Project No. 037005

CECILIA

Central and Eastern Europe Climate Change Impact and Vulnerability Assessment

Specific targeted research project

1.1.6.3.I.3.2: Climate change impacts in central-eastern Europe

D 6.8: Recommendations and development of management options for an improved land use systems in agriculture crop production and forest management under the regional climate change scenarios

Due date of deliverable: 43

Actual submission date: 43

Start date of project: 1st June 2006 Duration: 43 months

Lead contractor for this deliverable: National Forest Centre – Forest Research Institute Zvolen (FRI)

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

CONTENTS

1 AGRICULTURE – THE MARCHFELD REGION (AUSTRIA)

1.1 Used climate scenarios

For this deliverable following climate scenarios were available:

- **RCM: ALADIN-CLIMATE/CZ - CHMI**
  - Lateral boundary conditions (LBC) (driving model): ARPEGE-CLIMATE
  - Resolution of LBC: ~50 km
  - RCM domain: Lon: 7-27E; Lat: 44-51N
    - historic 1961-1990
    - ERA 40 1961-2000
    - GCM 2021-2050
- **Global circulation models: ECHAM 5, HadCM 3 and NCAR PCM - IAP**
  - Climate sensitivity (emission scenarios):
    - high: +4.5 K per doubling ambient CO_2 (B1)
    - middle: +2.6 K per double ambient CO_2 (A2 and B2)
    - low: +1.5 K per doubling ambient CO_2 (A1B)
  - daily weather generator is linked with the monthly weather generator (it should better reproduce low-frequency variability)
  - only changes in the monthly means are taken into account by the monthly weather generator
  - periods: 1961-1990 and 2021-2050

In a first step the RCM historic run as well as ERA 40 for the period 1961-1990 were compared with measured data from the weather station Gross-Enzersdorf in order to see if the RCM data fit in the investigation area Marchfeld. In figure 1.1 Kelvin changes of T_{max} (maximum temperature) and T_{min} (minimum temperature) of the RCM to the measured data are showed.

The annual T_{max} is a little bit overestimated in ERA 40 (0.2 K higher as the measured data), but underestimated in the historic run (0.1 K). The underestimation is in both runs particularly high during winter and spring time. T_{min} shows a bigger bias as T_{max}. In ERA 40 as well as historic run the annual T_{min} is higher as the measured data and the overestimations are especially strong from May until October.

T_{max}

Annual mean values:
Gross-Enzersdorf: 14.2°C
ERA 40: 14.4°C
Historic run: 14.1°C

T_{min}

Annual mean values:
Gross-Enzersdorf: 5.5°C
ERA 40: 6.5°C
Historic run: 6.1°C

Monthly differences:

Monthly differences:

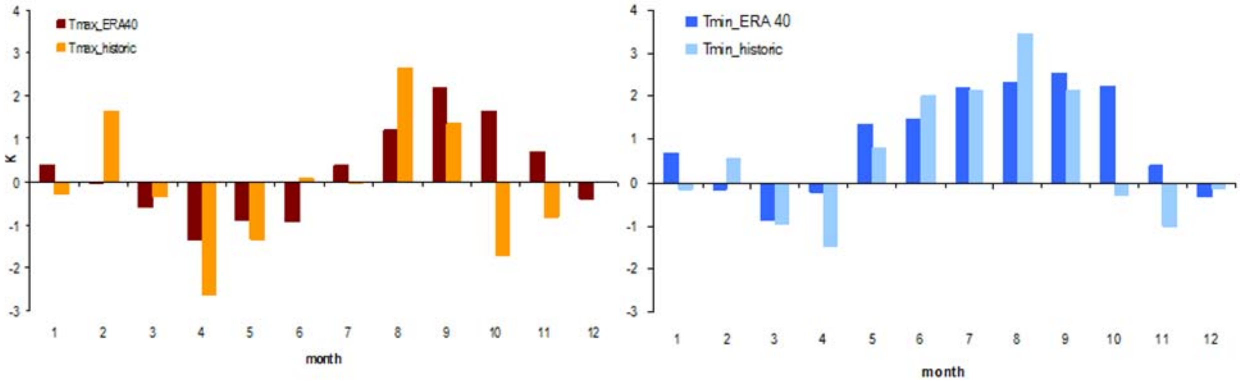


Fig. 1.1 *1961-1990 Kelvin changes [K] T_{max} and T_{min} of RCM to measured data of the weather station Gross-Enzersdorf*

Percentage changes of precipitation between RCM and measured data of the weather station Gross-Enzersdorf are showed in figure 1.2. In particular the historic run evinces big differences between the measured data and values over 70 % could be unhide.

Annual sum:
Gross-Enzersdorf: 550 mm
ERA 40: 570 mm
historic 628 mm

monthly differences:

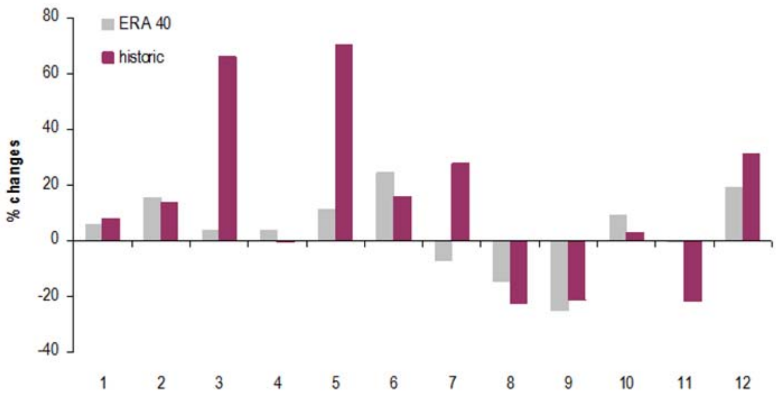


Fig. 1.2 *1961-1990 percentage changes [%] precipitation of RCM to measured data of the weather station Gross-Enzersdorf*

Such differences in temperature and precipitation have a big effect on the crop model output. In figure 1.3 the percentage changes of the mean winter wheat and spring barley yield of RCM inputs in comparison to the measured date of the experimental side Fuchsenbigl, Marchfeld, from 1961 until 1990 are showed. For winter wheat in all 5 soil classes (detail description of the soil classes can be found in D 6.1) the RCM overestimates the yields up to 12%; for spring barely an underestimation up to 10% can be noticed.

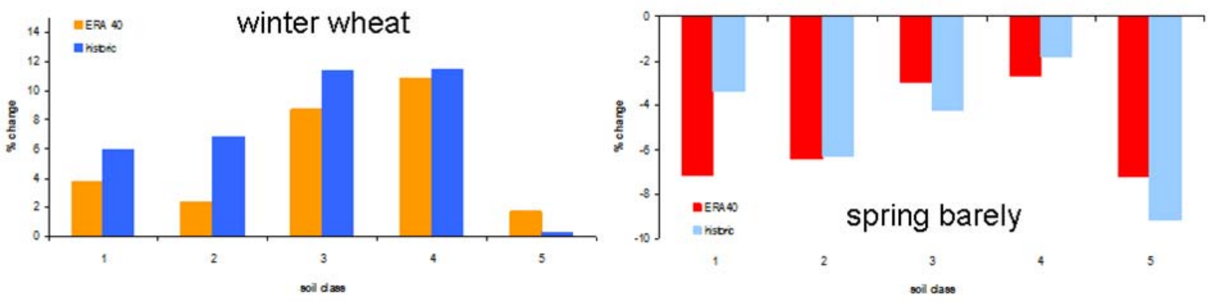


Fig. 1.3 *1961-1990 percentage yield changes [%] of RCM to measured data of the experimental site Fuchsenbigl, Marchfeld, for winter wheat and spring barely*

Since the differences between measured data and RCM outputs are so huge, a correction of the RCM data before using them as model input is necessary. This correction is supposed to be done from workpackage 3 but unfortunately it is not yet available. So far for the last deliverable the global circulation models ECHAM 5, HadCM 3 and NCAR PCM from IAP is been used.

1.2 Expected impacts of climate change on selected crops in the region Marchfeld

Climate change impacts in the region Marchfeld until 2035 according to the GCM scenarios can be summarized as follow:

- increase of the temperature
- less precipitation in summer, but more in winter months
- decrease of snow cover duration
- increase of relative frost risk
- increase in water shortage

These changes have also a big effect on the main crops in the target area:

- different phenological development stages of the main crops will append earlier and quicker due to higher temperature
- vegetation period will last longer
- CO_2 fertilizing effect
- changes in activity of pests and diseases
- less harvestable yield
- higher yield variablitly
- reduction in suitable areas for traditional crops

In D 6.6 the relative change of yield in 2035 from 3 crops (winter wheat, spring barley and maize) to the present conditions were presented (fig. 1.1-1.3). The results of the simulations indicate a shortening and an earlier occurrence of phenological development stages of the crops, as well as mostly yield stagnation or decrease in the near future.

Impact of the changed weather conditions in ECHAM5 and HadCM3 on winter wheat would lead to a yield depression until 2035 (the only exception is soil class 4 HadCM3 high), which would be most distinct on sandy as well as shallow soils in Marchfeld (soil class 1 and 2). Only NCAR PCM presents a slight increase of winter wheat yield on medium soils. In these simulations the atmospheric CO_2 enrichment according to the selected emission scenario until 2035 is already included. The yield decrease is caused primarily by a shortened growing season and by reductions in precipitation during the crop-growing season. The CO_2 fertilizing effect can not offset this yield drop.

Also for spring barley a yield loss in the Marchfeld region until 2035 can be expected. Light soils show the highest yield decrements (up to -15 % ECHAM5 high), medium soils yield changes between 0 (NCAR PCM high) and -8 % (ECHAM5 high) until 2035. Only NCAR predicts a yield increase for soil class 4 and 5 of up to 4%.

The decrease in simulated spring barley yield in 2035 is mostly caused by reductions in rainfall. Most GCM's simulate a decrease in precipitation from April to October, which affects soil moisture recharge during the growing period of barley in spring.

Maize shows similar, but more extreme, results: ECHAM 5 and HadCM 3 predict yield depression until 2035 on all soil classes up to 70%; on the other hand NCAR PCM shows yield increase up to 20 %.

The interannual yield variability of these 3 crops would increase for almost all soils, which leads to a higher economic risk for farmers. Without fertilizing CO_2 effect, mean yield would stronger diminish, especially on sandy and shallow soils.

1.3 Recommendations and development of management options for an improved land use systems in agricultural crop production under the climate change scenarios

A number of agronomic adaptation strategies can be recommended to avoid or reduce negative climate change effects and exploit possible beneficial options. Hereby short-term adjustments and long-term adaptation can be differentiated. The first ones imply changes in planting dates as well as cultivars, changes in external input like irrigation, and techniques to conserve soil water. Long-term adaptations include major structural changes to overcome disadvantages caused by climate change. Land use, breeding and biotechnology applications, crop substitution as well as changes in farming systems are some examples for long-term adaptations (Alexandrov et al. 2002).

Soil water should be assured until autumn and evaporation should be reduced in the target area. Following possible short term adaptations at farm level can be here named:

- a shift of average sowing dates
- a replacement of ploughing by minimum tillage and direct drilling
    - leads to an increase of plant available field capacity
    - better water supply for the cereal crops
    - decrease of unproductive water losses
- surface mulch (reduction of evaporation)
- crop rotation (less summer crops)
- support irrigation and improved irrigation efficiency

For this deliverable a shift of average sowing dates, a replacement of ploughing by minimum tillage and direct drilling as well as support irrigation and improved irrigation efficiency for winter wheat and spring barley were studied.

A change of planting dates in the future was already assumed in the simulations. It can be seen as a no-cost decision, which can be taken at the farm-level. On the other hand, a large shift in sowing dates could interfere with the agro-technological management of other crops, which grow during the rest of the year (Alexandrov and Hoogenboom 2000). For the Marchfeld region this argument is not so relevant: the sowing date for winter wheat would be later in autumn and more time for other cultivars would be available; before spring barley only intertillages are growing.

On the next step soil moisture conserving practices like minimum tillage and direct drilling were analysed for winter wheat and spring barley. A replacement of ploughing by minimum tillage and direct drilling can improve water supply for the crops and decrease unproductive water losses.

Within the 2035 scenario a replacement of ploughing by minimum tillage and direct drilling leads to an increase of mean yield for winter wheat up to 3% (area-weighted average NCAR PCM high). In particular on sandy and shallow soils (soil class 1) minimum tillage enhances yield potential up to 10% (Fig. 1.4). The water use efficiency for plant (WUE_{plant} [kg mm^{-1} ha^{-1}] = Yield/Transpiration) is in average 1 kg mm^{-1} ha^{-1} lower than on ploughed soil. For the other four soil classes WUE_{plant} values are between +0.2 (NCAR PCM low) and -0.5 (NCAR PCM middle) kg mm^{-1} ha^{-1} in comparison to ploughed soil.

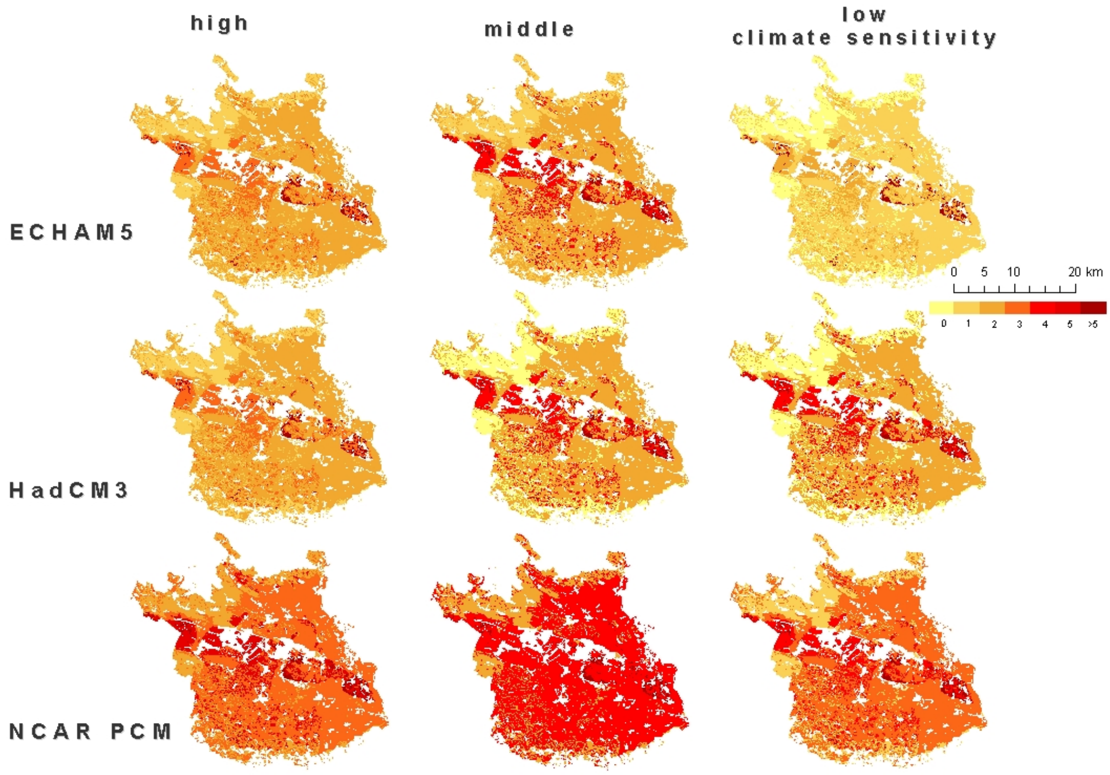


Fig. 1.4 *Relative change of winter wheat yield [%] if ploughing is replaced by minimum tillage in the Marchfeld region in the 2035 scenario*

For spring barley yield a change to minimum tillage would also have a positive effect. Yield loss on ploughed soil could be reduced by up to 4 % (area-weighted average HadCM3 high). The highest benefit of minimum tillage could be simulated based on the three GCM's with high climate sensitivity. Yields in almost the whole investigation area could benefit up to 6%. In the scenarios with middle and low climate sensitivity the highest advance could be found on sandy soils (soil class 1) (Fig. 1.5). Here the WUE_{plant} is in average 0.6 kg mm^{-1} ha^{-1} lower as on ploughed soil.

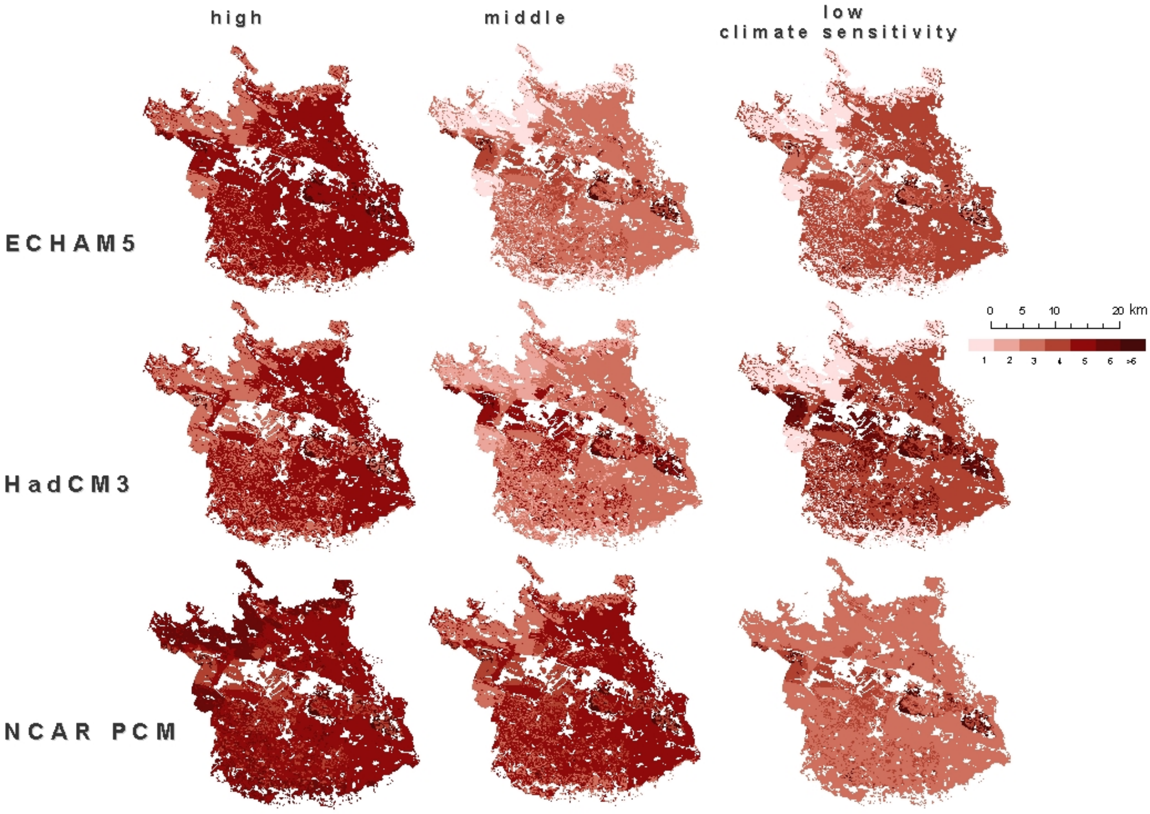


Fig. 1.5 *Relative change of spring barley yield [%] if ploughing is replaced by minimum tillage in the Marchfeld region in the 2035 scenario*

Presently in the Marchfeld region wheat and barley fields are not irrigated due to economical reasons. Irrigation systems in the target area are existing and in use for other cultivars. Whether in future a utilization of these systems for the two analyzed crops will be reasonable, will be a decision of the agro-economics.

In order to answer the question related to the quantity of water required in the near future in the study area to stabilize yields, the simulation option "automatic when required" for irrigation and water management was activated in the model. ECHAM5 and HadCM3 scenarios lead in the main line to similar results for wheat irrigation. The highest extra amount of water due to climate change (over 30 mm on soil class 3) would be required on medium soils. The sandiest soils show already today very low yields at full irrigation and additional irrigation would not help to obtain better results. NCAR PCM is the wettest scenario and predicts the lowest water requirement in the future. The crops can use the positive effect of the higher winter precipitations, especially those on March. NCAR PCM with high climate sensitivity predicts that even less water would be necessary to obtain the same yield like today (Table 1.1). A reason is the annual precipitation with 560 mm, which is around 6.3 % higher than today. Middle and low climate sensitive scenarios propose a little bit more water for the medium, and no need of additional water for the sandy soil classes.

Table 1.1 *Changes of irrigation water requirements [mm per year] for winter wheat in the Marchfeld region 2035 in respect to present conditions*

	ECHAM high	ECHAM middle	ECHAM low	HadCM high	HadCM middle	HadCM low	NCAR high	NCAR middle	NCAR low
soil 1	-10	-4	0	-10	-2	2	-30	-20	-13
soil 2	25	28	26	30	28	25	-10	-2	2
soil 3	33	34	32	36	34	32	0	5	19
soil 4	29	29	28	31	29	29	-3	3	8
soil 5	14	17	17	14	17	17	-11	-4	1

For spring barley the two scenarios ECHAM5 and HadCM3 also simulate similar trends. The differences of water requirements in all five soil classes are comparable and around 33-42 mm (area-weighted average) more irrigation water per year would be needed to obtain the same yield like today. NCAR PCM results - as wettest scenario – consequently lower values (between -2 and 18 mm per year) (Table 1.2).

Table 1.2 *Changes of irrigation water requirements [mm per year] for spring barley in the Marchfeld region 2035 in respect to present conditions*

	ECHAM high	ECHAM middle	ECHAM low	HadCM high	HadCM middle	HadCM low	NCAR high	NCAR middle	NCAR low
soil 1	29	26	28	26	26	27	-2	10	2
soil 2	36	32	34	40	35	37	7	15	10
soil 3	38	32	35	41	33	37	13	16	13
soil 4	44	37	41	46	40	45	11	18	14
soil 5	31	28	31	32	30	33	5	12	7

1.4 Summary

Higher temperatures and lower summer precipitation in the next decades imply higher water demand for the main crops in the target area Marchfeld, NE Austria. If not compensated by irrigation, longer and more frequent phases of drought and heat stress can occur. Higher temperatures will also shorten the growth period especially of winter wheat. Time available for photosynthesis and assimilation will be reduced, resulting in yield depression. Rising CO_2 concentrations in the atmosphere will partly mitigate drought stress by allowing higher water use efficiency of crops by stomata control. CO_2 also has a fertilizing effect on cereals producing larger and more vigorous plants, higher total dry matter yields and, mostly, greater quantities of harvestable products (Acock and Acock 1993) This effect will partly compensate growth depression.

For the crop model input were used the GCM ECHAM 5, HadCM 3 and NCAR PCM with different emission scenarios. The bias of the RCM was too big and could not be used for the target area. Hereby a correction of the RCM data before using as model input is necessary.

Nine scenario sets for 2035 (2020-2050) were used to estimate the uncertainty of climate change impact on the future winter wheat and spring barely yields. The results of the simulations indicate a shortening and an earlier occurrence of phenological development stages of the two crops, as well as yield stagnation or decrease in the near future. An exception presents NCAR PCM, with a slight increase of winter wheat as well as spring barely yield on medium soils. The interannual yield variability of both crops would increase for almost all soils, which leads to a higher economic risk for farmers. Without fertilizing CO_2 effect, mean yield would stronger diminish, especially on sandy and shallow soils.

As recommendations and development of management options for an improved land use systems in agricultural crop production under the climate change scenarios a shift of average sowing dates, a replacement of ploughing by minimum tillage and direct drilling as well as support irrigation and improved irrigation efficiency for winter wheat and spring barley were studied. A replacement of ploughing by minimum tillage and direct drilling within the 2035 scenario would lead to an increase of mean yield of winter wheat (up to 10 %) and of spring barely (up to 8 %) in 2035. This effect is mainly a result of improved water supply for the crops and a decrease of unproductive water losses. Compared to current conditions optimal irrigation of winter wheat would require between -3 and 33 mm more water per year (area-weighted average) in 2035. Irrigation of spring barley had to be increased between 11 and 42 mm per year (area-weighted average). Further recommendations for the target area would be crop rotation (less summer crops) and surface mulch (reduction of evaporation).

2 FOREST ECOSYSTEMS – THE SLOVAK REPUBLIC

2.1 Introduction

Recommendations proposed in this deliverable are based on several impact studies conducted in Slovakia (the Central Europe) and on broader European research on climate change impacts on forest. Wide span of natural condition of Slovakia, from lowlands to high mountains, allows for transferring the obtained knowledge to other European regions. The country belongs to the Temperate Continental Bioclimatic Zone (Rivas-Martínez et al. 2004). Projected temperate increase for this region in 2100 is 3-4°C. Annual mean precipitation is expected to increase by up to 10% mainly in winter, while summer precipitation is expected to decrease up to 10% (Giorgi et al. 2004, Christiansen et al. 2007). Mountainous regions (mainly High Tatras Mts.) are supposed to be faced to even higher temperature increase, while precipitation amounts and patterns are subject to uncertainty. Forest responses to climate change are supposed to be both positive and negative, depending on site conditions and regional variability of climate (Saxe et al. 2001, Geβsler et al. 2007). Forest growth, regeneration and survival are expected to be constrained mainly by water availability. Bark beetles (mainly *Ips typographus* and *Pityogenes chalcographus*) and some defoliators (*Lymantria dispar*, *Lymantria monacha*) are the most important insect pests in this region. Climate change induced impacts on their distributional and outbreak ranges as well as on their population dynamics have already been observed.

2.2 Recommendations on improved forest management

There are two complementary factors, which should be considered in the forest management under the climate change. First of all, direct impacts of climate change, which influence forest growth, regeneration and mortality through the changes in stands water regime, trees water use efficiency, resistance to abiotic stressors etc. Secondly, there are indirect impacts through the changes of forest disturbance regime, mainly changes in distribution and population dynamics of pests and pathogens. Such approach should also consider other forest related ecological problems, such as massive spruce decline observed throughout the Europe during the recent decades.

Recommendations are mainly aimed at optimizing forest distribution and species composition to respond the projected changes in forest production, natural mortality as well as changes in pest's activity. Silviculture and forest protection measures are addressed as well. Because of highly complex responses of forest ecosystems as well as wide range of forest management techniques, we complemented the recommendations based on the findings of this project by recent knowledge on forest adaptation to climate change obtain from other sources. On these bases, we recommend:

1. Reduce the monocultures of vulnerable species (mainly spruce) and increase the share of mixed and deciduous forests. Guidelines for optimized tree species distribution based on future development of selected forest trees production and mortality are summarized in the Deliverable D6.6. In fact, this process has already started in many European countries, although not as a result of adaptation strategies to climate change, but due to enormous forest damage by mostly wind and bark beetle.

2. Reduce the proportion of spruce in elevations up to 800 m a.s.l., where it is projected to be faced to increased pressure of bark beetle (mainly of the 3rd generation in 2071-2100). In contrast, vast forest decline regions are distributed in higher elevations, thus total spruce reduction should be done, throughout the all distributional range of spruce. Proposed reduction could reach in the near future (2021-2050, NFC) 17%

(from the actual 23%) and 12% in the far future (2071-2100, FFC) to approach the estimated natural proportion of spruce in the country (approximately 5%). The proposed values also reflect the technical feasibility of such reduction.

3. An important presumption is that despite a global increase of bark beetle activity, the pest preferentially attacks trees older 60 years (in fact, 40-60 years old stands in the vicinity of outbreaks in older stands in elevation below 400-500 m a.s.l. have been heavily damaged in the Czech Republic in 2009, thus this presumption should be reconsidered in the future). Anyway, spruce could remain in higher shares below 800 m a.s.l. in the commercial forests (mainly in stands with sufficient water supply), but the management must dynamically respond to potentially changes in climate and related forest disturbances.

4. Pay special attention to recent spruce decline regions (multifactorial spruce decline which is however difficult to associate only with climate change), where spruce stands conversion to more stable ecosystems must be done within a decade or sooner over vast regions.

5. Prefer forest tree species more tolerant to climate stress in the lowlands, colline and lower montane zone:

    a. On forest sites in lower elevations up to 500 m a.s.l. the drought-related stress is expected to become of limiting importance. Sensitivity analysis indicated the oak (*Quercus* sp.) is largely insensitive to climate change and oak-suitable climate conditions are supposed to expand to higher elevations. Thus increase of share of oak species is a promising adaptation measure. Notably oak species which are at the northern distribution limit in the CEE region - *Quercus pubescens* group, *Quercus cerris*, *Quercus frainetto* - appear to be the sound alternative for climatically exposed sites.

    b. Scattered species with similar climatic ranges similar to oaks, e.g. *Fraxinus ornus*, *Acer campestre, Sorbus torminalis Tilia cordata and T. argentea*, have a significant potential for adaptation to changed climate.

    c. Scots and Austrian pine (*Pinus sylvestris*, *Pinus nigra*) were widely planted in former oak coppices in the lower altitudes until 1990`s. Their further use could be cautions after the large-scale spread of needle blights caused by *Sphaeropsis* and *Dothistroma* (*Diplodia*) in Europe and Northern America. Increased incidence of these fungal infections is associated with more frequent climate stress. The blight results in chronically deteriorated health and even increased salvation felling, especially on nutritionally rich and calcarous sites.

    d. Black locust (*Robinia pseudoacacia*) should be treated cautiously. The species is frequently mentioned among the alternative forest tree species under the climate change due to its climatic tolerance and outstanding regeneration capacity. It should be able to maintain forest canopy and while appropriate cultivars are available, to produce valuable timber. Several other properties raise concerns about it for both ecological and economical reasons. First of all, it is probably the most invasive tree species in Central-Eastern Europe. Its aggressive spreading, exceptional regeneration by sprouting and strong allelopathy suppressing other tree species make this species a serious threat to the integrity of native forest ecosystems. Once established, it spreads to the account of economically more valuable trees of oak-dominated woodlands. With a tendency to strong domination and suppressing other tree species, black locust provides hardly other management alternative than recurrent coppicing in the long-term.

e. Among the coniferous species, long-term experiments at the species and provenance level proved the possibility to compensate the loss of Norway spruce in lower altitudes by the European silver fir, Europan larch and Douglas fir. Consistent results concerning these conifers come from Bavaria, Austria, Czech Republic, Poland, Slovakia and Serbia.

6. Improve the systems of pest's populations monitoring and make efficient ecological (biological) control available. The reason is that changes are expected in the frequency and severity of drought periods, which tend to result in changed population dynamics of several insect defoliators and change their fluctuation patterns. While beech will be preferred in the montane zone and oaks in the lower montane and colline zone, their periodical defoliations by Gypsy moth should not result in disruption of supply of forest goods and services (despite of projected increase of beech's mortality).

7. Promote more continuous-cover silviculture (shelterwood, selection cuts) during forest regeneration and conversions. Due to uneven distribution of precipitation, risk of soil erosion as well as heat waves will be more significant. Current canopy stand should therefore be used to buffer their effects on forest soils, seedlings and young growths.

8. Modify the frequency and intensity of thinning to reach stand structures more tolerant to projected climate, with special emphasis to extreme climatic events.

9. Differentiate the intensity of thinning on the basis of actual biotic hazard, i.e., in case of spruce stands, to minimize the intensity of thinning in regions with high risk of bark beetle outbreaks. In contrast, intensive thinning should be done in the regions with low biotic risk, where forests are supposed to fill mainly the wood production function.

10. Focus on specific game management methods that allow avoiding the limited success of natural regeneration because of overpopulated game that became an important factor in Europe.

11. Reduce the rotation length in order to decrease mean standing stock as well as to reduce the damage from insect pests and fungal diseases (lower trees suffer less from wind and snow damage, what are the main predisposing factors of bark beetle outbreaks).

12. Promote the biodiversity of species, provenances and forest types to reach diverse and resilient ecosystems. This is particularly important for larger secondary coniferous forests. Due to the dominance of a single coniferous species – mostly Norway spruce – the natural regeneration is often dominated by single species again.

13. Change the current system of forest protection considering the region-specific alterations of climate change induced forest disturbances. Projections elaborated in Deliverable 6.5 could be a part of such system.

14. Pay attention to precautionary measures and monitoring of pest which are currently of minor importance but may became key species (such as *Lymantria dispar* in beech stands, see Deliverable 6.5). Following the principles of integrated pest management emphasize the use biological methods of forest protection.

15. Take into the account the risks associated with spreading of new fungal agents and changed dominance of existing ones. Actual developments and trends in this area need to be taken into the account in the forest management planning. Climate-related stresses combined with continuing acidification and eutrophisation of forest soils, are

mentioned as predisposing factors of still more serious problems with *Armillaria* sp., *Phytophtora* sp. needle blights caused by *Sphaeropsis* and *Dothistroma* (*Diplodia*) *Chalara fraxinea*, etc.

16. Compensate the loss of traditional sources of forest reproductive materials (seed stands), which follows the shift of altitudinal ranges of the most vulnerable forest tree species. The ex situ network of seed orchards and generative reproductive plantations should be extended.
17. Control of invasive woody species, to prevent their further spread under warmer and drier climate. In the southern parts and lower altitudes of the CEE region, several invasive tree and shrub species spread to the cost of native forest ecosystems. Although it may not be viewed as core forestry activity, control of *Robinia pseudoacacia, Negundo aceroides* and Fraxinus species coming from North-America is to be done for ecology, landscaping but obviously also economical reasons. Of other invasive plants, *Fallopia*, *Solidago* and *Impatiens* species, threatening the integrity of lowland forest ecosystems, obviously spread into higher altitudes.
18. New orchards and reproductive plantations need to be located to climatically appropriate sites. Progeny tests are necessary for improvement of our knowledge about climatic tolerance of forest tree species.
19. Implement the cautions management of fungal agents with gradually increasing dominances in forest due to the warmer and dryer climate following acidification and eutrophisation of forest soils: Armillaria species, *Chalara fraxinea.*
20. Prevent an undesirable climate change induced loss of valuable gene pools by means of relocation to more appropriate, less exposed sites. Establishing synthetic sources of forest reproductive material ex situ for the most vulnerable tree species (clonal & generative seed orchards, reproductive plantations).

Following the conclusions of questionnaires on regional/national activities in forest adaptation to climate change recently elaborated for example by European Forest Institute, Standing Forestry Committee ad hoc working group on forestry and climate change of the EC or Cost Action ECHOES (Expected Climate Change and Options for European Silviculture), there are many gaps in the scientific understanding of forest responses to climate change as well as in the national climate policies. These two points are of a great importance in the elaboration of effective forest management strategies and their transfer to practice. Therefore, we complement the recommendations on forest management by some recommendations on research priorities. We recommend:

21. Develop a regional system of site/species vulnerability to climate change. Deliverables 6.5 and 6.6 provide parts of such system for the Slovak Republic.
22. Promote the research of forest tree species drought resistance. Deliverable 6.6. indicates the responses of main forest tree species and various species compositions to climate gradients at species lower (xeric) distributional limit, however such knowledge should be significantly extended.
23. Promote baseline research of ecological processes at the receding limit of forest tree species, which are extremely vulnerable by climate change. Current site/species-specific knowledge on this is highly insufficient.
24. Promote the research of genetic adaptive capacity of forest tree species and ways how to transfer such knowledge to forest management.

25. Promote the research of multifunctional use of forest. Mainly the importance of soil protective and recreational forest functions is expected to rise to the detriment of wood productive function. This however requires reconsidering the actual system of subsidies.

2.3. Final remarks

Complex and often nonlinear or threshold-type responses of forest ecosystems to climate change make the development of optimized forest management methods rather difficult. As has been described in Deliverables 5.6 and 5.7 (Sensitivity Analysis and Pests&Diseases), there is a wide range of responses of various species and age composition to changing climate. In the same time, direct responses of forest trees/stands differ in various natural conditions, often accompanied by specific alterations of distribution and population dynamics of pest and diseases. Forest adaptation is also limited by relatively stable forest structure, which can be changed by forest management in relatively long time periods (except for radical interventions), while pests can respond to changed climate almost immediately. In addition, life span of many forest tree species exceeds the range of climate change scenarios, which are obviously constructed up to 2100, thus increasing the uncertainty of projected forest development in the far future. The recommendations proposed in this deliverable are mainly aimed at three aspects of forest management – (i) optimization of tree species distribution at a scale of Slovakia to adapt the forests to future climate development and projected changes in distribution of main forest pests; (ii) silviculture measures, which should help building stable and diverse forest stands able to resist the climate change; and (iii) forest genetics allowing to preserve and use the valuable resources. On the end of the report we emphasized some gaps in the scientific understanding of climate change impacts on forest, mainly the need for more detailed research of processes at species receding distribution limit.

There are multiple risks and threats the occurrence of which will depend on the rate of changes and incidence of extreme events. First of all, the resilience of forest tree species and their populations has been weakened by changing dominance of the existing and influx of new pests and diseases. All the forest management will inevitably face of great uncertainty. Active adaptation of forests in regard to their species composition, spatial patterns and internal structure of individual stands is indispensable. Wherever it is possible to compromise forestry, society and nature conservation views, mixed stands with internally diverse structure should be either maintained or created in order to provide flexibility with respect to forest management, and help to reduce the risks associated with climate change.

Climate change is likely to alter the competition between trees and other plant species. This may significant impact the survival of tree species and even the existence of the present forest habitats in Europe (Euforgen & MCPFE 2006). The xeric limit of more forest-related tree species will be pushed further inside of Central-Eastern Europe. Threats by shifting climate will be more serious towards naturally scattered than stand-forming forest tree species with large natural cultivation ranges. In common forest tree species, populations currently close the xeric limit of individual forest tree species become particularly vulnerable. Their preservation will be difficult but makes practical sense while there are multiple proofs of better adaptation of such populations to climate-related stress.

The rate of climate change is expected to be incomparably faster than generation time (ontogenetic cycle) of most forest tree species in the Central Europe. Active forestry measures are necessary (already now) to adapt to new situations under such conditions. Translocation of forest tree species and their genetic resources into new areas fitting better their climatic requirements is among the most relevant activities. The fact that tree species that are scattered or with limited distribution are more vulnerable to climate change than common stand-forming and/or widely cultivated forest tree species should be considered.

Forestry adaptation and mitigation measures are both opportunity and necessity driven. The opportunities include a chance to increase quality and quantity of forest production, although at the risk of unpredictable interactions between forest trees and their parasites and pests. The costly necessities include, for instance, preserving of diverse sources of forest reproductive material such as seed stands and orchards. Multiple ex-situ (translocation) activities shall be needed at much bigger extent than at the present.

In order to include mitigation and adaptation measures in forestry into the rural policies, programmes and support schemes, adaptation strategies reaching more than forestry stakeholders are to be defined at the regional and local levels. They need to become an intrinsic component of national and regional forest programmes. Such programmes are already in place in many Central-Eastern European countries.

In the silviculture, maintenance of natural adaptation of forest trees and support to natural regeneration should be promoted, especially in areas where long-term natural regeneration is supposed to be self-sustainable despite the climate change. On the other hand, under expected major changes in climatic ranges, forest tree adaptation to climate change can be accelerated through tree breeding and transfer of potentially suitable reproductive material. Euforgen & MCPFE 2006 recommended developing the pan-European guidelines for the transfer of forest reproductive material in Europe on the basis of scientific knowledge. Implementation of this task has been taking initial shape by several EU-funded research projects.

3 AGRICULTURE – THE SOUTH-EAST ROMANIA

3.1 Introduction

Future climate projections show that the South-East Romania agricultural areas may be affected in a negative way by a number of climate changes that are predicted by regional climate models. Adapting to climate change through a better crop system management will benefit mainly from the knowledge given by our responses to severe climate events, when plans to adapt to and mitigate predictable climate change risks are implemented.

Thus, climate change effects mirror the modifications seen in precipitation regimes as well as in other environmental variables, in association with temperatures, sea levels and carbon dioxide concentrations in the atmosphere. Water shortages and droughts can lead to significant yield reductions.

Higher than optimal temperatures affect metabolic reactions, causing stress, while the modifications in low-temperature tendencies can easily increase freezing risks in sensitive species. Relative temperature and humidity, apart or combined, can foster weed growth, pests and virulent diseases, increasing thus the vulnerability to emerging pathogen agents in crops.

As a matter of fact, every agricultural aspect, from yields to their transport to the markets, is clime-related. Yields are likely to be influenced by increased CO2 concentrations in the atmosphere, which are connected to climate change; while the positive effects of carbon dioxide used as fertilizer are controversial, a concomitant increase in temperatures and frequency of droughts has opposite negative effects.

On this stage, the study is aimed to analyze possible climate change effects on winter wheat and maize growth, development and yielding, using the results and conclusions provided by six S-E Romania agrometeorological stations and applying the simulation models CERES-Wheat and CERES-Maize in combination with the RegCM3 climatic predictions (Georgi et al. 1993) at a very fine resolution (10 km) over 2020-2050.

Figure 3.1 shows the target area and table 3.1 include the six agrometeorological stations that are representative for S-E Romania's agriculture, covering the whole range of agro-pedo-climatic conditions in this region.

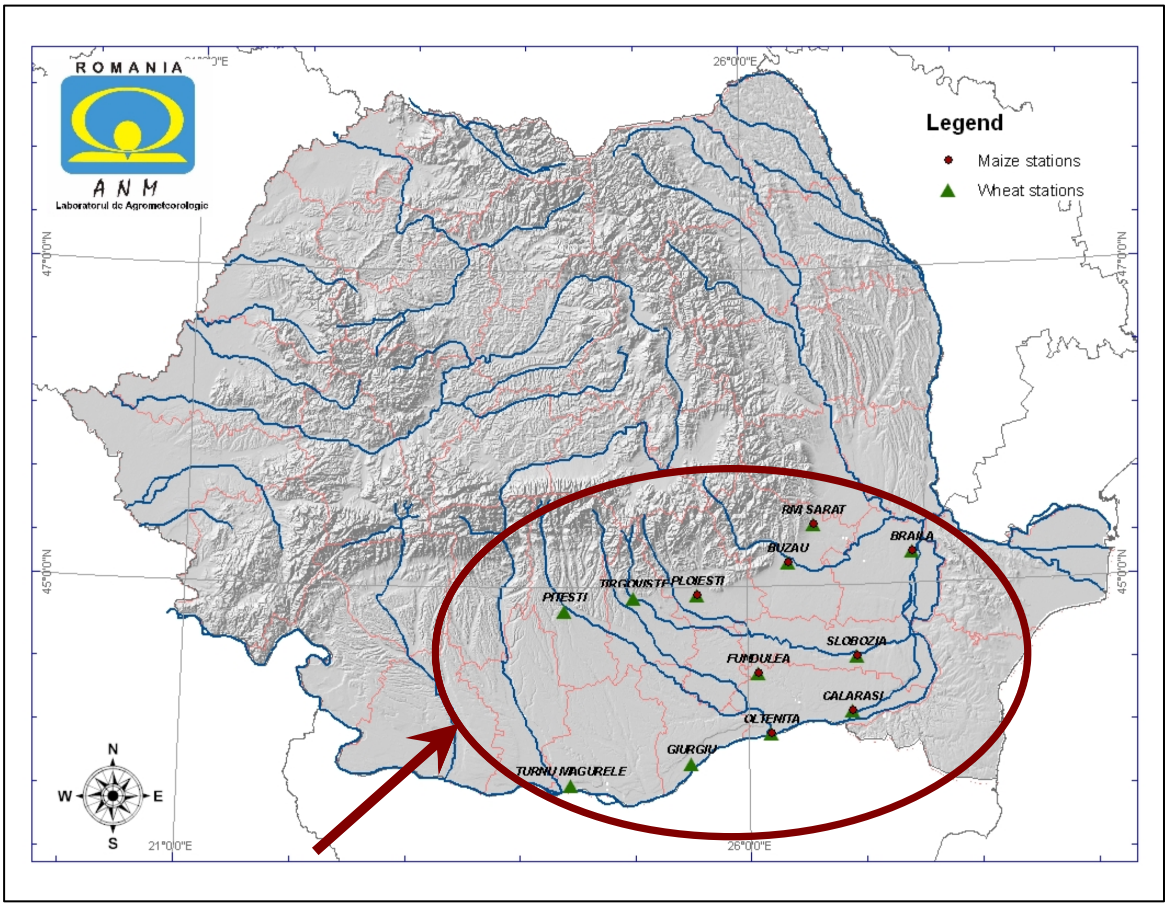


Fig. 3.1

Tab. 3.1 *Meteorological stations with agrometeorological activity covering the whole range of agro-pedo-climatic conditions across the project-related area*

Agrometeorological station	**Latitude** (°N)	**Longitude** (°E)	**Elevation** (m)	**Soil classes**
Buzau	45.09	26.49	96.0	Cambic chernozem – clay loam
Calarasi	44.12	27.21	19.0	Cambic chernozem
Fundulea	44.27	26.32	67.0	Cambic chernozem
Galati	45.30	28.02	71.0	Cambic chernozem
Grivita	44.45	27.18	50.0	Cambic chernozem
Ramnicu Sarat	45.23	27.03	152.0	Cambic chernozem

3.2 Crop models and management variables

The simulation models CERES-Wheat (D.C. Godwin et al.,1989) and CERES-Maize (J.T. Ritchie et al., 1989) as well as the Seasonal Analysis Program, integrated in the DSSAT v3.5 decision system, were used in assessing the impact of climate change upon winter wheat and maize crops. These models were minutely described in the previous stages of the project.

As regards the specific data on winter wheat and maize phenological development and growth, there were chosen only species whose genetic coefficients represent the average conditions over 1961-1990, as they are closer to the real values (phenology, yields) recorded in fields or standard platforms at the agrometeorological stations involved.

Used as inputs, the management variables of wheat crops resulted from calibrating and validating the model and they take different values according to the agro-climatic area; mean seeding date ranges between 8 and 11 October, average seed density 600-400 pl/m^2 , distance between rows 8-12.5 cm and seeding depth 4-6 cm. As to maize crops, seeding date and density were chosen according to the current average conditions: seeding date 15-22 April, density 45000-60000 pl/ha.

For every simulation, an average fertilization was kept constant, nitrogen stress not reaching below 50% of crop demand. Most crop inputs are specified in the so-called "*seasonal experiments"* (**.SNX)*. To run the seasonal analysis program, which is included in the DSSAT decision system, three basic steps were taken: carrying out the seasonal experiment, running the crop simulation model with the seasonal analysis program called "driver", and carrying out a biophysical analysis of the simulated results.

The ICPA-provided soil data include information on soil surface and profile, which can be found in the SOIL.SOL file. As soil data, the mean hydro-physical characteristics of three prevalent soil types were used: cambic chernozem, brown chernozem and levigated chernozem of several textures specific to each agrometeorological station. Clay, dust and sand contents, apparent density, organic carbon, pH, hydraulic conductivity, among others, are the soil parameters used as model inputs.

To assess the winter wheat and maize response in current clime conditions, there were used 1961-1990 climate data series recorded by six weather stations with agrometeorological activity involved in this study. The climate data files (*.CLI) include multi-annual monthly means of the following parameters: low and high temperatures, standard deviation in high and low temperatures, precipitation, and standard deviation in precipitation, asymmetry coefficient for precipitation distribution, probability of a "dry" day (no precipitation) after a rainy one, probability of a wet day after a wet day, number of days with precipitation and solar radiation.

In order to assess the RegCM3/2020-2050/SRES A1B scenario's effects upon winter wheat crops, the two crop models were run under future climate conditions, keeping the same management variables as in the current climate conditions.

3.3 The Regional Climate Scenario RegCM3/2020-2050/SRES A1B

Working at a very fine resolution (10 km), the regional climate model RegCM3 (Giorgi et al. 1993) is a limited-area model so adapted that it may improve its capacity to simulate climate and atmospheric circulation on a regional scale by modifying certain physical parameterizations, mostly in the fields of Radiative Transfer Physics and Land Surface Physics. This model has been continuously improved through user contributions provided by research centers worldwide, including Romania (Caian, 1998).

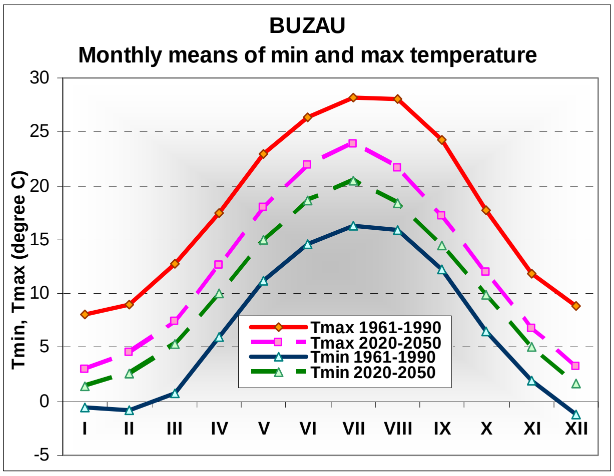
Table 3.2 and Figure 3.2 show the multi-annual means of air temperature highs and lows as well as of precipitation amounts under current climatic conditions (1961-1990) and those calculated according to the RegCM3 predictions over 2020-2050, SRES A1B scenario.

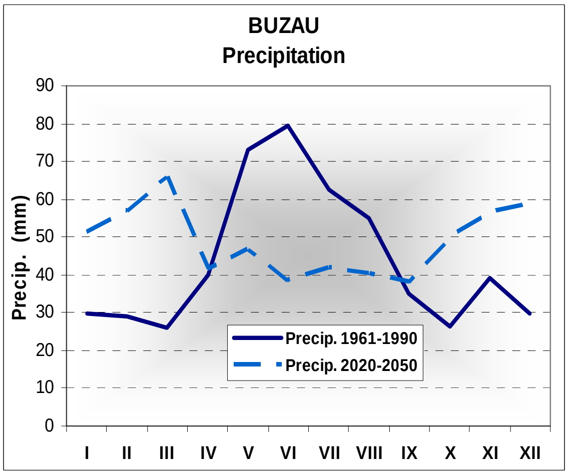
According to this scenario, climate predictions indicate lows higher by 2.4°C- 6.9°C, mostly in the warm season. Monthly mean highs are 2-5°C lower than in current climate conditions. Changes in monthly precipitation range from -33.8 mm to +29.7 mm. Precipitation amounts increase on the whole about 6-29.7 mm in the cold season (X-IV) and decrease during the warm season (V-IX) by 4-33.8 mm in comparison with the current clime conditions.

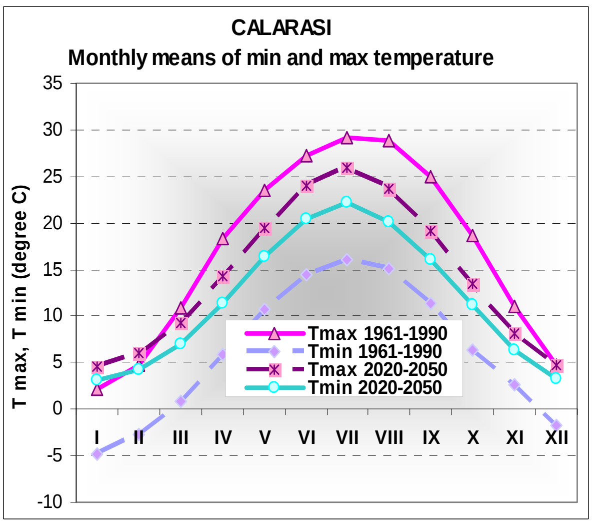
Tab 3.2 *Multi-annual monthly means of air temperature highs/lows and monthly precipitation under current climate conditions (1961-1990) and RegCM3 / 2020-2050 / SRES A1B predictions*

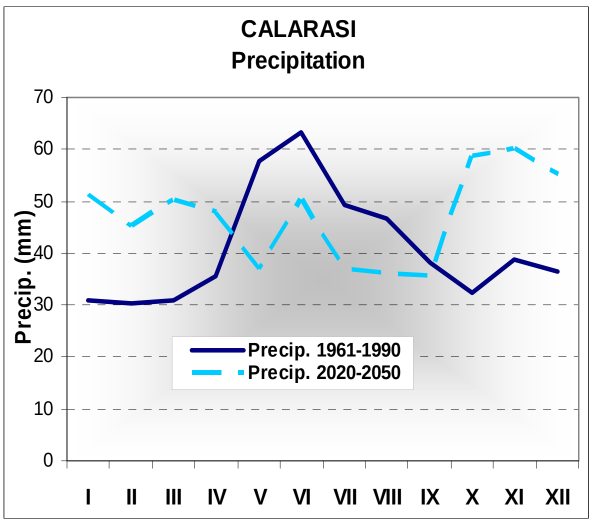
			1961-1990			2020-2050	
Station	**Month**	**T_{max}**	**T_{min}**	**Precip.**	**T_{max}**	**T_{min}**	**Precip.**
BUZAU							
	I	8.1	-0.5	29.6	3.0	1.4	51.2
	II	9.0	-0.8	29.1	4.5	2.6	56.7
	III	12.7	0.7	25.8	7.4	5.3	65.7
	IV	17.4	6.0	39.9	12.6	10.0	41.4
	V	22.9	11.2	72.9	17.9	15.0	37.9
	VI	26.3	14.6	79.5	21.9	18.7	46.7
	VII	28.2	16.3	62.4	23.9	20.5	38.4
	VIII	28.0	15.9	55.1	21.6	18.4	41.7
	IX	24.3	12.2	35.1	17.2	14.4	40.3
	X	17.7	6.5	26.2	11.9	9.8	49.7
	XI	11.8	1.9	39.2	6.8	5.1	56.3
	XII	8.8	-1.2	29.7	3.3	1.7	58.9
GALATI	I	8.0	-0.1	37.5	3.9	2.3	49.1
	II	8.8	-0.7	31.8	5.4	3.6	44.4
	III	12.2	0.6	27.1	8.6	6.4	55.3
	IV	16.8	6.0	37.8	13.9	11.1	37.0
	V	22.3	11.2	50.7	19.3	16.2	33.8
	VI	25.9	14.6	68.3	23.3	19.9	46.5
	VII	27.9	16.2	45.6	25.4	21.7	36.8
	VIII	27.5	15.8	46.1	23.1	19.7	33.0
	IX	23.5	12.0	42.2	18.4	15.5	37.2
	X	17	6.6	27.1	12.9	10.7	46.4
	XI	11.4	2.2	36.5	7.5	5.8	52.2
	XII	8.5	-1	33.8	4.1	2.6	46.8
GRIVITA	I	8.0	0.3	34.2	4.3	2.8	43.3
	II	9.2	-0.9	29.5	5.9	4.0	40.8
	III	13.1	0.3	27.2	9.1	6.8	48.7
	IV	18.2	4.9	33.1	14.2	11.4	37.0
	V	23.5	10.1	63.9	19.6	16.5	30.1
	VI	26.9	13.7	60.9	24.1	20.5	43.7
	VII	28.6	15.0	55.6	26.1	22.4	30.3
	VIII	28.2	14.4	55.9	23.8	20.3	31.9
	IX	24.5	10.6	37.7	19.1	16.1	31.5
	X	18.2	5.5	28.4	13.3	11.1	45.7
	XI	12.1	1.9	36.9	7.9	6.2	49.2
	XII	8.8	-1.0	31.5	4.4	3.0	46.8
RM.SARAT	I	8.5	-0.3	34.7	3.7	2.1	48.8
	II	9.5	-0.9	33.7	5.2	3.4	47.6
	III	12.7	0.8	30.8	8.2	6.0	58.7
	IV	17.3	5.9	44.2	13.6	10.9	38.3
	V	22.8	11.1	64.6	18.9	16.0	32.8
	VI	26.2	14.3	72.9	23.0	19.7	44.9
	VII	28	15.9	69.2	25.0	21.5	40.5
	VIII	27.7	15.5	48.4	22.7	19.4	36.0
	IX	23.9	11.7	43.8	18.1	15.3	38.8
	X	17.5	6.4	27.2	12.6	10.5	42.6
	XI	12	2.0	42.7	7.4	5.7	48.8
	XII	9.2	-1.3	32.6	4.0	2.4	46.9

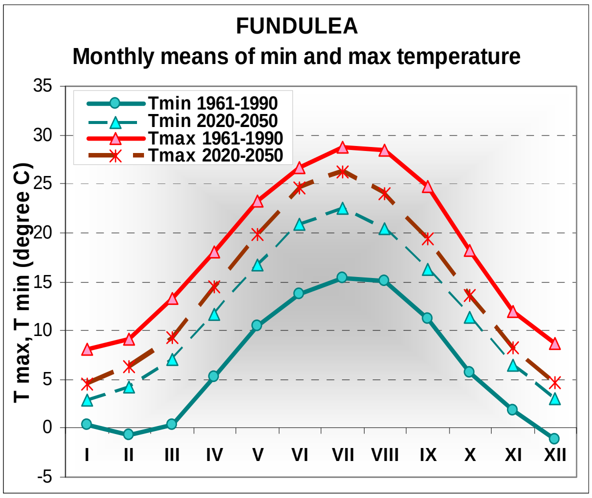
CALARASI	I	2.2	-4.8	31	4.6	4.6	51.2
	II	4.8	-2.7	30.4	6.1	6.1	45.3
	III	10.9	0.9	30.9	9.3	9.3	50.3
	IV	18.4	5.9	35.6	14.2	14.2	47.9
	V	23.5	10.8	57.8	19.5	19.5	37.0
	VI	27.2	14.4	63.3	23.9	23.9	50.5
	VII	29.1	16.1	49.2	25.9	25.9	37.1
	VIII	28.8	15.1	46.7	23.7	23.7	35.8
	IX	25	11.4	38.3	19.1	19.1	35.6
	X	18.6	6.3	32.5	13.4	13.4	58.5
	XI	11.1	2.6	38.7	8.1	8.1	60.0
	XII	4.8	-1.7	36.6	4.7	4.7	55.2
FUNDULEA	I	8.1	0.4	37.1	4.5	2.9	42.8
	II	9.1	-0.7	37.1	6.2	4.3	44.5
	III	13.3	0.3	37.6	9.3	7.0	49.9
	IV	18	5.2	44.5	14.4	11.6	35.4
	V	23.3	10.4	60.8	19.9	16.7	43.5
	VI	26.7	13.7	71.8	24.6	20.9	36.3
	VII	28.7	15.4	64.6	26.3	22.5	38.2
	VIII	28.4	15.1	51.5	24.0	20.5	35.3
	IX	24.8	11.2	43.2	19.4	16.3	34.2
	X	18.2	5.7	31.3	13.6	11.3	43.0
	XI	11.9	1.8	44.8	8.2	6.4	50.7
	XII	8.7	-1.2	43.4	4.6	3.1	47.6

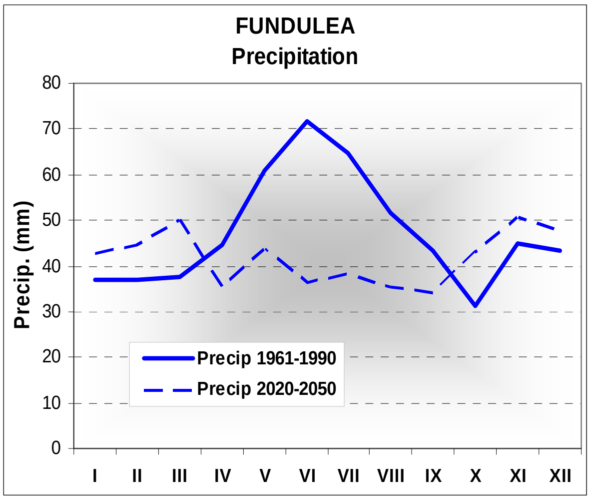


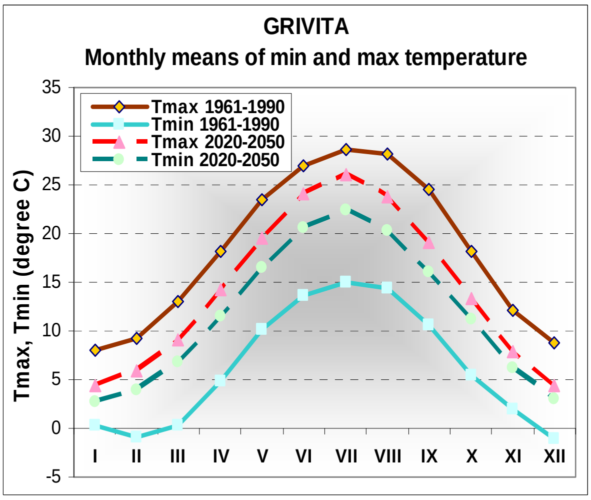


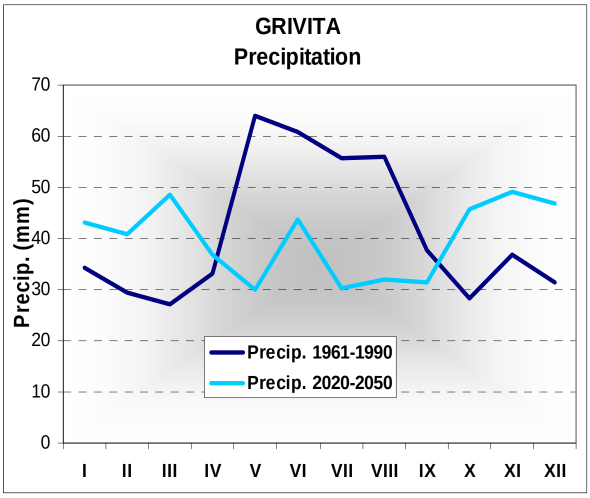


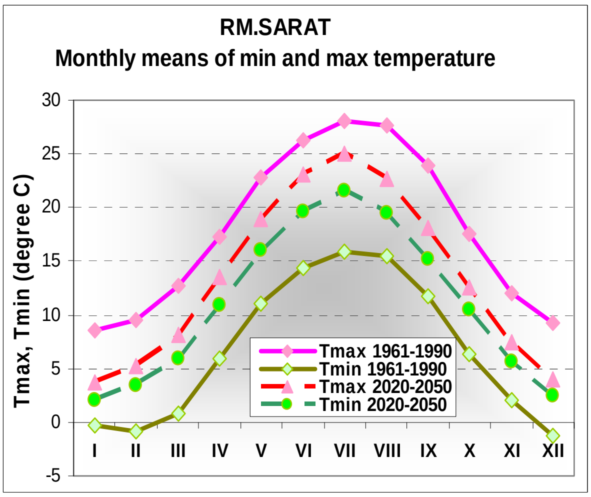


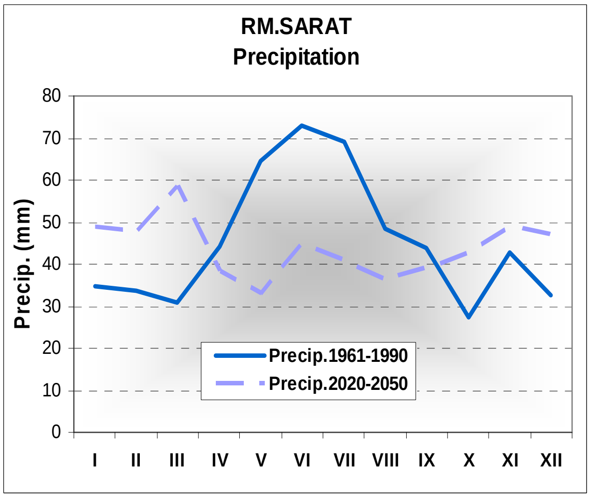

FUNDULEA
Monthly means of min and max temperature
T max, T min (degree C)
Tmin 1961-1990
Tmin 2020-2050
Tmax 1961-1990
Tmax 2020-2050
35 30 25 20 15 10 5 0 -5
I II III IV V VI VII VIII IX X XI XII


FUNDULEA
Precipitation
Precip. (mm)
Precip 1961-1990
Precip 2020-2050
80 70 60 50 40 30 20 10 0
I II III IV V VI VII VIII IX X XI XII


GRIVITA
Monthly means of min and max temperature
Tmax, Tmin (degree C)
Tmax 1961-1990
Tmin 1961-1990
Tmax 2020-2050
Tmin 2020-2050
35 30 25 20 15 10 5 0 -5
I II III IV V VI VII VIII IX X XI XII


GRIVITA
Precipitation
Precip. (mm)
Precip. 1961-1990
Precip. 2020-2050
70 60 50 40 30 20 10 0
I II III IV V VI VII VIII IX X XI XII


RM.SARAT
Monthly means of min and max temperature
Tmax, Tmin (degree C)
Tmax 1961-1990
Tmin 1961-1990
Tmax 2020-2050
Tmin 2020-2050
30 25 20 15 10 5 0 -5
I II III IV V VI VII VIII IX X XI XII


RM.SARAT
Precipitation
Precip. (mm)
Precip.1961-1990
Precip.2020-2050
80 70 60 50 40 30 20 10 0
I II III IV V VI VII VIII IX X XI XII

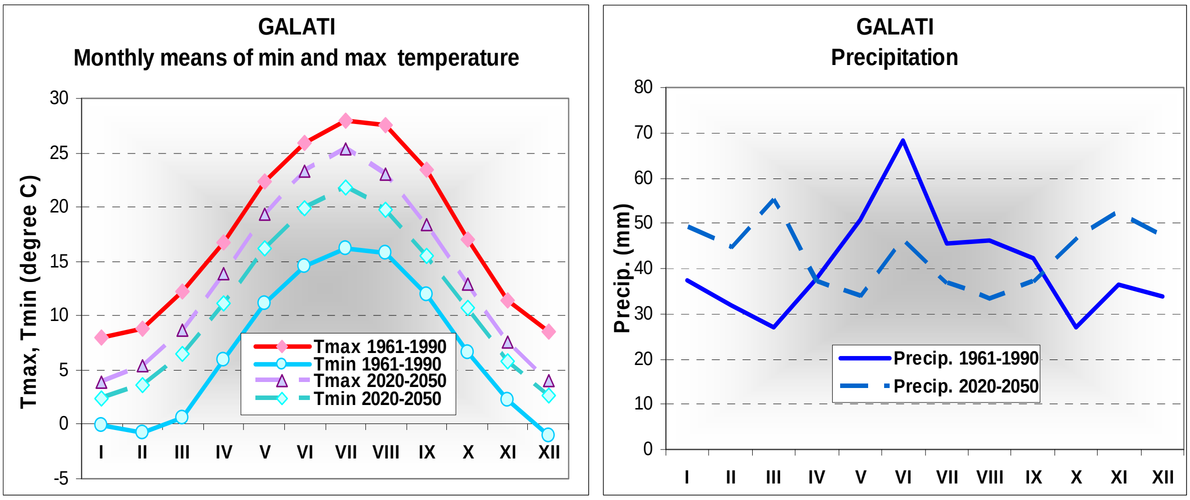


Fig. 3.2 *Multi-annual monthly means of air temperature highs/lows and precipitation amounts under current climate conditions (1961-1990) and RegCM3 / 2020-2050 / SRES A1B predictions*

3.4 *Simulated results*

To evaluate the climate change impact upon maize and winter wheat, CERES models were run for current climate conditions (1961-1990) as well as for the 2020-2050 regional climate scenario-anticipated conditions, considering the direct effect of increased CO2 concentrations (from 330 to 450 ppm) upon the photosynthesis processes. The results simulated under climate change conditions were compared to those obtained for the current climate. Thus, changes in yield levels and the length of vegetation period, as well as in cumulated precipitation and evapotranspiration during the vegetation season were quantified.

3.4.1 Winter wheat

Table 3.3 shows the CERES-Wheat outputs at every studied station and the relative differences in crop variables under the RegCM3/2020-2050/SRES A1B climate scenario conditions as against the current clime ones. Graphs 2-4 sketch the changes occurred in yield levels, length of the vegetation season and water use efficiency.

A 30-year mean of ***winter wheat*** yields, simulated under current climate conditions, ranges between 3599 kg/ha at Galati and 5016 kg/ha at Calarasi. Given the probable climate conditions according to the RegCM3/2020-2050/SRES A1B scenario-predicted future evolution, the mean wheat yield is higher by 8.5% - 58.9% than the 1961-1990 one. The highest increase (over 31 %) is seen at the Buzau, Grivita and Calarasi Stations.

Under current climate conditions, the mean length of the vegetation season (from seeding time to ripeness) ranges between 269 and 284 days, decreasing by 11-17 days with climate change. The fastest growth occurs at Fundulea Station, where the winter wheat ripens 17 days earlier than under current clime conditions.

The climate change-related increase in wheat yields is connected to the positive effect of higher CO2 levels in the atmosphere upon photosynthesis (from 330 ppm under current conditions to 450 ppm according to the RegCM3/SRES/A1B scenario), which counterbalances the negative effect of shorter vegetation periods due to higher temperatures.

The precipitation amounts cumulated over the vegetation season of winter wheat depend on local conditions, ranging between 357 mm and 424 mm. According to RegCM3/2020-

2050/SRES A1B, precipitation amounts increase by 6-24 % at three stations (Calarasi, Buzau and Galati), keep at the same level at two stations (Grivita and Rm. Sarat) and decrease by 11% at most only at Fundulea.

The higher amounts at those three stations over the vegetation season are connected to a significant increase over 2020-2050, by up to 15-30 mm above current levels from October to March as against the other stations, which have a smoother increase and a shorter vegetation period does not cause their decrease, excepting at the Fundulea Station.

The cumulated water lost to evapotranspiration over the vegetation season of winter wheat decreases at every station involved in this study as against the current levels by 16-24% due to an interaction between the two opposite processes: a vegetation period getting shorter and associated with high temperatures and the physiologic effect of increased CO2 concentrations upon crops.

The simulations highlighted also that**,** influenced by climate change, winter wheat uses more efficiently the available soil water, this parameter (a ratio between production and evapotranspiration) increasing significantly by 43 up to 92% as against the current clime conditions, due mainly to a higher CO2 assimilation rate. Generally, increased CO2 concentrations result in a higher photosynthetic rate, reducing also water losses in crops.

Tab. 3.3 *CERES-Wheat results simulated under current conditions and under RegCM3/2020-2050/SRES A1B predictions. Prod: grain yield; DS: length of the vegetation season; PRC: precipitation; ET: evapotranspiration; EUA: water use efficiency. Differences from current clime are shown in percentages.*

Station	**Scenario**	**Prod. (kg/ha)**	**DS (zile)**	**PRC (mm)**	**ET (mm)**	**EUA (kg/mc)**
Buzau	Current climate 1961-1990	4285	274	387	506	0.85
	Scenario 2020-2050	5621	263	437	425	1.32
	Differences (%)	**31.2%**	**-11**	**13%**	**-16%**	**56%**
Calarasi	Current climate 1961-1990	5016	269	357	473	1.06
	Scenario 2020-2050	7969	254	444	392	2.03
	Differences (%)	**58.9%**	**-15**	**24.4%**	**-17.1%**	**91.7%**
Fundulea	Current climate 1961-1990	4650	279	424	505	0.92
	Scenario 2020-2050	5727	262	379	392	1.46
	Differences (%)	**23.2%**	**-17**	**-10.6%**	**-22.4%**	**58.7%**
Grivita	Current climate 1961-1990	3880	284	374	492	0.79
	Scenario 2020-2050	5470	268	374	394	1.39
	Differences (%)	**41.0%**	**-16**	**0%**	**-20%**	**76%**
RmSarat	Current climate 1961-1990	3700	270	389	485	0.76
	Scenario 2020-2050	4014	255	390	367	1.09
	Differences (%)	**8.5%**	**-15**	**0%**	**-24%**	**43%**
Galati	Current climate 1961-1990	3599	272	357	464	0.78
	Scenario 2020-2050	4389	259	380	375	1.17
	Differences (%)	**22.0%**	**-13**	**6%**	**-19%**	**51%**

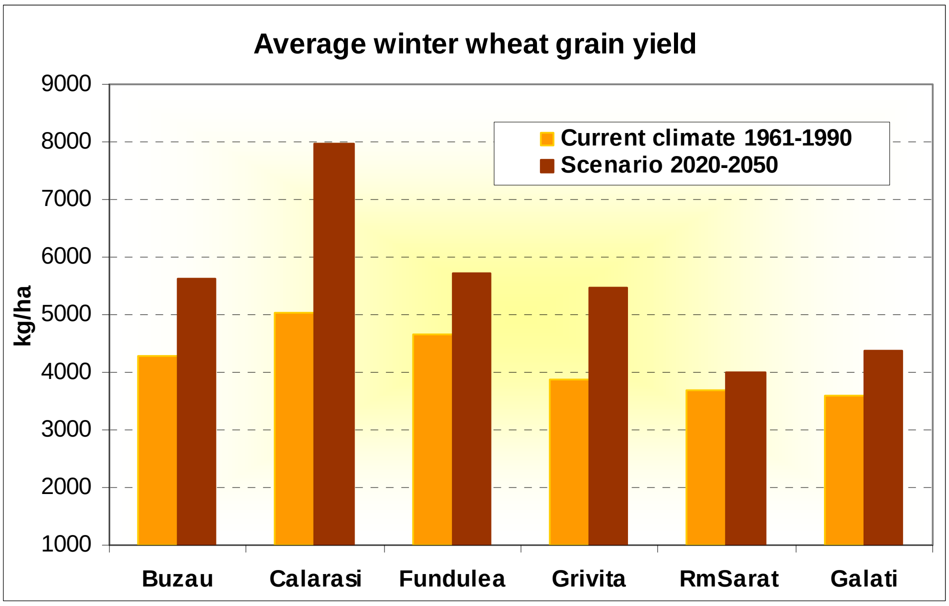


Fig. 3.3

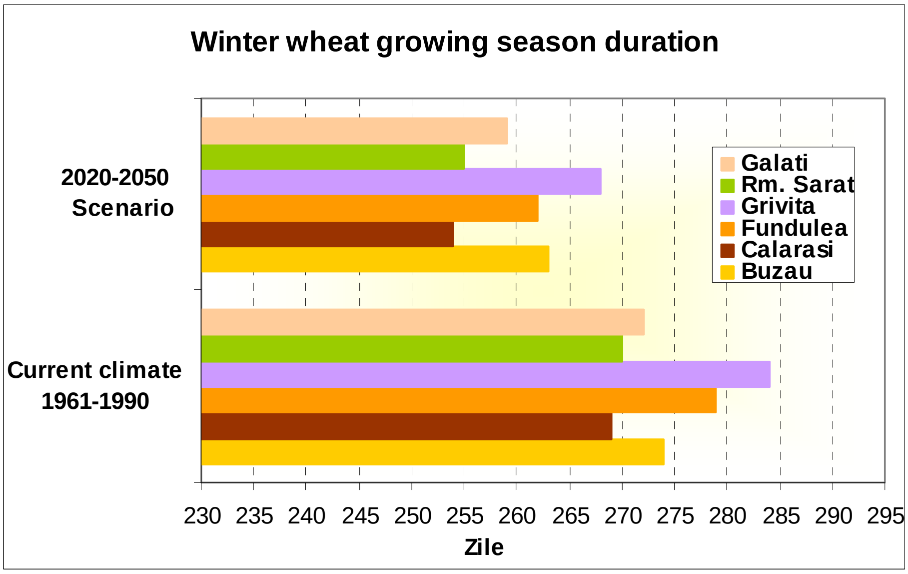


Fig. 3.4

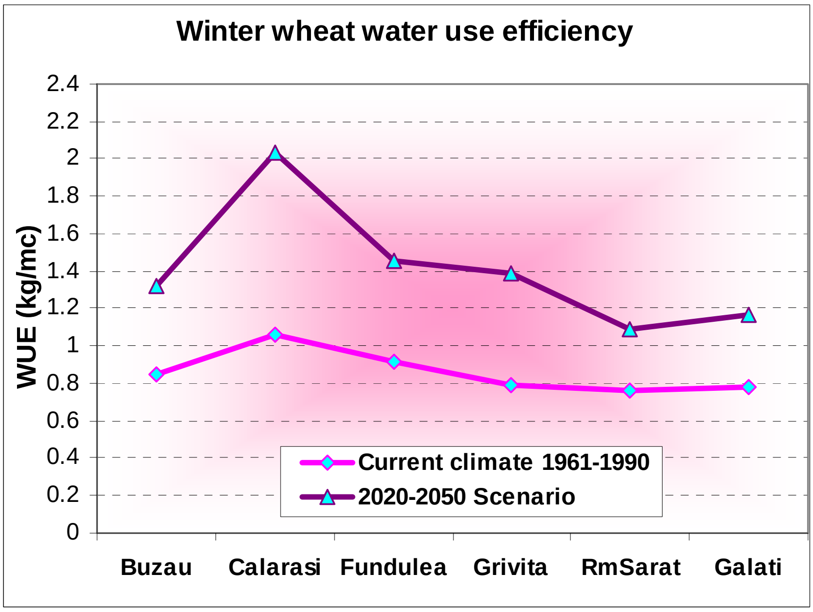
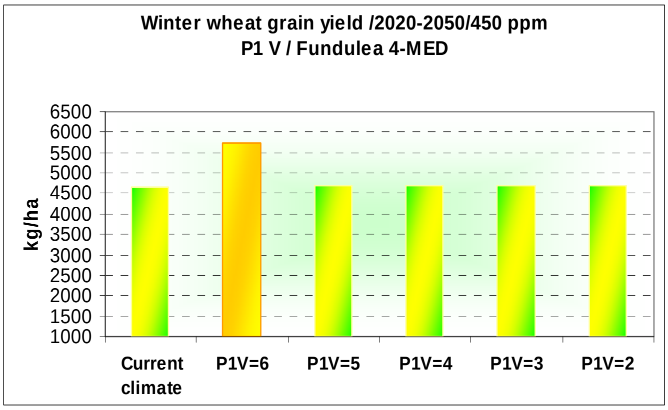


Fig. 3.5

Under climate condition for the winter wheat crop the most suitable genotype are varieties with high vernalization (P1V=6.0) and with moderate photoperiod requirement (P1D=3.5), figure 3.6.



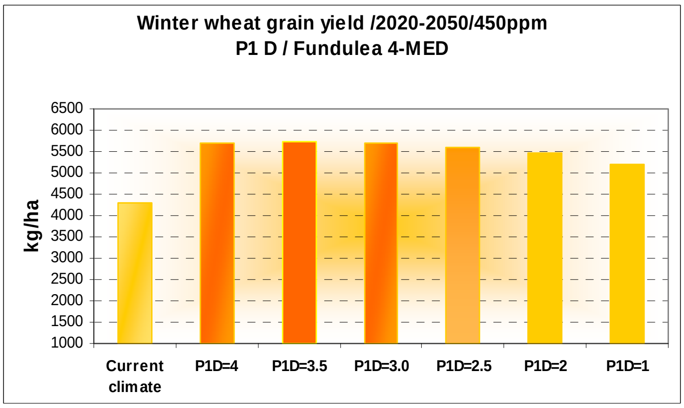


Fig. 3.6. *The selection of winter wheat genotype under climate scenario*

3.4.2 Maize

Table 3.4 shows the CERES-Maize outputs for the six analyzed stations and the relative differences in crop variables for the RegCM3/2020-2050/SRES A1B scenario as against the current clime case. Figures 3.7, 3.8 and 3.9 are graphs of the changes noticed in yields and length of the vegetation season.

In current clime conditions, the average wheat yield ranges between 4463 kg/ha at Buzau and 7005 kg/ha at Calarasi. Analyzing the simulated results highlighted that for maize, which is more sensitive than wheat to local climate and future climate severity, average grain yields tend to decrease lightly on the whole by roughly 2-4% at Grivita, Rm. Sarat and Galati, and more abruptly, by 18-33% as against the current climate conditions at the other three stations. Maize yields get lower due to a shortening of the vegetation season by 20-29 days, following an increase in temperature, as well as due to water stress during grain filling, caused by diminished scenario-forecasted precipitation amounts. Being also a C4 plant, maize benefits less from the effect of increased CO2 concentrations upon photosynthesis.

In comparison with the current clime conditions, precipitation amounts cumulated over the vegetation season of maize decrease significantly by about 38%-51% and total evapotranspiration diminishes by around 20-27% due mainly to a smaller number of days available to yield formation.

Given the 2020-2050 regional climate predictions, water use efficiency increases at most stations by 2-35% as against the current climate case, excepting the Buzau and Fundulea Stations, where efficiency decreases by about 1-12%.

Tab. 3.4 *CERES-Maize results simulated under current conditions and under RegCM3/2020-2050/SRES A1B predictions.* Prod: grain yield; DS: length of the vegetation season; PRC: precipitation; ET: evapotranspiration; EUA: water use efficiency. *Differences from the current clime case are shown in percentages.*

Station	Scenario	Prod. (kg/ha)	DS (zile)	PRC (mm)	ET (mm)	EUA (kg/mc)
Buzau	Current climate 1961-1990	4463	138	316	473	0.94
	Scenario 2020-2050	3290	118	172	352	0.93
	Differences (%)	**-26.3%**	**-20**	**-45.6%**	**-25.6%**	**-0.9%**
Calarasi	Current climate 1961-1990	7005	139	250	416	1.68
	Scenario 2020-2050	5722	119	154	333	1.72
	Differences (%)	**-18.3%**	**-20**	**-38.4%**	**-20.0%**	**2.0%**
Fundulea	Current climate 1961-1990	6585	141	281	439	1.5
	Scenario 2020-2050	4383	115	150	334	1.3
	Differences (%)	**-33.4%**	**-26**	**-46.6%**	**-23.9%**	**-12.5%**
Grivita	Current climate 1961-1990	5675	148	283	438	1.29
	Scenario 2020-2050	5569	119	139	321	1.73
	Differences (%)	**-1.9%**	**-29**	**-50.9%**	**-26.7%**	**34.5%**
RmSarat	Current climate 1961-1990	5314	144	299	458	1.16
	Scenario 2020-2050	5224	122	156	339	1.54
	Differences (%)	**-1.7%**	**-22**	**-47.8%**	**-26.0%**	**32.8%**
Galati	Current climate 1961-1990	4970	140	248	416	1.19
	Scenario 2020-2050	4781	117	138	321	1.49
	Differences (%)	**-3.8%**	**-23**	**-44.4%**	**-22.8%**	**25.2%**

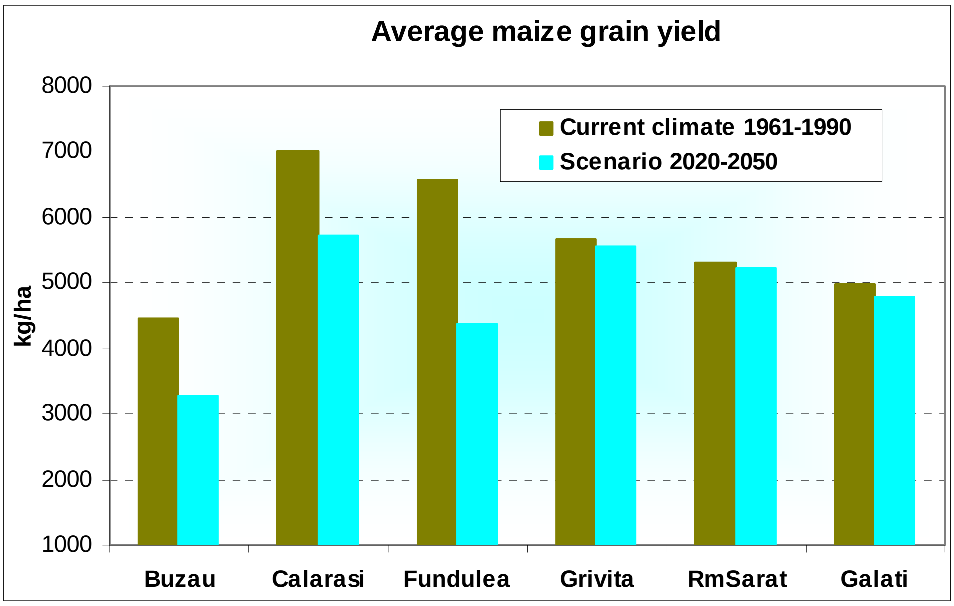


Fig. 3.7

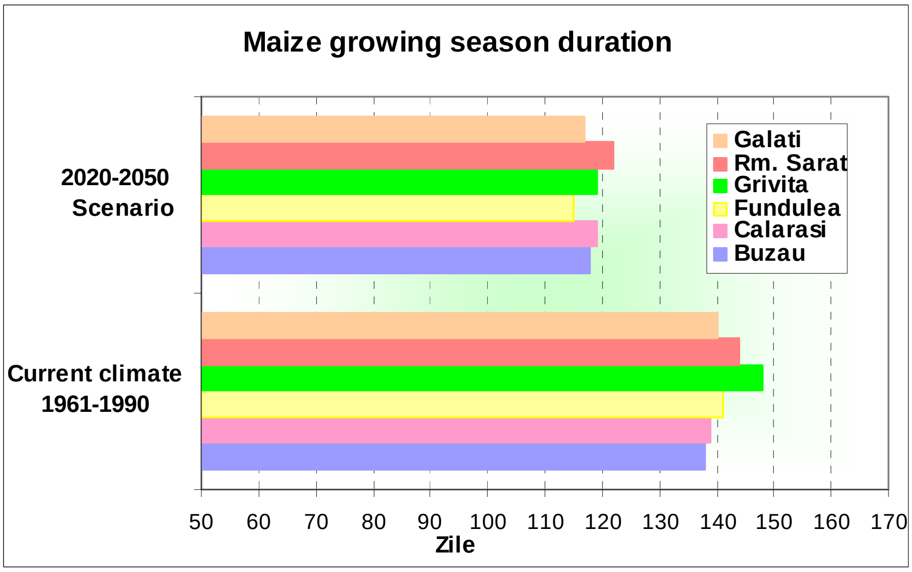


Fig. 3.8

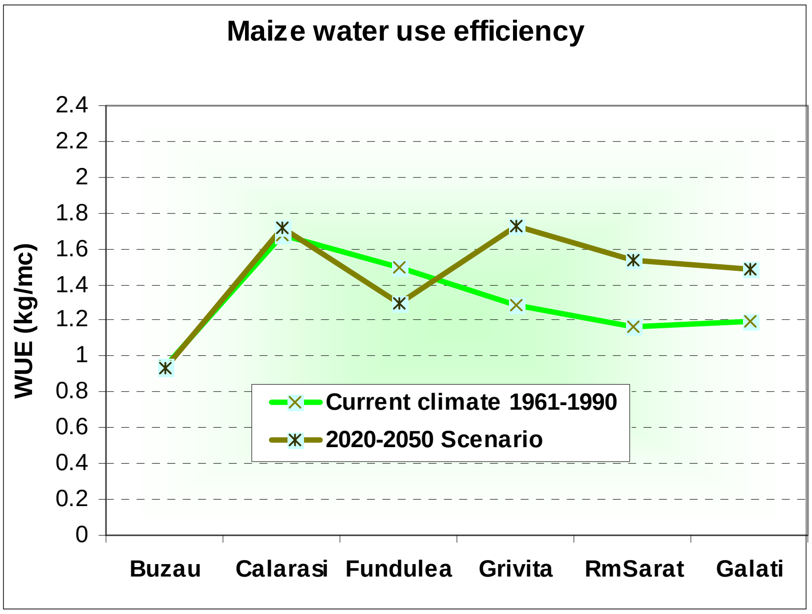


Fig. 3.9

A comparative analysis of the results obtained showed that future changes in regional scenario-based climate evolutions can have negative effects upon yield increase, development and formation. For both analyzed crops, the vegetation season gets shorter and there are fewer days available to reaching full ripeness. This shortening of the vegetation season is more marked in maize crops than in winter wheat. Such a forcing is mainly due to a probable increase in air temperature, estimated by the regional model.

As to the possible effects of climate change upon yields, they depend on the genetic type (C_3 or C_4), direct effects of increased CO2 concentrations on photosynthesis, local conditions and the severity of changes in climate evolution according to the two scenarios. So, maize yields decrease at every analyzed station in comparison with the current clime case, due to higher temperatures leading to shorter vegetation seasons associated with water stress, mainly during the phenological stage of grain formation and filling. In winter wheat, grain yields are higher than in current clime conditions at every station of the six analyzed, due to a positive effect of increased CO2 concentrations in the atmosphere (from 330 ppm to 450 ppm) upon photosynthesis and water use, which counterbalances the negative effect of a shorter vegetation period.

3.5 Conclusions

Analyzing the results simulated on the grounds of 2020-2050 climate change estimations made by regional climatic models highlighted that the future climate evolutions may he have important effects upon crops and they are conditioned by an interaction between the following factors: current climate changes on a local scale, severity of climate scenario-forecasted parameters, how the increased CO2 concentrations influence photosynthesis, and the genetic nature of plant types. Winter wheat can benefit from the interaction between increased CO2 concentrations and higher air temperatures, while maize is vulnerable to climate change, mainly in the case of a scenario predicting hot and droughty conditions.

As against current climate conditions, the RegCM3 scenario estimates that air temperature increases will shorten the vegetation season for every analyzed station and both crop types.

If climate changes according to the analyzed scenario, the maize yields will decrease at every analyzed station due to higher temperatures that shorten the vegetation season, coupled with a water stress, mainly during the phenological phases of grain formation and filling. In winter wheat, the yields will increase in comparison with the current clime conditions as a consequence of increased CO2 concentrations in the atmosphere (affecting photosynthesis) and of using water supplies to counter-balance the negative effect of shorter vegetation periods.

The cumulated amounts of water lost to evapotranspiration during the vegetation season in both crop types will decrease in every analyzed case, to a higher degree in maize crops, following an interaction between the two opposite processes: a high temperature-related shortening of the vegetation period and the physiological effect of increased CO2 concentrations upon crops.

Beside maize, wheat is more efficient in using the available soil water reserves given the regional climate predictions over 2020-2050 as against the current conditions due to higher CO2 assimilation rates, though this interaction can be restricted by higher temperatures and smaller amounts of available soil water.

The results shown in this study are very important and they can contribute to laying the grounds of and developing management options to adapt to and mitigate climate change-related negative effects affecting crop systems.

Specific measures for adaptation to climate change in agricultural field could include:

- *to improve the genotype varieties and yields:* altered genetic coefficients, respectively for winter wheat the vernalization an photoperiod (P1V and P1D). For winter wheat the most suitable combinations can be the varieties with high or moderate vernalization and moderate or shorter photoperiod requirements.

- *to improve the effective use of water by crops:* use of cultivars resistant to abiotic stresses (i.e. drought, high temperature) and resistance to specific diseases; using different soil classes; changing the seeding date and selection of cultivars with shorter germination and shorter growing season; application of irrigation and choose the most suitable irrigation method considering type of crop, soil type, technology, costs and benefits; changing the agricultural practices and crop rotation systems; perform periodical soil analysis and tests, in order to assess and correct the limiting factors which hinder the normal growth and development of plants (acidity, nutrient excess or deficit, etc.); use of natural organic fertilizers, adapted to needs/demands.

Climate is the ensemble of meteorological processes and phenomena specific to a geographical region. The management and sustainable development decisions should aim to increase the agricultural production by growing in each region the appropriate crops that have the largest benefit from the natural potential for agriculture, which is evaluated through analysis of agropedoclimatic conditions.

4 AGRICULTURE - BULGARIA

4.1 Most critical vulnerabilities

In the last decade, natural severe meteorological events occurred worldwide, raising the decision-makers' awareness of these recurring dangers. Over the 20th century, south-eastern 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 southeastern Europe and adversely affected the livelihood of many people.

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.

The climate in Bulgaria is temperate Continental-Mediterranean. Due to the geographical situation and the varied landscape, the contrasts in the climate are distinct among regions. The climate is with four distinctive seasons and varies with altitude and location. The Black Sea coast features a milder winter as opposed to the harsher winter conditions in the central north plains. Bulgaria has five climatic zones - Moderate Continental, Intermediate, Continental-Mediterranean, Maritime and Mountainous. The main factor distinguishing the first three zones is the latitude, the terrain for the mountainous and the Black Sea for the maritime. The air humidity is between 66 and 85% in the different regions of the country. There is a stable snow cover during the winter of about 20-200 cm. The Thracian Plain and the north-eastern coastal area suffer from low rainfalls. The total annual quantity of precipitation measured at the 40 monitoring meteorological stations vary from 455 to 93 mm, which is 60% to 137% of the norm. The mean values in 1999 was 619 mm, which is 98.84% of the annual norm, by about 4.3% lower than the value for 1998, and by 6.4% lower than the value for 1997. The tendencies over the last years are: almost ubiquitous reduction of precipitation, especially in the mountain areas of the country; total annual quantities of precipitation in northeast Bulgaria, Black Sea coast, Upper Thrace Low-down, southwest Bulgaria, Vratza-Pleven and Sofia regions are lower; no change in the established annual rate of non-precipitation days. The average wind speed is 1.2 m/s (1.3 m/s in winter time), while prevailing winds are west or northeast. The Balkan Mountains are the southern boundary of the area in which continental air masses circulate freely. The Rhodope Mountains mark the northern limits of domination by Mediterranean weather systems. The area between, which includes the Thracian Plain, is influenced by a combination of the two systems, with the continental predominating. Average precipitation in Bulgaria is about 630 mm per year. Dobrudja in the northeast, the Black Sea coastal area, and parts of the Thracian Plain usually receive less than 500 mm. The remainder of the Thracian Plain and the Danubian Plateau get less than the country average; the Thracian Plain is often subject to summer droughts. Higher elevations, which receive the most rainfall in the country, may average over 2,540 mm per year. The coastal climate is moderated by the Black Sea, but strong winds and violent local storms are frequent during the winter. Winters along the Danube River are bitterly cold, while sheltered valleys opening to the south along the Greek and Turkish borders may be as mild as areas along the Mediterranean or Aegean coasts.

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 has 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.

The climate and weather risk in each NUTS3 regions in the country were generalized by the National Civil Protection

A survey shows 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.

4.2 Adaptation in agriculture (focused on irrigation)

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
- 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.

4.3 Questionnaire on adaptation options (summary)

The following questions were included:

1. Is there climate change in Bulgaria during the last years?

2. Do you think that more extreme natural phenomena as droughts, storms, intense precipitations, floods, landslides, forest fires, etc. are being watched in Bulgaria in the last years?

4. Are you convinced that the Bulgarian agriculture should be adapted to the contemporary meteorological conditions (with increased tendency to extreme situations) as well as to the expected climatic conditions in the country during the 21st century (warming and summer precipitation reductions)?

5. Do you have impression what information is needed to analyze and offer measures for adaptation of the Bulgarian agriculture to climate change?

6. Please mark the correct (according to you) answers and try to comment the following adaptation measures of agriculture under climate change in Bulgaria:

6.1. new zoning of agroclimatic resources:

6.2. raising the upper limit of agricultural production from 800 to 1000 m a.s.l. due to warming also in the high elevations:

6.3. developing land management practices to adapt to changes in soil properties:

6.4 restoring natural features such as hedgerows to help reduce erosion:

6.5. adopt measures to reduce the impacts of extreme precipitation events:

6.6. introduce measures to secure safety of livestock during extreme flooding events:

6.7. changes in technology for yield harvesting, transportation and conservation under summer drought conditions:

6.8. transfer of technologies from relevant climatic zones:

6.9. introduction of new crops that adapted to higher temperatures:

6.10. develop breeds or change to breeds adapted to changed conditions, especially drought and heat resistant varieties:

6.11. changes in sowing dates:

6.12. increase in irrigation area and or water volume:

6.13. introduction of new management techniques e.g. requiring less water:

6.14. adopt water re-use technology:

6.15. changes in fertilizer use:

6.16. develop farming practices that minimize susceptibility to new pests and diseases:

6.17. maximizing effectiveness of labor and machinery:

7. Do you think that some of the above-mentioned adaptation measures would cause the necessity for monitoring of environmental changes, e.g. changes in biodiversity?

8. Is it necessary to develop an information system (e.g. by engaging internet, media, lectures, courses, etc.) related to climate variability and change and their impact on agriculture?

9. Who should provide funds in order to apply adaptation measures of agriculture under climate change in Bulgaria?

Major findings are:

- Targeted studies are needed
- Studies carried out are related to farming systems that reduce the risk of soil erosion. Partial measures are taken occasionally. The problem requires a complex multi-disciplinary approach to solving it.
- Most of the measures are considered or planned in the country, but for economic reasons do not apply. If it is considered that some areas are vulnerable, probably monitoring should be used
- The majority does not have info on a new zoning of agroclimatic resources, but assume it is extremely necessary. Modern mapping options will make this information more accessible and usable.
- It must be taken into account both the soil and climatic conditions before making a recommendation. In some cases, soil characteristics will be limitation to such a measure
- In our practice of irrigation is in desperate condition because of lack of consistent policy in this regard over the last 20 years
- Research in the country and abroad are on the level of practical implementation methods for increasing efficiency in irrigation, reducing water losses. And discussed in detail in publications, including dissertations and international scientific journals and popular magazines. In general practice most commonly observed in most irrigation vandal way
- There are technologies developed for re-use of wastewater for irrigation
- There is a possibility to implement models for fertilization, consistent with agrochemical characteristics of soil and crop requirements; at a research stage of the Institute of Soil Science, etc.
- Information support system to provide daily information to farmers on evapotranspiration reference for precise irrigation system adapted to the technology of irrigation, soil properties, etc. Will increasingly pose problems related to additional payments in agriculture and due to unfavorable weather conditions. Must have available information on agro-environmental resources and indicators of adverse climatic events, the impact on agriculture and possible adaptation measures.
- It is necessary to conduct regular discussions between politicians and a society of scientists as well as technocrats, because the researchers have the knowledge to developed specific measures to adapt agriculture to climate change
- The state is willing to implement adaptation measures in agriculture, as it involves not only the development of this sector in the country, but also the protection of nature as a whole, because the risk of desertification

4.4 A strategy evaluation of irrigation management of maize crop under climate change in Bulgaria

Adaptation 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.

The greatest part of the national maize production is concentrated in the areas with elevation below 800 m. Besides, the most of global circulation models (GCMs) are with smoothed orographic features. That is why, 21 experimental crop variety stations in Bulgaria with elevation below 800 m were selected for the simulation study. Meteorological and agrometeorological data from the above-mentioned stations were gathered from 1971 to 1995. The 30-year baseline climate data were based in this study on the period 1961-1990, recommended by the World Meteorological Organization (WMO). Several climate change scenarios were created by changing observed data from the current climate (1961-1990) according to doubled CO_2 simulations of 7 GCMs. The altered temperature and precipitation databases corresponding to each of the climate change scenarios were used to run the CERES GENERIC 3.0 simulation model of maize. Crop management, technology, and distribution of cultivated land were assumed to be constant.

Agricultural production is very sensitive to change and variation in weather conditions during the regular growing season. All the developmental processes, starting as early as the germination process immediately after planting, and as late as the ripening process during physiological maturity, are affected and controlled by temperature. All scenarios projected a shorter vegetative (sowing-silking) and reproductive (silking-full maturity) growing season of maize (Fig. 3a). These changes were driven by the temperature increases of the scenarios. Simulated grain maize yield decreases in Bulgaria were caused primarily by warming and precipitation deficit during the growing season of this crop.

The DSSAT Seasonal Analysis program was run in order to determine the most appropriate timing and water amount of irrigation applications under the expected climate change during the growing season of maize. Both biophysical and economic analyses were done. The strategic analysis, was done in respect to the simulated value of harvest maize yield and net return. The tested treatments of the irrigated numerical experiment assumed maize growth and development under rainfed conditions, different date(s) and water amount of irrigation. In a similar way, the economic analysis of the Seasonal Analysis computer program calculates means, standard deviations, maxima and minima of the economic returns, and plots these as box plots, cumulative function plots, or mean-variance diagrams. Formal strategy evaluation of all treatments is carried out using mean-Gini stochastic dominance (Tsuji et al., 1994). In contrast to the biophysical analysis returns per hectare of the 6th treatment are lower than returns of the 4th and 5th treatments due to more water being applied. By running the "Strategy Analysis" option of the Seasonal Analysis program, the mean-Gini dominant treatment of the irrigated experiment can be calculated, in terms of the costs and prices used to analyze it. Actually, the dominant treatment was the 5th treatment - 40 mm water applied per every day (total 3 days) of irrigation.

4.5 Recommended and feasible adaptation options

National Overview

Agriculture in Bulgaria

- The agriculture is one of the most important sectors of the Bulgarian economy. Much of the Bulgarian population is involved in it.
- The sector forms a relatively small share of the GDP.
- Cultivated agricultural land covers 48% of the total territory of the country.
- Agriculture is still in a crisis at present.
- Most of the farms are small and do not have at their disposal significant financial means. Various European funds are not enough efficiently used.
- The government must invest to get out quickly of the crisis in this important structural sector of the Bulgarian economy.

Changes in irrigation

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.

Changes in sowing dates

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.

Changes in crop cultivars and varieties

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.

New crop zoning

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.

5 AGRICULTURE – THE SLOVAK REPUBLIC

Climatic conditions become the most important factor influencing variability of field crop yields in Slovakia today. Increase of annual mean air temperature by about 1 °C was occurred on most of climatic stations in Slovakia during the last century. On the other hand, annual precipitations decreased by about 10% on lowlands of Slovakia (Danubian and east Slovakian lowlands) during this period. Precipitation totals varied also in mountainous regions, but no significant trend was found during the last century (*Lapin et al.*, 2001).Two indices were selected for sensitivity analyses of the territory of Slovakia: the climatic water balance and evapotranspiration deficit. Temperature and drought characteristics were evaluated for growing seasons limited by daily mean air temperatures *T* >10.0 °C, henceforth signed by GS10. Climatic water balance was used for proposal of agro climatic regionalization of the Slovak Republic (*Šiška* and *Špánik*, 2008).

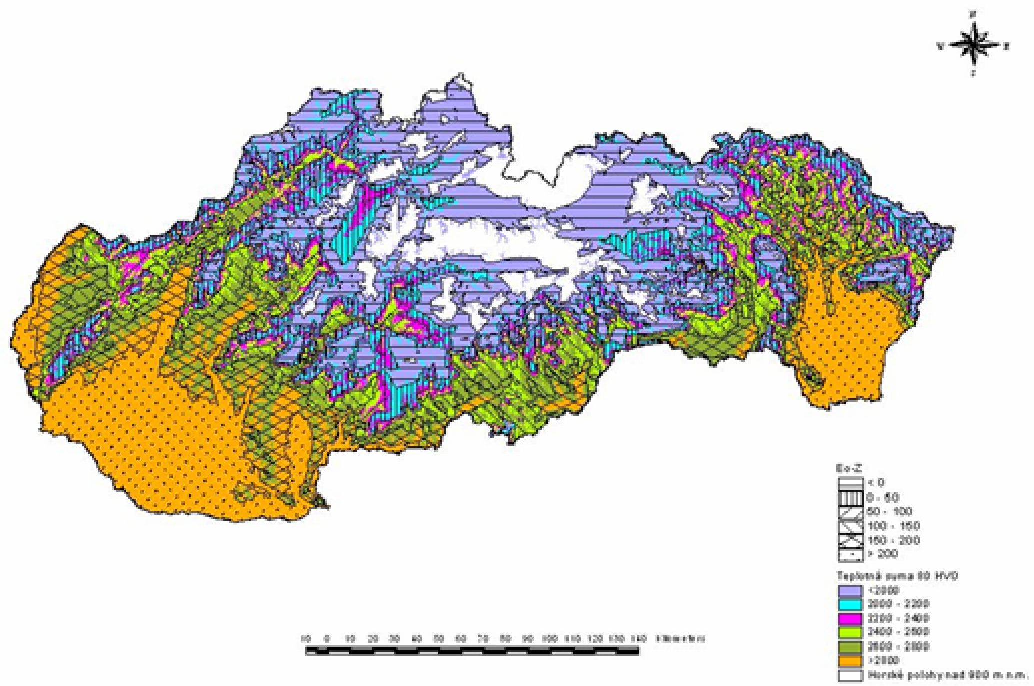


Fig 5.1 *Agroclimatic regions of SR*

Tab 5.1 *Agricultural regions and related climatic regions*

Region	Sub region	*TS10*	*E_0-R*	*Agricultural region (Productive type)*
Cold	Wet	< 2000	< 0	Mountainous
Moderately warm	Normal	2000 - 2400	0 – 50	Potato
Warm	Dry	2400 -2800	50 – 150	Sugar beet
	Very dry	> 2800	>150	Maize

5.1 *Duration of growing season*

The main growing season (GS10) is limited by the onset and end of daily mean air temperature T >10 °C, and it is the period when drought conditions are frequently observed. As resulted from trend lines of the onset and end of GS10, the onset of GS10 would start significantly earlier by about 28 days in climate conditions of the 2×CO_2 climate in the whole altitudinal profile as compared to climate conditions of the 1×CO_2 climate. The end of the GS10 period will be delayed by about 14 days under the 2×CO_2 climatic conditions as compared to the 1×CO_2 climatic conditions.

The duration of the GS10 of the maize region related to the reference period 1×CO_2 is 175 days or which represents about 34% of total acreage of agricultural regions. Those conditions will occur on 80% of the total agricultural regions acreage in 2×CO_2 climatic conditions and the duration of GS10 can exceed 200 days in the Danubian lowland, east Slovakian lowland, and Zahorie lowland. **Duration of GS10 influences positively photosythetically active period of maize and, therefore, also biomass creation. On the other hand, a longer duration of GS10 also increases the potential risk for drought occurrence.**

Precipitation (R)

Generally it is supposed, that the precipitation total increases in 2×CO_2 climatic conditions. Except for the GCM, this fact is influenced also by a rising duration of GS10. **An increase of *R* by about 60 mm in the lowlands of southern and eastern Slovakia and by 79–134 mm in northern Slovakia will probably not be sufficient.** All regions should receive more than 390 mm precipitation during GS10 in 2×CO_2 climatic conditions, and raising rainfall could favorably influence the yield of some crops (e.g., maize and other cereals). **The distribution of precipitation generated by the GCM in the context of rising air temperatures and consequently increasing crop water demands during GS10 will, however, very probably result in increasing occurrence of drought conditions reducing yields of field crops.**

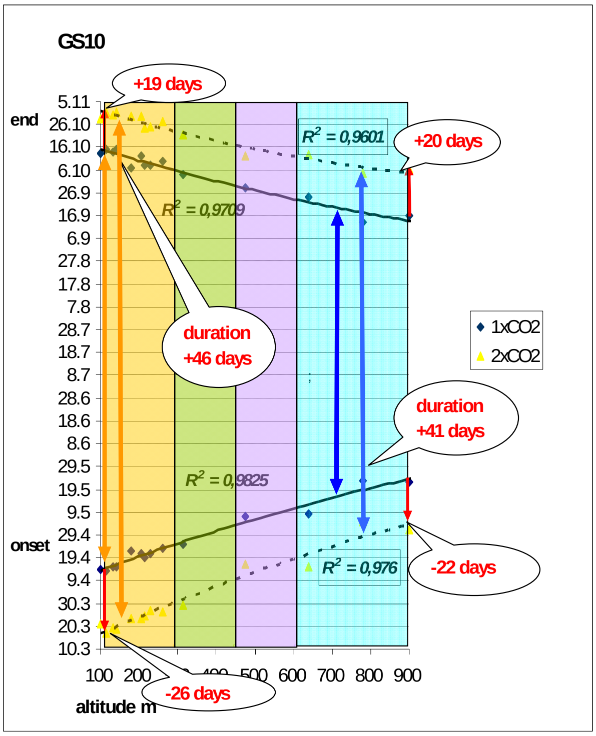


Fig. 5.2 *Onset and end of growing seasons GS10 in dependence on altitude for 1×CO_2 and 2×CO_2 climates.*

Changes of evapotranspiration characteristics

Potential evapotranspiration of E_0>450 mm during the GS10 period in the whole agricultural area, and even E_0 exceeding 700 mm, can be expected in the warmest areas of Slovakia (south of Danubian lowland, and the lowest areas of east Slovakian lowland). **Such high E_0 totals call for the need of effective management with water resources and for building irrigation systems in most of the territory of Slovakia to eliminate negative effects on yield production**.

Climatic water balance

The supposed air temperature increase and consequent increase of GS10 duration influence the E_0 increase in the 2xCO_2 climate on the whole area of Slovakia. During GS10, E_0 will increase in the lowlands of Slovakia by 160–170 mm, i.e., by 27–30%, on uplands by 106 mm, i.e., by 34%. E_0>500 mm can be expected in all agricultural regions of Slovakia, E_0 >750 mm can be expected in the warmest regions of Slovakia (south of Danubian lowland and east Slovakian lowland). Such high E_0 totals during the relatively short GS10 period (compared to GS5) will increase the potential of the occurrence of drought periods. **Effective management of water resources can, therefore, eliminate the negative influences of evaporation demand on agricultural production in the majority of regions in Slovakia.**

K_{GS10} is changing in the whole altitudinal profile of Slovakia significantly. The original classification scale of drought-wet conditions proposed for Czechoslovakia by *Kurpelová et al*. (1975) was based on 50 mm differences of the index. According to this criterion, 5 categories of drought conditions can be defined for the reference ($1\times CO_2$) climate. **Most of the agricultural acreage belongs to the areas where wet conditions prevail in altitudes above 550 m. According to the calculations based on GCM outputs, those conditions can be found in future in altitudes higher than 700 m. Other two categories of drought can be defined, where the deficit of water exceed 250 mm during GS10 (*Fig.5.3*). These two new categories of drought will cover the most productive regions of the Slovak Republic – the Danubian and east Slovakian lowlands that represent the maize region productive type.**

Evapotranspiration deficit

Evapotranspiration deficit ΔE as an important compound of water balance was also used for evaluation of drought conditions in Czechoslovakia (*Tomlain,* 1979). Except for meteorological factors, the calculation of actual evapotranspiration takes into account also soil water content and therefore, this parameter can better reflect drought conditions of agricultural regions.

According to the index ΔE, the territory of Slovakia looks even more vulnerable to drought than according to the previous index *K*. While $\Delta E \leq 100$ mm was calculated for sites with altitude over 300 m for the reference climate $1\times CO_2$, those conditions will be found in altitudes above 500 m for the $2\times CO_2$ climate. These values represent potato and mountainous productive regions.

Tab 5.2 *Climatic index of drought ($E_0 - R$) and evapotranspiration deficit ($E_0 - E$) related to agricultural productive regions for $1\times CO_2$ and $2\times CO_2$ climates in Slovakia*

Agro regions	**$E_0 - R$ [mm]**		**$E_0 - E$ [mm]**	
	$1\times CO_2$	**$2\times CO_2$**	**$1\times CO_2$**	**$2\times CO_2$**
Maize	150 – 250	250 – 360	130 – 220	240 – 350
Sugar beet	75 – 150	150 – 250	70 – 130	140 – 240
Potato	0 – 75	–20 – 150	30 – 70	90 – 140
Mountainous	< 0	< –20	<30	<90

As resulted from calculations based on GCM outputs, two new very dry categories of drought can be defined, where $\Delta E \geq 250$ mm (*Fig.5.4*). Except for the Danubian and east Slovakian lowlands, also valleys of Slovakian rivers up to altitudes of 300 m will suffer from drought. On the other hand, the acreage of agricultural regions, where $\Delta E < 50$ mm, will diminish under conditions of climate change.

Conclusion

- Duration of GS10 influences also potential for drought occurrence.
- Two very dry and hot regions can be defined where deficit of water exceeds 250 mm in condition of climate change. These two categories of drought will cover the most productive regions of Slovak republic – Danubian and East Slovakian lowlands that represent from the point of view of agricultural regions maize productive type.
- According to drought indices most of the agricultural acreage belongs to the areas where wet condition prevails in altitude above 550m a.s.l. in reference climate $1xCO_2$. As resulted from calculations based on CCCM outputs those conditions can be found in altitude higher than 700 m.
- Except for agroclimatic regionalization these facts should be taken into account in breeding strategies of new crop varieties suitable for future climate of Slovakia.

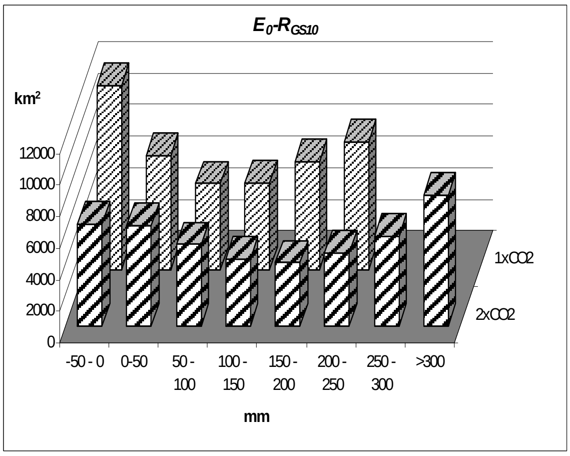


Fig. 5.3 *Relative representation of regions according to climatic water balance for 1×CO_2 and 2×CO_2 climates in Slovakia*

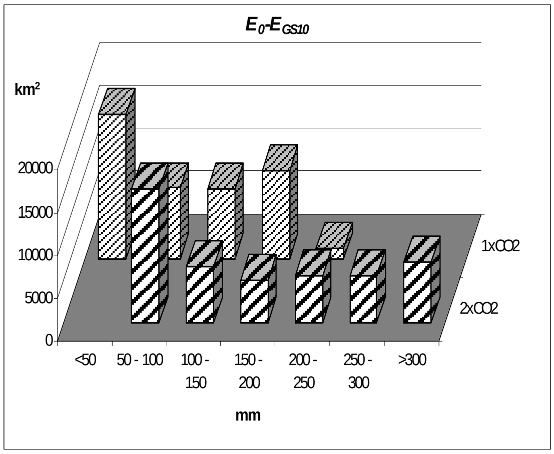
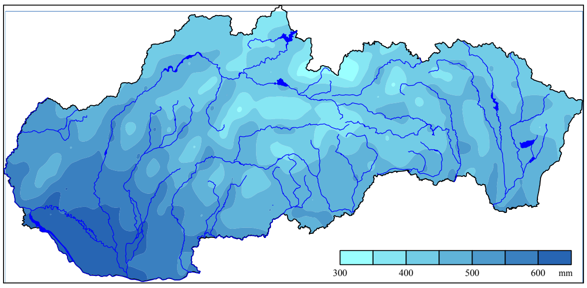
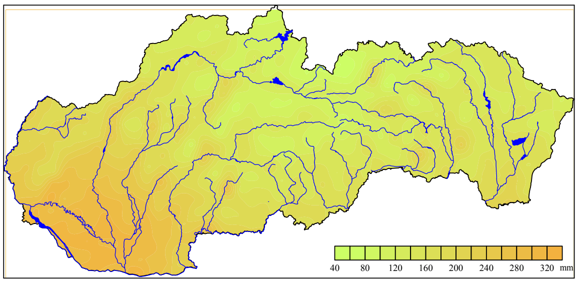


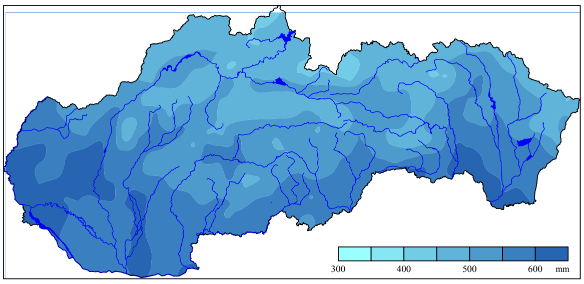
Fig. 5.4 *Relative representation of regions according to evapotranspiration deficit for 1×CO_2 and 2×CO_2 climates in Slovakia*



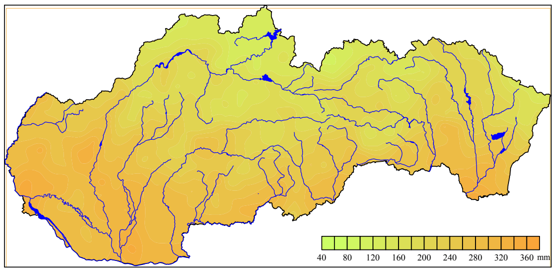
ET_0 - growing season IV-IX (1961-1990)



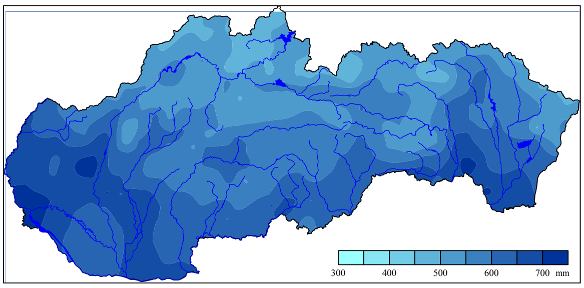
ET_0-E - growing season IV-IX (1961-1990)



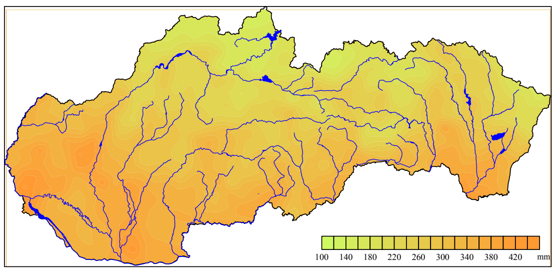
ET_0 - growing season IV-IX (2021-2050)



ET_0-E - growing season IV-IX (2021-2050)



ET_0 - growing season IV-IX (2071-2100)



ET_0-E - growing season IV-IX (2071-2100)

Fig. 5.5 *Potential evapotranspiration during growing season in Slovakia for different time slices 1961-1990, 2021-2050, 2071-2100)*

Fig. 5.6 *Potential evapotranspiration during growing season in Slovakia for different time slices 1961-1990, 2021-2050, 2071-2100)*

5.2 Climate change impact on relations among evapotranspiration, water use efficiency and crop yields on Danubian lowland

Simulation models are practically the only complex tool to estimate crop response on the climate change without carrying out expensive experiments. Winter wheat as a strategic crop was the most simulated crop in Slovakia. Spring barley and maize were not evaluated so frequently as compare with winter wheat.

New generation of climate change scenarios is available for agroclimatic modeling in conditions of the Slovak republic. The aim of this study is to evaluate possible climate change impact on spring barley and winter wheat yields in conditions of the most productive areas in Danube river basin according to new generation of GCM in two variants of emission scenarios – high sensitivity (SRES A2) and low sensitivity (SRES B2). Nutrient and irrigation level were tested as possible adaptive measures to reduce negative impacts of climate change in conditions of Danubian lowland.

Tab. 5.3 *Annual and seasonal mean air 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

Evaluation of the climate change impacts on soil water regime under field crops was based on simulations by agroecological model DAISY. DAISY is a one-dimensional model simulating water, energy, nitrogen and soil organic matter balance. Crop development and yield is possible to simulate in dependence on crop rotation and various management strategy. DAISY simulates plant growth and development, including the accumulation of dry matter and nitrogen content in different plant parts. The main plant-growth processes considered in DAISY are photosynthesis, respiration, partitioning of assimilates, stress factors and leaf and root development. DAISY allows for building complex management scenarios (Hansen et al. 1990; Hansen 2000).

Crop parameters of spring barley, winter wheat, maize and sugar beet were calibrated and validated for the Slovak conditions. Calibration of Daisy was based on experimental results from the Experimental field station in Most near Bratislava. Simulated crop yields were validated using the crop yield data from the field experiments from the period 1973 – 2006 (Fig 5.7). Evaluation of agreement between simulated and observed data was done using statistical tools. Based on the comparisons between measured and simulated dry matter (DM) production, nitrogen uptake and soil inorganic nitrogen content the overall performance of the model under Slovak conditions was considered satisfactory.

Based on the hydrophysical analyses of soils (Nováková 1996) medium textured chernozem soil profile with 3.5 % humus content in topsoil was considered as representative. Chernozems are the most productive soils in Slovakia. Each horizon of soil profile was characterized by texture, retention curve, hydraulic conductivity, humus content and C/N ratio.

The selection of the crops (winter wheat, spring barley, sugar beet, maize, potato, winter rape, alfalfa, pea) included in the crop rotations was based on the areal coverage of crops dominating in the region of Danubian Lowland. 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 (winter wheat 150, spring barley 60, maize 120 kg $N.ha^{-1}$)

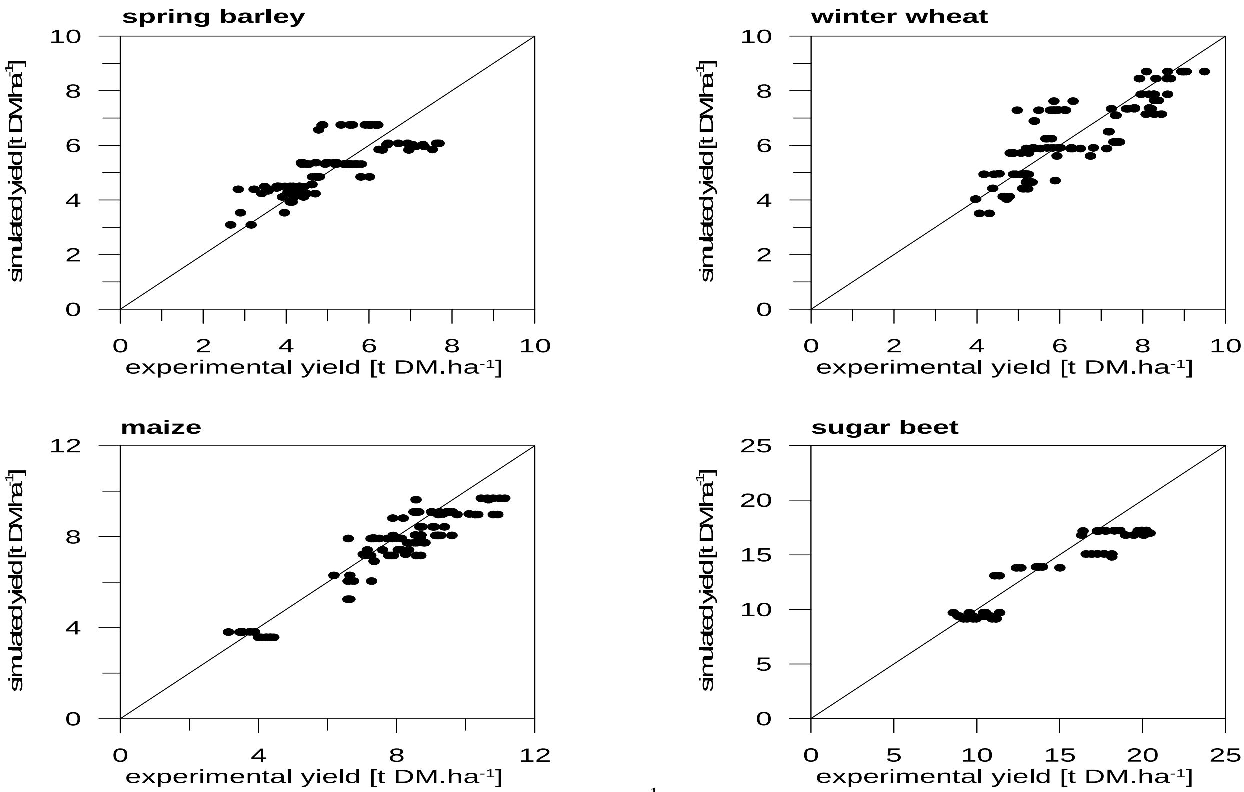


Fig 5.7 Observed and simulated yields [t $DM.ha^{-1}$] of crops from the field experiments from the period 1973 – 2006.

CO_2 effect on photosynthesis rate was evaluated in simulations on level with the effect of gradual increase of CO_2 concentration. Daisy simulates photosynthesis rate using a light saturation response curve. The effect of CO_2 concentration was included to the Daisy parameterization according to light saturated photosynthesis rate *Fm* [g $CO_2.m^{-2}.h^{-1}$] and initial light use efficiency ϵ [(g $CO_2.m^{-2}.h^{-1}$)/($W.m^{-2}$)].

Crop yields were related to the evapotranspiration and consequently water use efficiencies were calculated as follows:

$$WUE = \frac{Y}{ET}$$

where *WUE* is crop water use efficiency [$kg.mm^{-1}$], *Y* is crop dry matter yield [kg] and *ET* is evapotranspiration total [mm] from the sowing to the harvest.

Soil moisture is one of the most variable soil properties. Soil moisture regime is seasonally influenced on lowlands of Slovakia. The maximum soil water content is recorded in dependence upon winter rains or date of snow melting at the end of winter period or at the beginning of spring and the minimum soil water content is recorded during summer months. Median values (every second year) of the integral water content bellow 50 % of AWC lasted according to model simulations

since June till the end of September. If the upper quartile (3 from 4 years)values are considered only the water content bellow 50 % of AWC is recorded since the beginning of July until the second decade of September.
Simulations with climate change scenarios data increase variability of water content regime during year. Generally the decline of AWC during growing seasons especially in summer months (since May till September) confirm decreases of all evaluated statistical characters, upper and lower quartiles, medians and averages (fig. 5.6). Simulations according to SRES A2 show that the upper quartile of the water content in soil layer 0 – 100 cm will be deeply below 50% of AWC since half of June till half of September up to horizon of years 2071-2100. On the other hand in some years the AVC below 50 % are not calculated.
According to both emission scenarios consequent increase of potential evapotranspiration and crop water requirements will gradually increase up to time horizon 2071–2100. Rising CO_2 concentration will positively influence productivity of C3 crops due to increase of water use efficiency (fig. 5.10).
As resulted from simulations of climate change impacts the shortage of soil water will decline. Number of days with available water capacity

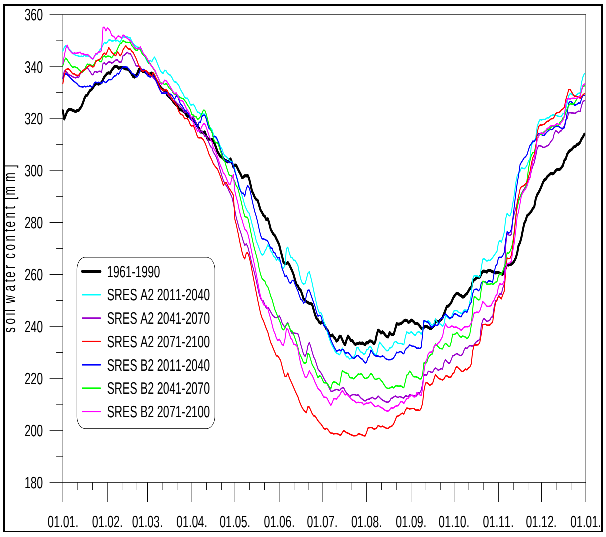


Fig 5.8 *Annual course of mean soil water content in the horizon 0 – 100 cm [mm] on Danubian Lowland in the period 1961 – 1990 and according to the climate change scenarios*

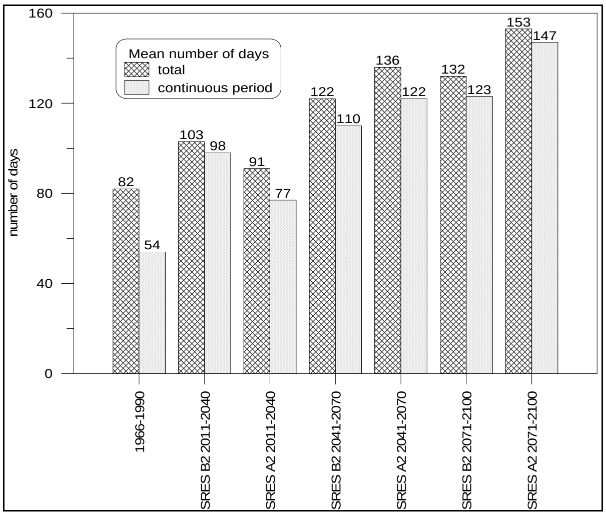


Fig 5.9 *Mean annual number of days with soil water content below 50 % of available water capacity in the period 1961 – 1990 and according to the climate change scenarios*

below 50% will increase during the growing season of field crops and evoke increase of irrigation requirements. The irrigation season will start earlier and will persist for longer time (Fig. 5.8, 5.9). Irrigation can be in case of insufficient water sources the limiting factor of sustainable yields of field crops.
Rainfall totals and their distributions in growing season do not cover raising water demand of plant production even today. Irrigation plays important role to reach sustainable yields of field crops. Simulated irrigation requirements for different crops in reference period of years and condition of climate change are given on Fig. 5.8.
According to SRES B2 irrigation requirements of different field crops can increase by 21-105% up to evaluated horizons of climate change and by 20– 55 % according to SRES A2 as compared with reference period of years. The highest increase of irrigation requirements was found for sugar beet crops: 56–105 % according to SRES B2 and 50–155 % according to SRES A2. Another aspect of irrigation requirement in conditions of climate change is increase of its variability. Except for sugar beet the increase of variability on irrigation requirements in different year was found also for maize, spring barley and winter wheat

Simulations show that time schedule of irrigation will also change during growing season of field crops. In dependence on crop, SRES and time horizon of climate change **the first irrigation should be applied in average by 7-27 days earlier then in conditions of reference climate and by 11-38 days in extreme years on Danubian lowland.** Duration of irrigation season will be longer and water will become the most important limit of sustainable plant production.

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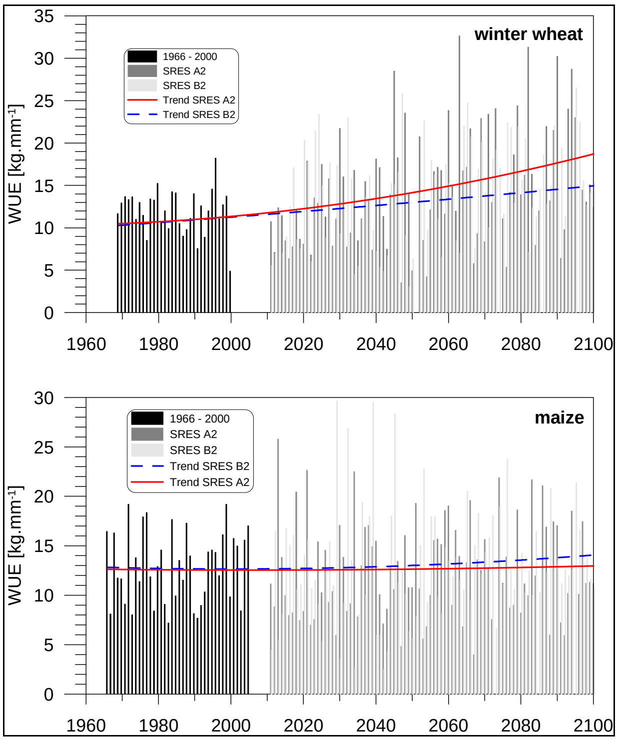

Fig. 5.10 *Winter wheat (up) and maize (down) water use efficiency WUE [kg.mm^{-1}] in 1966–2000 and according to the climate change scenarios*

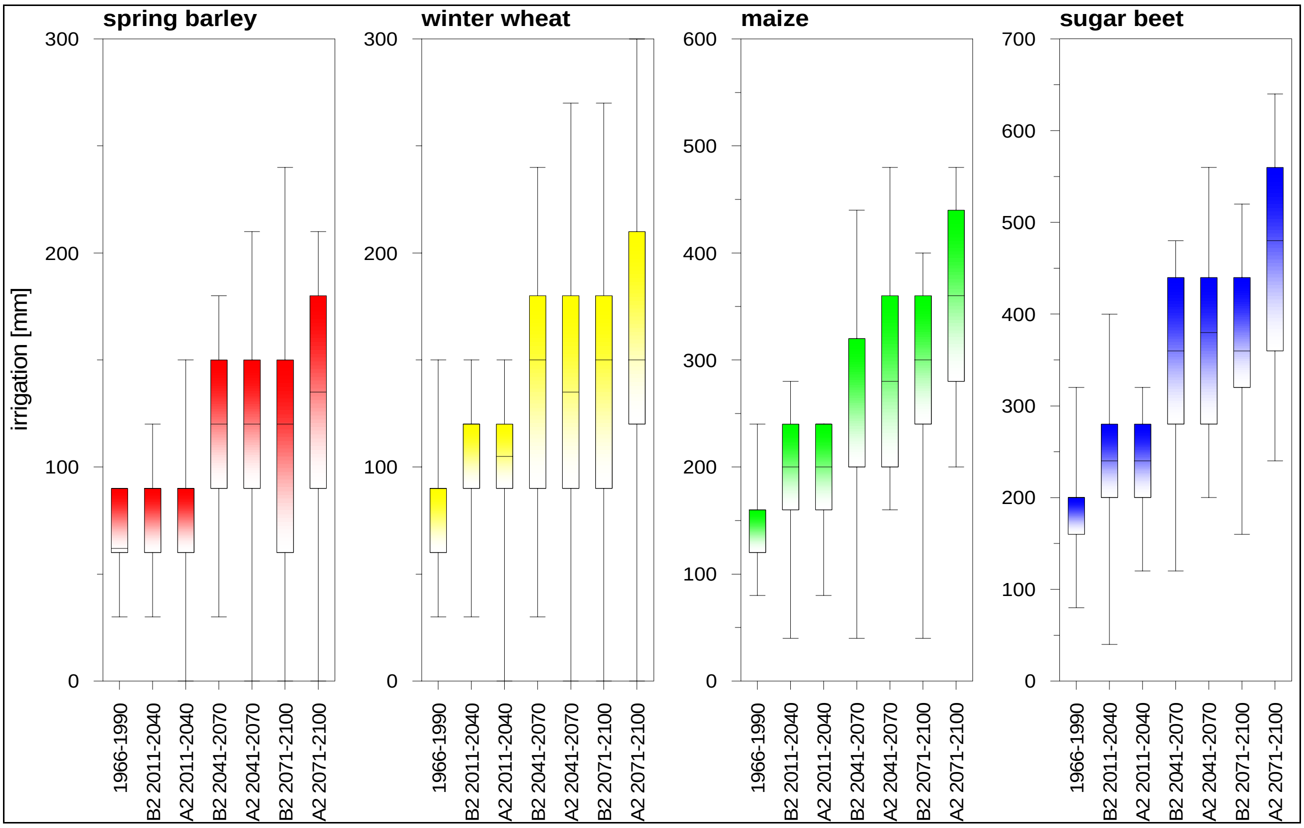

Fig 5.11 *Statistical characteristics of irrigation requirement [mm] of field crops in the period 1966 – 1990 and according to the climate change scenarios*

Water use efficiency was influenced by complex effect both of elevated CO_2 concentration and available soil water content. 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 5.10). More extreme differences of WUE between time slice 2071-2100 compared to reference period of years were calculated according to SRES A2. Those differences according to SRES B1 are relatively small. This fact is related with the nature of climate change scenarios when high air temperatures reduce yields both of winter wheat and maize.

Increase of CO_2 concentration and consequent increase of photosynthesis rate will positively affect the yields of spring barley, especially towards more distanced time horizons. On the other hand, course of meteorological elements generated by general circulation models cause some negative effects which frequently led to the fall of simulated yields. Generally, the yield increase in conditions of climate change will not correspond to the theoretical level of efficiency of photo synthetically active radiation for both spring barley and winter wheat crops that was calculated in dependence upon CO_2 concentration in the atmosphere for emission scenarios SRES A2 and SRES B2.

Results of crop yield simulations are influenced by interactive effect of factors taken into account. Shortage of water and/or was expressed in yield decline. Spring barley as well as winter wheat yields are also affected by duration of growing season and possible absorption of photosynthetic active radiation. Due to global warming the growing season will move towards months at the beginning of year that are characterised by lower radiation inputs.

Based on the simulation results, fertilisation effect of CO_2 on spring barley and winter wheat top dry matter yield in rainfed conditions is evident according to both emission scenarios. Because the role of CO_2 concentration on photosynthesis rate in DAISY model is dominant as compare with other factors influencing formation of yield most significant increase of biomass yield was found in simulations according to SRES A2. According to the scenario SRES B2 the effect of CO_2 on top dry matter yields in Danubian Lowland is insufficient to compensate the negative effect of the other environmental factors

Top dry biomass yield will be formed mainly by straw yield in future climate. Simulated harvest index dropped in range from 2 to 12 per cent in average as compared with reference period of years. Grain yields would be probably reduced by high temperatures during ripening. Transport of assimilates from other parts of the plant into grains is not so effective because of accelerating effect of high temperatures on ripening of cereals (Šiška, 1997). If compare rainfed and irrigated variants, variability of yields is significantly smaller in irrigated ones. Irrigation would be effective measure to reach stabile yield of cereals in future climate. **Irrigation was confirmed as an effective adaptive measure reducing yield loss and significant factor stabilizing top dry matter and grain yields. Harvest index of irrigated crops was higher than the harvest index of rainfed crops.**

Soil water content seems to be the main limiting factor of crop yields. Spring barley top dry matter yield increased by 27 per cent and grain yields by 24 per cent in water and nutrient non stressed conditions. Yields are influenced by CO_2 concentration first of all in the $2xCO_2$ climate. Effect of CO_2 on spring barley yields was suppressed in rainfed variants with limited irrigation and variants with limited nitrogen fertilisation, mainly according to the scenario SRES B2, which assumes less raise of CO_2 concentration.

Increase of irrigation demands of spring barley by about 3 – 20 per cent in dependence on the soil properties, region, scenarios and time horizon was found. According to simulations the irrigation season of cereals will start by about 14 days earlier in time horizon 2070. On the other hand, irrigation efficiency of spring barley and winter wheat decreases according to the scenarios in average. Nevertheless the maximum values of irrigation efficiency of spring barley and winter wheat in dry years increased to 4.1 – 4.3 $kg.m^{-3}$ and 4,3 – 4,6 $kg.m^{-3}$ respectively.

According to the statistical analyses of simulated yields there was found significant interactive effect of irrigation and fertilisation on spring barley and winter wheat grain yields. Yields of spring barley increased by 53 per cent according to SRES A2 and 45 per cent according to SRES B2 in average as compare with rainfed variants. Yields of winter wheat increased by 88 per cent according to SRES A2 and 35 % according to SRES B2 in average as compare with rainfed variants.

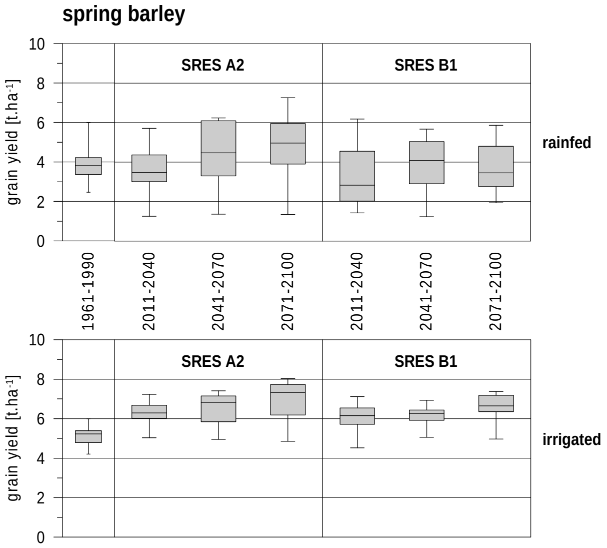

Fig 5.12 *Variability of rainfed and irrigated grain yields of spring barley [t.ha^{-1}] according to the scenarios SRES A2 and B1*

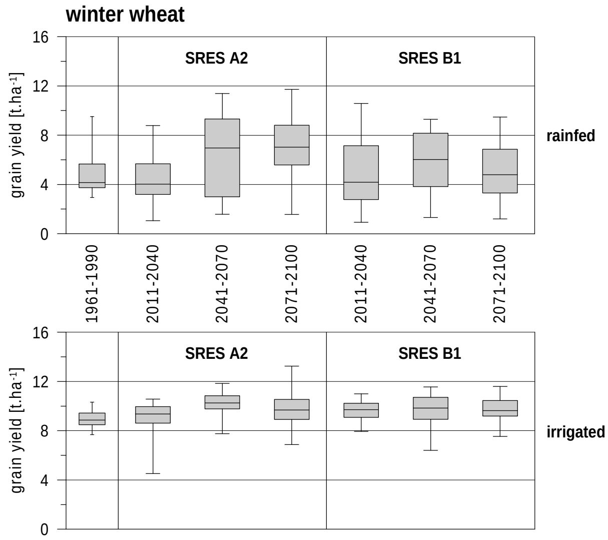

Fig 5.13 *Variability of rainfed and irrigated grain yields of winter wheat [t.ha^{-1}] according to the scenarios SRES A2 and B1*

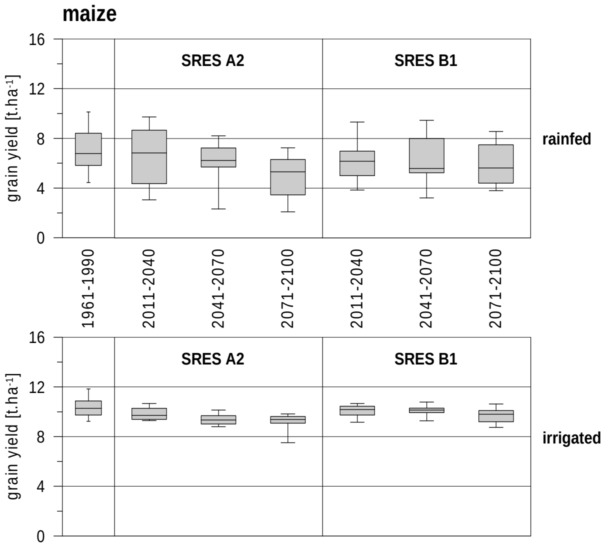

Fig 5.14 *Variability of rainfed and irrigated grain yields of maize [t.ha^{-1}] according to the scenarios SRES A2 and B1*

5.3 Summary

Simulations confirmed the acceleration of crops developments due to temperature increase. The first irrigation should be applied in average by 7-27 days earlier then in conditions of reference climate and by 11-38 days in extreme years on Danubian lowland.

Course of meteorological elements generated by general circulation models cause some negative effects which frequently led to the fall of simulated yields.

Yield increase in conditions of climate change will not correspond with the theoretical level of efficiency of photo synthetically active radiation for spring barley crop that was calculated in dependence upon CO_2 concentration in the atmosphere for emission scenarios SRES A2 and SRES B2.

Soil water content was the main limiting factor of crop yields.

Irrigation is an important factor of spring barley yields stabilisation in conditions of the climate change.

Despite the fact that shortage of water does not allow fully to utilise positive effect of CO_2 concentration on yield formation of spring barley the 10-day irrigation interval was found as the sufficient interval for yield stabilisation.

6 AGRICULTURE – THE CZECH REPUBLIC

6.1 Climate scenarios

One of the major restrictions of the climate change studies in Central Europe has been availability of climate data with sufficient density. In order to overcome this hurdle, outputs of the regional climate model (RCM) ALADIN-Climate/CZ , were applied using the scheme presented in Fig. 6.1. The first step in preparing the study was to conduct a high-resolution simulation of the baseline (1961-2000) climate conditions, which was performed with ALADIN-Climate/CZ ove r the Central Europe domain. The domain covers the entire area of Central Europe between latitudes 45° and 51.5° N and longitudes 8° and 27° E, including at least partly the territories of Austria, Czech Republic, Germany, Hungary, Poland, Romania, Slovakia, Switzerland and Ukraine. For the present climate run, the perfect lateral boundary condition (LBC) represented by ERA-40 re-analysis (Uppala *et al.*, 2005) was used, and the nesting technique was applied to enable RCM ALADIN with a 10 km grid to be driven by a coarse resolution ERA-40 reanalysis. The ALADIN 50 km grid integration forced by ERA-40 re-analysis was taken to drive the model at 10 km resolution over the smaller, Central European, domain. A summary of the experimental settings and results of the run in comparison with observed data can be found in Skalák and Štěpánek (2008).

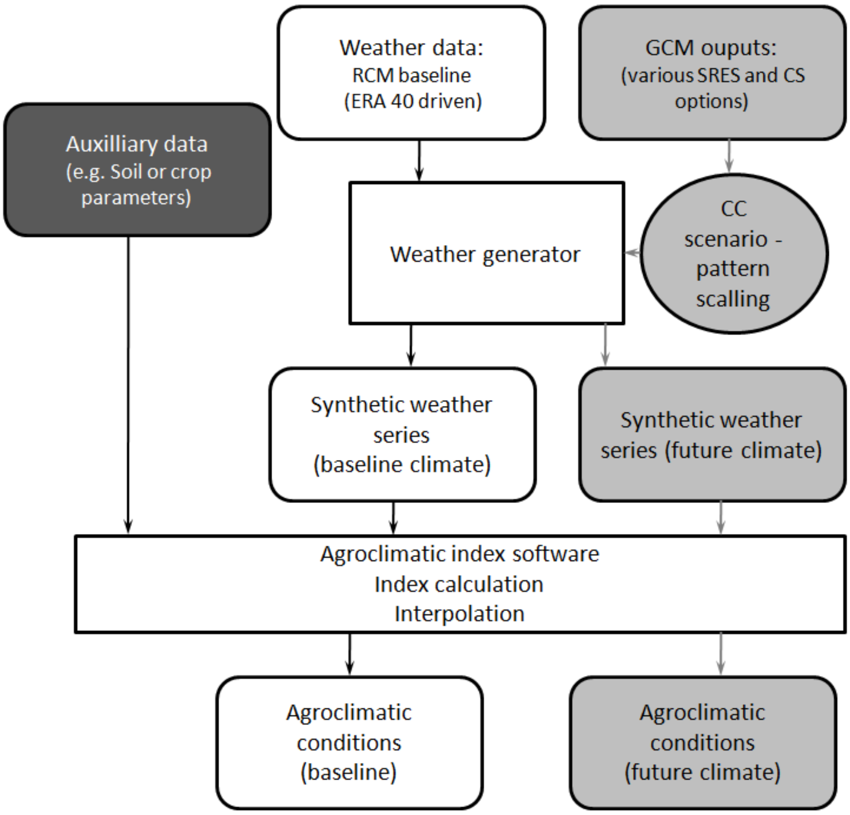

Fig. 6.1 *Flowchart of the study methodology with GCM meaning "global circulation models," RCM is "regional circulation models," CC is "climate change" and SC is the "scenario."*

In most of the studies where the RCMs are used to produce high resolution data for the future climate conditions, the boundary conditions of RCMs are derived from a run of a global circulation model, and the RCM is nested within the global domain of a particular global circulation model (GCM). The main disadvantage of this conventional approach is that it requires run times of several months, which limits the number of GCMs that are considered. As the inter-GCM variability for the Central European region is considerable (e.g. Dubrovský *et al.*, 2005), the alternative approach was proposed and applied in the study (Fig. 6.1). To avoid long run times, the climate change scenarios were developed by means of combining the RCM data for the baseline climate and GCM-based scenarios. At first the parameters of the weather generator were derived for each ALADIN-Climate/CZ grid from the ERA-40 driven ALADIN-Climate/CZ run for the period (1961– 1990). Then, the weather generator (WG) M&Rwin (a follower of Met&Roll described in Dubrovsky *et al.* 2000; Dubrovsky *et al.* 2004) was applied in each grid to obtain the set of WG parameters for the present climate. These grid-specific parameters were perturbed according to the appropriate GCM-based climate change scenarios derived by the "pattern-scaling" technique (Santer *et al.*, 1990). In this approach, the climate change scenario is defined by the product of the standardised scenario and the change in global mean temperature (ΔT_G). The standardised scenarios, which relate to the increase in global mean temperature by 1 K, were derived from the outputs of three GCMs from an IPCC-AR4 database (HadCM3, NCAR-PCM, ECHAM5). The value of ΔT_G was determined by the MAGICC model (Harvey *et al.* 1997, Hulme *et al.* 2000) assuming high climatic sensitivity (4.5 K) and emission scenario SRES-A2. The MAGICC estimate for these settings is ΔT_G = 2.3 K, which is slightly lower than the change in global mean temperature for 2100 assuming middle climate sensitivity (2.6 K) and middle emission scenarios (ΔT_G = 2.7 K for SRES-B2, ΔT_G = 3.0 K for SRES-A1b). As a result, the present impacts for 2050 (using "high" versions of GCM-based scenarios) are about the same as those for the end of the 21st century with "middle" versions of the climate change scenarios. Based on the results of Dubrovský (2009b), we assume that ECHAM, HadCM and NCAR would provide a rather representative triplet, as they represent various versions of the expected climate for the region. As the outcome of the procedure (Fig. 6.1), the daily weather series of meteorological data (daily sum of global radiation, maximum and minimum temperatures, sum of precipitation, daily mean air humidity and wind-speed) were prepared. They were then used as inputs for assessment of the agroclimatic conditions and definition of adaptation options

6.2 Quantitative indicators of agriculture productivity

Agroclimatic indices attempt to describe complex relations existing between climate and crops (their development and/or production) as well as the agrosystems as a whole (Orlandini and Nejedlík, 2008). In order to describe agroclimatic conditions, a total of nine agroclimatic indicators were selected from a plethora of available options. The goal was to use as few indices as possible that would be relevant for various aspects of crop production but would not in the same time compete with other and sometimes more suitable tools (e.g. process-based crop models, soil workability models etc.). Instead, the selected indices can be seen as complement to crop modeling tools, describing aspects not fully addressed or covered by crop models for an overall assessment of crop production conditions. The final list included: **(a)** sum of effective global radiation, **(b)** number of effective growing days, **(c)** Huglin index, **(d-e)** water balance during the period from April to June (AMJ) and during the summer (JJA), **(f-g)** proportion of days suitable for harvesting of field crops in June and July and **(h-i)** proportion of days suitable for sowing in early spring as well as during fall.

The sum of the effective global radiation was calculated as the sum of global radiation during the period with mean air temperature continuously above 5°C (and without snow cover or frost occurrence) and with sufficient soil water available for evapotranspiration (ratio between the actual and potential evapotranspiration had to be above 0.4). Similarly, the number of growing days represents days without frost and snow presence, with a daily mean air temperature continuously above 5°C and the same soil water requirements as in the previous case. The temperature thresholds used followed suggestions by Brown (1976), Chmielewsky and Köhn (2000), Mitchell and Hulme (2002), and Larcher (2003). The direct effect of drought stress on crop growth is often expressed as the ratio between actual and potential transpiration (van Ittersum *et al.,* 2003). However, in situations where evaporation from soil is not a large component, the use of evapontrnspiration values will provide reasonable results. According to a number of studies (e.g. Eliasson *et al.*, 2007), growth of the crop on a given day is not considered water limited if the ratio of daily actual and potential evapotranspiration exceeds 0.5. For this study we deliberately chose a lower threshold (0.4), thus allowing for a certain level of drought stress in order to limit over-reporting drought by the used indices.

The Huglin index (HI) is calculated from April 1st to September 30th in the Northern hemisphere. This index enables different viticultural regions to be classified in terms of the sum of temperatures required for vine development and grape ripening (Huglin, 1978). The HI value was calculated for the period from April 1 until September 30. Different grape varieties are thus classified according to the minimal thermal requirement for grape ripening. The minimal Huglin index for vine development is defined between 1500-1600. As the HI considers only thermal conditions during the growing season, the results must be interpreted with caution especially in the eastern part of the domain where continental climate is predominant as wine growing is prevented by frequent occurrence of winter temperatures below -20°C.

The availability of water was assessed with the help of climatological water balance (i.e. difference between reference evapotranspiration ETr and the precipitation) during the period from April to June, which is crucial for the formation of all crops grown in the region, and also during the summer (JJA) when this deficit is usually the highest.

In order to evaluate suitability for sowing, the early spring period was defined as the period between March 1 and April 25 (55 days), while the fall sowing window is assumed to begin September 15 and lasts until the end of November (76 days). A given day is considered suitable for sowing when the soil water content in the top layer of soil (the top 10 cm) is between 10% and 70% of the maximum soil water-holding capacity of a given soil. In addition, a suitable day has to be without snow cover, and the mean daily air temperature during at least two consecutive days has to be above 5°C. The day is also not considered suitable if there is precipitation above 1 mm on the date of sowing or above 5 mm the preceding day. These thresholds were tested using the reported sowing dates of spring barley, winter wheat and maize at 30 experimental stations at the State Institute for Agriculture Supervision and Testing during the period from 1985 to 2005 in the Czech Republic. A similar approach was used by Leenhardt and Lemaire (2002) and Maton *et al.* (2007) to estimate maize sowing dates for regional water management in France.

Finally, the proportion of days suitable for harvesting in June and July were considered. The suitable days have to have a soil water content below 70% of the retention capacity in the top layer of soil and no precipitation above 1 mm on the given day or above 5 mm on the preceding day. As only days between June and July were evaluated in terms of harvesting suitability, snow cover and temperature requirements were not considered. The thresholds of soil moisture used to define days suitable for sowing and harvesting were stricter than those used by Rounswell *et al.* (1993) and Cooper *et al.* (1997) in order to avoid soil compaction, which is unsustainable in the long-term.

6.3 Climate change and agroclimatic conditions

The changed climate under the considered climate scenarios would positively affect the annual sum of effective global radiation through increases in the duration of the potential growing period (i.e. with mean air temperatures continuously above 5°C). Additionally, the effective annual global radiation would be affected in some cases by the increase in global radiation as a result of decreased cloudiness associated with precipitation decreases, especially during the summer months. However, the decrease in precipitation also increases the probability of water deficit, leading to a decrease in the overall value of this key parameter. As shown in Fig. 6.2a-d, under present conditions the southern and south-eastern part of the domain have the highest values of this parameter, indicating the potential productivity of rainfed agriculture. It is the western and northern parts of the domain that would benefit most from the changed climate conditions, with areas in Germany, Poland, parts of Austria, Slovakia and Czech Republic showing sustained increase in the values of this parameter (Fig. 6.3). The largest decreases are to be expected within the Pannonia lowland, which includes almost all of Hungary, northern Serbia and Croatia as well as parts of southern Slovakia, eastern Austria and western parts of Romania. The most marked changes (both positive and negative) within the regions are to be expected under HadCM-driven scenarios, while the NCAR-based results indicate a much lower rate of change. However, the overall spatial pattern of these changes remains the same. If the distribution of the annual effective global radiation values over the whole domain, taking into account the present area of arable land, is plotted (Fig 6.3), it is possible to observe the marked shift within the shape of the distribution of this key indicator over the whole domain. All three GCMs based scenarios would result in significant increases in the indicator value over the whole domain, which is already suggested from Fig. 6.2b-d. When the changes on the national level are plotted (Fig. 6.3), it is clear that the Czech Republic, Slovenia and partly Slovakia and Austria would benefit from the shift of climate conditions (if we consider the national productivity only in terms of the sum of effective global radiation that disregards the soil conditions and terrain configuration). In the case of Hungary, a substantial drop in the sum of the effective global radiation is to be expected. It should be noted, however, that in many regions the negative trends in agriculture productivity could be overturned by the use (or increased intensity) of irrigation, which is not considered in the study as we have been interested only in the suitability for the rainfed agriculture that dominates in the area (Table 6.1). A similar pattern of change as in case of the effective global radiation is to be expected also for the effective growing days (Fig 6.2e-h), with the largest gains being expected in the northern and western parts of the domain with some reduction in the southeastern parts of the domain. Still, in terms of effective growing days there is a tendency towards more uniform distribution of this parameter across the whole domain.

The significant increase in the Huglin index value across the whole domain (Fig 6.4a-h) is understandable as a direct consequence of the expected temperature increase that might take place within the next 40 years with dramatic consequences for agriculture. Fig 6.4a shows that the present 20-year lows of the Hunglin index (Fig. 6.4a) do not allow a permanent successful harvest of the wine across most of the domain except in areas established as wine growing regions already. Alternatively, in the warm years (i.e. 20-year return period), Fig 6.4e shows that very good thermal conditions for wine growing are to be found especially in the southeastern part of the domain (name the regions). Under the changed climate, the potential wine growing area would increase substantially, providing Huglin index values sufficient for wine production across much of the region with the exception of mountainous areas (however, small scale local climatic variations based on the terrain effects such as the slope effects on temperature are not considered in this study). It must be stressed that the Huglin index takes into account only temperature requirements during the summer period, which is by any means a sole factor affecting wine production. However, the results clearly show that the present wine growing regions in Central Europe will be faced overall with much warmer conditions, requiring in some cases different cultivars than those planted nowadays. They also indicate that there is a prospect of wine growing even in the northern limits where wine production is off limits due to the present climate.

The spatial patterns in the intensity of a 20-year drought during the first part of the growing season (April-June) differ for the three GCMs considered (Fig. 6.5b-d). While HadCM and ECHAM-based scenarios predict an increase in the 20-year drought intensity across the domain (despite accounting for the positive effect of CO_2), realisation of NCAR-based projections would lead to only a slight deterioration in the eastern part of the domain and slight improvements in the west and north. However, when the shifts in the value of 20-year droughts are investigated only over the presently arable land (Fig. 6.6), it is clear that more intensive water deficits are likely to endanger rainfed agriculture systems of Central Europe. The scale of the study made it possible to analyse consequences of water balance changes for several countries. Fig. 6.5b-c and Fig. 6.6a show that realisations of ECHAM or HADCM projections would lead to an increased intensity in 20-year

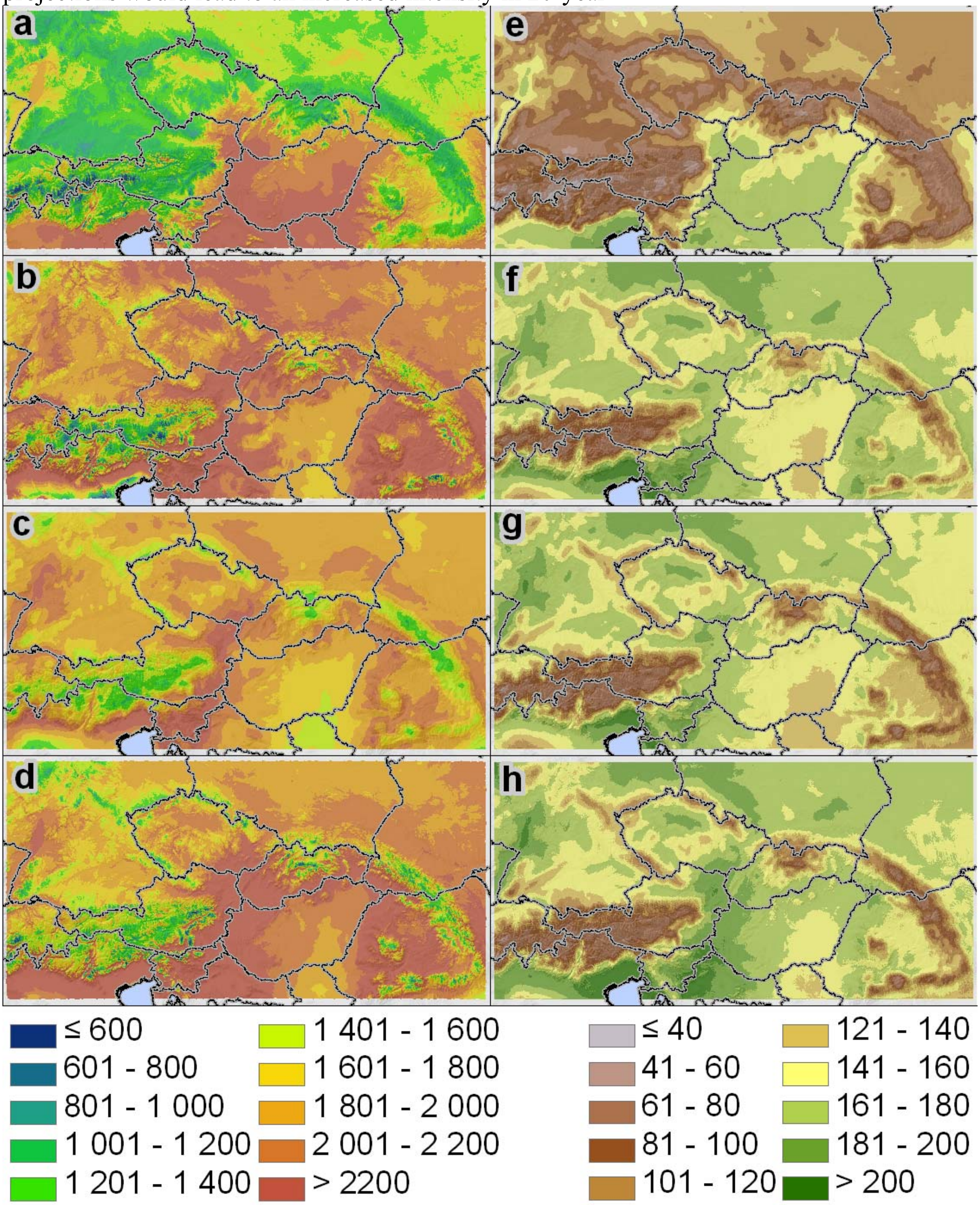

Fig. 6.2. *Median of the annual global effective radiation (MJ.m-2-.year) and number of effective growing days (days) plotted for the domain. Baseline (1961-2000) conditions are captured by maps a and e, while the projections for 2050 are captured by maps b-d and f-h.*

The projections based on GCM HadCM are presented at maps b and f, ECHAM at c and g and NCAR results at d and h.

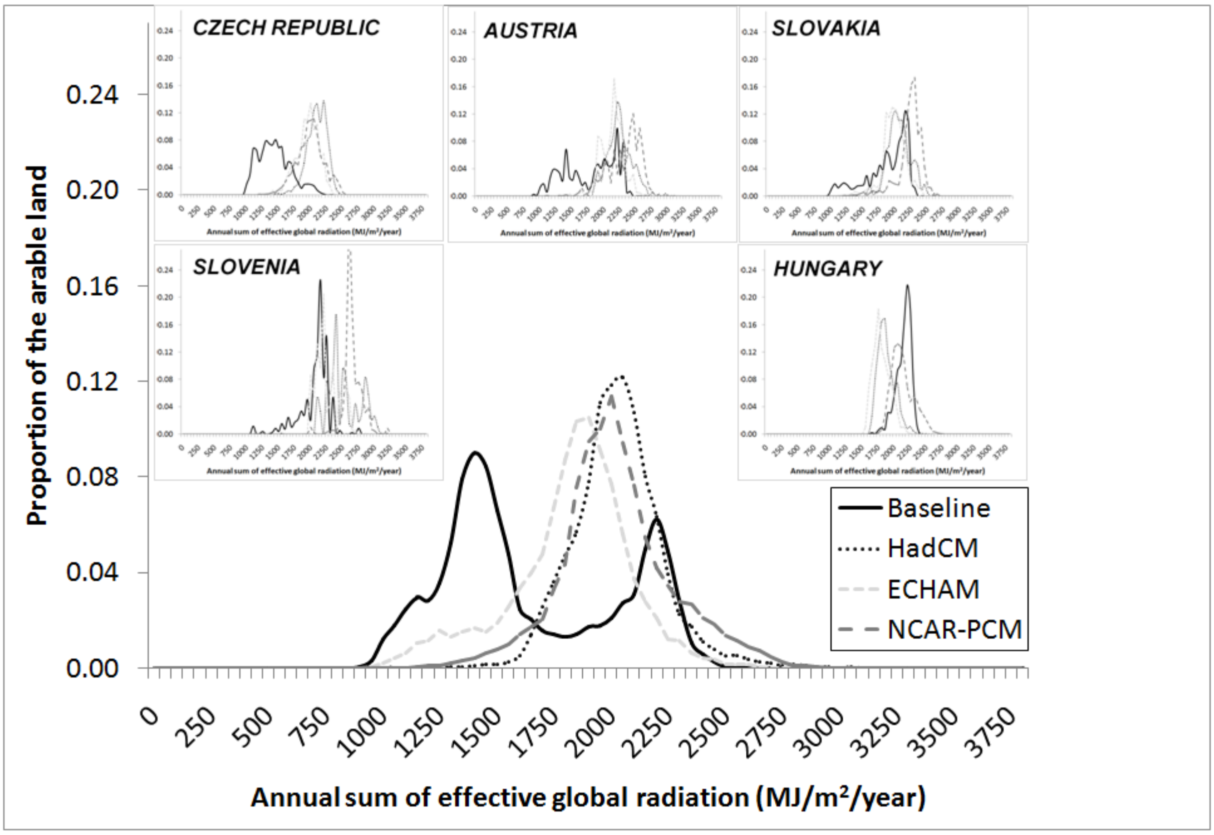

Fig. 6.3 *Distribution of the mean sum of effective global radiation across the agriculture land over the whole domain and in five countries within the domain for the baseline (1961-2000) conditions and those expected by 2050 using three GCMs (HadCM, ECHAM and NCAR).* Note: As the digital elevation model with 10 km resolution was used in the study, an overestimation of areas between 1000-1500 m in the Alps was obtained that partly explains the bimodal shape of the distribution curve, especially in the case of Austria under the present climate.

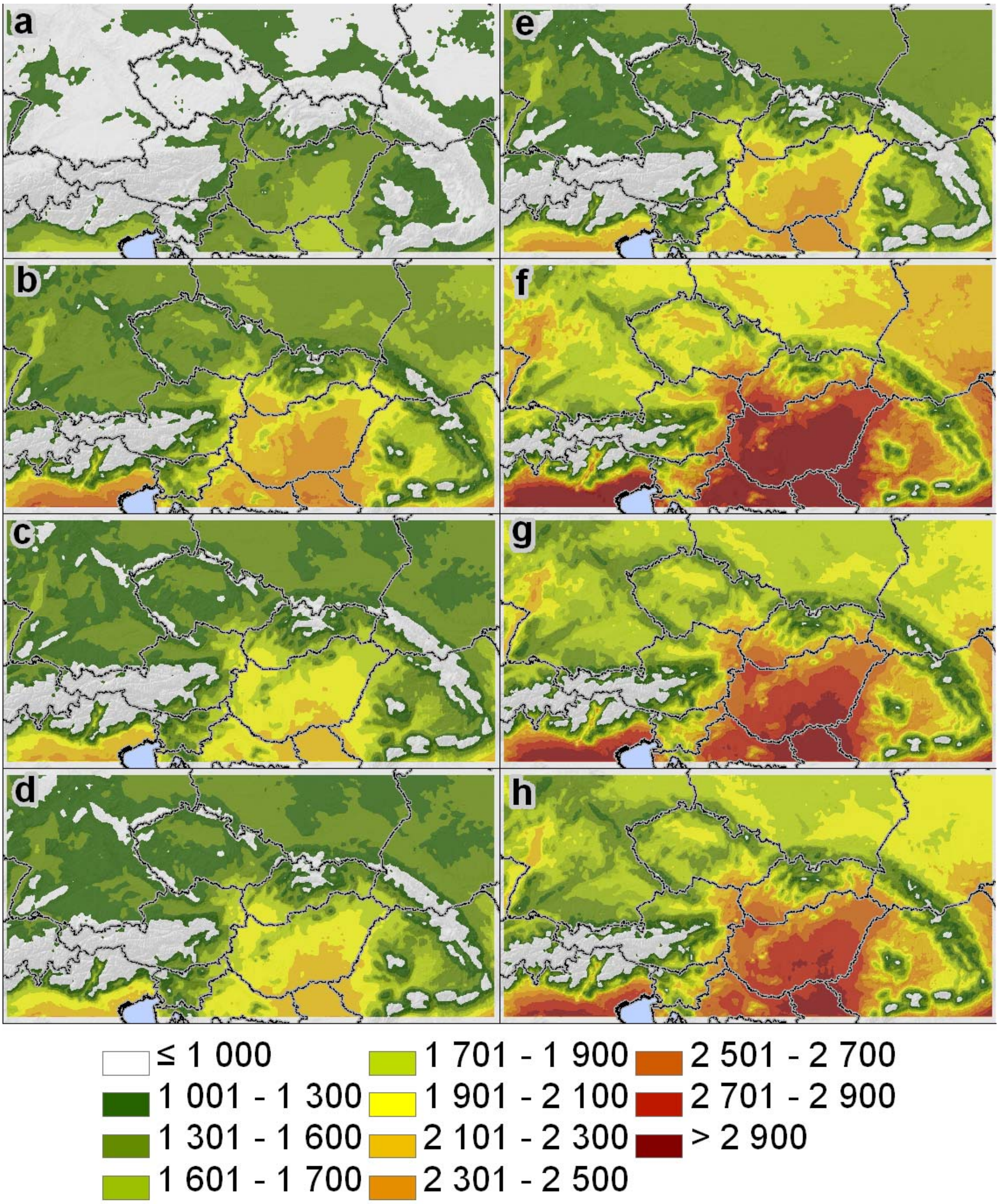

Fig. 6.4 *Values of 20-year lows (a-d) and highs (e-h) of the Huglin Index. The baseline (1961-2000) conditions are captured by maps a and e, while the projections for 2050 are captured by maps b-d and f-h. The projections based on GCM HadCM are presented at maps b and f, ECHAM at c and g and NCAR results at d and h.*

droughts in all five countries considered. The magnitude of the changes has a southeastern gradient, as the arable land in the Czech Republic would be affected least, and Hungary and Slovenia show the most marked changes. On the other hand, realisation of the NCAR scenario would mean a slight easing of the 20-year drought intensity in the Czech Republic, Austria,

Slovakia and Slovenia, leaving only the arable land in Hungary worse off.
The results presented in the report suggest that there is a probability that the wet years (with return period of 20 years) are going to lead to higher water excess compared with the present situation (Fig. 6.5e-h; Fig. 6.6b), especially in the north and northeastern part of the domain and also in the highest parts of the Alps. The highest increase in the water excess in this area is associated with the realisation of ECHAM and NCAR-based scenarios. It seems that in the central and northern parts of the domain (including also the Czech Republic, Austria, Slovakia and partly in Hungary), there is a tendency towards greater interannual variability of water balance between dry and wet seasons with a 20-year return probability (i.e. more severe dry and wet episodes are likely).
The earlier start to the growing season will be accompanied by changes in the proportion of days suitable for sowing. However, three GCM-based predictions show little agreement in terms of percentage of suitable sowing days during early spring (Fig. 6.7a-d). While the NCAR-based projections would lead to a slight decrease in suitable days in the centre and north and increases in the south of the domain, the ECHAM-based results show an overall increase in early spring sowing suitability (except small regions in the northeast and southwest). The HadCM (Fig. 6.7b) differs from the other two predictions, showing a substantial drop in the number of suitable days in most of the Czech Republic, Bavaria, northern and eastern Austria and in some regions of Hungary and Romania. At the same time, the number of suitable days increases sharply in northern Italy, eastern Hungary and in parts of Saxony that are within the domain. This particular result is most likely due to the predicted increases in the precipitation during March and April according to the HadCM model compared to the present. The increase in suitable days during the fall (from September 25 to November 25) is very pronounced, and all three projections indicate sharp increases in the suitable days, due particularly to the drop in precipitation in September and partly also in October and November.
While, according to the NCAR-based scenario, the harvest suitability in June (Fig. 6.8a-d) is likely to remain the same or decrease slightly over the main producing areas if the NCAR scenario is realised, the realisations of the ECHAM-based scenario indicate increases in the harvesting window, especially in the southern parts of the domain. The HadCM-based results indicate a relatively sharp drop (on average by more than 10%) in suitable harvest days in June, especially across most of the Czech Republic, parts of northern and eastern Austria as well as almost all of Bavaria with improvements over northern Italy and eastern parts of Hungary.

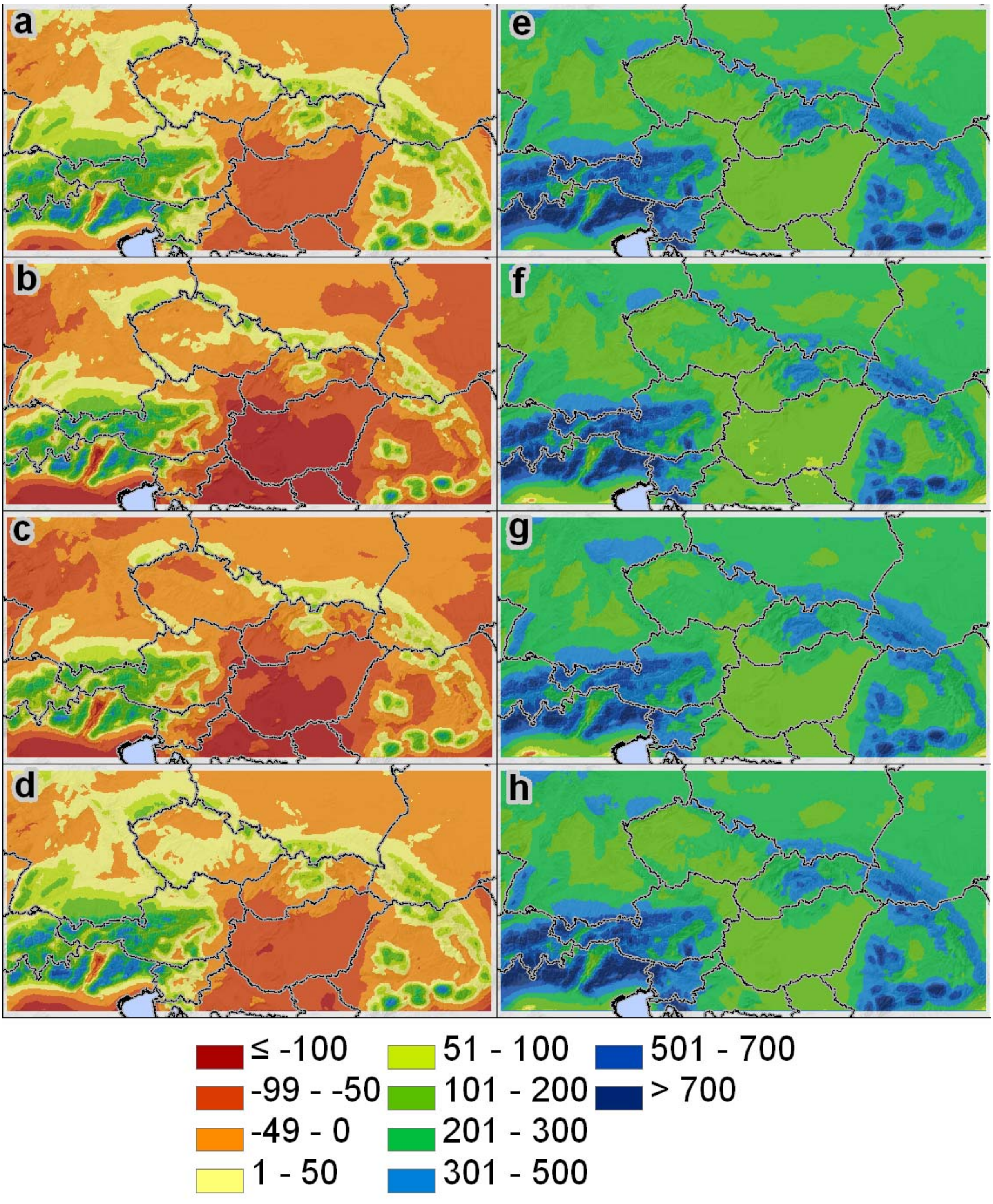

Fig. 6.5 *Values of 20-year lows (a-d) and highs (e-h) of April to June water balance (mm), i.e. difference between sum of precipitation and reference evapotranspiration. The baseline (1961-2000) conditions are captured by maps a and e, while the projections for 2050 are captured by maps b-d and f-h. The projections based on GCM HadCM are presented at maps b and f, ECHAM at c and g and NCAR results at d and h.*

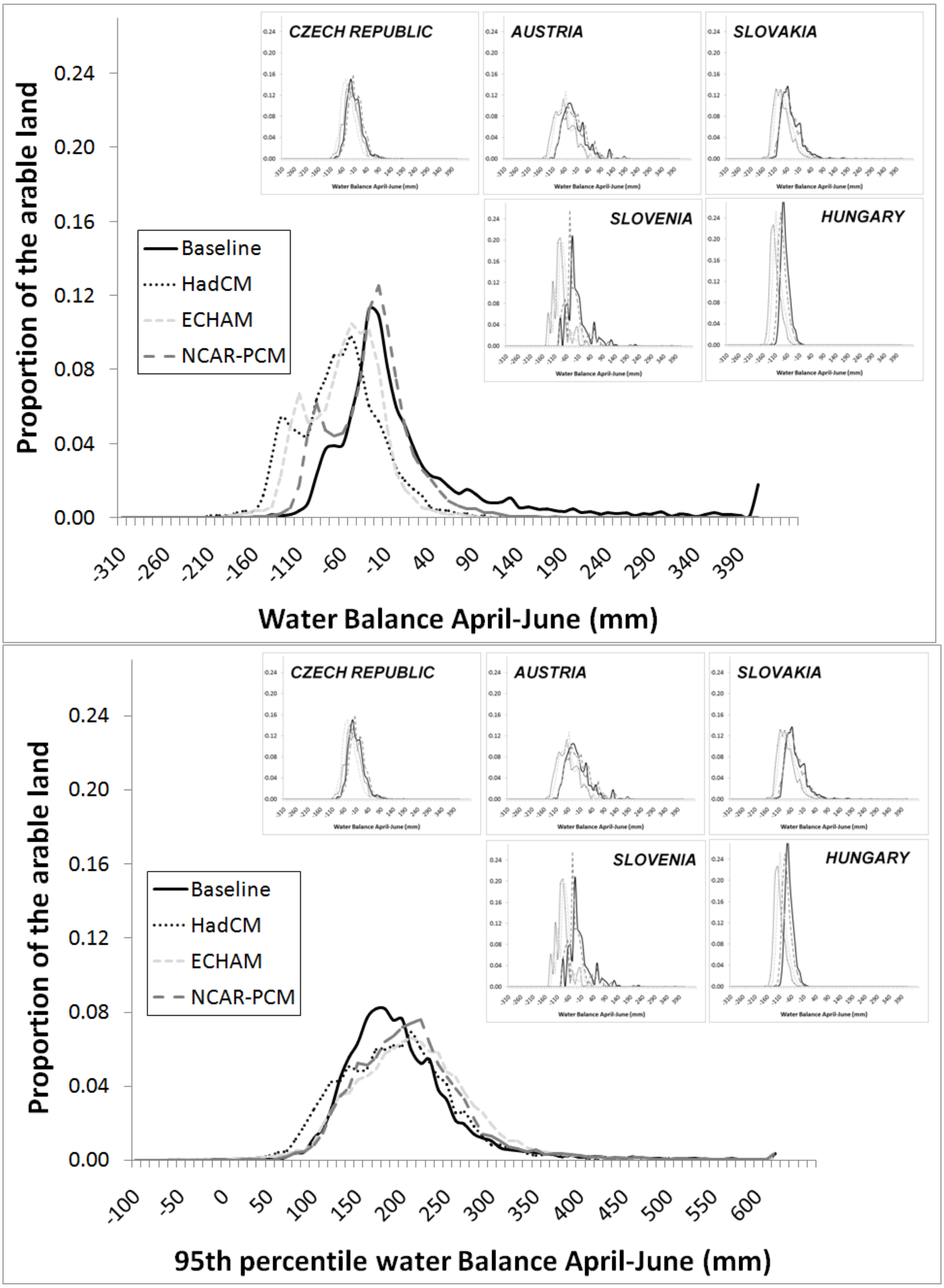

Fig. 6.6 *Distribution of the water balance (April-June) values during the "dry" season with a 20-year return period (a) and the wet season (the same return period i.e. 20 years) over the agriculture land within the whole domain and in five countries. The baseline conditions represent values valid for the period from 1961-2000, while projections are based on those expected by 2050 using three GCMs (HadCM, ECHAM and NCAR).*

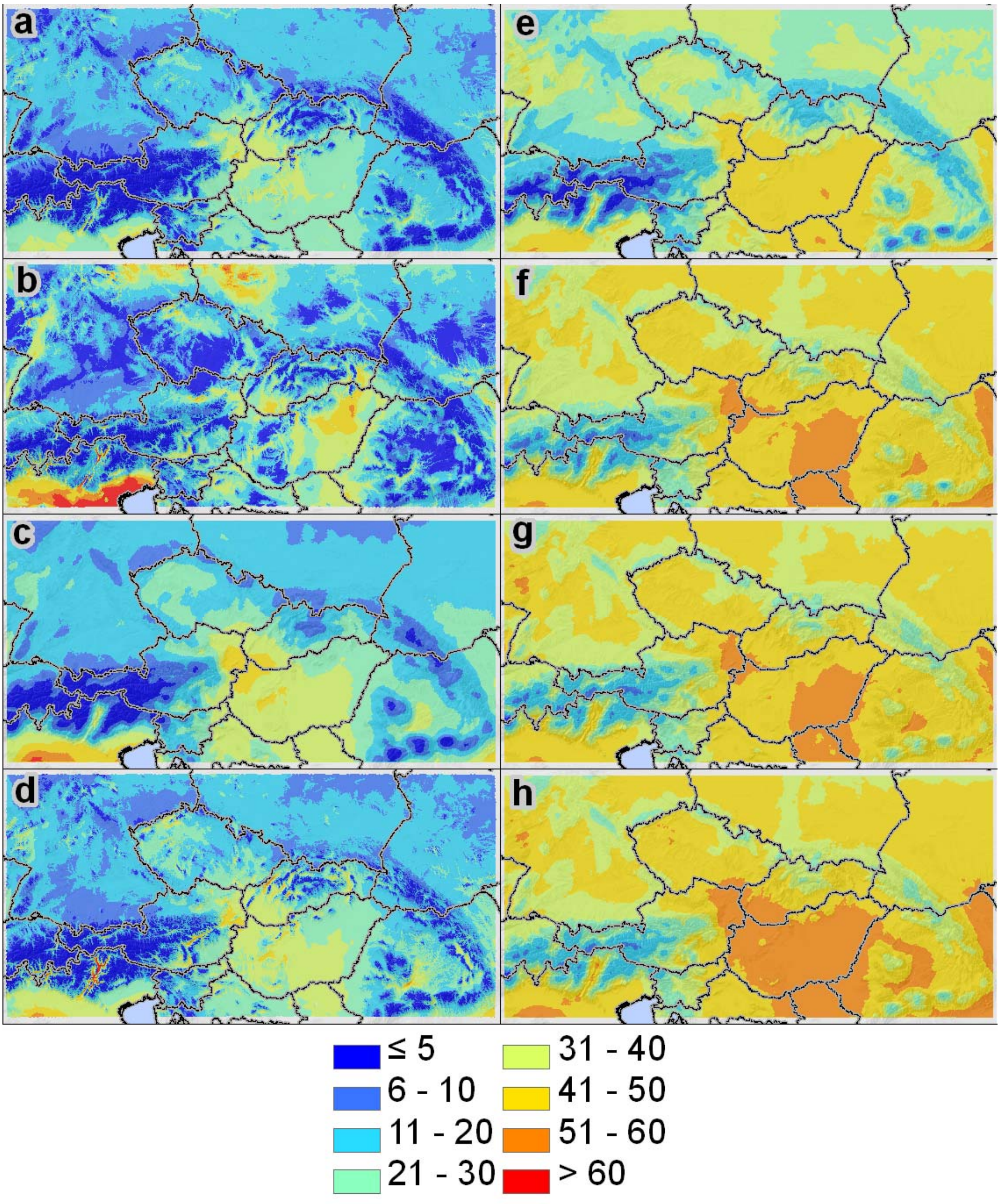

Fig. 6.7 *Proportion of days suitable for sowing (%) during the early spring sowing window (a-d), defined as the period from March 1 to April 25 (55 days), and the fall sowing window (e-h), which is assumed to begin September 15 and last until the end of November (76 days). The baseline (1961-2000) conditions are captured by maps a and e, while the projections for 2050 are captured by maps b-d and f-h. The projections based on GCM HadCM are presented at maps b and f, ECHAM at c and g and NCAR results at d and h.*

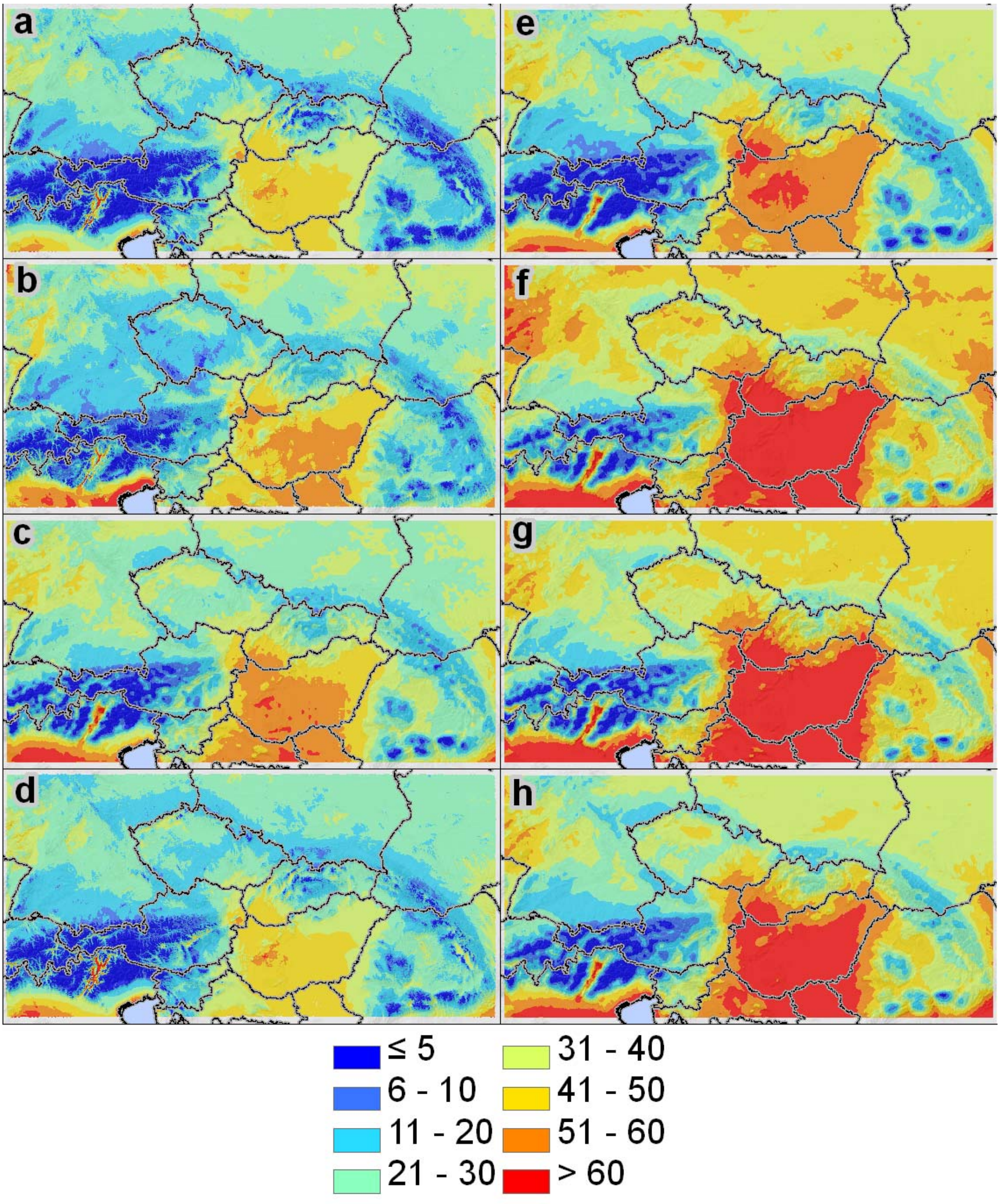

Fig. 6.8 *Proportion of days suitable for harvest (%) during June (a-d) and July (e-h). The baseline (1961-2000) conditions are captured by maps a and e, while the projections for 2050 are captured by maps b-d and f-h. The projections based on GCM HadCM are presented at maps b and f, ECHAM at c and g and NCAR results at d and h.*

6.4 Recommendation on the improved agriculture management (adaptation options)

1) The changes expected in the annual sum of effective global radiation and annual sum of effective growing days suggest that there is a high probability of increase in both indicators in northern and western Europe as well as in higher altitudes (Alps in particular) and of decrease all over the Pannonia basin and the Mediterranean. This should have a positive effect on the overall production potential over the domain. However, its increase is accompanied by an increase in water deficit over the summer months (June-August) that in some parts of the domain might result in two short growing seasons (one in spring and the second during fall) Production in the summer without irrigation systems will be difficult or not possible at all and therefore crop portfolio and irrigation option should be considered in the appropriate region.

2) The significant increase in the Huglin index across the whole domain is understandable, but it must be stressed that the Huglin index takes into account only summer temperature requirements of wine production, which is not by any means a sole factor affecting wine production. Additionally, small scale terrain effects on local climates have to be taken into consideration for a small scale assessment of wine production potential. However, the results clearly show that the present wine growing regions in Central Europe (similar to results of Stock *et al.,* 2005 or Eitzinger *et al.*, 2009) will be faced with much higher values of the index, requiring in some cases different cultivars than those planted nowadays. Results also indicate that there is a prospect of wine growing even above its present northern limits. The likely shift of the northern limitation of the culture of grapevines in Europe has been analysed by e.g. Moisselin *et al.* (2001), Seguin and Cortazar (2005) or Eitzinger *et al.* (2009), with Moisselin *et al.* (2001) claiming that an increase in mean temperature by 1°C would shift the boundary northward 180 km. The magnitude of such a shift is supported by the historical analyses of Legrand (1978) and Eitzinger *et al.* (2009). This might eventually increase competition for the traditional viticulture regions (if that is permitted e.g. by Common Agricutlural Policy of EU). This study offers a new perspective as it provides the range of Huglin index values with a 20-year return probability. The analysis of the range between warm and cool years indicates a likely increase in the variability of the Huglin index values, which might in turn affect the quality of individual vintages. Proper cultivars as well as wine producing techniques should be used and northward shift in wine producing areas must be taken into account when replanting existing vineyeards.

3) The most significant for agriculture production are projected estimates of the water balance changes during the period from April to June, which has been shown to be critical for the water stress sensitivity of field crops in the region (e.g., Eitzinger *et al.*, 2003; Hlavinka *et al.*, 2008; Brázdil *et al.*, 2009) as they indicate worrying trends for rainfed agriculture. The climate change might lead to either an increase in incident global radiation or higher ambient air temperatures (or both), which will lead to increased saturation deficits. Consequently, a higher rate of reference evapotranspiration is expected under future climate conditions, and this might not be matched either by an adequate increase in precipitation or by increased water use efficiency, leading to a more severe water deficit across most of the domain (Fig. 6.5b-c). This tendency seems to have support in the studies based on the past measurements, as the whole region has shown significant drying trends since the 1940s (e.g. Dai *et al.*, 2004; van der Schrier *et al.*, 2006; Brázdil *et al.*, 2009b; Trnka

et al., 2009b). The results in the report correspond well with the conclusions of Olesen *et al.* (2007) for the Mediterranean region and the results for the Alpine Region reported by Calanca (2007). Realisation of ECHAM or HadCM-based scenarios would put large areas of Austria, the Czech Republic, Slovenia, Hungary and Slovakia in need of either irrigation for drought sensitive crops or measures for increasing agricultural water use efficiency (e.g. an improved irrigation water use efficiency). This would be a challenging task to achieve given that only a fraction of the arable land has access to the irrigation (Table 6.1), and in some countries (e.g. Czech Republic) there is only a limited number of water reservoirs suitable for substantial increases of irrigated areas during periods of prolonged water deficits. One of the key recommendation under climate conditions skewed towards higher likelyhood of extreme drought would be reliable and high resolution drought monitoring and short to seasonal forecasting that is presently absent in the region.

Table 6.1 *Overview of the agriculture and irrigated area in the represented countries within the ALADIN domain during the period from 2003-2007 (aquastat and faostat databases - http://www.fao.org/corp/statistics/en/)*

Country	Country area (1000 ha)	Agricultural area (1000 ha)	Arable land area (1000 ha)	Area equipped for irrigation: total *(1000 ha)*	Area actually irrigated as % of area equipped for irrigation (%)	Agricultural water withdrawal as % of total renewable water resources (%)
Austria	8387	3240	1382	119	33.5	0.025
Czech Republic	7887	4249	3032	47	36.8	0.456
Hungary	9303	5807	4592	153	49.2	2.36
Slovakia	4903	1930	1377	180	24.9	NA
Slovenia	2027	500	177	4	50.6	NA

4) While severe droughts during early parts of the growing season might have dire consequences for crop production, the excess of water during this period also has a negative effect on the crop production and its quality as it increases the risk of diseases, leads to root anoxia, nutrient leaching and makes tillage operation more difficult. The results of the CECILIA project suggest that the wet years (with return probability of 20 years) are going to lead to higher water excess compared with the present situation (Fig. 6.5e-h; Fig. 6.6b), especially in the north and northeastern parts of the domain and also in the highest parts of the Alps. Although this is not directly related to flood frequency it might be concluded that higher level of runoff and nitrate leaching are likely and more stringent land management will be required in the regions listed.

5) The reported increase in the interseasonal variability in the proportion of suitable days for sowing in the spring as compared to the baseline conditions is in agreement with findings of Trnka *et al.* (2009c). While the number of suitable days is, in general, increasing, a higher variability in sowing-limiting conditions is to be expected and can also contribute to higher interannual yield variability as postulated in recent crop simulation studies (e.g., Thaler *et al.*, 2008). The study by Trnka *et al.* (2009c) estimated that the number of days suitable for harvesting in the central part of the domain (i.e. the Czech Republic and Austria) should generally increase by 12-35% by 2050 (using the same set of scenarios), accompanied by a decrease in interseasonal variability during August and September. This agrees well with findings of Olesen and Bindi (2002). Also, in the case of July, this study found a positive trend regarding the number of suitable days, which agrees well with Fig. 6.8e-h. As the growing season and sowing will tend to move to the beginning of the year, the proportion of

area that will be harvestable in June is likely to increase. However, June generally has the lowest number of suitable days for harvesting in the evaluated period (Fig. 6.8a-d), primarily due to a comparatively higher probability of rainfall and, consequently, a wet soil profile. Even in the warmest part of the domain, the mean proportion of suitable days is below 50%, compared to 70% in July (Fig. 6.8e-h). In addition, the results show considerable interseasonal variability that would put further stress on the farmers' workload during the harvesting period and decrease the availability of machinery during the requested time. Fig. 6.8 also reflects uncertainty resulting from different GCM runs. Overall it could be concluded that more efficient harvesting methods might be necessary to minimize losses caused by unfavorable weather during early harvests.

6) While uncertainties about the future climate change impact remain (and many of them were not explicitly considered in the study), the results presented in this report seem to indicate that the mean production potential of the domain (expressed in terms of effective global radiation and number of effective growing days) is likely to increase as a result of climate change, while interannual yield variability and risk may increase. However, this is not true for the Pannonian and Mediterranean parts of the domain where increases in the water deficit will further limit rainfed agriculture but increasingly probably also irrigation agriculture if local water resources are diminishing. The areas that are already warm (in the southeastern part of the domain) and relatively dry, such as the central and western parts of the domain, will likely experience an increase in the severity of the 20-year drought deficit and a more substantial water deficit during the critical part of the growing season. Similarly, the interannual variability of water balance is likely to increase over the domain. There is also a chance of deteriorating conditions for sowing during spring due to the unfavourable weather. One of the obvious solutions would be increased proportion of winter crops, which is already likely due to their ability to withstand spring drought stress events. Harvesting conditions in June (when harvest of some crops might take place in the future) are not improving beyond the present level, making the planning of the effective harvest time more challenging. This shift would on the other hand require intensive breeding of winter barley varieties to maintain high quality of the malting product which is essential income for many famers (e.g. in Czech Republic or Slovakia).

7) Based on the evidence provided by the report, it could be concluded that rainfed agriculture might face more climate-related risks, but the analysed agroclimatic indicators will likely remain at the level allowing for acceptable yields in most of the seasons. However, the evidence also suggests that the risk of extremely unfavourable years resulting in poor economical returns is likely to increase and thus some form of long-term robust solution will be required to sustain economical viability of farming in the region.

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