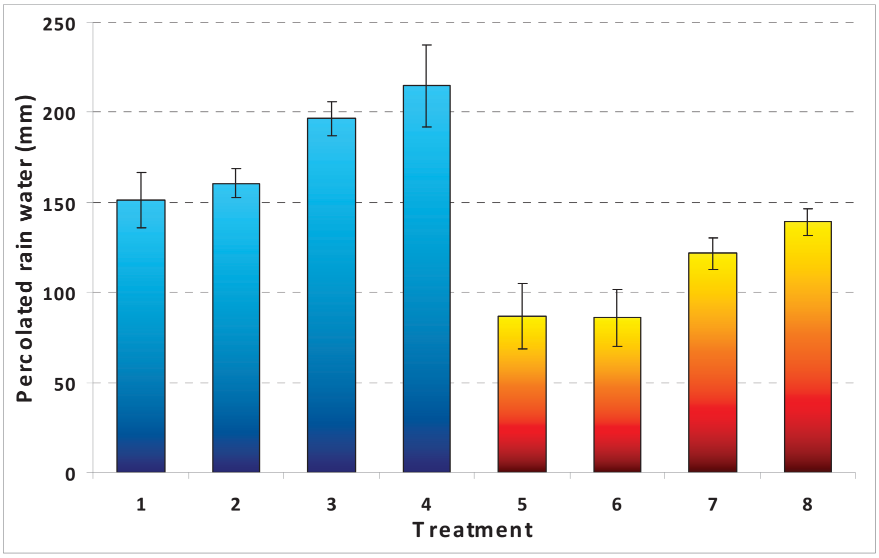

Fig. 2: Rain water (mm) percolated through soil profile (beyond 1.5 m) as affected by soil warming and projected rainfall patterns (Oct. 08-April 09) (s.e. bar lines are with n=4)

Fig.3: Wheat growth & leaf area coverage in heated plots (left) & non-heated plots (right) by end of Mar. 2009

Both projected future rainfall amount (treatment 3, 4, 7 & 8) and reduced rainy days (treatment 2, 4, 6 & 8) significantly increased the rain water percolation losses and with it the nitrogen leaching also increased.

Both NO_3-N and NH_4-N forms of nitrogen leached down with percolating rain water are being monitored on weekly basis and results for the period October 2008 through January 2009 indicate three fold increases in nitrate-N leaching with future rainfall patterns (treatment 3 and 4) in control plots (Fig. 4). However this was on much lower scale in heating plots as soil warming increased evapo-transpiration all through the experimental period.

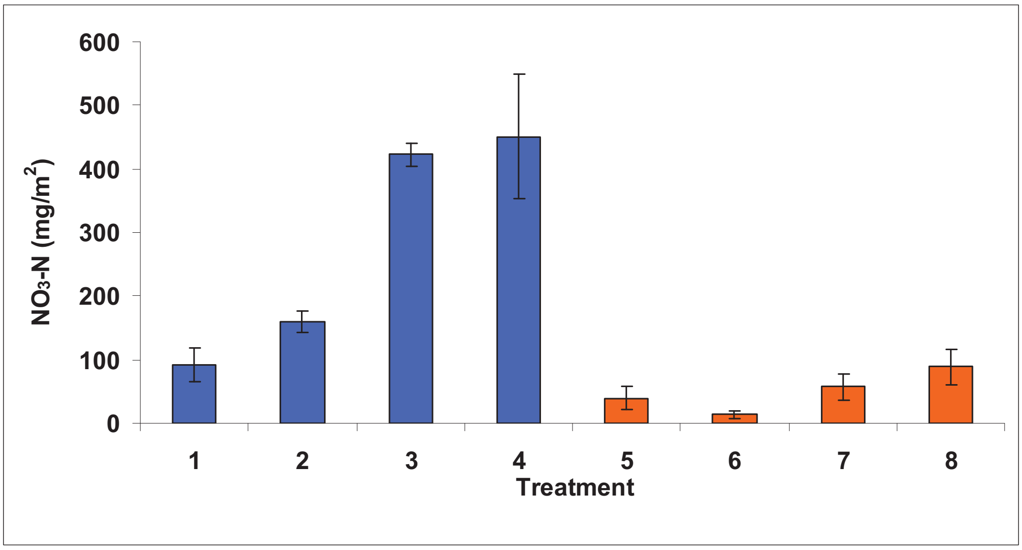

Fig. 4: Nitrogen losses (NO_3-N) through percolated water as influenced by soil warming and future rainfall patterns (Oct. 08 through Jan. 09)

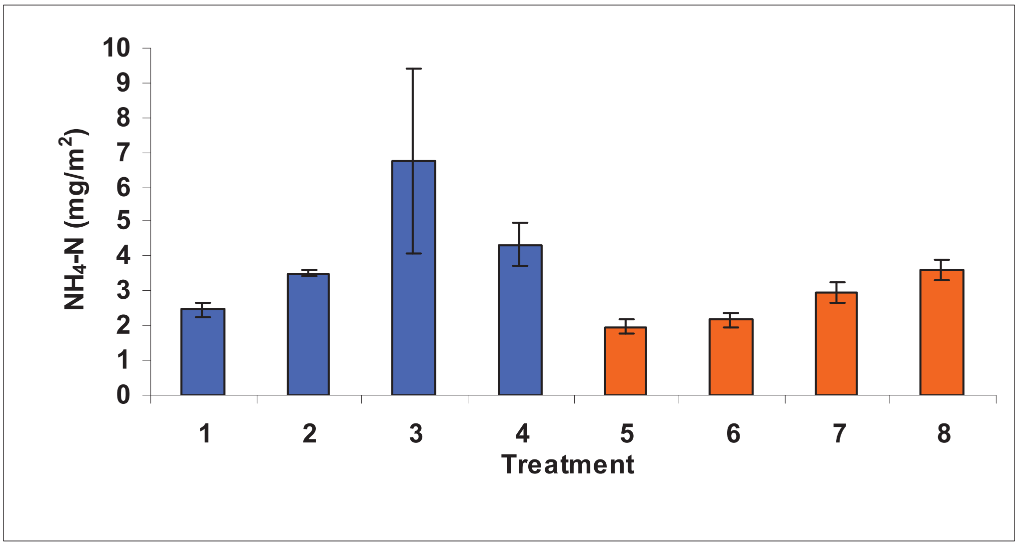

Fig. 5: Nitrogen losses (NH_4-N) through percolated water as influenced by soil warming and future rainfall patterns (Oct. 08 through Jan. 09)

Whereas, NH_4-N losses through leaching was on much lower scale in comparison to NO_3-N losses, but it followed the same trend (Fig. 5). These results indicate to have a profound effect on seasonal soil nitrogen availability, losses and uptake by winter wheat and its effect on final yield and quality of grains.

Keywords: climate change, soil warming, rainfall patterns, soil N dynamics, winter wheat

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A MODELLING FRAMEWORK FOR ASSESSING ADAPTIVE MANAGEMENT OPTIONS OF FINNISH AGRICULTURAL SYSTEMS TO CLIMATE CHANGE

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Abstract

Agrifood systems need to adapt to cope with the risks and opportunities related to global changes in climate, markets and policies. The impacts of these changes on food production, the environment and farmer livelihoods, as well as those of changes to technology and management practices, are not clearly understood. There is a need for improved assessment methods and tools that consider multiple factor and scale interactions (Van Ittersum et al., 2008). In recent years, European-wide consortia, such as SEAMLESS, have worked for creating flexible and widely applicable frameworks for integrated assessment and and modelling of agrifood systems That work has been valuable in developing common concepts, methods and more flexible frameworks (Ewert et al., 2009).. However, their relative generic character reduces its applicability when it comes to detailed regional applications, e.g. as needed in identifying promising climate change adaptation and mitigation options for agricultural systems.

In Finland, there are several individual, well-developed modelling tools available for the analysis of the environmental and socio-economic impacts of agricultural activities from field to national scales. Recently, a new project focussing on integrated assessment modelling of agrifood systems (IAM-Tools) (MTT, 2009) has been launched at MTT Agrifood Research Finland to gather, evaluate, refine and develop these component models and to link them in an IAM framework for Finnish conditions. The framework was developed for ex-ante assessment of alternative policy and management options in relation to climate change adaptation and mitigation, biodiversity and reducing nutrient emissions from agriculture. A set of alternative scenarios of the main global or national driving factors are down-scaled to construct regional scenarios of the major factors likely to influence agro-ecosystems. The framework is being built by revising existing and designing new models, interlinking the models or their results at the farm and regional (sub-national) level and integrating the information into GIS. The component models applied are, for example, a dynamic regional sector model of Finnish agriculture (DERMFIA), a static agent model of agriculture (SAMA), a dynamic crop growth simulation model (WOFOST), models describing the nutrient dynamics in agricultural systems (INCA-N, ICECREAM and COUP) and a hydrological rainfall-runoff model (WSFS-P) (Table 1). .

Table 1: Component models included so far in the Finnish Integrated Modelling Framework for agrosystems analysis

DREMFIA	- a dynamic regional sector model of Finnish Agriculture *Lehtonen, H. 2001. Principles, structure and application of dynamic regional sector model of Finnish agriculture. Academic dissertation. Systems Analysis Laboratory, Helsinki University of Technology. Publisher: Agrifood Research Finland, Economic Research (MTTL). Publications 98. Helsinki. 265 pages.*
SAMA	- Static Agent Model of Agriculture developed for several farm types in Finland - *Helin, J., Laukkanen, M., Kiokkalainen, K., 2006. Abatement costs for agricultural nitrogen and phosphorus loads: a case study of crop farming in*

	south-western Finland .Agricultural and Food Science, 15(4): 351-374 *http://www.mtt.fi/afs/pdf/mtt-afs-v15n4p351.pdf*
COUP	– a model for soil-plant-atmosphere systems *Jansson, P.-E. and Karlberg, L. 2004. Coupled Heat and Mass Transfer Model for Soil-Plant-Atmosphere Systems. Royal Institute of Technology, Dept of Civil and Environmental Engineering, Stockholm, Sweden, 435 pp.*
WOFOST	– a dynamic crop growth simulation model *Boogaard, H. L., C.A. van Diepen, R.P. Rötter, J.M. Cabrera, and H.H. van Laar, 1998. User's guide for the WOFOST 7.1 crop growth simulation model and Control Center 1.5, Alterra, Wageningen, The Netherlands, 143 pp.*
INCA-N	– an integrated nitrogen model for multiple source assessment in catchments *Wade, A., Durand, P., Beaujoan, V., Wessels, W., Raat, K., Whitehead, P.G., Butterfield, D., Rankinen, K. and Lepistö, A. 2002. Towards a generic nitrogen model of European ecosystems New model structure and equations. Hydrology and Earth System Sciences 6, 559-582.*
WSFS-P	- a hydrological rainfall-runoff model *Huttunen, I., Huttunen, M., Vehviläinen, B., Tattari, S. 2007. Large scale phosphorus transport model. In: Heckrath, G.,Rubaek, G. H., Kronvang, B. (eds.). Diffuse Phosphorus Loss :Risk Assessment, Mitigation options and Ecological Effects in River Basins: The 5th International Phosphorus Workshop (IPW5), 3-7 September 2007 in Silkeborg, Denmark. Aarhus, Aarhus Universitet, Faculty of Plant Science. P. 215-217. DJF Plant Science; 130. ISBN 87-91949-20-3.* *http://www.agrsci.dk/var/agrsci/storage/original/application/115f2ba1481b6a113288c6f9a773d572*
ICECREAM	**-** a field-scale nutrient transport model Yli-Halla M., Tattari S., Bärlund I., Tuhkanen H.-R., Posch M.,Siimes K. and Rekolainen S. 2005. Simulating processes of soil phosphorus in geologically young acidic soils in Finland. Transactions of the ASAE 48(1): 101–108.

This framework represents a novel approach to the integration of data and output from several existing models. The aim is to apply the tool in relation to questions of high importance for Finnish agriculture, especially policy interventions targeting more sustainable agriculture-environment interactions, for example, in terms of water quality, greenhouse gas emissions and adaptation to climate change.

Keywords: integrated assessment, modelling, climate change, adaptation and mitigation options, agrifood systems, multiple scale interactions, scenarios

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MTT, 2009., www.mtt.fi/iam-tools IAM-Tools project webpage by MTT Agrifood Research Finland

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DIFFERENT RESPONSES OF MODIS-DERIVED DROUGHT INDICES IN VARIETY OF AGRO-CLIMATIC CONDITIONS

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Abstract

Although drought is a complex phenomenon where its severity is related to the specific climatic region, it can basically be defined as a period of abnormally dry weather, which further results in a change in vegetation cover condition (Heim, 2002; Tucker et al., 1987). Drought is a recurrent climate process that occurs with uneven temporal and spatial characteristics over a broad area and over an extended period of time. Therefore, detecting drought onsets and ends and assessing its severity using satellite-derived information are becoming popular in disaster, desertification, and climate change impact studies. Over the last decades, observations showed that the frequency and intensity of droughts have increased in several parts of the world (Hulme et al., 1993; McCarthy et al., 2001). There has been a large drying trend in many parts of the world over the last three decades (Dai et al., 2005) and many regions have been suffering a water crisis. If this trend continues as expected by climate change scenarios (e.g. by decreasing of precipitation and/or increasing of potential evapotranspiration) in combination with increasing water demand of the population, the consequences may be severe in only a couple of decades and could pose significant water resource challenges to many key sectors (IPCC, 2007; Shindell et al., 2006). Therefore, satellite remote sensing of surface moisture status and drought conditions is of great interest and can contribute for sustainable development of eco-environments.

Recently, a simple method for the estimation of surface dryness, namely the perpendicular drought index (PDI), has been developed (Ghulam et al., 2007a) and further demonstrated to be effective in large-scale applications using Moderate Resolution Imaging Spectroradiometer (MODIS) data (Qin et al., 2008). Regarding inherent constraints and limitations of PDI, Ghulam et al. (2007b) developed a modified perpendicular drought index (MPDI). The MPDI is based on the combination of two important indicators of drought: soil moisture (SM) and fraction of green vegetation (fv). The method shows potential advantages for regional surface dryness estimation, yet its responses on plant cover dynamics at different phenological conditions. Therefore, drought estimation criteria of this index need to be examined further.

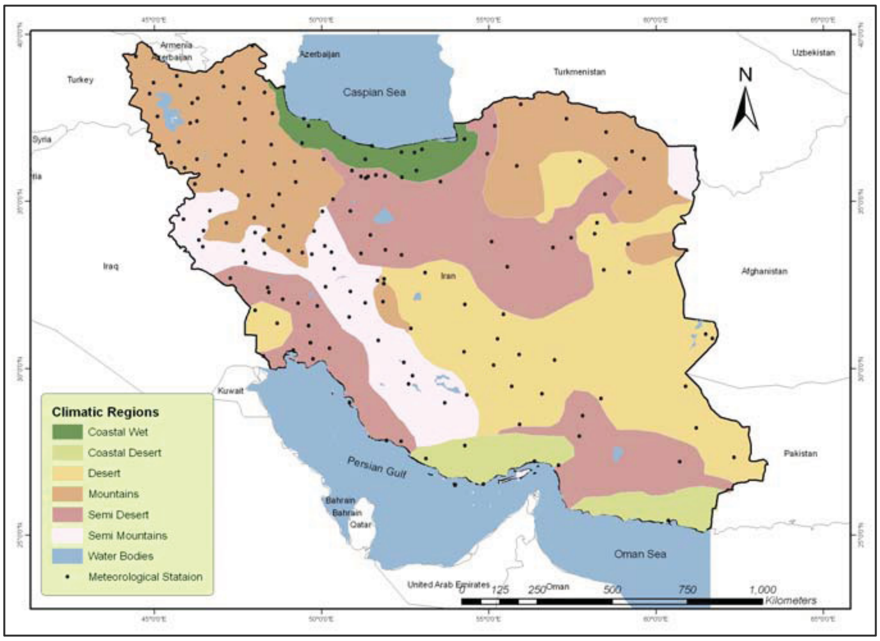

Figure 1. The study area classified into six climatic regions

The main objective of this study is evaluating and refining an appropriate drought estimation method for semi-arid regions, demonstrated for Iran, using remote sensing. Recently developed methods, the Perpendicular Drought Index (PDI), Modified Perpendicular Drought Index (MPDI), Enhanced vegetation index (EVI) and Vegetation condition index (VCI), are selected as satellite based drought indices in this study. Time series of MODIS satellite images (MOD13A3 V005) have been collected over the region spanning the time interval between February 2000 and December 2005 and PDI, MPDI, EVI, VCI were calculated. Then, these indices were evaluated against meteorological drought indices including Z-score (Z), China-Z index (CZI) and modified China-Z index (MCZI) over 180 meteorological observing stations in Iran (Figure 1).

Results indicate that only in some stations located in mountain and semi mountain regions EVI and VCI have the highest correlation with precipitation. In the other parts of Iran, the MPDI (96 out of 180 stations) and PDI (36 out of 180 stations) show the highest correlation. According to Figure 2, the MPDI index has the highest correlation with precipitation especially in wet regions such as in the coastal wet and mountain regions. The PDI however shows the best results in some parts of the dry regions such as the desert and semi desert regions (Tables 1 and 2). As a main result, it can be concluded that the two remote sensing indices PDI and MPDI show the strongest correlation with precipitation on monthly basis as well as in spatial distribution. In contrast, EVI and VCI do not show statistically enough significant correlation with precipitation in this aspect.

Table 1. The Spearman's correlation coefficients (*r*) for the PDI, MPDI, VCI and EVI versus precipitation.

Climatic Region	PDI	MPDI	VCI	EVI
Coastal Desert	-.269**	-.228**	.211**	.138**
Coastal Wet	-.323**	-.215**	-.042	-.145**
Desert	-.390**	-.379**	.087**	-.061**
Mountains	-.427**	-.334**	-.044**	-.167**
Semi Desert	-.509**	-.482**	.206**	.012
Semi Mountains	-.501**	-.431**	-.005	-.163**

** Correlation is significant at the 0.01 level (2-tailed).

Table 2. The Spearman's correlation coefficients (*r*) for the PDI, MPDI, VCI and EVI versus precipitation in several months.

Month	PDI	MPDI	VCI	EVI
January	-.047	-.110**	.233**	.193**
February	-.199**	-.162**	.189**	.136**
March	-.321**	-.241**	.183**	.100**
April	-.409**	-.336**	.309**	.222**
May	-.585**	-.468**	.497**	.401**
June	-.507**	-.392**	.426**	.346**
July	-.398**	-.331**	.345**	.275**
August	-.386**	-.278**	.266**	.189**
September	-.504**	-.401**	.298**	.193**
October	-.569**	-.435**	.325**	.178**
November	-.488**	-.358**	.376**	.220**
December	-.183**	-.119**	.195**	.149**

** Correlation is significant at the 0.01 level (2-tailed).

For assessing the temporal distribution of indices and comparison of their fluctuations in several climatic regions, the fluctuations of PDI and MPDI versus precipitation at six weather stations representing the six climatic regions of Iran investigated for the period of February 2000 to December 2005(Figure 2).

Both, PDI and MPDI have in general the same reverse behavior to fluctuations of precipitation in several climatic conditions. Whenever a rainfall occurred, PDI and MPDI showed a decreasing trend and inversely in dry periods (no rainfall period) a significant increasing trend. However, these two indices were still varying in the different climatic zones, which mean that the values of PDI and MPDI are related to the climatic conditions as well. As shown in Figure 3a, 3b and 3d in mountainous areas, represented by stations of Mashhad, Shiraz and Abadan, the fluctuations of PDI and MPDI are very similar to each other. Nevertheless, in the rest of regions there are some differences between fluctuations of PDI and MPDI versus precipitation especially at the station Gorgan (Figure 3f). Additionally, it seems that MPDI represented fluctuations of precipitation better than PDI. This is caused by its structure and the consideration of the factors f_v (the fraction of vegetation defined as the fraction of ground surface covered by vegetation) and R_v,*Red* and R_v,*NIR* (that are pure vegetation reflectance in the Red and NIR bands, respectively), which are very sensitive to dry and wet conditions in vegetated area. This sensitivity has been shown clearly in vegetated climatic regions including the coastal wet, mountain and semi mountain climatic zones which are the most vegetated areas of Iran.

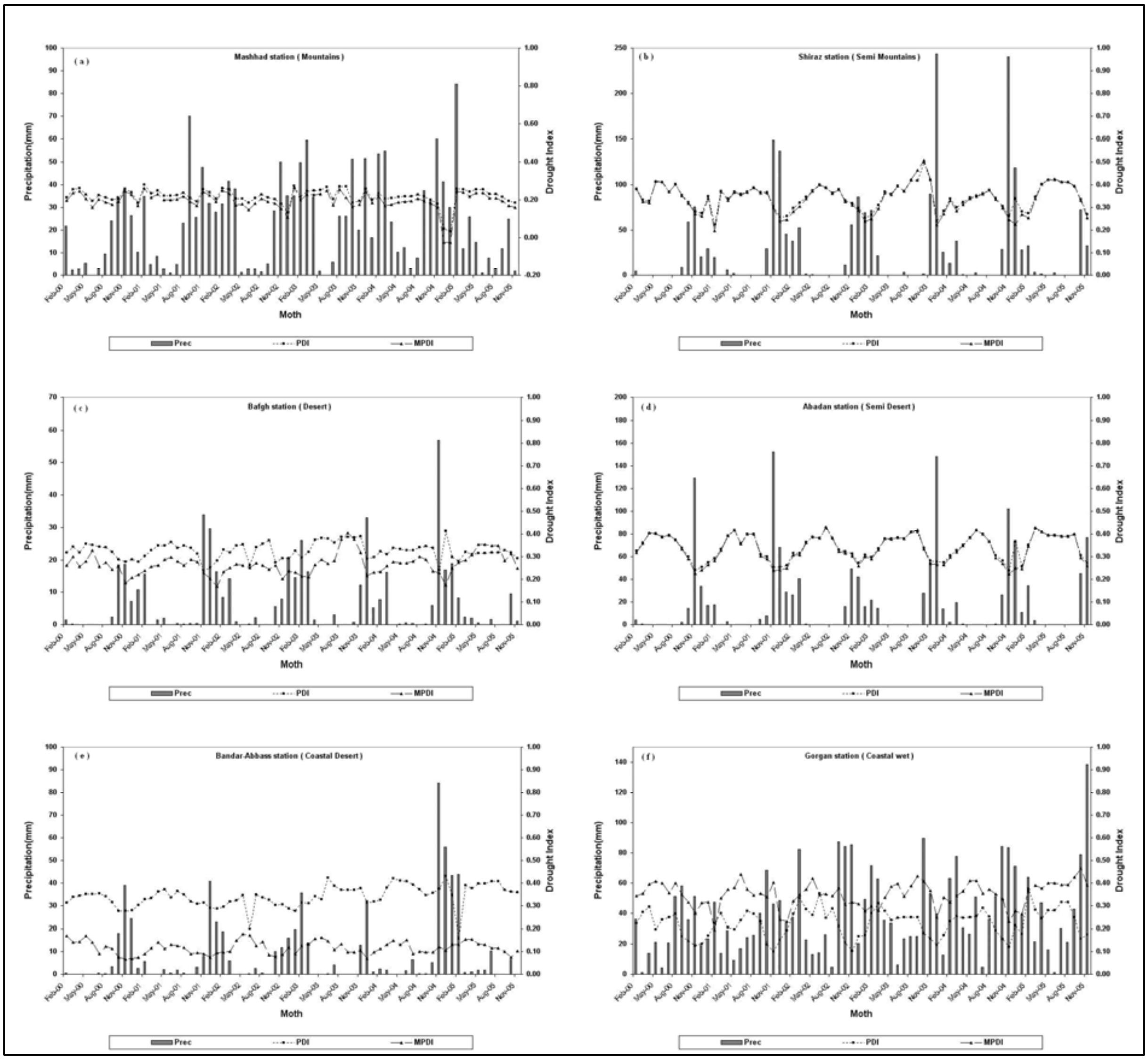

Figure 2. Temporal distribution of remote sensing indices (PDI and MPDI) vs. precipitation during Feb. 2000 to Dec. 2005 of six climatic regions in Iran;
(a) Mashhad station located in mountain climatic region, (b) Shiraz station located in semi mountain climatic region, (c) Bafgh station located in desert climatic region, (d) Abadan station located in semi desert climatic region, (e) Bandar-abbass station located in coastal desert climatic region, (f) Gorgan station located in coastal wet climatic region.
(The X–axis represents the time (month), the left Y-axis represents PDI and MPDI and the right Y-axis represents precipitation (mm). Each panel belongs to a weather station located in one of six climatic regions).

In developing countries gaps in meteorological data in both temporal and spatial scales are frequently observed. Additionally the necessary quality of meteorological data is not always given and significant delay from measurement time and data providing can occur. For that reasons it is suggested to use remote sensing drought indices as a powerful agricultural drought monitoring tool for both vegetated and bare surface as shown in this paper. However, before application, analyzing of thresholds by using field observations is strongly recommended.

Keywords: drought monitoring, drought indices, drought classes, remote sensing.

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HOW TO MONITOR AGRICULTURAL DROUGHT? – A CHALLENGE FOR DROUGHT MANAGEMENT CENTER FOR SE EUROPE

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Abstract

Problem identification
Recent more frequent, severe and prolonged droughts in South-Eastern Europe have emphasized the vulnerability of economy to shortages of water supply, especially in agriculture. It alerted the public, governments and operational agencies to many socio-economic problems accompanying water shortage and the need for drought mitigation measures. Therefore the need to establish a Drought Center for SE Europe to alleviate the problems caused by drought in the area became evident at the end of the past century. The idea was further elaborated by International Commission on Irrigation and Drainage (ICID) and UN Convention to Combat Desertification (UNCCD). The UNCCD national focal points and national permanent representatives with the World Meteorological Organization have agreed upon the core tasks of the Drought Management Center for South Eastern Europe (DMCSEE) and the proposed project document.
In response to the growing concern about the impact of future climate change on water resources and agriculture drought, DMCSEE initiates the research on the evaluation and selection of the most effective and reliable tools for drought assessment in the region.

The purpose of this paper is to document the current status of agricultural drought monitoring of DMCSEE held at the Environmental Agency of the Republic of Slovenia (EARS) and recent progress on this field. It discusses more specifically the usage of The Global Precipitation Climatology Centre (GPCC) data, some preliminary maps of the SPI (Standardized Precipitation Index) and crop water balance modelling for Slovenia, verified with soil water measurements. First products generated by implementation of the NMM numerical weather prediction model are presented.

DMCSEE meteorological drought monitoring
One of the first and very important objectives of DMCSEE is to assess the data available for effective drought monitoring and early warning system. There exists little knowledge regarding the current institutional capacity of DMCSEE member countries in the areas of drought monitoring and early warning, risk assessment, mitigation, and preparedness. As a first step, the DMCSEE will conduct an assessment of institutional capacity, including Meta data available. Further tasks are to ensure data homogeneity and quality control and to design appropriate data base. Recently DMCSEE is directing an increasing share of its efforts to evaluate and select the most effective and reliable indices and indicators for drought assessment.

All types of drought are often described in terms of drought indices, which represent convenient way to integrate great amount of data that relates to drought into a representative value. There exists numerous drought indices, but special consideration should be put on the selection of indices for monitoring different types of drought. The lack of data is usually the most difficult problem to overcome, especially with complex indices. Simple indices, which depend only on precipitation data, are the only choices in regions, where other data are not available or are too scarce. Drought management and impact reduction goals should rely on multiple indicators in order to develop effective drought plans.

The effect of drought on agriculture is best described by amount of water that is available for plant growth during vegetation season and should be measured on the basis of rainfall, potential evapotranspiration and soil moisture indices (Marrachi, 2002). When monitoring agricultural drought, SPI should be used in combination with other indices that also integrate the effect of soil water depletion on evapotranspiration. Same precipitation deficiency can lead to wilting of plants (the state, when plant can no longer establish turgor in cell walls), grown on soil with low available water holding capacity, whereas plants grown on soil with higher water retention capabilities show hardly detectable signs of drought. Most widely used indices, which incorporate that information, are PDSI (Palmer

Drought Severity Index) and agro-hydro potential. Agricultural drought in Hungary was best characterized with SPI on two to three months time scale (Bussay et al., 1998). Study in Slovenia (Ceglar et. al., 2008) revealed that SPI is strongly correlated with PDSI on longer time scales (nine to twelve months), which is also in good agreement with results for Hungary, published by Bussay et al. (1998). SPI on shorter time scales responds more rapidly to precipitation anomalies than PDSI, which makes PDSI more stable in general (Szalai and Szinell, 2000, Ceglar et al. 2008).

The severity of meteorological drought depends on precipitation deficiency, which can be best described by simple indices, such as SPI and percentiles. SPI has several advantages over other indices, namely its standardized nature, flexible time scale and its simplicity (it depends only on precipitation data). SPI can be calculated on different time scales when long-term precipitation data is provided, which makes it applicable in monitoring all types of drought. Weekly or decadal SPI is good indicator of meteorological drought whereas monthly time scale is usually best choice for monitoring agricultural drought. Hydrological drought is caused by longer time period of precipitation deficiency (several months to year).

DMCSEE is currently using SPI and precipitation percentiles for drought monitoring. Percentiles method is simple to use and its results can be used for preliminary analyses (Bonacci, 1993). More indicators are to be implemented into the drought monitor of DMCSEE, such as PDSI and (if necessity occurs) water balance related tools for agricultural drought monitoring purposes. Palfai aridity index (Palfai, 1990) was also proposed, but further research has to be done to use it outside Hungarian climate conditions (Pereira, 1990).

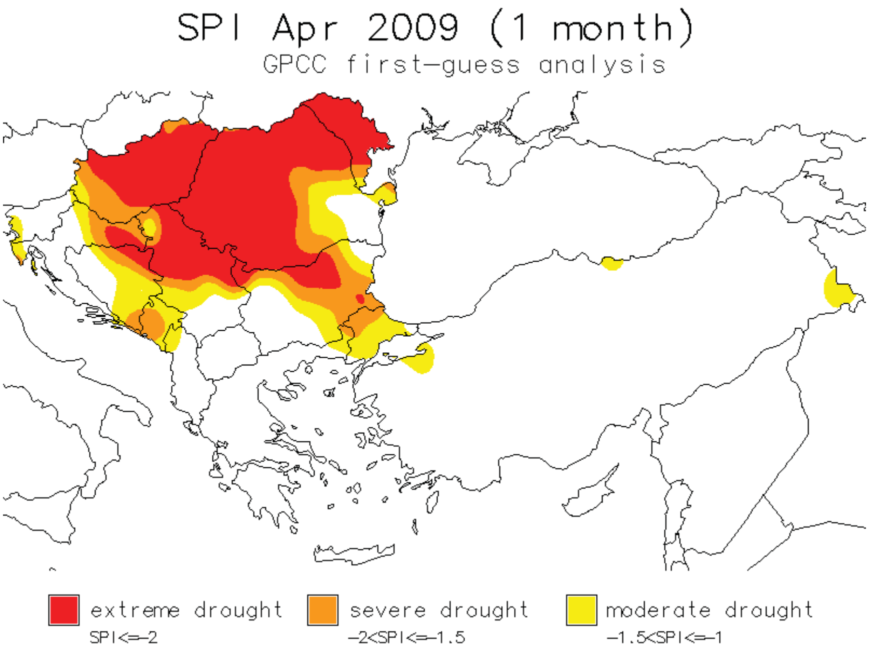

Fig.1. SPI indicates developing extreme drought in April 2009 in most of southeastern Europe.

Using GPCC data, some preliminary maps of the SPI, Percentiles and Precipitation for the region were prepared. Maps are updated twice per month. Final data maps with two months delay are available after 20th day of the current month. First-guess maps are available after 5th day of the next month. Final data are available from January 1986, first-guess from August 2004. For the period 1951-2000 maps are available on the web page www.dmcsee.org.

For making maps monthly precipitation data from GPCC are used. This data are land-only in latitude/longitude format in resolution 1 degree x 1 degree. For calculating monthly percentiles (5, 10, 15, 20 and 25 - with R) data from IMG&GPCC VASClimO (resolution 0.5 degree x 0.5 degree) for all period (1951-2000) are used. For calculating SPI modified version of program from Colorado Climate Center is used. Data are imported into GRASS GIS and interpolated to 100x (50x) better resolution (0.01 degree) with r.resamp.rst (using regularized spline with tension and smoothing). For reprojecting maps into Lambert Conformal Conic Projection (lcc) nearest interpolation method is used.

Crop water use

Specific tasks that are undertaken in DMCSEE projects are designing and building a user-friendly interface for crop water balance monitoring that allows for drilling down to the local level to assess drought and fostering a process of user feedback. It provides the environment to facilitate the integration of different data for water balance modelling and indicates the potential for the drought impacts estimation. The system is currently under work in Slovenia, but some similar decision support systems are also available in the region.

The IRRFIB model is a decision support tool in the frame of agrometeorological information system and enables quick and accurate transfer of information on crop water balance to farmers.

Recently IRRFIB and DMCSEE tools verification is based upon Trime TDR measurements on different soil types and in different climatic regions.

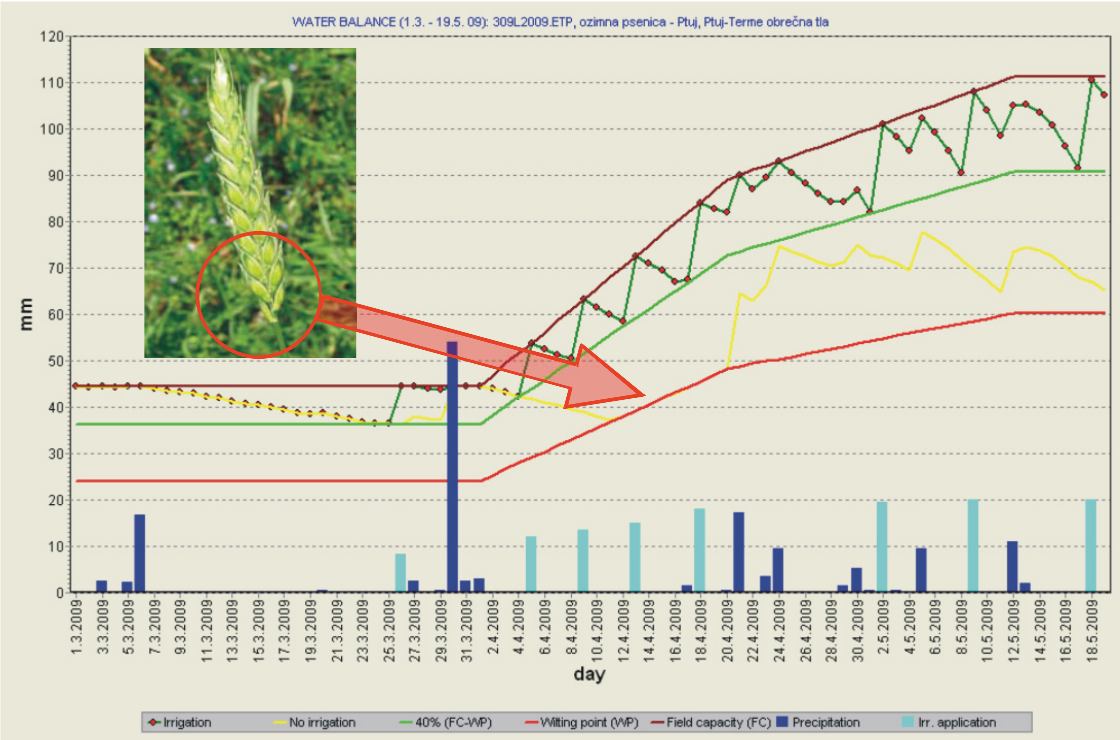

Fig.2. IRRFIB crop water balance modelling: Cereals spikelets development suffered due to drought in northeastern Slovenia in April 2009.

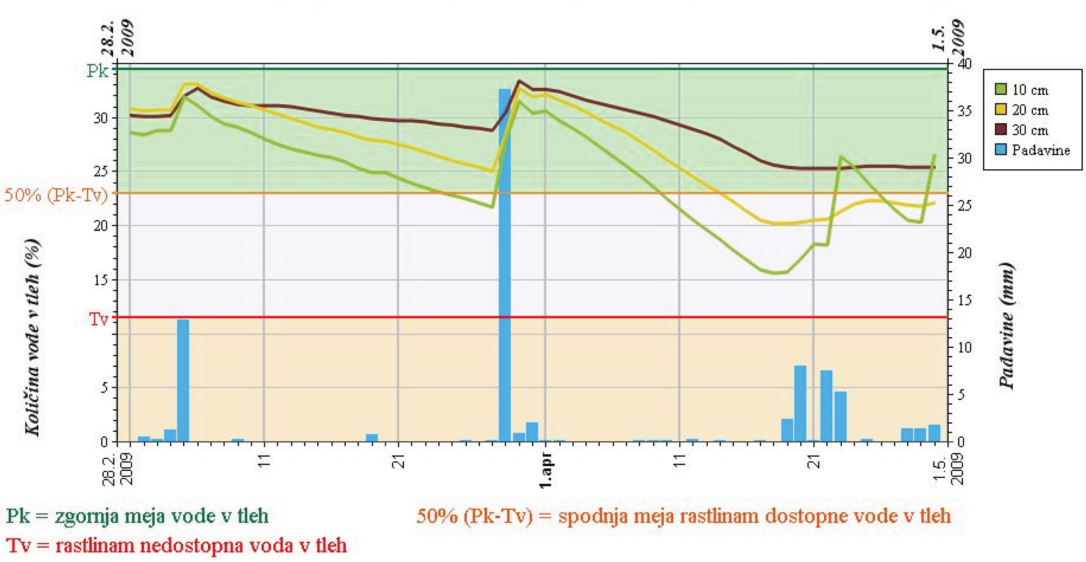

Fig.3. Soil moisture measurements are used for models verification (northeastern Slovenia, March-April 2009).

Use of the NWP model as an analytical tool for drought monitoring
The main goal of using a NWP model is to compute model climatology for some drought related variables using historical reanalyzes and to develop a tool for drought monitoring in the SEE like METEOALARM. Decadal time scale was chosen and deviations from normal values instead of direct model outputs, as well as percentile classes were used.

Historical DMCSEE model climatology was computed by Non-hydrostatical Meso-scale Model (NMM, see: http://www.dtcenter.org/wrf-nmm/users/). NMM was developed by the National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Prediction (NCEP). It is designed to be a flexible, state-of-the-art atmospheric simulation system that is portable and efficient on available parallel computing platforms. NMM is suitable for use in a broad range of applications across scales ranging from meters to thousands of kilometers. The key features of the NMM are: it is fully compressible, non-hydrostatic model with a hydrostatic option; has a hybrid (sigma-pressure) vertical coordinate; uses Arakawa E-grid and forward-backward scheme for horizontally propagating fast waves, implicit scheme for vertically propagating sound waves, Adams-Bashforth Scheme for horizontal advection, and Crank-Nicholson scheme for vertical advection. The same time step is used for all terms.

To get DMCSEE model climatology, the 7305 daily simulations from 1 January 1989 until 31 December 2008 were driven by ECMWF (European Center for Medium Weather Forecast) ERA-Interim data set (see: http://www.ecmwf.int/research/era/do/get/era-interim). Using simulated daily aggregates for some chosen variables (soil moisture, water balance etc.), supposing to describe water availability, some statistics have been computed (mean, standard, deviation, percentile classes etc.) for the entire data time period (1989 - 2008).

Current ECMWF operational data set, truncated to the ERA-Interim horizontal resolution (Cycle T511) is used to simulate ongoing weather patterns, which are compared on a decadal basis to the historical statistics to analyze water availability and get signal on potential ongoing drought severity.

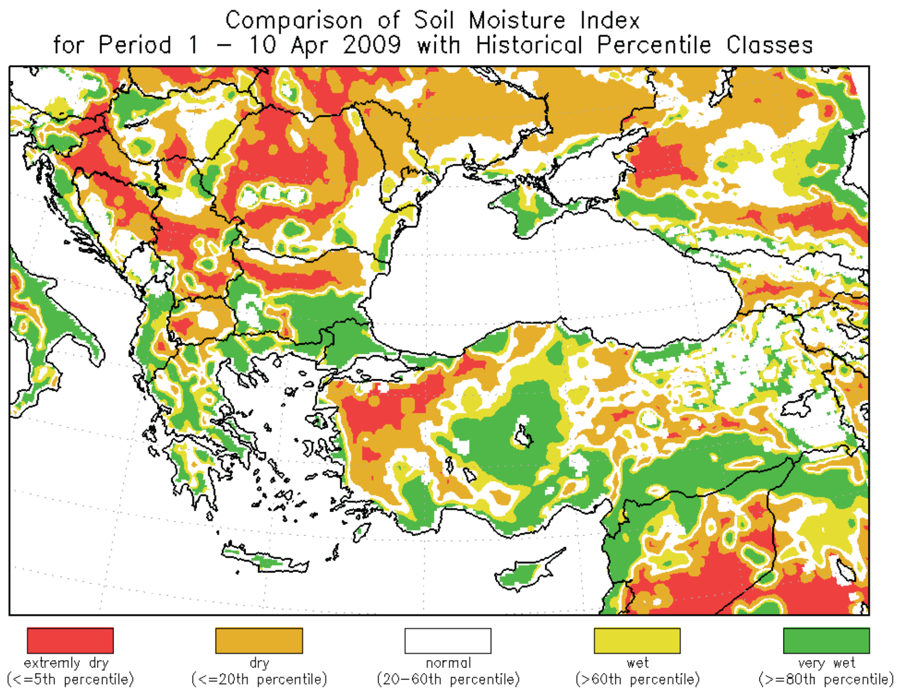

Fig.4. Soil moisture index (NMM model) comparison with historical percentile classes enables drought severity evaluation (10 day summary for first decade of April 2009).

Conclusions
An important aspect is the trade-off between keeping the amount of input data low in order to avoid scaring off new users, and, on the other hand, providing facilities for input of detailed soil, crop and weather data to provide more exact results. It should be understood that drought can not be

interpreted by one field of expertise. Developing more integrated drought monitoring is crucial part of efficient risk management.

DMCSEE is channelling an increasing share of its efforts towards fulfilment of its mission, with the goal of reducing the vulnerability of the agricultural sector to future episodes of severe drought with establishment of a common methodology for drought assessment upon existing experiences and depending on the availability of data. Finally, accurate, timely and wide available information from drought monitoring would enable more reliable decisions in drought management, especially in increasing drought risk conditions.
Unfortunately, aspects associated with global warming appears to got little attention in relation to the future drought contingency planning at national and regional level.

Keywords: drought monitoring, agriculture, SPI, numerical modelling, crop water balance

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PRECIPITATION RELATED CROP YIELD VARIATIONS AND ADAPTION STRATEGIES FOR THE CULTIVATION OF MAIZE IN STYRIA

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Abstract

The problems with the cultivation of maize in the South-East Alpine foothills in Styria have become evident for the first time in 1976. From the 1st of June until the 19th of July in 1976 the precipitation in Leibnitz only reached 26 mm (see tab. 1, R. LAZAR 1977).

Station	Seehöhe m	Juni-Monatssumme mm	% des Mittels 1901/70 (61/70)	maximale Tagesmenge	Summe vom 1.–19. Juli	% des Mittels 1901/70 (61/70)	maximale Tagesmenge	Gesamtsumme v. 1. 6. — 19. 7.	% des Mittels 1901/70 (61/70)
Bad Gleichenberg	292	37	35	10	19	29	13	56	34
Leibnitz	276	17	15	6	9	11	5	26	13
Graz/Thalerhof	342	22	19	6	15	19	7	37	19
Wiel	900	28	(17)	12	7	(7)	3°	35	(13)
Schöckel	1432	25	17	10	6°	6°	3°	31	13
Präbichl	1227	57	32	**19**	53	41	**30**	**110**	36
Judenburg	730	7°	6°	2°	6°	7	5	13°	7°
Aigen/Ennstal	635	59	(54)	**19**	48	(60)	14	107	(56)
Mariazell	865	**62**	39	16	**54**	57	22	106	46

Tab. 1: Distribution of the precipitation during the drought period from 1st of June until 19th of July 1976. Source: LAZAR 1977

In Judenburg in the Upper Mur Valley it was only 13 mm in this period, which led to considerably high deficits especially concerning the hay harvest in this part of the Upper Styria. In the foothills the maize was worst affected. In the middle of July the maize had only reached a height of 50 cm, whereas 150 cm would have been regular at this stage (see Fig. 1).

Fig. 1: Maize field in the Grazer field, July 1976. Source: Band Naturwissenschaftlicher Verein Steiermark, 1977

The second example with huge crop shortfalls was the year 1992. In this case the high temperatures and the low precipitation in August led to this development. In the years to follow there have been problems with droughts especially in the period from 2000 to 2003, as to be seen in the Fig. 2.

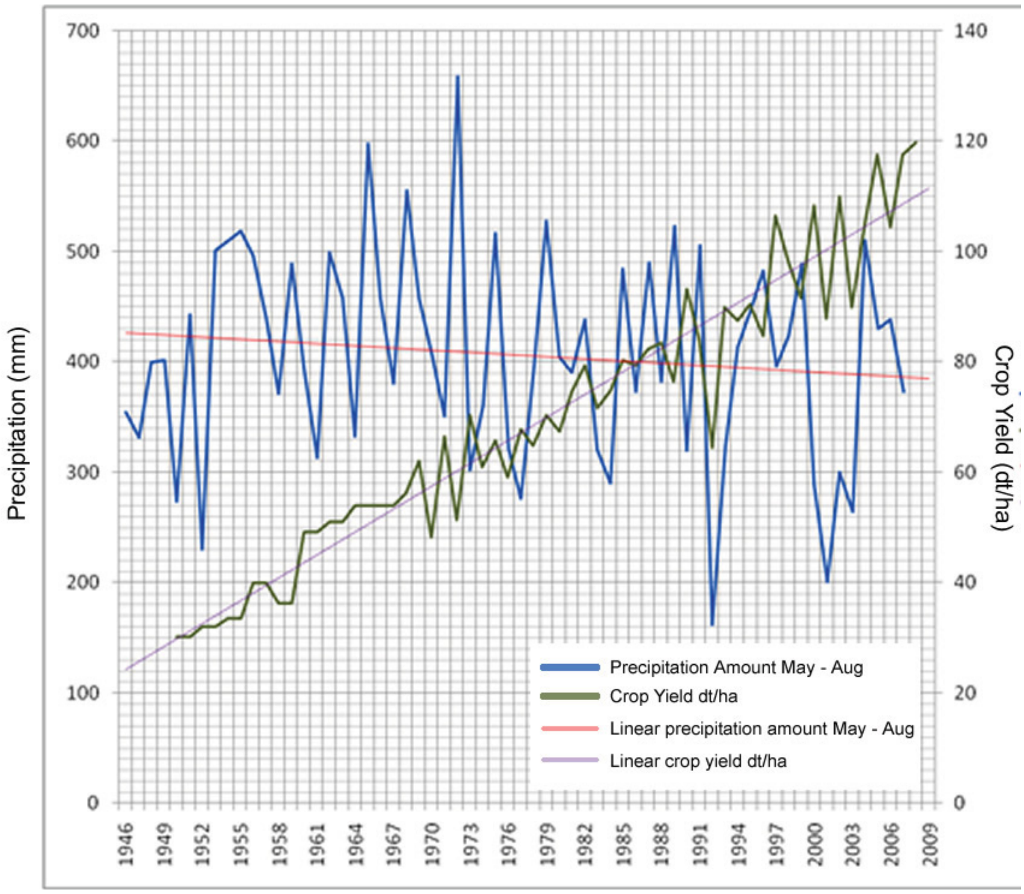

Fig. 2: Precipitation and Crop Yield in Bad Gleichenberg, 1946 – 2008. Source: Landwirtschaftskammer, edited

1992 was more dramatically though; the losses in the period from 2000 to 2003 mostly concerned the dry Würm terrace soils in the Leibnitzer and Grazer Field, but also the Lower Mur Valley. In this basin valley mostly shallow Cambisols on Pleistocene gravel are predominant. The water storage capacity is quite low and generally stays below 100 mm. This is very contrasting to the heavy soils in the tributary valleys, where the amount of fine material is a lot higher.

The climate in this region of Styria has been changing over the last 50 years. The mean summer temperature has risen by about 3K at the station of Bad Gleichenberg and in the same period the mean annual amount of precipitation decreased about nearly 100 mm from 900 to 800 mm. The data indicate strongly towards dryer and hotter summers and therefore a higher risk of stress due to dryness for soils and crops.

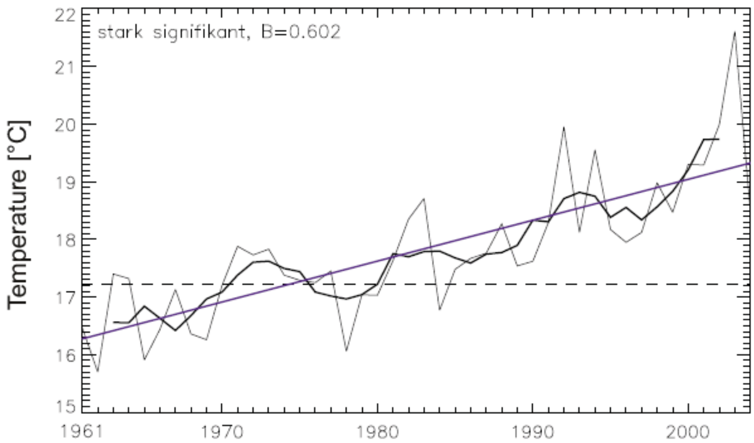

Fig. 3: Mean Air Temperature during the summer in the South-East of Styria from 1961-2004. Source: KABAS 2004

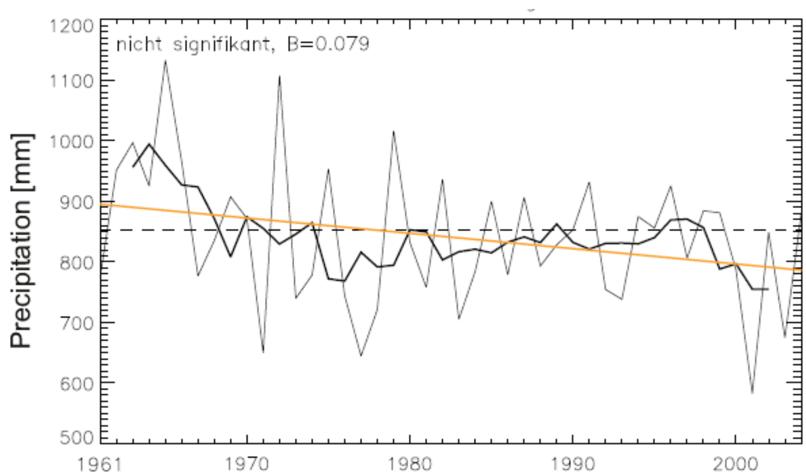

Fig. 4: Mean Annual Amount of Precipitation in the South-East of Styria from 1961-2004. Source: KABAS 2004

The strategy for the adaption to the climate change mainly focuses on the selection of the soils. Maize areas in the slightly sandy soils of the Grazer and Leibnitzer field and sections of the Lower Mur Valley will probably be given up and used by crops more adapted to the changed precipitation conditions like millet; there are still difficulties with millet concerning weeds though. The situation looks much better in the tributary valleys of the foothills with heavy soils. Irrigation as a supportive method is to be excluded due to the insufficient aquifers as well as a variety of maize cultivars being more resistant to dryness due to the legal prohibition of genetic engineering. In the year to come there will be studies in collaboration with the Landwirtschaftskammer of Styria (DI. Arno MAYER) concerning the behaviour of different soils in the area of cultivation.
Another strategy would be the earlier sowing, which will result in a decrease of the risk of soil erosion too. Early attempts in different areas show good results as the maize plants reach a bigger height earlier.

Keywords: crop yield, maize, precipitation, temperature, soils

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CLIMATE CHANGE AND AGRICULTURE - IMPACTS, MITIGATION AND ADAPTATION MEASURES IN POLAND

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Abstract

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 they affect the functioning of the natural environment and agriculture - the sector of economy with closest relations to nature. These changes are manifested worldwide, including Europe and Poland. It is important 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 country. This abstract contains selected results of studies of the Polish group of experts, who have identified hazards and proposed potential actions adapting agriculture to climate change. It describes already visible climatic changes effects in Poland. A gradual increase of temperature has been confirmed (Fig. 1.), which is manifested primarily in a decrease of differences in a mean temperature of spring (an increase in temperature) and autumn (no significant change).

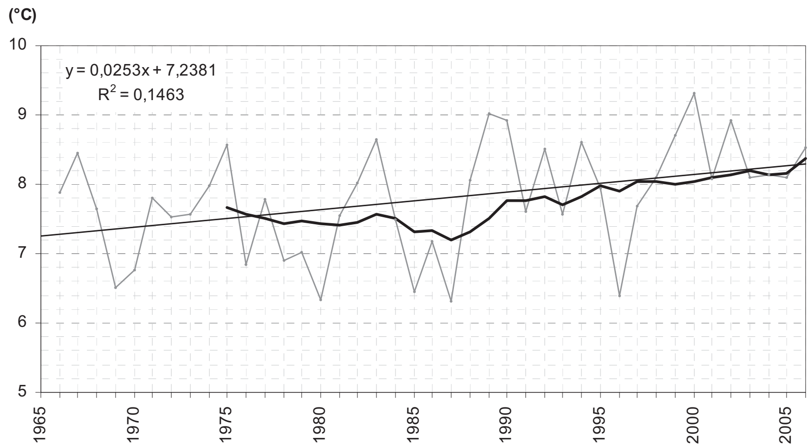

Fig. 1. Mean annual and decadal (thick line) air temperatures (°C) in the area of Poland and trend line for 1966-2006 (Mager et al. 2009).

The most important factors/weather phenomena impacting the crop growth/development during winter and vegetation periods under climatic conditions of Poland proposed by Czarnecka, Koźmiński and Michalska (2009) are listed below.

Plant wintering period: adverse weather conditions in the autumn during frost hardening of winter crops, incidence of subzero temperature (at 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.

Vegetation period: delayed beginning of the following periods: economic (>3ºC), vegetation (>5ºC), active plant growth (>10ºC) and ripening (>15ºC), 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 a 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.

In warmer climate conditions, some of the factors listed above will have relatively bigger impact on plant development and will cause higher yields loses.
Due to increasing occurrence frequency of these hazards the mean annual reduction of yields in Poland ranged from 6 to 18%. The highest losses were 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% (Czarnecka 1997, 1998, 2004, 2005, Czarnecka, Koźmiński and Michalska 2009, Koźmiński and Michalska 1998, 1999, 2000 a,b; 2002, 2005 a,b,).

Actions and measures for mitigating the effects of droughts are the challenge that planners, designers, farmers, agricultural and extension services will have to cope with. The actions should modify the needs of water users to force them for saving water during droughts. A modification of the technology of water use on farms and in the field should play a great role (Łabędzki 2009).

Particular actions and measures proposed by Łabędzki (2006, 2007, 2009) 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 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 evapotranspiration,
4. improvement in the social awareness of droughts, their effects and countermeasures.

Expected climate warming in Poland will provide conditions conducive to extension of geographical range of more therophytic species. At the same time, changes will be observed also in cropping patterns, especially in terms of the extension of cultivation of more therophytic species and the introduction of new species, and along them - the appearance of new agrophages and intensified incidence of many native pests. Intensifying overdrying of topsoil will require changes in cultivation methods, simplified tillage, which result in changes in the incidence of presently reported agrophages.
The primary task, in terms of response to changes in the harmfulness of agrophages as a result of progressing climate warming, is to develop scenarios and analyses of increased risks caused by the presently occurring agrophages, as well as develop risks analyses concerning the penetration of new agrophages to Poland, including quarantine and invasive species. Agrophages registration and forecasting are primary tasks carried out by the plant protection and seed production inspection services, supported by the activity of research centres. Model studies, based on computer simulation programs, e.g. Climex or Dymex, needs to be carried out to develop forecasting tools. Another essential task is to develop effective methods and ways to delay the occurrence of agrophages in Poland by the consistent realization of adequately specific, efficient, detailed quarantine regulations, followed by programs to reduce population growth of both new and native agrophages. In the latter case, existing plant protection programs will require appropriate specification, especially since climate changes lead to changes in the incidence and extension of occurrence of numerous agrophages.
A positive effect of climate change may be a phenomenon observed together with the inhabitation of new agrophage species, i.e. the appearance of their natural enemies, such as e.g. a lady-beetle *Harmonia axyridis*.

Pests
Forecasts prepared so far indicate that it is necessary to develop or adapt appropriate plant protection programs resulting from an increased hazard to crops by at least the following pests: aphids and other insects from orders of both homopterans and heteropterans, thrips, mites and dart moths. It has to be expected an increased hazard for maize cultivation posed by European corn borer, Western corn rootworm and knot grass, especially in view of the further expected increase in the area cropped to this plant species. The importance of Colorado beetle is also going to increase. We need to expect an increased hazard for rape posed by *ceutorrhynchid* beetles in the autumn season. With an intensified occurrence of aphids the hazard for crops posed by viral diseases will also increase, thus it is also necessary to modify both cultivation technologies and viral disease control programs in specific cases.
It will be necessary to develop the best methods to detect, monitor as well as implement realistic methods of effective response during the first focuses of infection after species from southern Europe penetrated to Poland, such as San Jose scale and fall webworm.

Diseases
Forecasts of disease incidence in Poland indicate that the hazard to plants by viral, bacterial and fungal diseases, as well as those posed by other disease agents will increase. We need to expect an increased importance of such cereal diseases as powdery mildew, barley rust, yellow rust, barley scald and septoria leaf spot. A higher hazard will be posed for beets by cercospora leaf spot, powdery mildew and rhizomania. A higher hazard than that reported to date will be observed for rape by dry-rot of cabbage. In Poland population size of species from genus *Phytophthora* will increase, the range of some of the species, to date reported in indoor cultures, will be expanded to outdoor areas. Thus, a necessary task will be to specifically develop existing plant protection programs.

Weeds
Climate warming will create conditions conducive of the development of therophytic weed species, primarily earlier dates of their appearance in cropped areas. It seems necessary to further develop protection technologies for individual crops. We need to expect that species from southern Europe will penetrate to Poland, among which the most dangerous species will be ragweed. It is also forecasted that the development of phytophages on weeds will be accelerated, which will facilitate their more effective reduction and potential purposeful introduction of biological protection in relation to such species as bent-root amaranth, European glorybind and meadow buttercup. It seems advisable to further develop existing crop protection programs against weeds, especially as the efficiency of herbicides may be reduced in relation to deeper rooted weeds from species classified as C3 plants (in terms of photosynthesis).

The above mentioned changes have already affected agriculture in Poland 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 these hazards several adaptation strategies have been proposed. However, it needs to be stressed that they have to be implemented in a comprehensive way 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: impact of climate change on agricultural, hazards and potential actions adapting agriculture to climate change, supporting agricultural policy.

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ASSESSMENTS OF CROP WATER STRESS IN EASTERN EUROPE UNDER PRESENT-DAY CONDITIONS AND FUTURE CLIMATE SCENARIO

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Abstract

Water limitations on crop productivity are expected to increase in the coming decades as a consequence of climate change and variability. This study as a part of CLAVIER EU project (Climate Change and Variability: Impact on Central and Eastern Europe) investigates the impacts of climate change on the likelihood and intensity of crop water stress in selected areas of Romania (AGRIROM) and Bulgaria (AGRIBUL) (see Fig.1) for the decades 1976-1985 and 2041-2050. AGRIROM is situated in North-West of Romania and ranges from the Pannonian basin to the eastern Carpathians. AGRIBUL is located in North-East of Bulgaria and is delimited by the Danube to the North, the Black Sea to the East, the Balkans to the South, and the Lom River to the West. A simple water balance model used climate model data from REMO57-A1B for the period 1951-2050. Additionally, soil properties from the European Soil Database (ESDB) were included for the purpose (ESDAC, 2009).

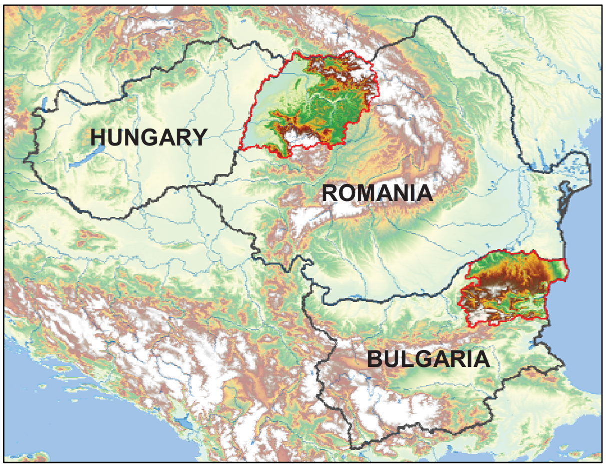

Fig.1. Study areas

In this study crop water stress were computed as the ratio [0-1] between the amount of water which can actually evapotranspirate on the base of soil water availability (actual evapotranspiration) and the amount of water which can potentially evapotranspirate (reference evapotranspiration) under current weather conditions and crop growth stage (crop evapotranspiration).

The model is based on the FAO-Penman-Montheith model (Allen et al., 1998) and allows to compute the daily water balance for a certain crop and at a specific location, starting from meteorological data (temperature, precipitation, wind, humidity, and global radiation) and information on soil properties (field capacity).

As different crops exploit different periods of the growing season for their development and growth, calculations were carried out for two different time steps, the winter and summer crop periods (Allen et al., 1998). The present analysis is limited to four representative crops, namely winter wheat and barley for the winter crop period, and maize and sunflower for the summer crop period. Within each period, the life-cycle of the respective crops was subdivided in five subsequent stages, namely initialisation, development, mid and late season, and end (see Fig. 2). All processed data were integrated into a Geographic Information System (GIS).

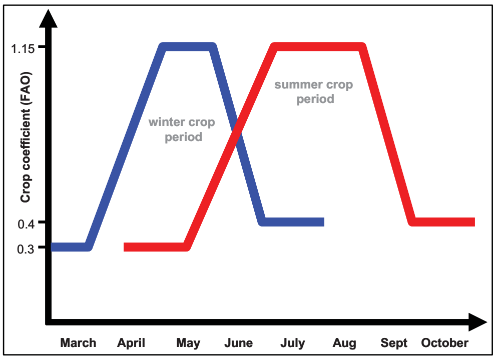

Fig.2. Crop Coefficient for winter and summer crop period

Reference evapotranspiration (ET_0) describes the potential water vapour loss (in mm) occurring on a standard vegetated surface with sufficient water availability as sum of atmospheric evaporation and plant canopy transpiration (see Fig.3). Crop water stress represents the relation between actual evapotranspiration and potential crop evapotranspiration (ET_0 * Crop Coefficient).

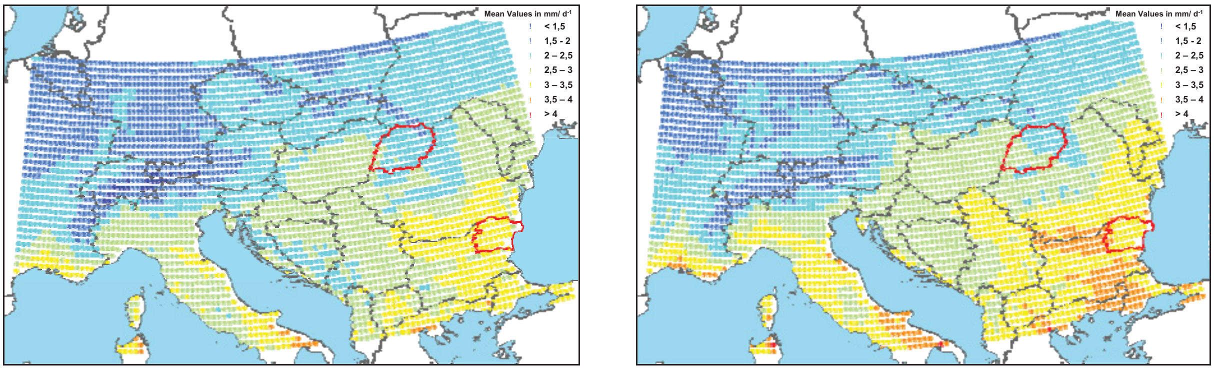

Fig.3. Average reference evapotranspiration (ET_0) across the CLAVIER domain in the decades 1976-1985 (left) and 2041-2050 (right) in 25 km resolution

The results showed a generalized increase of crop water stress by 2041-2050. Climate change impact on crop water stress are expected to be slightly higher in North-West of Romania than in North-East of Bulgaria (see Fig.4). While the initialisation and development stages will rely on sufficient water availability also in the coming decades, subsequent growth stages will be hit by increasing water limitations. In particular, the late and end stages of the winter crop period and the mid and late stages of the summer crop period will experience much drier conditions than in the reference decade. Water stress is expected to raise the most in plain regions, where the bulk of agricultural land is concentrated. Contrarily, mountain areas appear to be weakly affected by water stress increase.

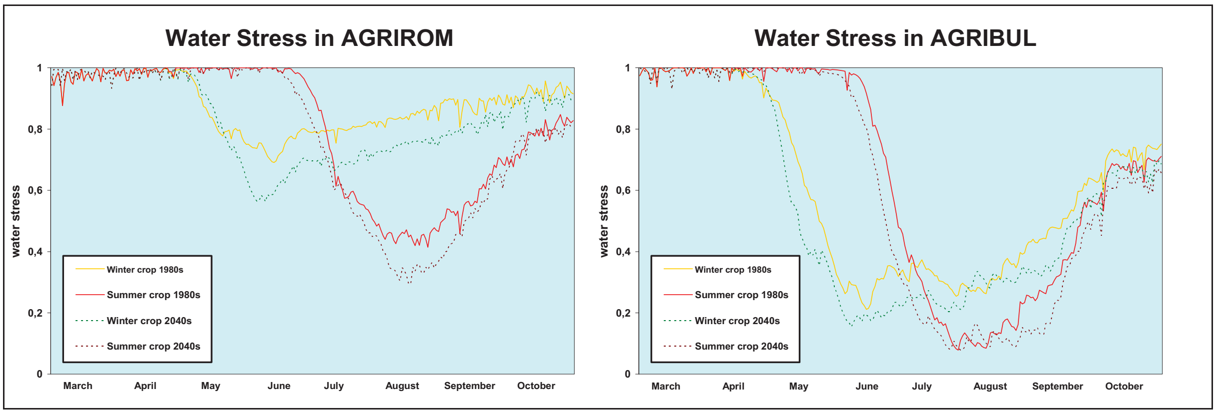

Fig.4. Water Stress (none = 1; high = 0) in AGRIBUL and AGRIROM (mean values of all grid points across the winter and summer crop periods of each decade)

If water scarcity becomes more severe, current farming practices (business as usual) can hardly be maintained. The shift from summer crops to winter crops, the cultivation of premature verities with short life cycles and the development of drought-tolerant varieties may represent meaningful adaptation strategies. However, in areas with particularly severe drought problems, irrigation for specific crops will become indispensable.

Keywords: climate change impact, agriculture, water stress, evapotranspiration

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