Project No. 037005

CECILIA

Central and Eastern Europe Climate Change Impact and Vulnerability Assessment

Specific targeted research project

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D 6.2: Results of the drought damage potential and crop water use efficiency as influenced by climate change effects and regional conditions

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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)	

AGRICULTURE

Czech republic (IAP)

Introduction

The drought phenomenon is referred to as the most complex and least understood of all natural hazards, affecting more people than any other extreme event (Wilhite *Ed.*, 2000). It should be perceived as a natural part of climate under all climatic regimes as it occurs both in humid and arid areas (clearly with different impacts unique to the existing ecosystems). Central Europe is not frequently thought of as being a particularly drought prone region in the European context with the exception being the Panonian basin, which includes among others eastern Austria and large part of Hungary. As a consequence, only recently has the importance of a systematic research of drought climatology been recognized in countries like the Czech Republic, where high dependency on the precipitation, as the main water source might lead to future conflicts between competing water users. Incorrect estimation of drought risk or omitting drought related issues in the process of strategic planning might have serious consequences not only for the stability of remaining natural ecosystems, but also for the economy and society as a whole. This is partly due to the fact that there is a marked distinction between impacts of short-term extreme events (e.g. floods or severe storms) and persistent ones (e.g. drought). Unlike drought, short-term extreme events tend to be neutral or even stimulating, for economical growth in developed countries through higher public and private spending on the reconstruction efforts that follow. On the other hand, a prolonged drought spell can not only inflict severe economical loses, but it can potentially paralyze agriculture production over several seasons and restrain other segments of the economy as well (e.g. White *et al.,* 2003 or Horridge *et al.,* 2005).
The high vulnerability and devastating effects of droughts that are commonly associated with specific climatic regions, e.g. African Sahel or recently Australia is rarely experienced in Central Europe. However even here drought episodes have played an important role since the early Neolith, when relatively short drought periods significantly influenced the location of early settlements (Kalis *et al.,* 2003). Recently, the region was faced with so-called "green droughts" i.e. droughts associated with still relatively ample annual rainfall amounts (especially compared to the arid regions) but reduced agricultural productivity due to poorly timed rains. The most severe of these events was recorded in 1947 with less pronounced ones seen in 1978 and 1994 (Blinka, 2005 or Brázdil *et al.,* 2007). The recent wave of drought episodes was experienced throughout Central Europe during 2000, 2001 and particularly 2003. The last event was a result of prolonged periods of suboptimal rainfall, combined with extremely high summer temperatures (e.g. van der Schrier *et al.,* 2007). It influenced full range of ecosystems throughout central Europe reducing some of the basic ecosystem services starting with fodder production (Schaumberger *et al.,* 2006) and ending with carbon sequestration (Ciais *et al.,* 2005). The anticipated increase of air temperature over Central Europe that has been signaled by the number of global circulation models is expected to be accompanied by lower precipitation in summer months and more rainfall during winter (e.g. Dubrovský *et al.,* 2005). Therefore, it is very likely that the frequency of drought spells and their severity will increase at least during some seasons (Hayes *et al.* 2005). This may counteract the expected positive effects of a longer growing season and erode productivity of ecosystems that would be then reversed from carbon sinks to sources and would contribute to the positive carbon-climate feedbacks (Ciais *et al.,* 2005). There is a real possibility that with increasing drought spell frequency, duration, and severity that the impacts will not be limited to a particular season (e.g. decreased productivity of the field crops or stream levels) but could accumulate over time with severe long-term impacts e.g. increasing tree mortality (Elliot and Swank, 1994), or could lead to a drastic reduction of reservoirs levels. An overall drying of the landscape would further increase demand for water for domestic and industrial purposes and would at the same time exert yet another pressure over remnants of natural ecosystems that are already severely strained.

There exists no precise definition for drought, and any such definition should be based on particular needs, which are sector- and region-specific. Generally, four types of drought are recognized (Heim, 2002): 1) *meteorological drought*; 2) *agricultural drought*; 3) *hydrological drought*; and 4) *socioeconomic drought*. Meteorological drought usually relates to the departure of precipitation from its normal over some period of time. Agricultural drought also accounts for soil moisture, and hydrological drought typically covers water resources (supply) in the form of streamflows, groundwater and reservoir levels. Socioeconomic drought is associated with the supply and demand of some economic good, with elements of the three previous types of drought.

Numerous drought indices have been developed to characterize drought (for reviews, see, e.g., Keyantash and Dracup, 2002; Heim, 2002). Of these, the most common indices used worldwide include the *Standardized Precipitation Index* (SPI) (developed by McKee et al., 1993) and the *Palmer Drought Severity*

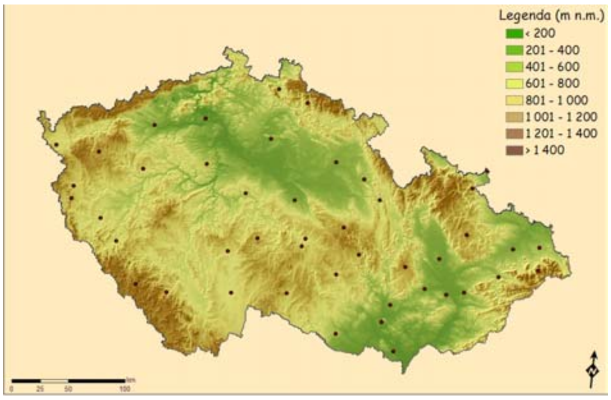
Index (PDSI), developed by Palmer (1965). Complete descriptions of the equations can also be found in Alley (1984). In addition soil moisture regime using the USDA soil clasification (Soil Survey Staff, 1999) serve as a valuable insight into the long-term shifts in the water balance character of the region.

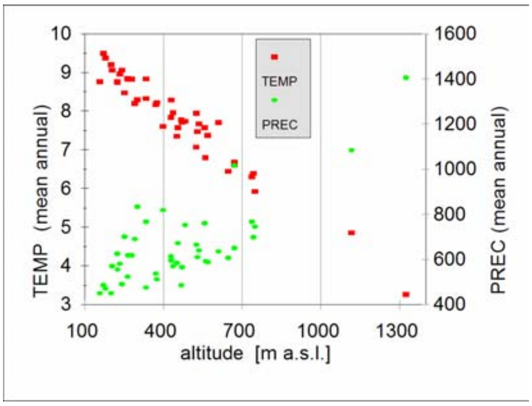
In the CECILIA project, we introduce the *relative indices*, which can be used either to compare drought conditions at different sites during a given period or to compare drought conditions for a single site during different periods and that were developed and applied by Dubrovský *et al.* (2007). The relative indices differ from the self-calibrated indices by using two different weather series in the two-step process. In the first step, the model of the drought index is calibrated using the reference weather series, which may either relate to some reference station (in between-station comparisons), or to a reference period (in between-period comparisons). Having calibrated the model, it is then applied to the second series, hereafter called the tested series. The tested series relates either to the different station (to compare the drought conditions in that station with respect to the reference station) and/or to the different period (to compare drought conditions in that period with respect to the reference period). Alternatively, we use the reference series created by aggregating data from a set of stations in our analysis. In this case, the resultant reference series represents a wider spectrum of precipitation-temperature situations, which should make the model applicable for a wider spectrum of climatic conditions. From now on, we shall denote the two relative drought indices as rSPI and rPDSI, while scSPI and scPDSI will be used for the self-calibrated indices. SPI and PDSI symbols will be used when both types of the indices are under question or when we discuss the properties that are common for both the self-calibrated and relative indices. In order to describe changes in the soil moisture regime a new version of Newhall Soil Moisture Regime model (NSMR-3) have been developed partly with the support of the CECILIA project. The NSMR-3 is based on well calibrated daily water balance model that is used to estimate soil moisture dynamics within the profile and then to classify the soil moisture and temperature regimes. For more details Trnka *et al,*(2006) and Kapler, (2006) should be reffered.

The above mentioned methodology is focused mostly on the aspect of meteorological drought thus taking into account the climatological variables alone. However agricultural drought is by definition impact-based and thus it should be expressed e.g. in terms of drought stress experienced by the crop or at least to quantify relationship between the meteorological drought severity and crop yields. In the CECILIA project both methods were used. At first the relationship between the crop productivity and meteorological drought were evaluated (both for whole territory and for the target regions) using the method proposed by Trnka *et al.,* (2007). In this case the relationship between the selected drought indices was used to determine those regions where drought significantly affect interannul yield variability and also to determine critical threshoulds below which the yields are severely reduced. Then the frequency and impact of drought stress on the winter wheat and spring barley was evaluated using a dynamic crop growth model to pinpoint the areas most at risk from drought (in 1x1 km resolution) for the present climate as well as limited set of climate change scenarios.

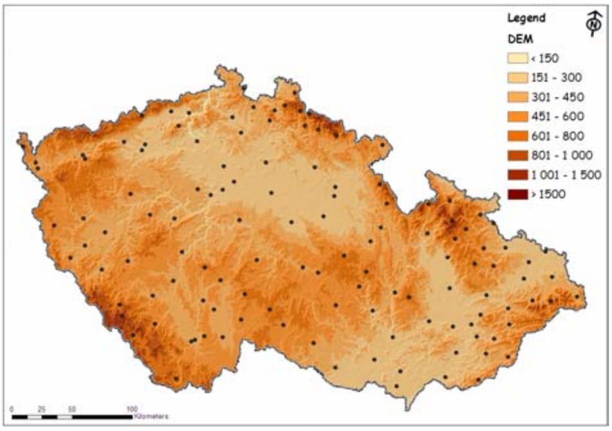
Regional and local conditions

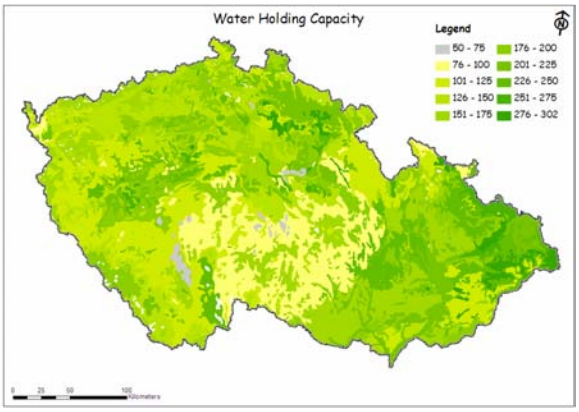
Figures 1a shows the Czech Republic's the main soil characteristics and orographic features as well as the basic sets of climatological stations. The SPI, PDSI and NSMR-3 analysises are partly based on this basic dataset consisting of 40 years (1961-2000) of observational data from 45 Czech stations; the station locations are displayed in Fig. 1 and more details could be found in Dubrovský *et al* (2007). Fig. 1b shows that the annual mean temperature nearly linearly decreases from 9.5 to 3.3 ºC as the altitude of the stations increases from 158 to 1324 m a.s.l [in reality, the altitude of Czechia ranges from 115 m (the location where the Labe river leaves the Czech territory) to 1602 m a.s.l. (Snezka mountain)]. The mean annual precipitation exhibits positive correlation with the altitude and ranges from 449 to 1406 mm.





a) b)





c) d)

Fig. 1. Spatial distribution of the basic set of 45 sites used in the primary analysis of drought (a) and the relationship between the annual mean temperature (annual precipitation sum) and altitude (b) at these sites. At Fig (c) the spatial distribution of 125 stations used for subsequent analyses are visualized together with the soil water holding capacity (based on Tomášek, 2000) used in the simulation runs (d).

The warmest month is usually July with January or February being the coldest. The summer season (June-August) is typically characterized as the wettest with precipitation amounts accounting for 37% of annual totals (ranging from 27 to 43%) on average. On the contrary, winter is typically the driest season accounting for around 18% of the annual precipitation (from 11 to 28%) followed by fall and spring. In case of the crop growth model spatial runs another set of 125 sites with daily observational data available for 1961-2000 was employed in order to achieve as high accuracy as possible Fig 1c with very detail soil map Fig. 1d. Some of the analysis employing the rZ-index took advantage of 233 sites where monthly data were available for the period 1961-2000 and that cover evenly whole Czech territory. In both databases the stations are spread evenly within the country altitudinal range with the mean altitude of the stations being 435 m, which is close to the country mean altitude (430 m) provided by the Czech Statistical Office (CSO, 2005). The mean annual temperature and sum of precipitation are almost identical to the mean climatological values for the Czech Republic (CSO, 2005).The grided data based on the GCM grids were used only exceptionally mainly to put the regional results into the continental perspective (see latter in the text). The large array of methods used in depicting the characteristics of the drought under the present climate makes possible to distinguish various aspects of drought.

The Figure 2 outlines the basic drought characteristics of the region showing that even though the highly variable soil conditions alter significantly soil moisture departures (expressed at Fig 2a as rPDSI) there are apparently two major drought prone regions (i.e. south-eastern part of the Czech Republic and north-west) that are comparably drier and show high risk of meteorological drought than is the regional climatological mean. The former area has been because of it selected as the key study region for the latter stages of the CECILIA project whilst other three regions considered in the study are characterized by relatively moist climate with lower frequency of drought compared to the region 1 (Fig. 3). However in the climatological context event the driest area of the country could by characterized by rather moist subhumid udic and dry tempudic soil moisture regimes that in most years allow for the rainfed production and the soil moisture in the rooting zone rarely falls to the wilting point (Fig. 2b). However there are quite large differences between the individual soils, crops and individual developmental stages as well as Fig 2c-d demonstrates. Whist winter wheat before anthesis (Fig 2c) is under present climate rarely exposed to the water deficit that would negatively influenced photosynthesis (mean level of water stress above 0.1) and almost never to values severely reducing it (stress levels above 0.33) the mild water stress during grain filling (Fig. 2d) is quite common even at the more moist regions. This is caused by the comparably low soil water holding in the rooting zone that does not constitute sufficient buffer in the latter stages of the growing season.

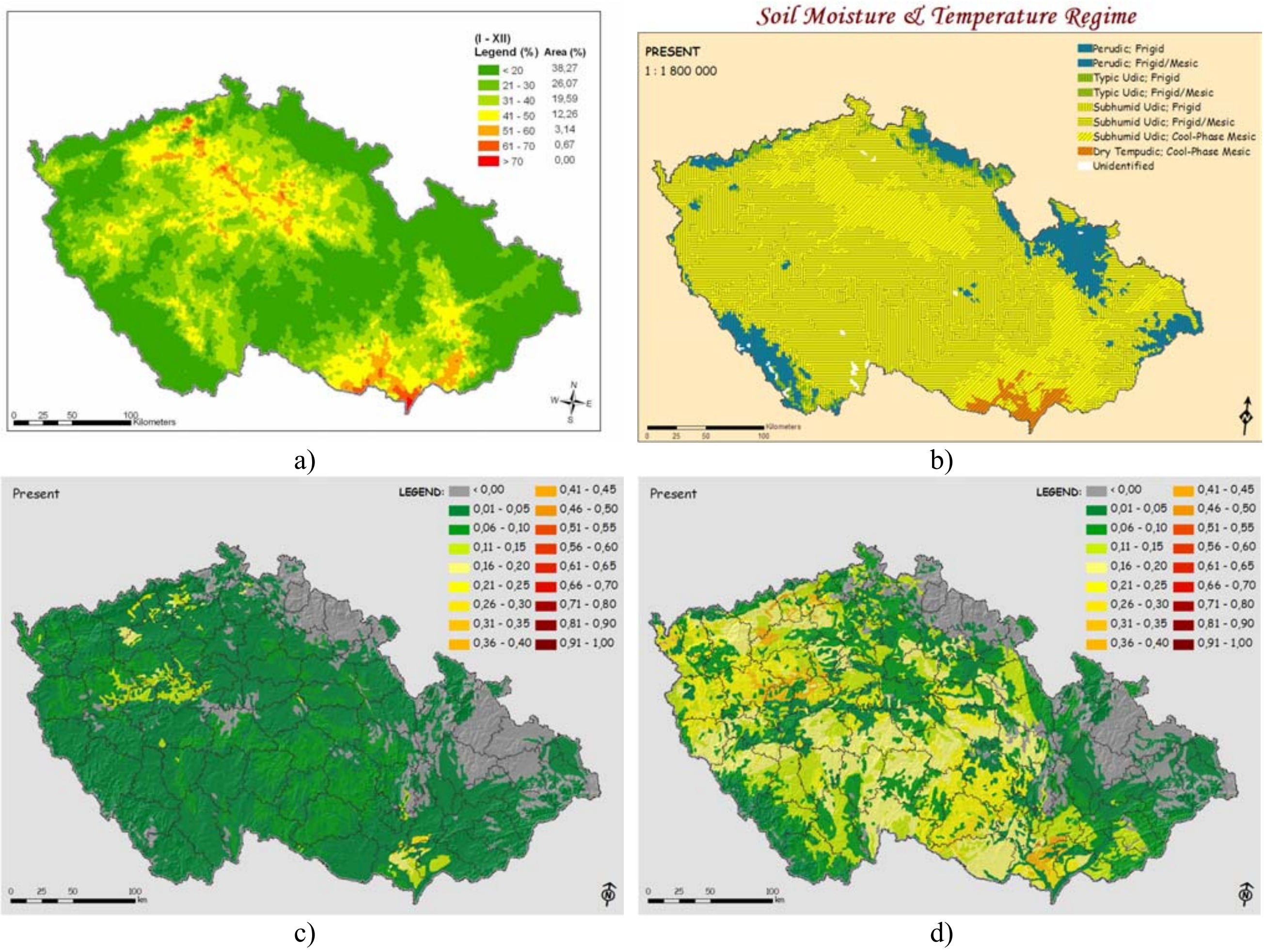


Fig. 2. The present (1961-2000) level of water stress expressed by various methods and based on range of data sets: a) Proportion of months in the drought episode according to the rZ-index; b) the soil moisture and temperature regimes according to NSMR-3 and the mean level of water stress for winter wheat as predicted by CERES-Wheat for the period from emergence-anthesis (c) and anthesis-maturity (4). *Note: Whilst the figure 2a is based on data from 233 stations with monthly data; the 2b-d are based on daily time step with b) being based on 45 weather stations whilst c-d on 125.*

Drought in the context of climate change

Most of the global circulation models (both 3rd and 4th assessment reports) indicate relatively small changes in mean sum of precipitation for the Central Europe and thus the main driving force causing the water balance changes will be 1) change in water uptake due to higher temperatures and 2) change in the precipitation distribution with less rainfall during the peak of growing seasons. The expected situation in the Central Europe is put into the perspective using the datasets of 7 GCM models (3rd assessment report) in their original grid to calculate values of drought indices (rZ-index and rPDSI) both for the present defined here as 1991-2020 period and future 2070-2099. The set of maps at Figure 3 indicate that the areas with increased drought stress (under a changed climate) as indicated by PDSI and Z-index changes are quite large. In European context, this increase is most significantly exhibited in its southern and eastern regions. Z-index

indicates that the drought stress will increase mostly in summer. In winter, only CCSR/NIES shows significant increase in winter drought stress along Mediterranean coast (but also in Central U.S.). Except for few regions in some GCMs (SW coast of U.S. in CGCM, northern part of N.America in NCAR and HadCM /to a lesser extent/), the PDSI-based drought risk will increase in all parts of Northern America and Europe.
These findings are supported by results of rZindex and rPDSI calculations at set of 45 sites (Fig 1a) that are presented at Figure 4. In this case the indices were calibrated using an aggregate of all station data, and then applied separately to each single station. As it is apparent from Figure 1b the drier (wetter) stations mostly encounter warmer (colder) temperatures and as a result, rPDSI indicates prevaling dry conditions in low precipitation stations and exaggerates wet conditions in the higher precipitation stations. These results also shows that the drought risk indicated by the mean value of rPDSI will significantly increase in both winter and summer under each of the five GCM-based scenarios (3^{rd} assessment report). In summer, the increase in drought risk due to decreased precipitation will be augmented by increasing temperature. In winter, the effects of the temperature rise and decreasing precipitation will act in opposite directions, but the effect of increased temperatures will dominate. Because of the persistence of the drought index (with no apparent annual cycle being involved, the difference between the summer and winter changes is small. The most significant effect of climate change on the rPDSI values is found in the CCSR/NIES scenario, which exhibits the most significant temperature rise. The Fig. 4 may be used to make assumptions about the shifts of the Czech stations drought conditions due to climate change. For example, in summer under the CCSR/NIES scenario, nearly 70% of stations may encounter drier (in terms of mean rPDSI values) conditions compared to the driest station under the present climate. This shift is, however, lower in other GCMs (because of lower temperature increases) Our results may suggest that the growing season will be negatively affected by more frequent summer droughts. The Fig. 4c-d also indicate that droughts (at least in terms of rPDSI) will be more intensive according to all scenarios tested than under the present conditions and at the stations that presently rank as the dries previously unknown levels of drought intensity will likely be experienced.

The results of NSMR-3 that could be directly linked to the long-term soil climate are even more worrying. As the Fig. 2b documents under the present climate only a fraction of the territory is situated within the drought risk area with dry tempudic soil moisture regime. Drought risk area is confined only to well known dry region of the country i.e. South Moravia. Under the changing climate a notable gradual increase of the areas with a high probability of dry events was noted (Fig. 5). When the model was run with data accommodating for increase of greenhouse gases emissions according to A2-SRES, the shifts in the soil climate characteristics were rather dramatic and took place within decades rather than centuries (Fig 5). It is obvious that by the year 2100 the most of the Czech Republic arable land would be faced with relatively frequent wet tempustic soil moisture regime events accompanied also by higher probability of drought spells (as it is clear from Fig. 3 and 4). This type of the soil climate have not been recorded up to now at the territory and is in the same time accompanied by significant increase of soil temperature (especially towards the end of the century). As the aridization of the soil climate regimes is closely related to other drought impacts such as decrease of crop yields, damage to forest stands, low stream flow and reservoir levels or change etc., a significant increase of drought related economic and social economic losses is likely under the climate change conditions. Besides direct loss of production in dry years the change of the soil moisture regime might in the long run lead to a significant alteration of conditions for most of the soil related processes including soil water dynamics, nitrification, mineralization, organic matter accumulation or erosion.

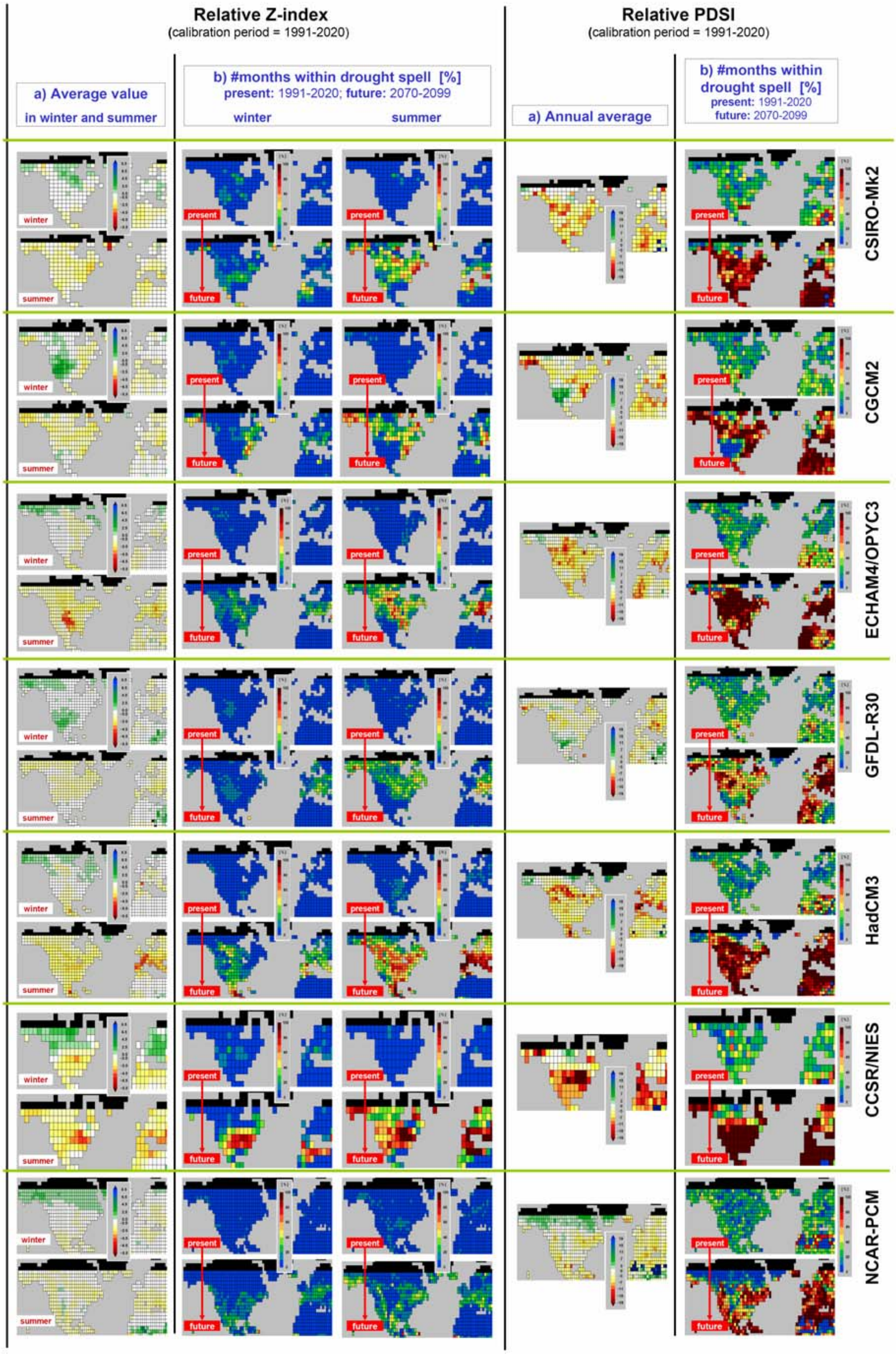


Fig. 3. Overview of the drought intensity and frequency according to the rZ-index and rPDSI based on the seven global circulation models (GCM) for the region of north America and western and central Europe.

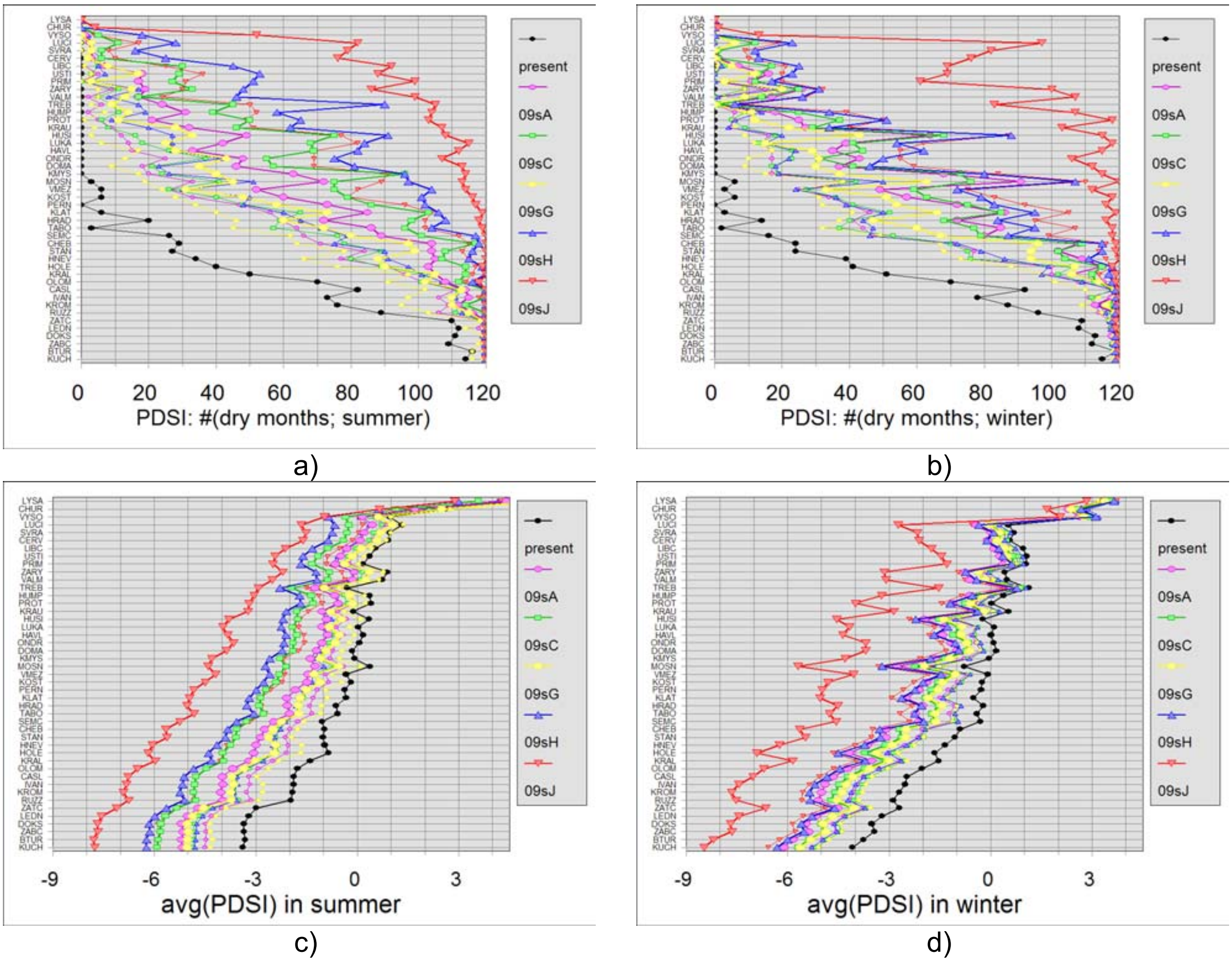


Fig. 4. Relative (calibrated with all-station data) PDSI in the present (1961-2000) and changed climate (2060-2099). a-b) number of months in drought episode (120 months is the maximum in 40 year data series) during summer (June-August) and winter (December-February) months of the year. c-d) average value of rPDSI in a whole year. Climate change scenarios were based on five GCMs (A = CSIRO-Mk2, C = CGCM2, G = GFDL-R30, H = HadCM3, J = CCSR/NIES AGCM + CCSR OGCM). The GCMs were run using SRES-A2 emission scenario, and the climate change scenarios are interpolated for a location defined by latitude = 49.5º N and longitude = 16º E, which is close to the center of Czechia.

The above mentioned changes in the drought frequency and intensity (in terms of rZ-index and rPDSI) could seriously affect the crop productivity of the CECILIA target region (south-eastern part of the Czech republic). In order to determine the most vulnerable areas (soils) the extensive crop modelling exercise is being carried out. It includes runs for number of time slices (2020,2030, 2040 and 2050) with several of GCMs (ECHAM, HadCM and CSIRO – 4th assessment report versions) and using three SRES scenarios (A2, B1 and A1B) for the time being. The crop model CERES-Wheat and CERES-Barley are being used and the effect of carbon dioxide is either included (so called combined effect of climate change) or not included and in this case the simulation runs depict only indirect effect of climate change (i.e. only the impact of shifts in climate). The reason for modelling both alternatives (i.e. with/without CO_2 positive CO_2 effect) is that the final magnitude of the positive effect is not yet fully agreed amongst plant physiologists. The crop model runs included the medium level of intensity (in terms of nitrogen dosage 60 kg/ha for barley and 100 kg/ha for winter wheat) and good quality pre-crop has been considered in both cases (leguminous crop). The simulation accounted for the operational adaptation on the side of farmers as the variable sowing date was simulated based on the soil temperature and soil workability. This procedure ensures optimum sowing date both for barley and winter wheat.

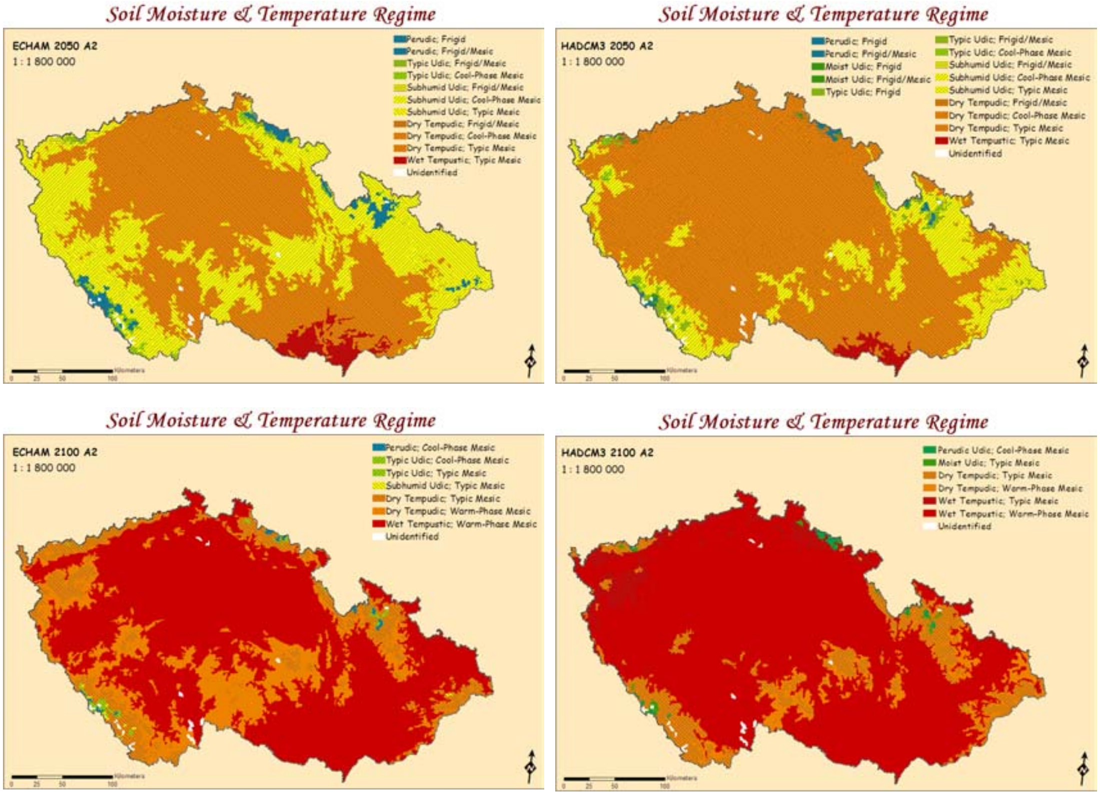


Fig. 5. Change in the soil moisture and temperature regimes expected under A2-SRES scenario and HadCM3 and ECHAM4 around 2050 and 2100 in the Czech Republic. (Compare with 2b = present climate).

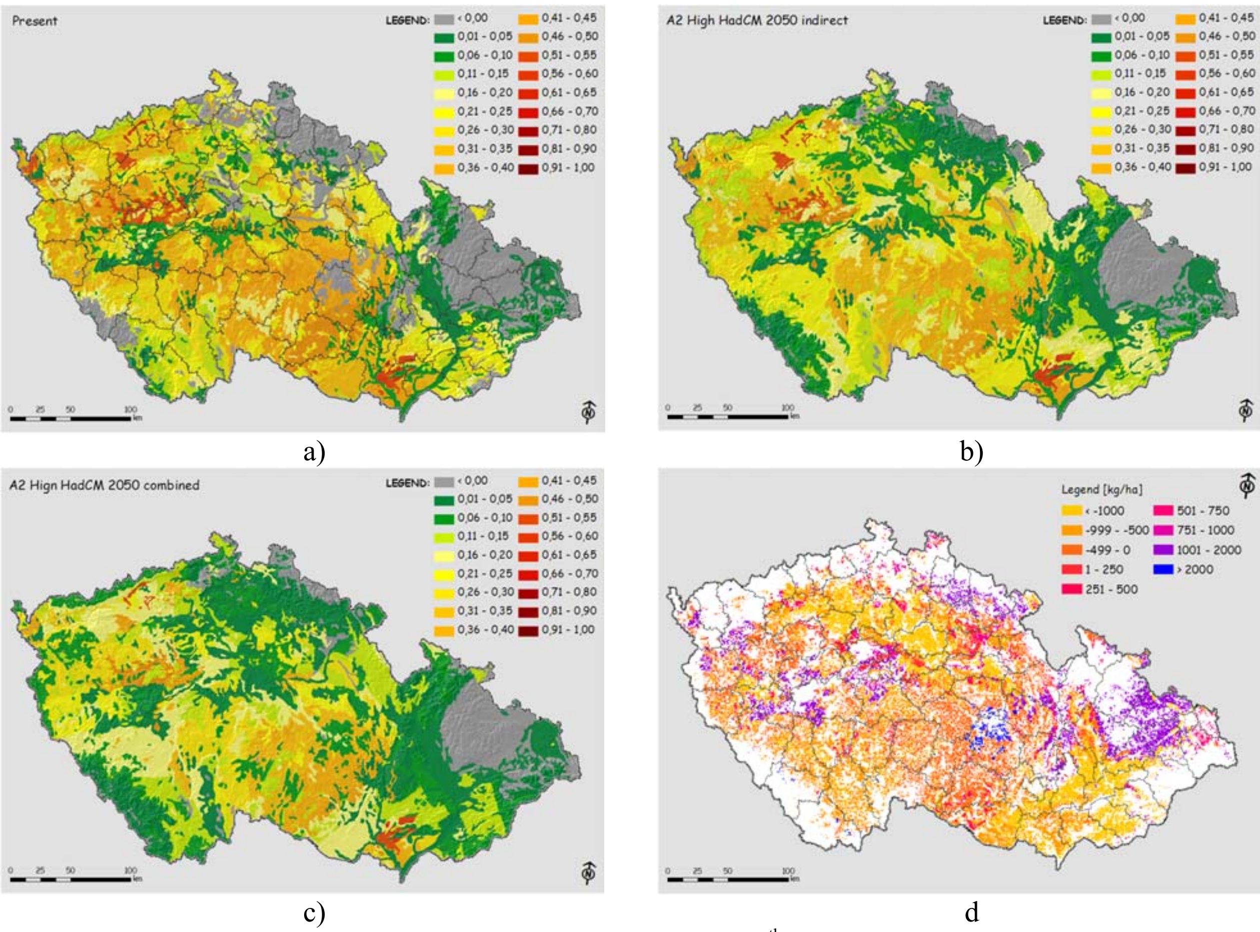


Figure 6. Level of the water stress in case of winter wheat during 5th driest season from 99 simulation runs under present climate (a) and conditions expected by 2050 according to the HadCM GCM and A2 SRES scenarios without the

positive effect of CO2 (b) and with inclusion of the effect (c). The figure d) depicts the difference in the mean yield between the 2050 indirect climate – present yield level. Note: for better visualization the maps a-c include whole territory. All analysises however were done based only on the polygons on arable soil (as in case Fig. 6d).

The example of the results is presented at Fig. 6. which depicts the intensity of water stress in the 5^{th} driest season from 99 simulation runs for present conditions and those expected in 2050 (both including and excluding CO_2 effect) in case of winter wheat. In addition a map representing the mean level of water stress (i.e. 50^{th} driest season) that can serve as a reference can be found at Fig 2d. Whilst during the period from emergence-anthesis there is very little or no change compared to the present stress levels the latter part of development (including crucial period of grain-filling) might be subjected to higher stress levels (if the CO_2 effect is not accounted for) despite the earlier sowing and harvest (approximately by 20-25 days). Even with the inclusion of CO_2 effect the drought stress in south-eastern region could still increase especially on the shallow soils like rendzinas (or calcisol) as might be seen at Fig .6c (brown arrow). Therefore even earlier start of growing season and higher winter precipitation will not fully alleviate for the increased drought stress in rainfed cereals (at least at some areas and years) especially on light and shallow soils. The impact of changed climate and especially the increased drought risk on the crop yield is presented at Fig. 6d, which represents the trends in the expected yields under future climate conditions. It is apparent that the most sensitive to the climate change (in a negative way) are regions where the drought stress is a dominant factor (Fig. 6d) even under present climate conditions. On the other hand areas with sufficient reserve in precipitation and good quality soil might benefit from the changing climate conditions (pink to violet areas at Fig. 6d).

Summary

The study results could be summarized in the following points:

- Drought indices indicate that during next 50-100 years Czech Republic will be faced with dry episodes of intensity and duration that were not usual in past 100 years.
- The area at risk from drought episode will widen and the drought will be more intensive.
- As a consequence significant portion of the Czech Republic will be faced with changing soil moisture and temperature regimes.
- These changes would activate multilevel cascade of changes affecting e.g. the landscape water balance, nutrient cycling or composition of soil organisms.
- Soil would become drier in general thus increasing drought risk and drought vulnerability of the area. The change is unavoidable but its magnitude depends on future emissions of green house gases.
- Due to the shifts in the vegetation season (earlier start in the spring and later end in the fall) is the main factor in the reducing cereal vulnerability to drought under the future climate. However this will be possible only if the early (in case of spring barley) or late sowing (in case of winter cereals) will still be possible. The higher concentration of CO_2 will increase water use efficiency however at some sites (especially with shallow or very light soils) even this will not be sufficient to prevent increase drought risk.

Austria (BOKU)

Introduction

One of the major field crops production areas of Austria - the Marchfeld region - was chosen as the investigation area. This region, located in the north-eastern part of the country, is influenced by a semi-arid climate with low annual rainfall.
Five different soil classes according to the total amount of available soil water capacity were created and a field near Fuchsenbigl (lat. 48.322°, lon. 17.000°, elev. 149 m a.s.l.) was selected as reference area.
The DSSAT CERES model was used in order to determine the vulnerability of current agricultural management systems for the selected crops. Winter wheat (*Triticum aestivum* L.) cultivar “Capo” was calibrated as a cultivar; it is currently grown on large acreages in the Marchfeld.
New regional climate scenarios for NE Austria were used to perform the simulations. These were carried out with the CSIRO, HadCM and ECHAM global circulation models (GCMs), based on SRES-A2 emission scenario.

Regional and local conditions

The region Marchfeld is influenced by a semi-arid climate: winters are usually cold with frequently strong frosts and few snowfalls, and summers are hot and intermittently dry (Müller 1993). The annual average temperature is around 9.8°C and the annual precipitation sum is 550 mm (1961-1990) at the reference weather station Fuchsenbigl.

The soils in this region are light or medium agricultural soils, with low and moderate water-storage capacity. Five different soil classes were chosen as the modelled soil types, according to the amount of total available water capacity of the soil within a depth of 1m (Murer et al. 2004), see fig 7. The first two soil classes - with an available water capacity up to 140 mm - are mostly Parachernosems. They are classified as loamy sand respectively sandy loam soils. Soil classes 3 and 4 are medium Chernozems and Fluvisols, with an available water capacity between 140 until 300 mm (class 3: sandy loam, class 4: loamy silt). A colluvial Chernosem has the highest available water capacity with over 300 mm and is qualified as soil class 5. It is a light to medium soil and the high water-storage capacity is a result of the deep soil profile of 150 cm.

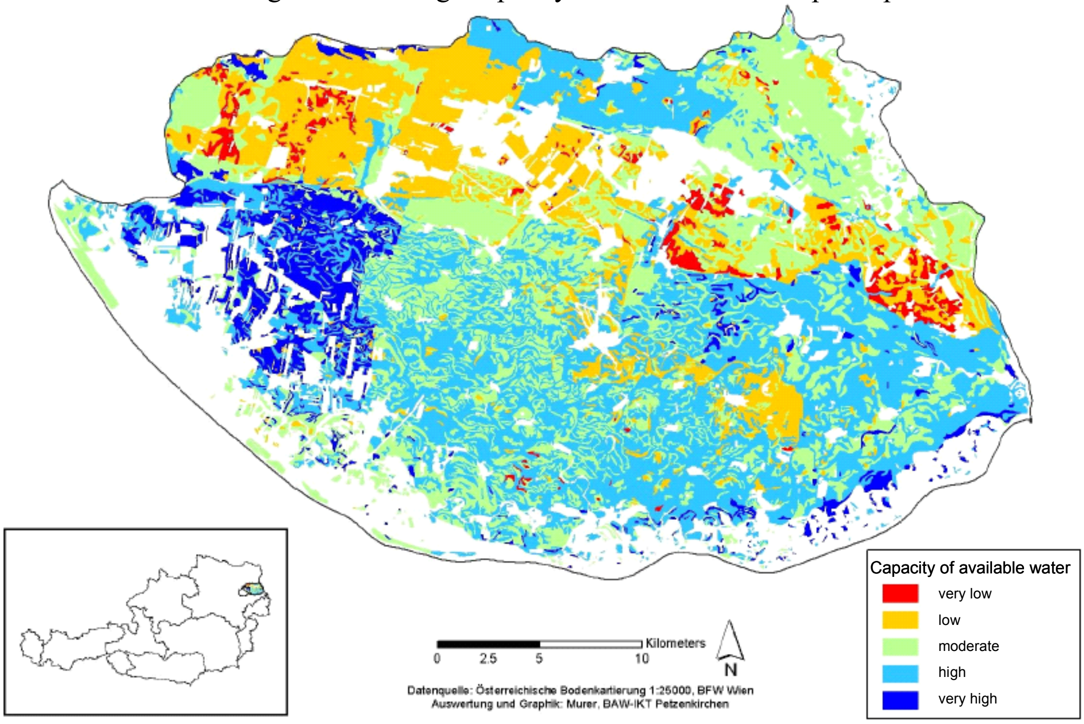


Fig 7: Available water capacity of mineral, agriculturally used soils in Marchfeld region (Murer et al. 2004)

Winter wheat (*Triticum aestivum* L.; cultivar "Capo") yield [kg ha^{-1}] was simulated with the DSSAT CERES model for the reference station Fuchsenbigl as well as for 5 selected soil classes (Fig. 8).

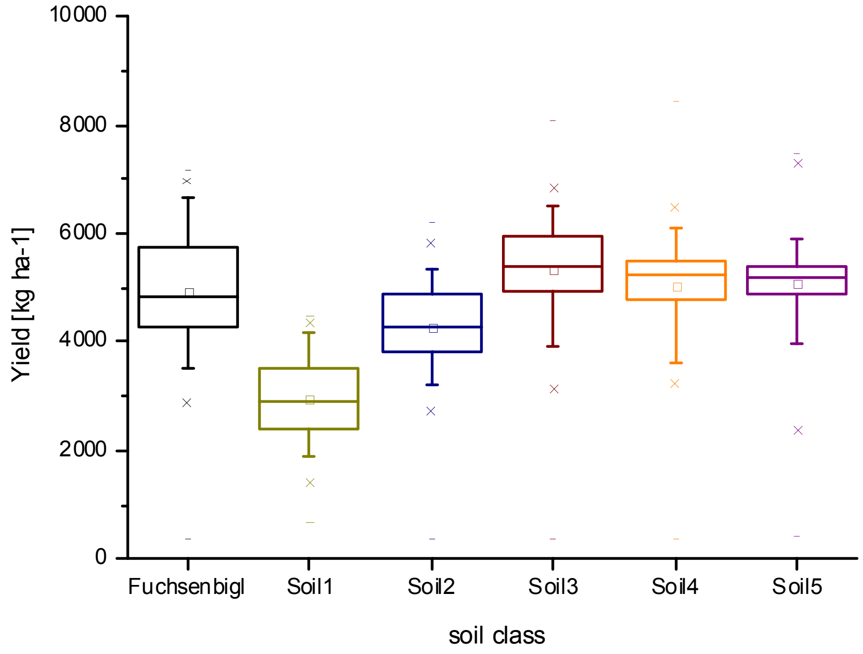


Fig 8: Winter wheat yield [kg ha^{-1}] for the reference station Fuchsenbigl, in black, as well as for the 5 soil classes – present conditions

The soil class with the lowest available water capacity (soil class 1) resulted about 40 % and soil class 2 around 14% lower yield than at the reference station Fuchsenbigl. Soil classes 3 until 5 result higher average yields than the reference soil (from 2 to 8 %). These findings suggest that, on soils with total available water capacity over 140 mm, mainly other factors than physical soil conditions (precipitation, nutrients etc.) will be the relevant limiting factor for crop development in average years.

The water use efficiency is a measure of crops (WUE_{plant}) or cropping systems (WUE_{field}) performance in the use of available water for reproductive growth. The WUE_{plant} can be calculated as follows:

$$WUE_{plant}\ [kg\ mm^{-1}\ ha^{-1}] = Yield/Transpiration$$

WUE_{plant} is shown for the reference station Fuchsenbigl and for the different soil classes in fig 9. Soil class 1 has, with around 33 kg mm^{-1} ha^{-1}, a 19% higher WUE_{plant} than the reference soil. Due to the lower available soil water in this light soil, the wheat plants have to deal with water scarcity. Therefore they use water more efficiently. The other 4 soil classes present similar results for WUE_{plant} of around 27 kg mm^{-1} ha^{-1}. Especially on soil classes 3 and 4 the water consumption of the crop is less restricted.

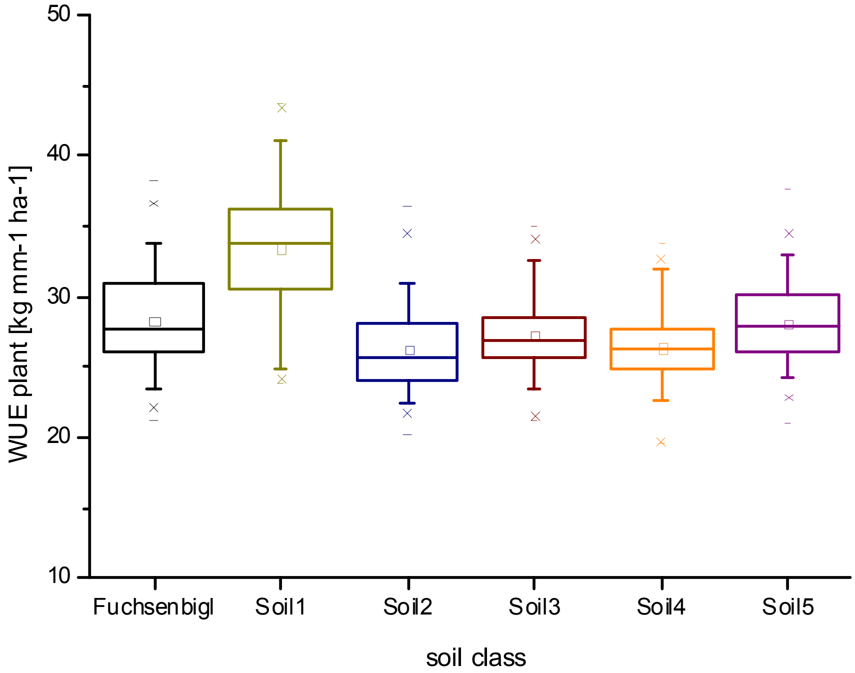


Fig 9: WUE_{plant} [kg mm^{-1} ha^{-1}] for the reference station Fuchsenbigl and for the different soil classes – present conditions

The water use efficiency of the cropping system also includes the evaporation, which can be calculated as follows:

$$WUE_{field} \text{ [kg mm}^{-1}\text{ ha}^{-1}\text{]} = \text{Yield/Evapotranspiration}$$

Soil classes 3 until 5 have a similar WUE_{field} with an approximate value of 9-10 kg mm^{-1} ha^{-1} (fig 10). For soil class 1 and to a lesser extent for soil class 2 a relatively high evaporation loss leads to low WUE_{field} values. The ratio between transpiration and evaporation is shifted towards evaporation. A reason for the higher evaporation is the low plant density on these light soils.

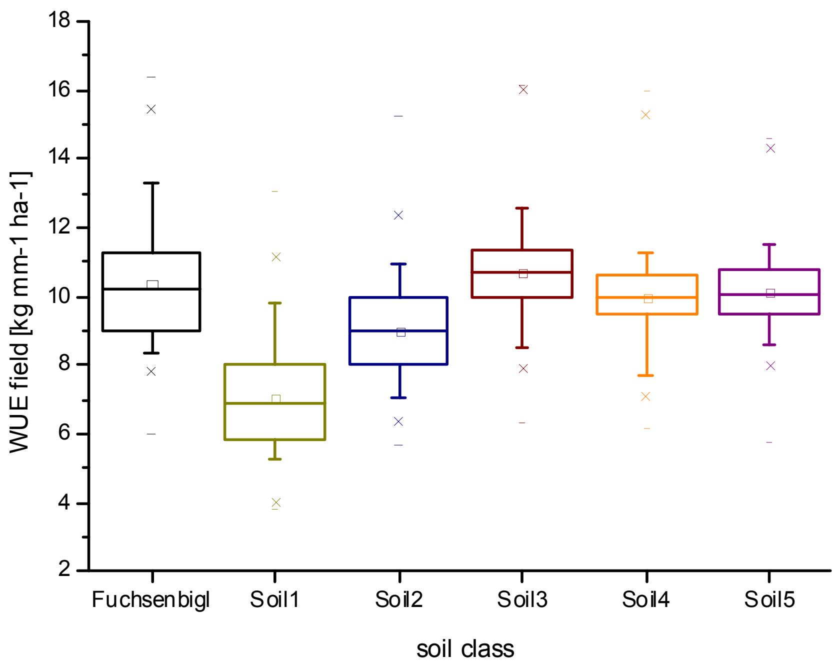


Fig 10: WUE_{field} [kg mm^{-1} ha^{-1}] for the reference station Fuchsenbigl and for the different soil classes – present conditions.

Drought occurrence in the NE Austria in the context of climate change

The regional climate scenarios for NE Austria are performed with the global circulation models (GCMs) CSIRO, HadCM and ECHAM, based on SRES-A2 emission scenario. Synthetic daily weather series (input to crop growth models) were produced with stochastic weather generator (Met&Roll) for present conditions (reference period 1961-1990), 2025 and 2050. To account for the uncertainties 6 (3x2) scenario sets were defined:

- uncertainty in scenario pattern: 3 sets of GCMs with HadCM, ECHAM and CSIRO.
- uncertainty in the scaling factor: function of emission scenario and climate sensitivity -> 2 versions of the scaling factor for a given period:
    - high : high CS (+4.5 K)
    - low : low CS (+1.5 K)

A CO_2 concentration in the atmosphere of 360 ppm was assumed for present conditions, 438 ppm for 2025 and 535 ppm for 2050.

In table 1 the range of the maximum and minimum temperature in Marchfeld for 2025 and 2050 in °C change in respect to the present conditions for low and high climate sensitivity are summarized.

2025	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Tmax low sensit.	0.9-1.0	1.0-1.1	0.7	0.5-0.6	0.2-0.4	0.7-1.0	1.0-1.3	0.9-1.4	0.6-0.9	0.1-0.3	0.7-0.8	0.7-0.9
Tmin low sensit.	1.6-2.1	1.7-1.9	1.0-1.2	1.6-1.9	1.1-1.7	1.1-1.7	1.7-2.4	1.6-2.8	1.7-2.5	0.9-1.5	0.9-1.3	1.5-1.9
Tmax high sensit.	0.9-1.2	0.8	0.6-0.7	0.5-0.6	0.2-0.4	0.6-0.9	0.8-1.1	0.7-1.3	0.4-0.8	0.2-0.6	0.4-0.6	0.5-0.6
Tmin high sensit.	1.8-2.5	1.6-1.8	1.0-1.3	1.5-1.8	0.8-1.5	1.0-1.5	1.5-2.3	1.3-2.7	1.3-2.4	0.9-1.8	0.7-1.2	1.4-1.7

2050	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Tmax low sensit.	1.1-1.4	0.9-1.0	0.8-0.9	1.4-1.5	0.4-0.9	0.6-1.0	1.1-1.5	1.3-2.1	1.2-1.7	0.5-0.9	0.8-1.0	1.0-1.2
Tmin low sensit.	1.1-1.5	0.9-1.0	0.9-1.1	1.0-1.2	0.4-0.8	0.7-1.1	0.9-1.5	0.9-1.9	0.8-1.5	0.7-1.3	0.5-0.9	0.9-1.1
Tmax high sensit.	3.2-4.1	2.9-3.1	1.6-1.9	2.0-2.4	1.6-2.7	1.9-3.0	2.8-4.1	2.6-4.8	2.9-4.3	1.9-2.9	1.7-2.4	2.8-3.4
Tmin high sensit.	3.2-4.5	2.6-3.0	1.7-2.2	1.9-2.5	1.3-2.6	2.0-2.9	2.5-4.0	2.2-4.8	2.3-4.1	1.5-3.0	1.1-2.1	2.8-3.3

Table 1: Range of maximum and minimum temperature in °C change in respect to the present conditions for low and high climate sensitivity – 2025 and 2050

For the selected area of study, the highest temperature increases can be expected in the months of July, August and September (up to +4.8°C). A decrease in the precipitation is predicted in spring and summer, an increase in winter (table 2).

2025	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Prec low sensit.	+1.0-+8.9	+5.9-+7.2	-1.5-+2.2	-4.0-+0.6	-12.7--7.4	-4.3--0.8	+0.6-+10.6	+2.3-+11.0	-2.6--0.5	+2.2-+6.0	-3.9-+0.6	+4.2-+6.7
Prec high senit.	+13.0-+34.5	+4.1-+7.0	-6.9-+1.7	-10.3-+0.3	-12.7-+0.3	-14.4--6.4	-10.1-+13.7	-16.0-+3.5	-14.6--9.9	-7.9-+0.7	+5.0-+17.0	+16.7-+23.0

2050	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Prec low sensit.	+12.3-+26.1	+12.6-+14.6	-4.2-+1.5	-10.1--3.3	-14.9--6.8	-10.7--5.5	-14.7--1.0	-13.9--2.1	-11.7--8.7	-3.7-+2.0	-0.1-+7.1	9.6-+13.6
Prec high senit.	+15.9-+55.5	+2.9-+7.9	-8.1-+8.0	-9.6-+10.2	-19.1-+3.0	-16.3- -1.5	-29.4-+9.6	-30.9-+4.5	-24.0- -15.5	-4.4-+12.4	-6.5-+12.9	30.8-+42.6

Table 2: Range of precipitation in % change in respect to the present conditions for low and high climate sensitivity – 2025 and 2050

Fig 11 shows the relative yield changes in 2025 in respect of present conditions for the different soil classes. The light soils have the lowest increases; some models predict also a yield loss in that group. On Chernosems and Fluvisols highest yield increases can be expected. Up to 9 % higher yield is simulated, based on the ECHAM model with high climate sensitivity. Yields on soil class 5, a light to medium soil, enhance 3 – 4 %. The yield rise is mainly a result of the enhanced CO_2 concentration in the atmosphere. CO_2 has fertilizing effects on the wheat crop. The grain filling period will be shortened up to 1 day in 2025 due to the earlier completion of the temperature sums.

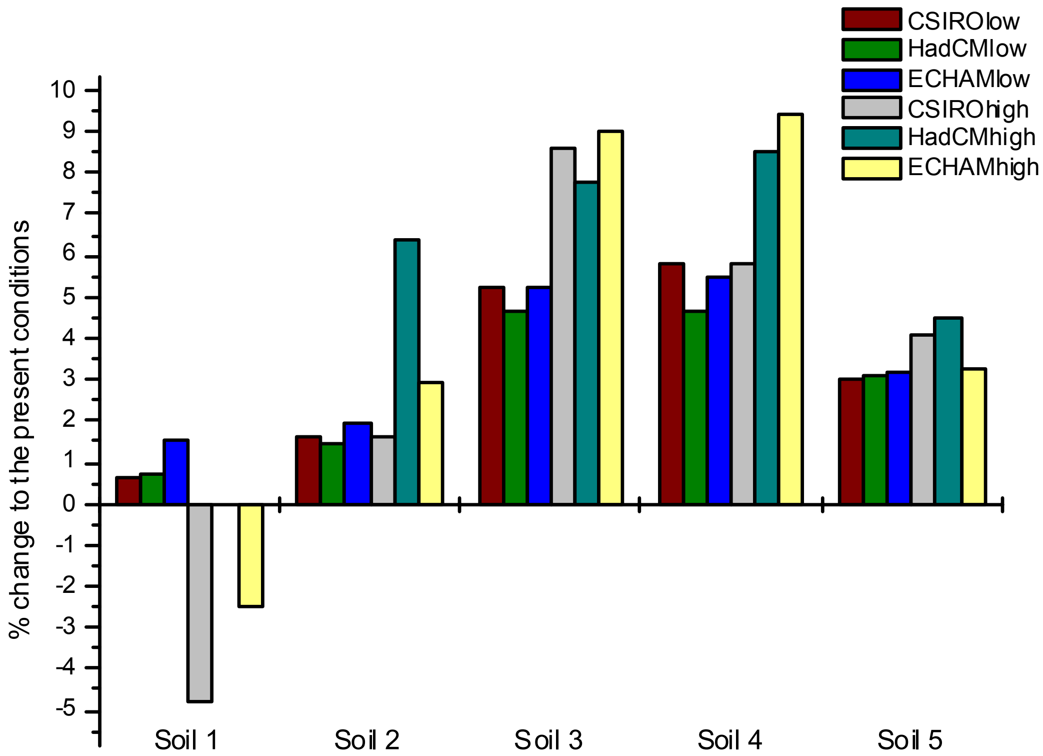


Fig 11: Relative change of the yield to the present conditions for the different soil classes and GCMs – 2025

Also for 2050 the highest grain yield increment can be predicted for the soil classes 3 and 4 (fig 12). The low climate sensitivity scenarios show a rise of approximately 12 %, while the high ones show a rise of 14 until 18 %. For soil class 1, a lower yield can be expected by the CSIRO low sensitivity model, as well as by all high climate sensitivity models.
The grain filling period will be shortened up to 3 days for all soil classes.

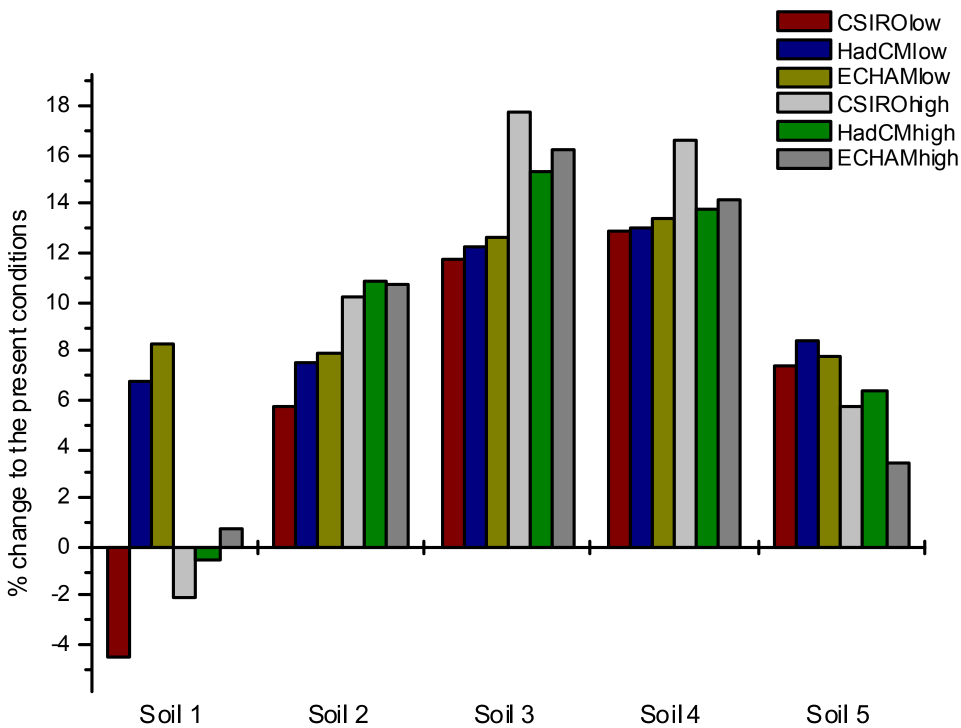


Fig 12: Relative change of the yield in respect to the present conditions for the different soil classes and GCMs - 2050

Enhanced levels of atmospheric CO_2 increase water use efficiency of plants by improving growth rates and suppressing transpiration per unit leaf area. The plants growing on light soils show the highest WUE_{plant} increases compared to the present conditions (Table 3). According to this the wheat plants have to deal with stronger water scarcity on this kind of soils. WUE_{field} will increase especially on medium soils (table 3). On light soils shallower stands lead to higher evaporation losses.

2025	**WUE_{plant}**					**WUE_{field}**				
	Soil 1	Soil 2	Soil 3	Soil 4	Soil 5	Soil 1	Soil 2	Soil 3	Soil 4	Soil 5
CSIRO low sensit.	12.7	13.7	25.6	6.4	19.1	1.5	2.5	4.7	6.3	3.8
HadCM low sensit	19.5	21.8	16.6	20.3	16.0	1.8	2.6	5.4	5.6	5.0
ECHAM low sensit	11.5	27.4	25.1	6.8	21.7	3.4	3.1	5.9	7.3	5.2
CSIRO high sensit.	15.4	19.0	10.1	6.4	16.5	-2.5	3.7	9.4	6.3	7.1
HadCM high sensit.		28.0	11.5	14.3	17.0		12.4	12.1	13.1	10.6
ECHAM high sensit.	14.1	21.2	12.0	14.5	17.8	2.6	8.1	13.1	13.9	9.6

2025	**WUE_{plant}**					**WUE_{field}**				
	Soil 1	Soil 2	Soil 3	Soil 4	Soil 5	Soil 1	Soil 2	Soil 3	Soil 4	Soil 5
CSIRO low sensit.	10.1	29.0	17.7	22.0	26.9	0.6	12.4	17.4	19.0	15.6
HadCM low sensit	30.1	30.6	18.8	23.0	27.7	14.9	14.9	18.7	20.2	17.6
ECHAM low sensit	29.7	31.1	19.1	23.7	28.4	16.4	15.5	19.2	20.7	17.2
CSIRO high sensit.	42.3	44.0	25.9	32.0	40.2	-0.6	12.5	18.5	18.3	10.2
HadCM high sensit.	38.4	45.5	29.7	32.9	38.7	8.8	21.1	24.1	23.9	18.2
ECHAM high sensit.	40.9	47.8	27.9	34.6	41.4	9.7	20.8	24.9	23.9	15.5

Table 3: Relative change of WUE_{plant} and WUE_{field} in 2025 and 2050 in respect to the present conditions

The potential evapotranspiration was calculated with the FAO-56 Penman-Monteith (FAO-56 PM) method and defines an upper limit to evapotranspiration for a well watered reference crop. A hypothetical crop with an assumed height of 0.12 m having a surface resistance of 70 s m^{-1} and an albedo of 0.23 is selected as reference crop. This crop is closely similar to the evaporation of an extension surface of green grass of uniform height, actively growing and adequately watered (Allen et al. 1998). The actual evapotranspiration is the amount of water that is actually removed from a surface due to the processes of evaporation and transpiration. It is determined by atmospheric, plant and soil conditions. Drought stress can be expressed by the ratio between actual and potential evapotranspiration and can be used as an indicator of drought.

The low climate sensitivity scenarios lead to arise of the potential evapotranspiration (FAO-56 PM) about 5 %, the high ones lead to about 11 % in 2025. At the same time, a decrease of the actual evapotranspiration on average of around 5-7 % for the low climate sensitivity scenarios and 5-8 % for the high ones can be expected.

For 2050 an increase of the potential evapotranspiration of up to 5 % is predicted (low sensitivity scenarios) as well as around 13 % (high ones). Simultaneously the actual evapotranspiration will decrease about 6 %.

In Table 4 the actual and potential evapotranspiration for each soil type and climate scenario are summarized.

2025	**Soil 1**		**Soil 2**		**Soil 3**		**Soil 4**		**Soil 5**	
	ET_{act}	**ET_{pot}**	**ET_{act}**	**ET_{pot}**	**ET_{act}**	**ET_{pot}**	**ET_{act}**	**ET_{pot}**	**ET_{act}**	**ET_{pot}**
present	424	731	480	730	505	731	510	731	506	731
CSIRO low sensit.	423	755	478	755	507	755	513	755	504	755
HadCM low sensit.	418	762	473	762	501	762	506	762	498	762
ECHAM low sensit.	418	754	473	754	501	754	507	754	498	754
CSIRO high sensit.	414	779	470	779	503	780	513	780	494	779
HadCM high sensit.			454	798	486	798	491	798	480	797
ECHAM high sensit.	403	777	457	778	488	778	493	778	479	777

2050	**Soil 1**	**Soil 2**	**Soil 3**	**Soil 4**	**Soil 5**

	ET_{act}	ET_{pot}	ET_{act}	ET_{pot}	ET_{act}	ET_{pot}	ET_{act}	ET_{pot}	ET_{act}	ET_{pot}
present	424	731	480	730	505	731	510	731	506	731
CSIRO low sensit.	406	765	455	765	486	766	490	766	477	765
HadCM low sensit.	394	776	448	777	478	777	482	777	469	776
ECHAM low sensit.	395	764	448	764	478	764	481	764	468	764
CSIRO high sensit.	415	820	469	820	502	820	505	820	486	820
HadCM high sensit.	386	846	439	846	468	846	471	846	456	846
ECHAM high sensit.	388	809	439	809	471	810	472	809	454	809

Table 4: Actual (ET_{act}) and potential (ET_{pot}) evapotranspiration (FAO-56 PM) for the 5 soil classes and different GCMs – 2025 and 2050

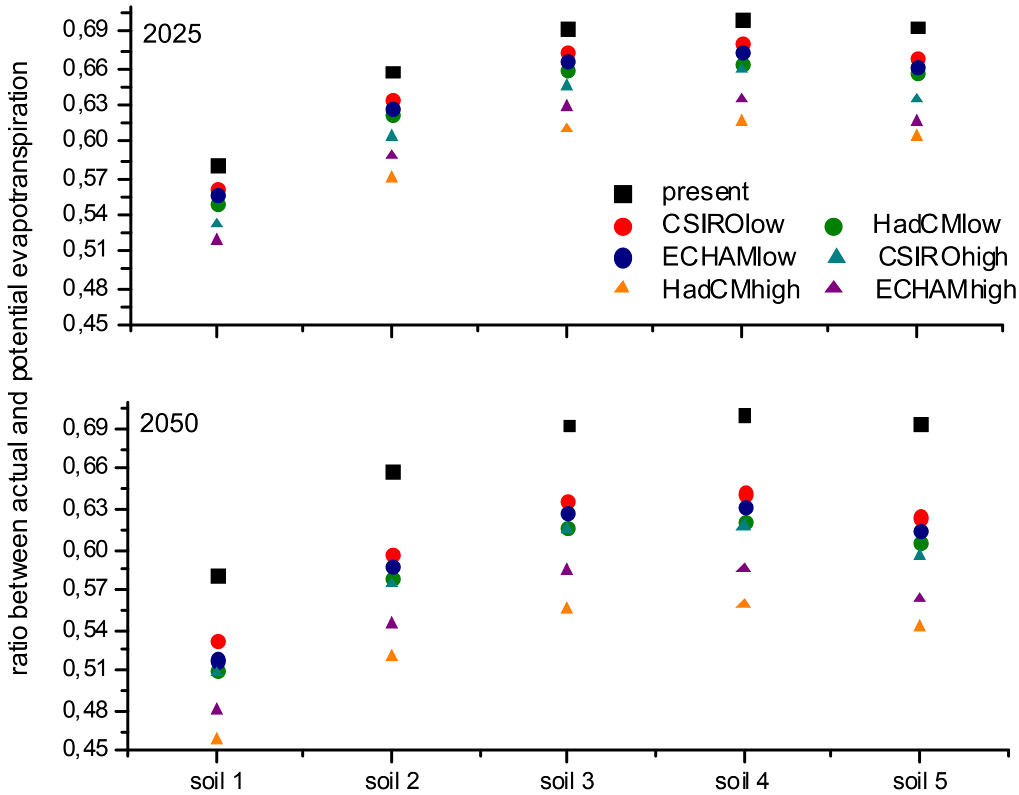


Fig 13: Ratio between actual and potential evapotranspiration for the different soil classes: present, 2025 and 250

The ratio between actual and potential evapotranspiration for the different soil types and scenarios is shown in fig 13. For 2025 the ratio will be about 10-11 % less in the low and about 16-18 % less in the high climate sensitivity scenarios in respect to present conditions. Until 2050 a decrease of the ratio on average of around -11 % for the low climate sensitivity scenarios and -18 % for the high ones can be expected. Lower values mean higher drought stress for the plants, where light soils are most sensitive.
Despite higher drought stress, winter wheat yields increase due to a compensation by higher CO_2 concentrations.

Summary

As the investigation area, the region Marchfeld in NE Austria, one of the most important agricultural production areas, was chosen. The soils in this region include light and medium soils with low and moderate water-storage capacity respectively. The climate is semi-arid.
A winter wheat cultivar (Capo) was calibrated and validated and regional climate scenarios for NE Austria, based on SRES-A2 emission scenario, were used to perform the simulations.
The highest increase of winter wheat yield can be expected for the medium soils (Fluvisols and Chernozems) – up to 9 % until 2025 and up to 18 % until 2050 (high climate sensitivity models). This is mainly a result of the enhanced CO_2 concentrations in the atmosphere. Light soils show much lower yield increments or even yield losses. Simultaneously, the yield variability increases in all soils, this leads to a higher economic risk for the farmers. The grain filling period will be shortened up to 1 day in 2025 and up to 3 days in 2050 due to the earlier completion of temperature sums.
In general WUE_{plant} will be enhanced. Higher CO_2 concentration will enable the plants to reduce stomata opening and water losses. The plant stands on light soils show the highest WUE_{plant} increases compared to the present conditions. This means that the wheat plants have to deal with stronger water scarcity on light soils in the future.

WUE_{field}, which also includes evaporation, will increase especially on medium soils. On light soils shallower stands lead to higher evaporation losses.
The ratio between actual and potential evapotranspiration was used as a measure of plant drought stress. For all soils, a lower ratio, which means a higher drought stress, was calculated for each of the climate scenarios. Light soils show a higher increase of stress than medium soils. Despite higher drought stress, winter wheat yields increase due to compensation by higher CO_2 concentrations (except very light and shallow soils).
In a next step spring barley and maize will be simulated for the 5 soil classes in Marchfeld. In addition the Palmer‘s Z Index will be calculated as an other parameter for drought damage potential. Management alternatives for example reduced tillage, modified sowing dates, drought resistant cultivars as well as changes in the occurrence of pests and diseases due to climate change effects will be considered.

Czech republic (CHMI)

In frame of Czech Hydrometeorological Institute (CHMI) the moisture characteristics are counted by agroclimatological model AVISO. This model has been used for calculation of potential evapotranspiration PEVA, actual evapotranspiration AEVA and reference evapotranspiration REVA, moisture balance (potential PMB and actual AMB) and moisture deficit. The calculations are using one day interval of input items. The meteorological input variables are following:

Average air temperature (°C)
Average relative air humidity (%)
Wind velocity ($m.s^{-1}$)
Actual duration of sunshine (hours)
Precipitation total – for computing of AEVA

The results of the evaluation are based on the database of meteorological elements measured in the network of climatological stations of the Czech Hydrometeorological Institute (CHMI) and processed by standard procedures. For CECILIA project will be process those moisture characteristics in high resolution network (10 km) for three timescale periods – present climate (1970-2000) and changed climate (2020-2050 and 2070-210). Climatological outputs from the model ALADIN will be used as input for the model AVISO. On the base of the results it will be possible to compare those time periods from the viewpoint of moisture conditions.

For expression of moisture conditions the moisture balance has been used very often. It means the difference between precipitation and total evapotranspiration. Potential moisture balance based on reference evapotranspiration (very close to PEVA) computed in accordance with FAO methodology (worldwide accepted, based on modified Penman-Monteith method) does not express actual amount of water amount within landscape but serves for comparing indicator of individual sites and years. Reference evapotranspiration means evapotranspiration of hypothetical crop which is very close to standard grass cover, with the uniform height 0.12 m, full canopy closure and optimum moisture conditions during whole year, surface resistance 70 $m.s^{-1}$ and albedo 0.23. The changes in reference evapotranspiration are caused by changes in meteorological elements. Positive moisture balance means surplus of precipitation, a negative one a lack of it. From this reason it is possible to employ the moisture balance as an indicator of drought.

FAO equation:

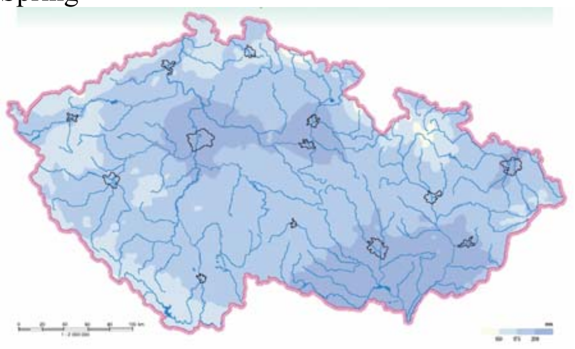
$$LE = \frac{\Delta (R - G) + \rho_a c_p (e_o - e) / r_a}{\Delta + \gamma [1 + (r_s / r_a)]}$$

where: L is latent heat, E evapotranspiration, Δ is the change of saturated water vapour pressure with respect to temperature, R is the radiation balance, G is the soil heat flux, ρ is the density of the air, c_p is the specific heat of the air, e_o is the saturated water vapour pressure over the reference level and e at a given level of the atmosphere, r_a is the aerodynamic resistance, γ is the thermodynamic psychrometric constant, and r_s is the resistance of the evaporated surface for the water vapour transfer.

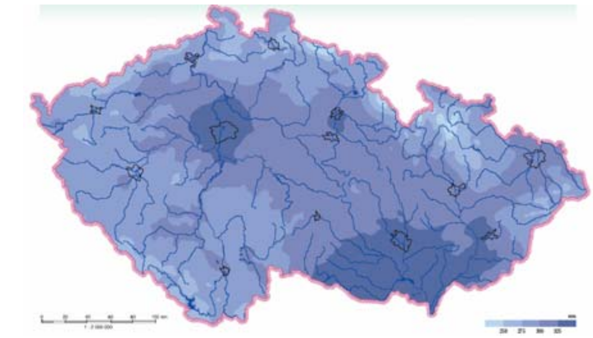
The examples of evapotranspiration and moisture balance computing results published in Climate Atlas of Czechia:

Map 14-17: Average reference evapotranspiration (1961-2000)

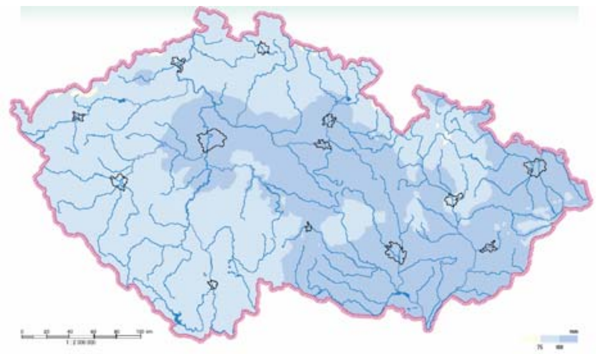
Spring



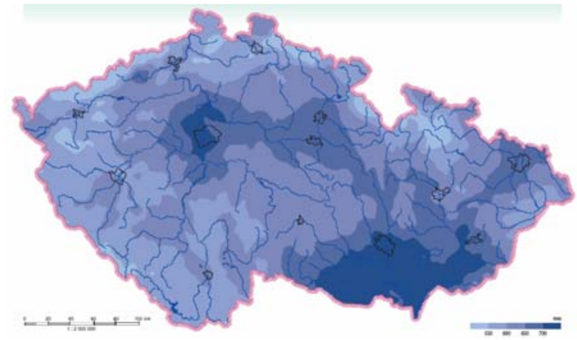
Summer



Autumn

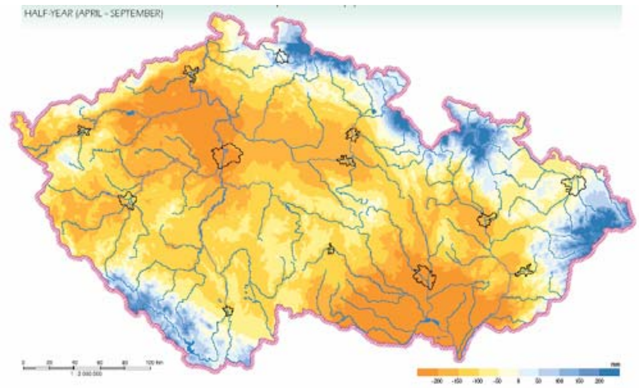


Annual

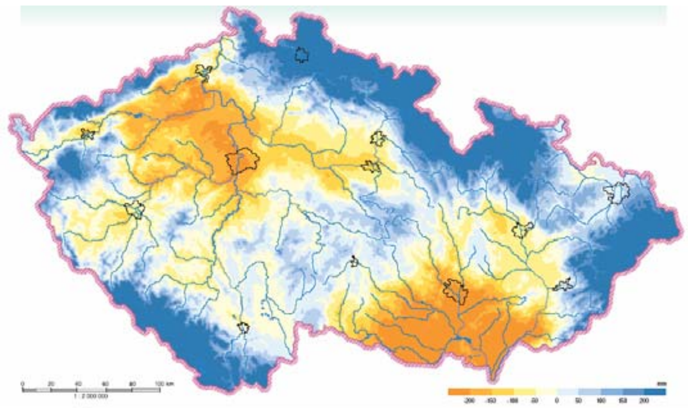


Map 18-19: Moisture balance (1961-2000)

Summer



Annual



Territory of Czech Republic lies in the temperate zone which is at the same time a region of transitional central-European climate. The climate of south Moravia is significantly influenced by circulation and geographical conditions. During the predominant part of the year, air of the temperate zone prevails, and further, the tropical air mass has an influence, and in short time segments also the arctic air mass (in winter time). Our climate is influenced by the Atlantic Ocean, but also in smaller measure by the Euro-Asian continent. The continentality of our territory from west to east increases approximately by 10 %. The oceanity of Eastern Moravia is about 50 %. In Moravia there are greater temperature amplitudes. This is shown by the mild effect of the sea climate especially in the winter period. On the other hand in the summer period, partial continental influence is shown by higher air temperatures.

Czech mountains have a significant influence on the climate, as they form so-called climatic dams, where they partly prevent the intrusion of cold air from the North, and relative to the Northern circulation they cause rainfall shadow. The climatic diversity is more influenced by elevation and the articulation of the terrain than geographical location. Generally is possible to say, that climate of south Moravia is dependent mainly on the cyclonal activity, which in turn causes that individual years are very variable.

Bulgaria (NIMH) DROUGHT AND CROP WATER USE IN NORTHEAST BULGARIA AS INFLUENCED BY CLIMATE (VARIABILITY AND CHANGE EFFECTS)

Introduction

Drought is undoubtedly one of man' worst natural enemies. Not only does it affect the social and economic life of millions of people every year, but for time to time the existence of a whole nation is endangered. Its beginning is subtle, its progress is insidious and its effects can be devastating. Drought may start any time, last indefinitely and attain many degrees of severity. Available hydrometeorological data indicate that droughts have occurred throughout the last century in Bulgaria (Fig.20) and that they are a natural part of the climatic cycle of the entire Balkan Peninsula.

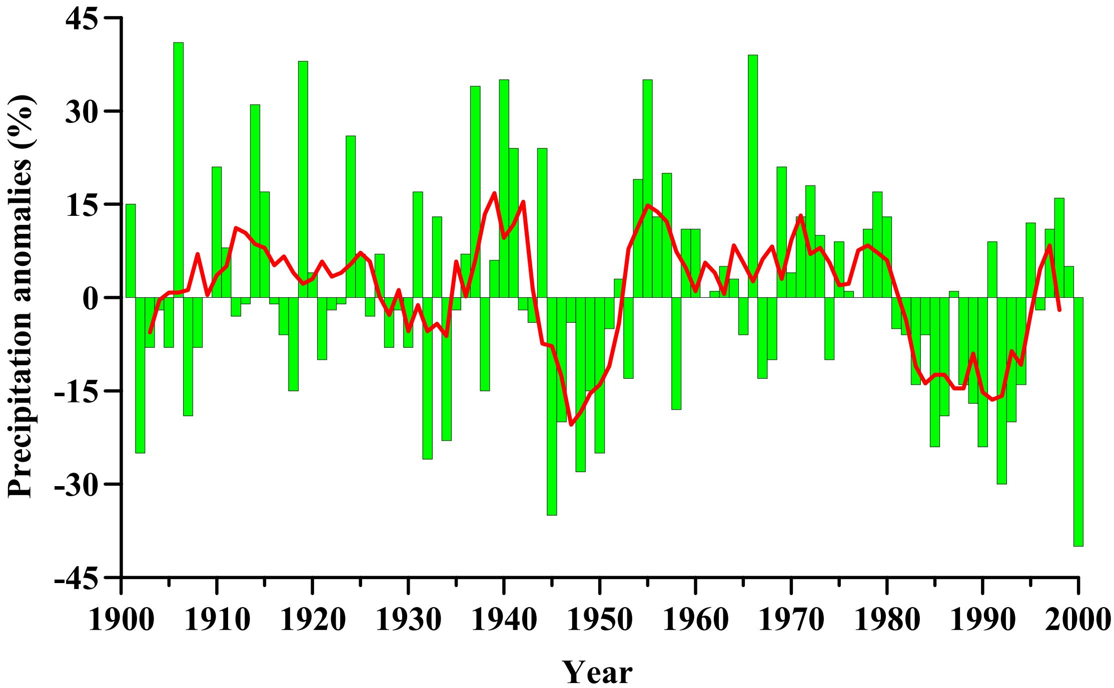


Fig 20. Anomalies of annual precipitation in Bulgaria, relative to 1961-1990

Unfavorable meteorological conditions cause twice as many losses in agricultural production as they do in most other business sectors. The intensity, time of occurrence, duration and area of impact are important dimensions of unfavorable meteorological events when they seriously decrease crop yields. Drought is usually the most important constraint limiting crop production in the rainfed areas in the country (Fig. 21).

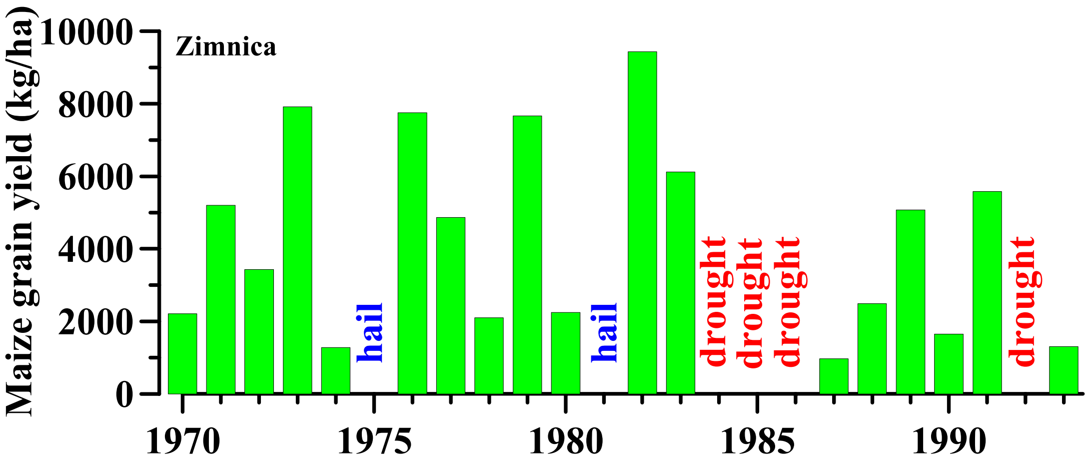


Fig 21. Maize grain yield under rainfed conditions

Regional and local conditions

Figure 22 presents the selected NUTS2 (Northeast) region and experimental crop variety stations in it. And Figure 23 shows the NUTS3 and NUTS4 regions in the selected NUTS2 area.

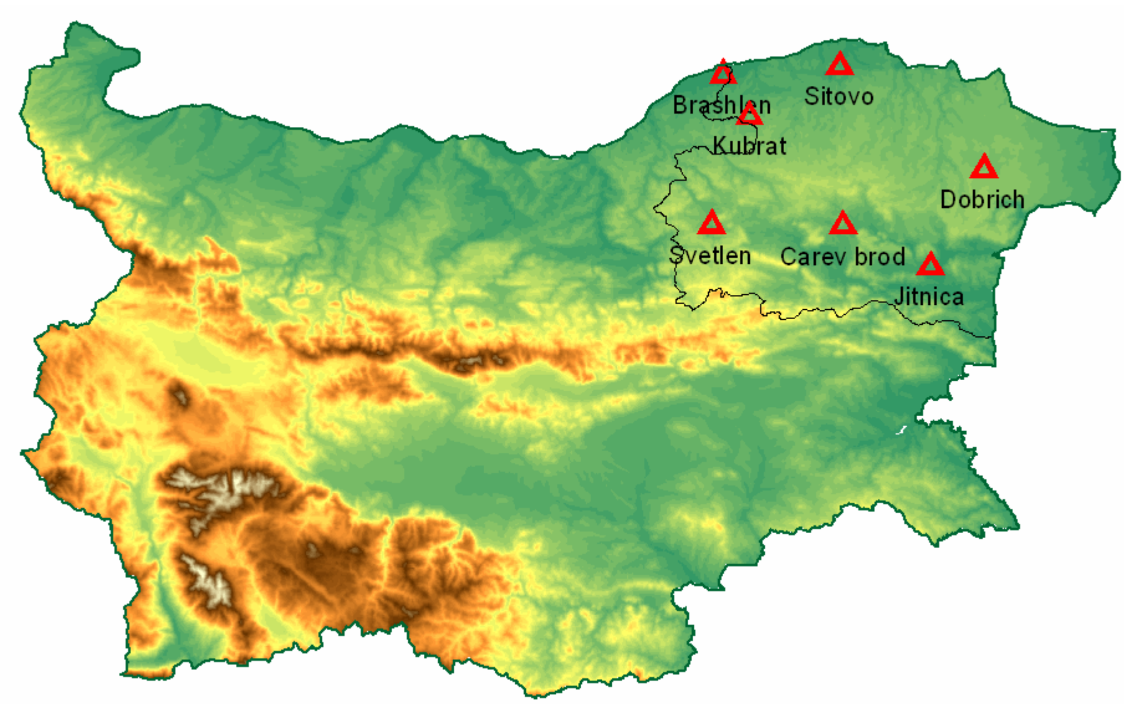


Fig. 22. Bulgaria, selected NUTS2 (Northeast) region and experimental crop variety stations (△) in it

Fig. 23. The selected NUTS2 (Northeast) region and its NUTS3 and NUTS4 units

Spatial distribution of precipitation during different seasons was applied to classify the drought risk of the NUTS4 units in Northeast Bulgaria (Fig 24-27). It was found the most vulnerable are the eastern territories of the considered region. The selected region was also classified according to soil type, structure and moisture content (Fig. 28-31).

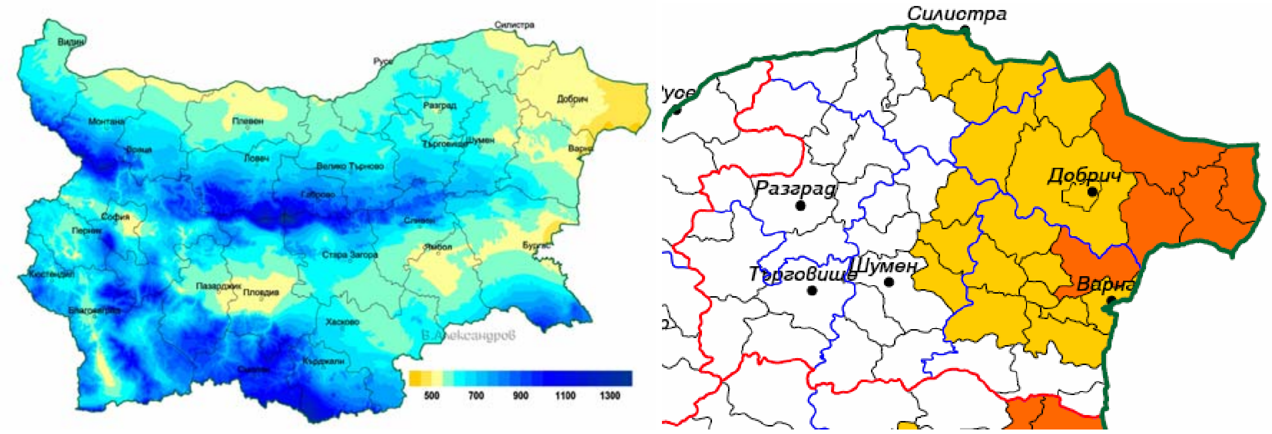


Fig. 24. Annual precipitation and drought risk in Northeast Bulgaria

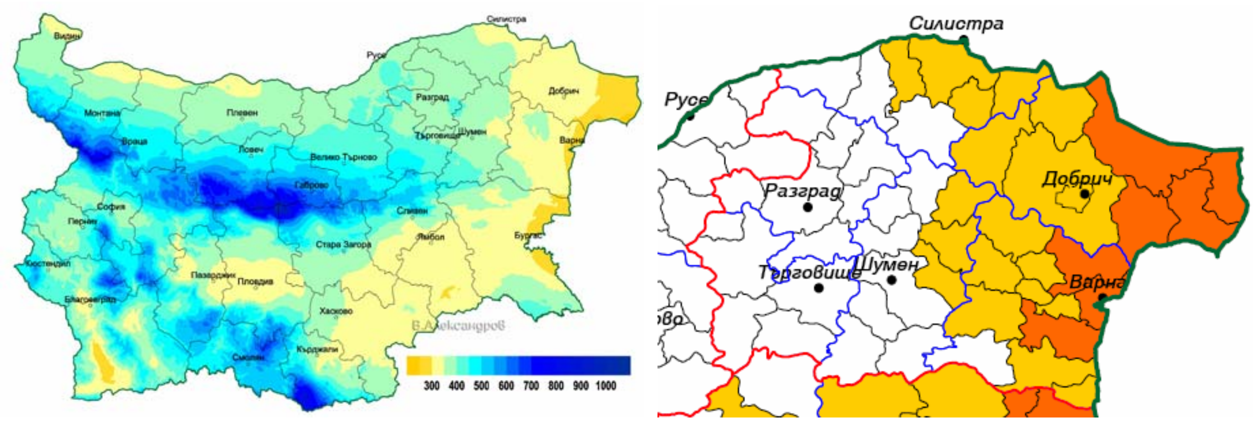


Fig. 25. April-September precipitation and drought risk in Northeast Bulgaria

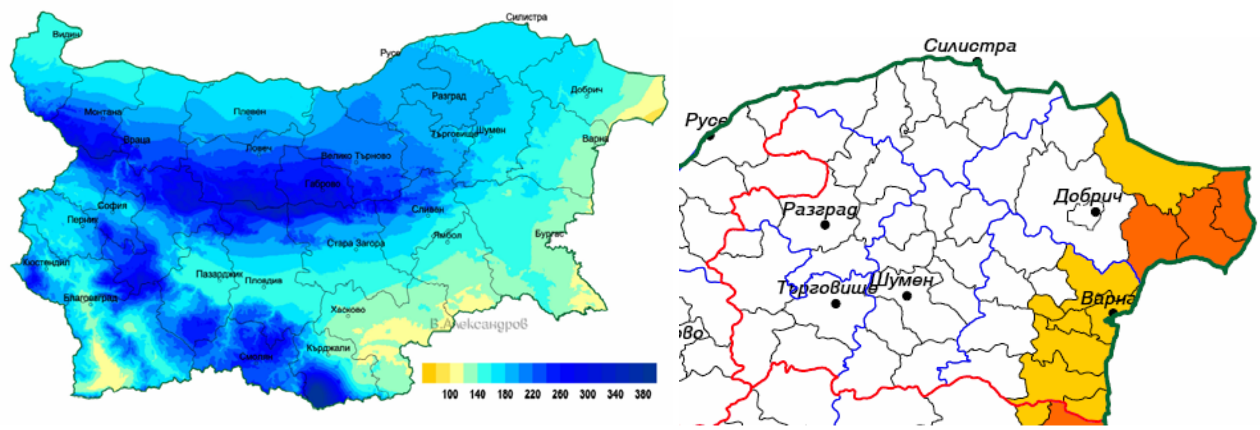


Fig. 26. Summer precipitation and drought risk in Northeast Bulgaria

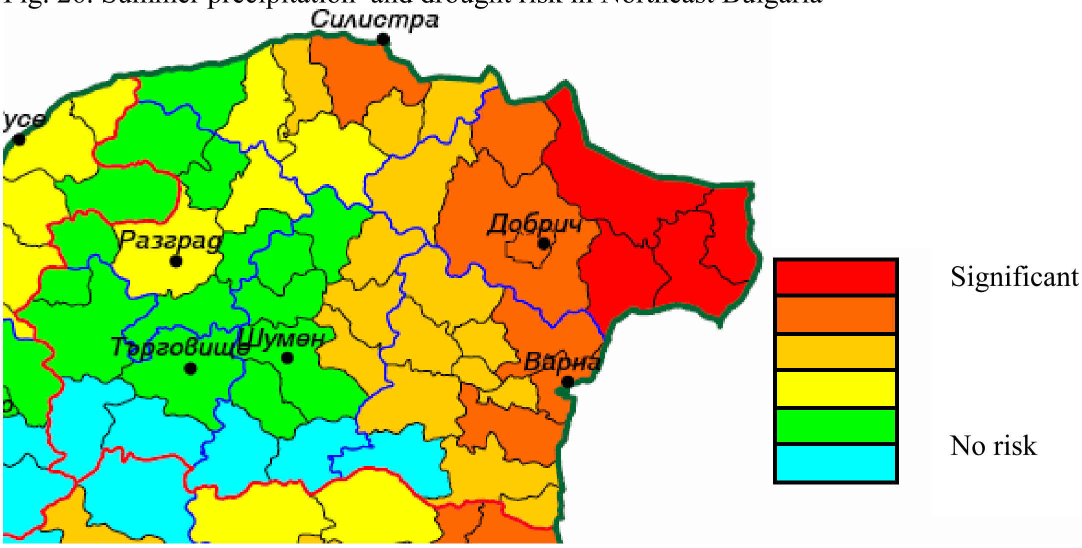


Fig. 27. Drought risk in Northeast Bulgaria related to atmospheric drought

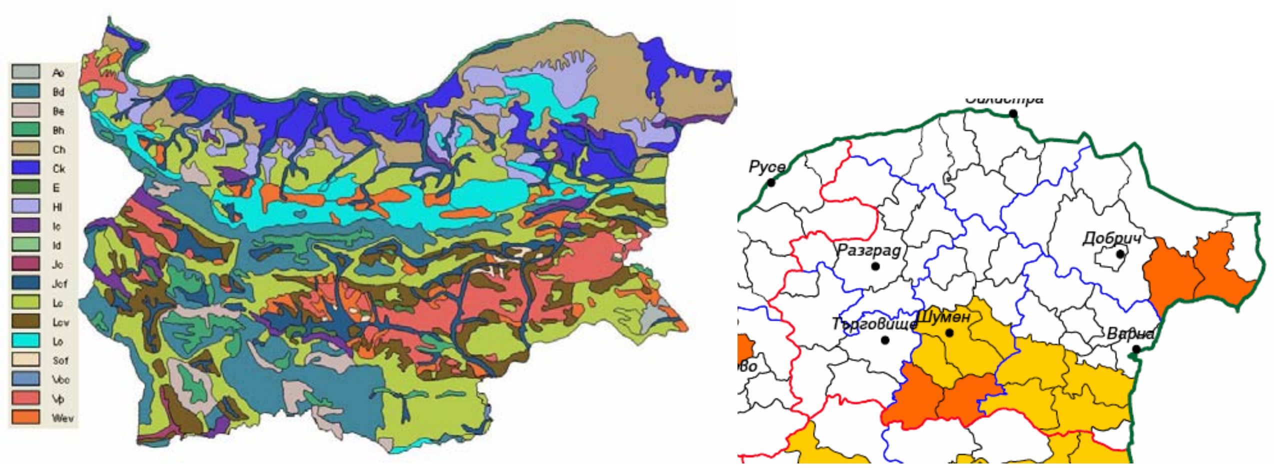


Fig. 28. FAO soil classification and drought risk in Northeast Bulgaria

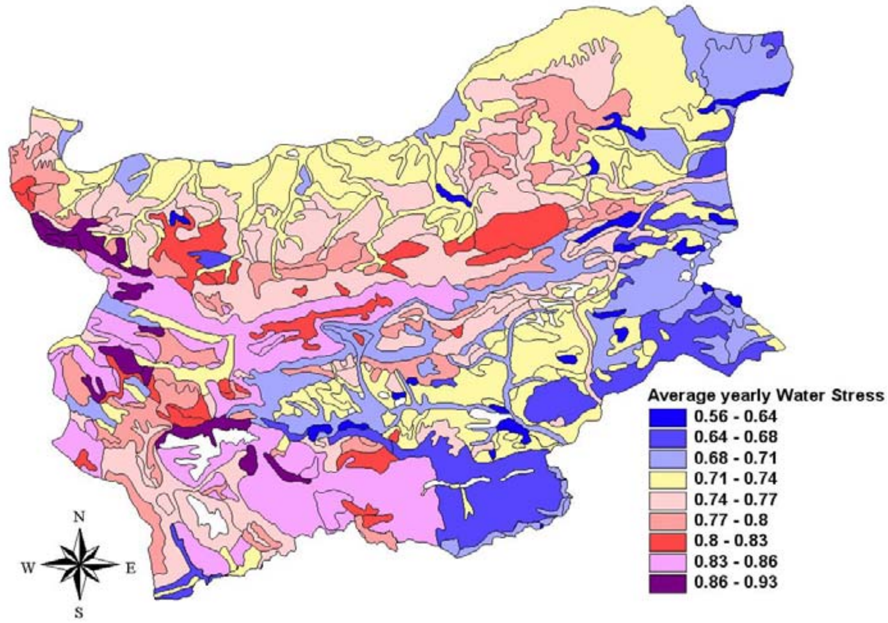


Fig. 29.The water stress as the ratio between actual and potential evapotranspiration

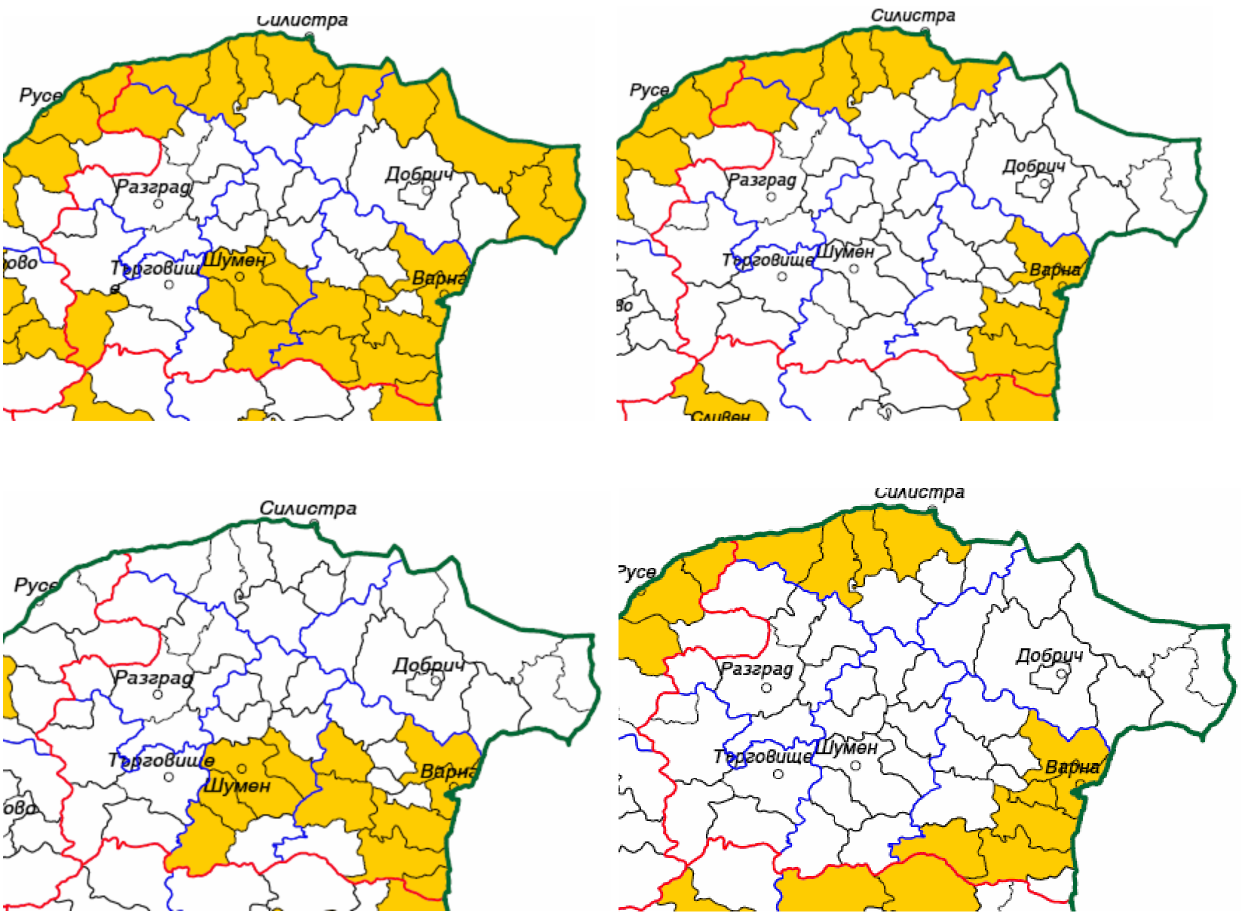


Fig. 30. Drought risk in Northeast Bulgaria related to soil moisture content at given crop stages

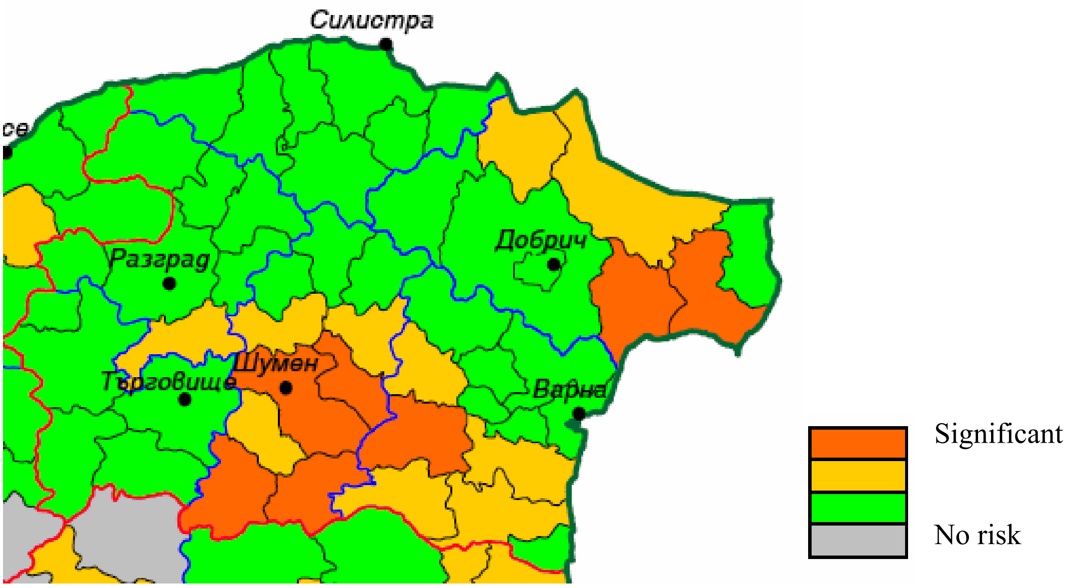
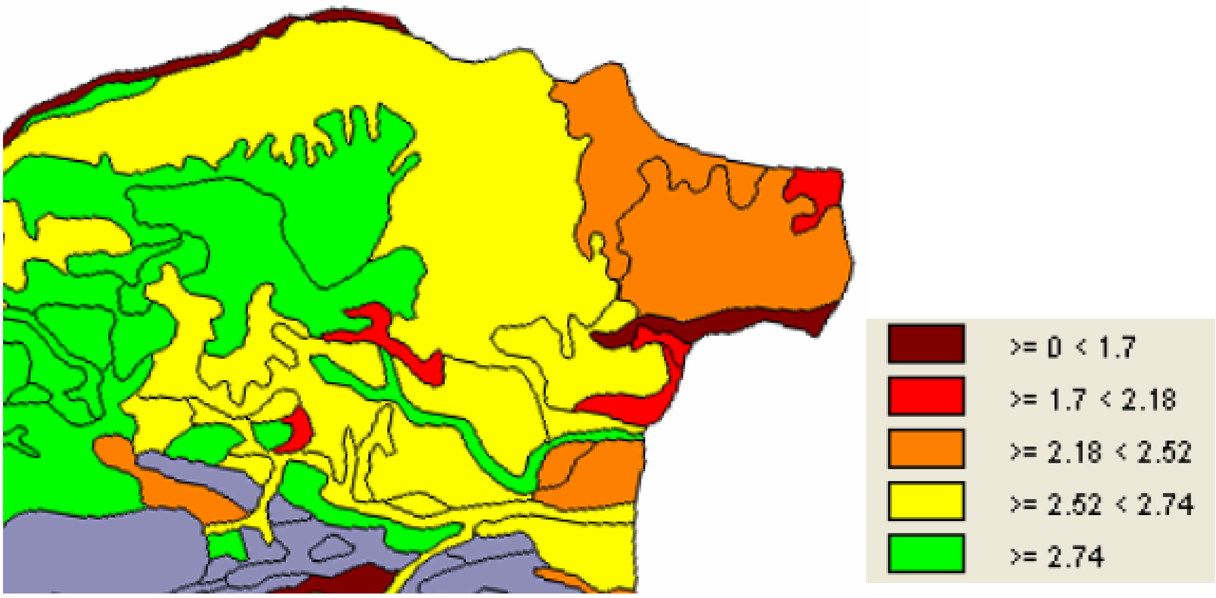


Fig. 31. Drought risk in Northeast Bulgaria related to soil drought

Due to the significant drought risk and occurrence in the eastern part of the selected region, the modeled maize and sunflower yield showed lower values at that part (Fig. 32).



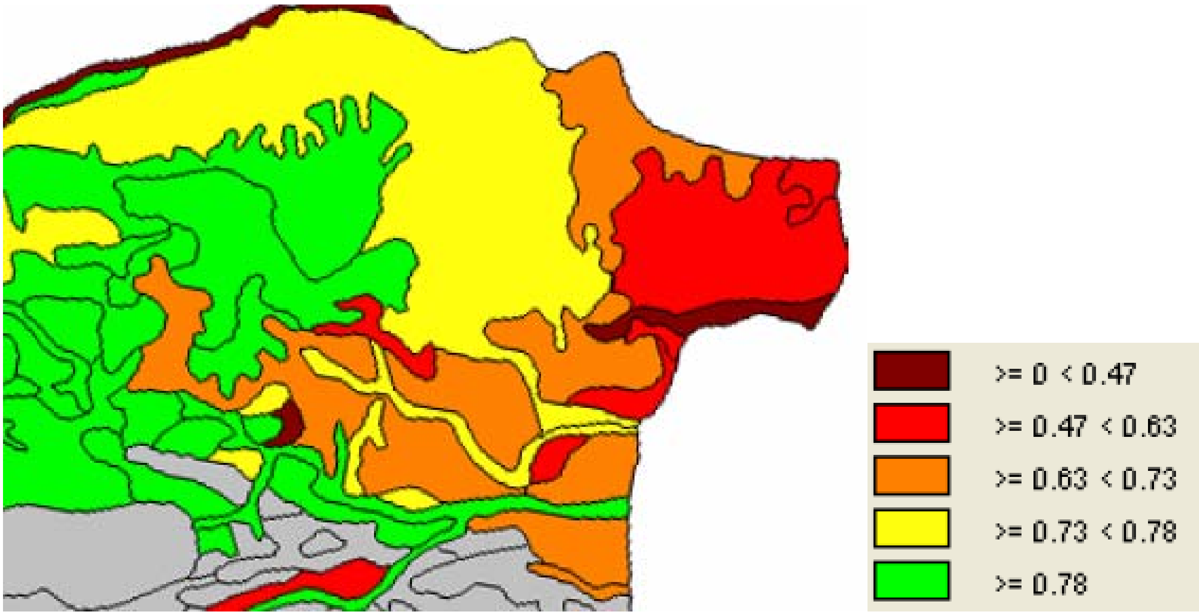
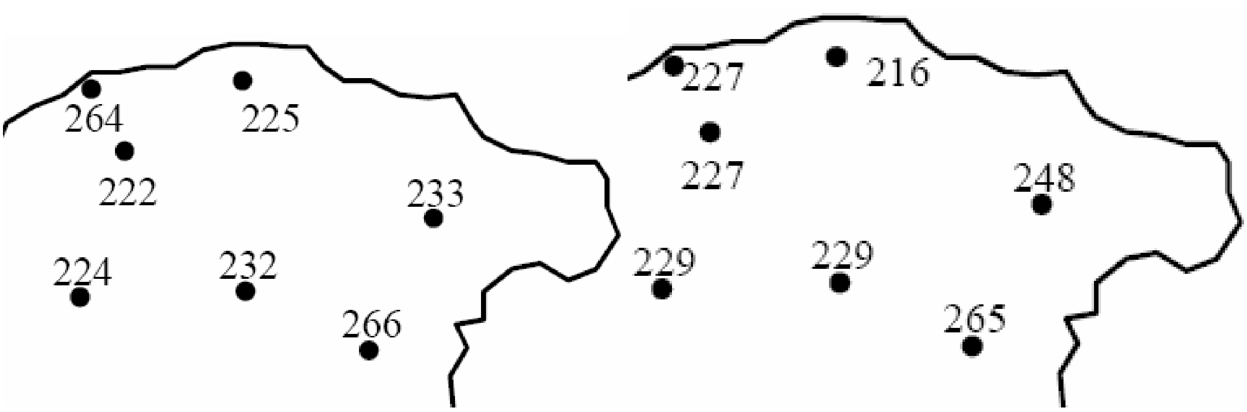


Fig. 32. Simulated maize (up) and sunflower (bottom) yield averaged for the current climate conditions (1991-2000)

Drought in the context of climate change

Maize water use

The DSSAT Seasonal Analysis program was used to simulate different components of the soil water balance during the crop-growing season of maize from 1961 to 1997. All parameters of the water balance were averaged for the 30-year period 1961-1990, still recommended by the World Meteorological Organization (WMO) as a “current” climate period. The results for the irrigation totals during the crop-growing season of maize for every experimental crop variety station in Bulgaria are presented in Figure 33. It is necessary to mention again that these results were obtained when the automatic irrigation option of the CERES maize model was selected for irrigation applications, so that water would not be a limiting factor in the simulation. The CERES model for maize was also run assuming that all experimental crop variety stations have the same soil profile. The maize-growing seasonal irrigation amounts for the period 1961-1990 under the soil profile “medium silty clay” are higher than the totals for the other two selected soil profiles (“medium silty loam” and “medium sandy loam”). The lowest irrigation total amounts during the crop-growing season of maize were simulated under “medium silty loam”.



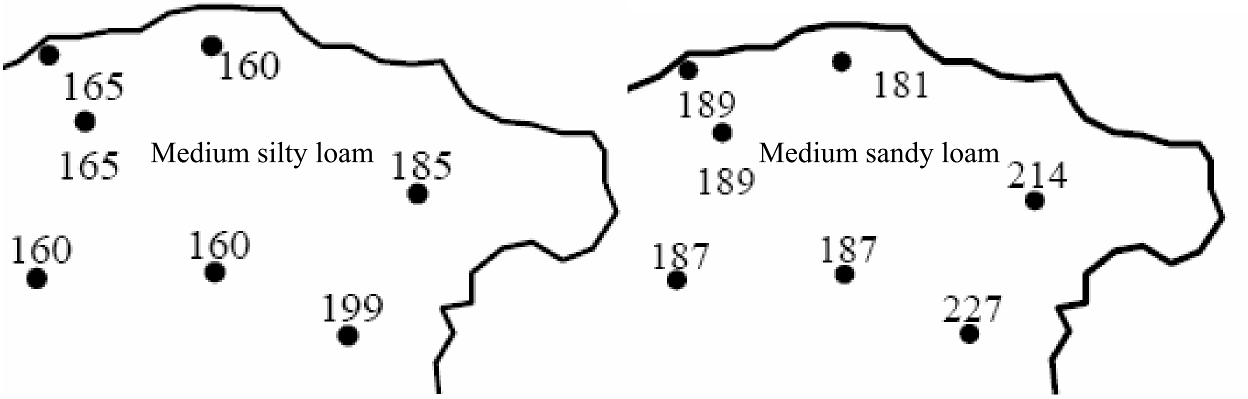


Fig. 33. Maize water use (irrigation totals, 1961-1990)

The anomalies of the water balance components during the maize-growing season were compared to the 1961-1990 normals (Fig. 34). There is an obvious increasing trend in the number of irrigation applications during the last two decades. Most of irrigation totals anomalies were also positive during the last considered years due to significant precipitation reductions across the country. Most of the seasonal surface runoff anomalies during the period 1961-1997 were negative because of some significant positive anomalies and especially lower precipitation in the 1980s and 1990s.

An irrigation strategy for maize – a case study

Historical weather data from 1961 to 1990 were again applied. The major goal was to determine the most appropriate timing and water amount of irrigation applications for every experimental crop variety station under current climate 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. An example for crop variety station Carev brod is given below. The tested treatments of the irrigation numerical experiment assumed maize growth and development under rainfed conditions, different date (or dates) and water amount of irrigation (Table 5).

Table 5. Description of the treatments examined

Treat-ment	Dates of irrigation	Water applied [mm]
1	rainfed	-
2	8.VIII	40
3	29.VI	40
4	29.VI, 14.VII	80
5	29.VI, 14.VII, 8.VIII	120
6	29.VI, 14.VII, 8.VIII	240

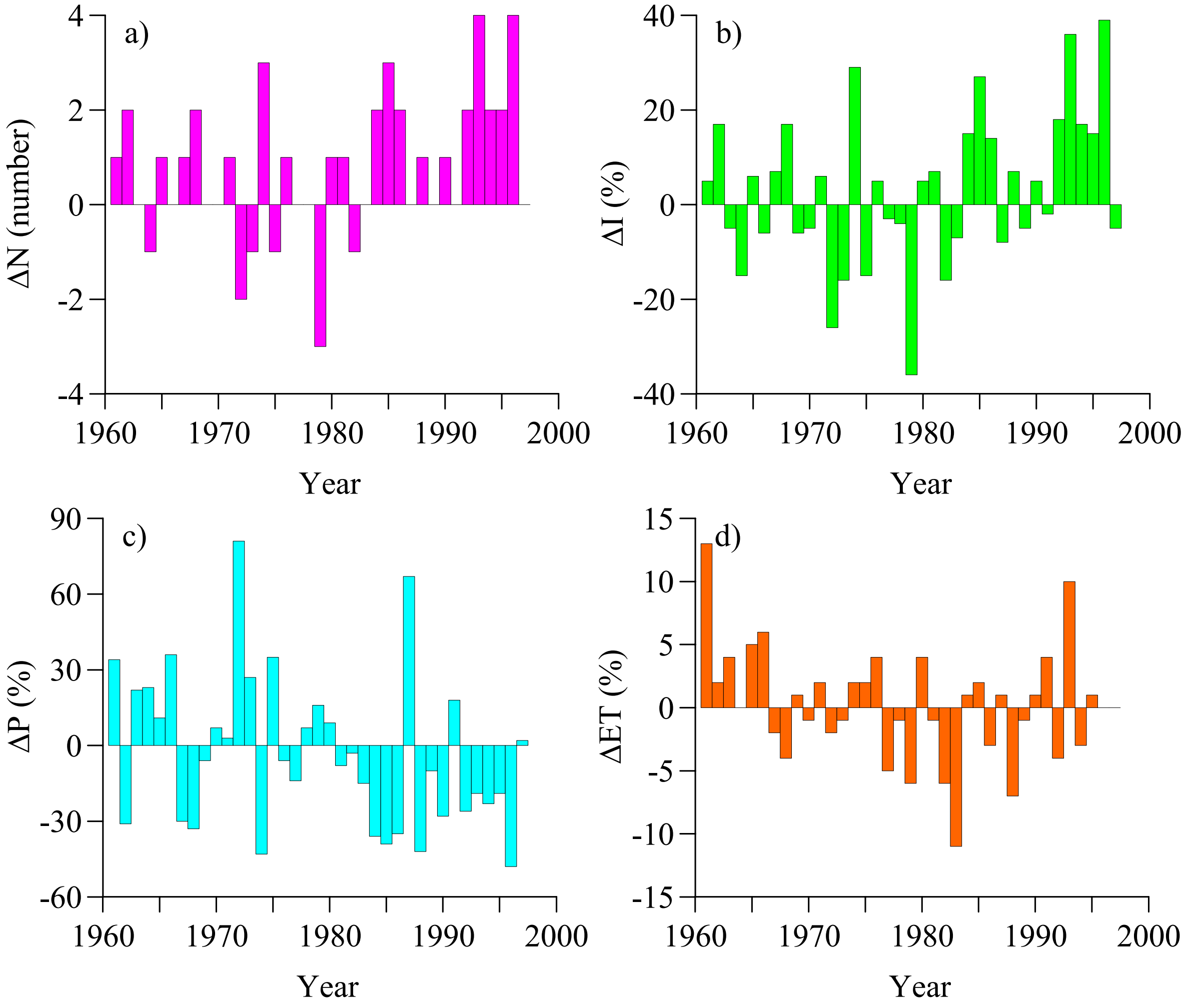


Fig. 34. Anomalies of maize-growing seasonal number of irrigation applications (a), irrigation total (b), precipitation (c), evapotranspiration (d) in Northeast Bulgaria, relative to the period 1961-1990.

Some statistics of the simulated harvest yield of maize calculated by means of the Seasonal Analysis program are presented in Figure 35. There is little to choose between treatments 5 and 6 in terms of their mean and variance.

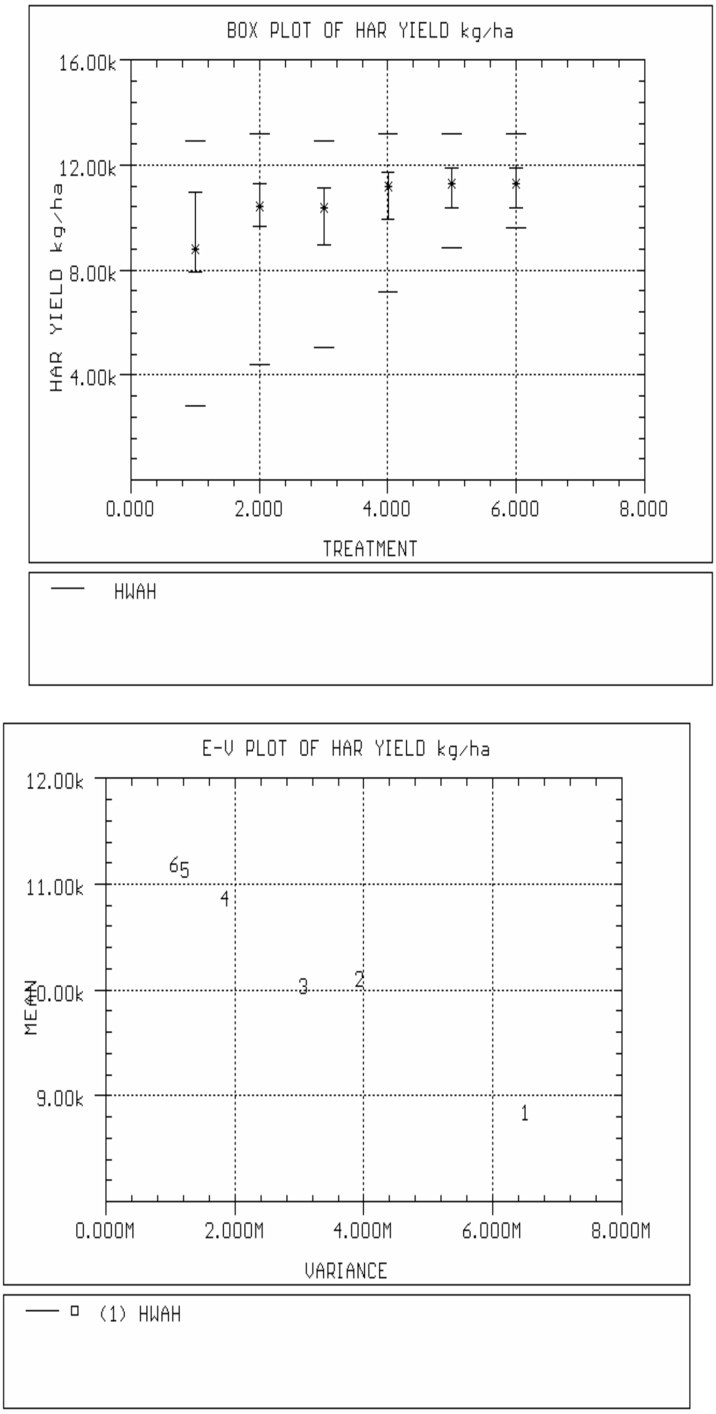


Fig. 35. Box (top) and mean-variance (bottom) plots of the simulated harvest yield (HWAH) of maize

Visually, these box plots are sometimes clearer than cumulative probability curves if there are many treatments. When a cumulative function plot is using, output variables by treatment are plotted as cumulative functions plots (Fig. 36). Here, the output distribution for each treatment is plotted against equal increments of cumulative probability. The strategy with a cumulative probability function (CPF) to the right is considered the "best". In this case, the 6th treatment concerning 3 times of irrigation and water amount of 80 mm per application could be considered as the most appropriate irrigation strategy. The 5th treatment assuming half amount of water applied (relative to the 6th treatment) is also a good approach for high maize yield under irrigation. Naturally, when growth, development and yield formation of maize had been simulated under rainfed conditions the calculated harvest yield was lowest and the relevant CPF was to the left (Fig. 30). Generally, using an irrigation application for a day or 2 times increased maize yield.

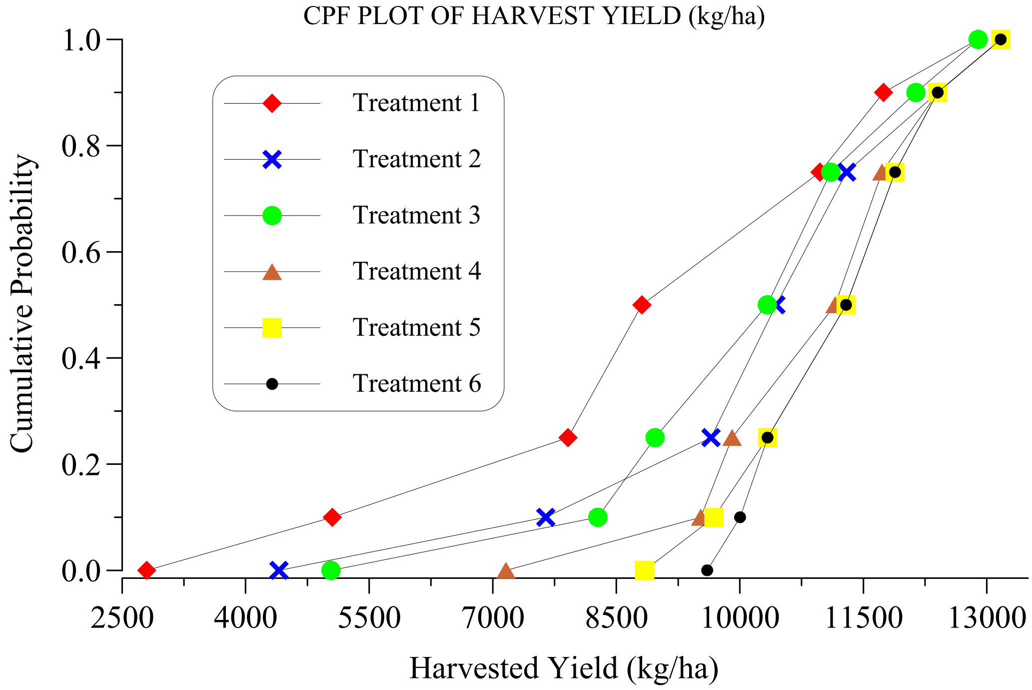


Fig. 36. Cumulative probability function plot of the simulated harvest maize yield

In a similar way, the economic analysis of the DSSAT 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 4^{th} and 5^{th} 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 (Table 6). The dominant treatment was the treatment assuming 5 - 40 mm water applied per every day (total 3 days) of irrigation.

Table 6. Strategy analysis determining the dominant numerical treatment examined

Treat- Ment	E(x)-G(x) [money/ha]	Efficient [Yes/No]
1	906.1	No
2	1111.4	No
3	1119.2	No
4	1236.5	No
5	1265.3	Yes
6	1219.3	No

Legend: E(x) - mean return; G(x) - Gini coefficient.

Water Balance Parameters under climate change

The Decision Support System for Agrotechnology Transfer DSSAT was also used to simulate the impact of climate change scenarios on maize growth, development and yield formation and the parameters of the water balance during the maize growing season (from sowing to maturity). The automatic irrigation option of the DSSAT CERES model was used. The altered temperature and precipitation databases corresponding to each of the climate change scenarios were used to run the DSSAT CERES-Maize simulation model.

On the first hand, total precipitation during the potential crop-growing season will increase due to projected increase of the duration of the potential crop-growing season caused by warming. On the second hand however, the total precipitation amount during the actual crop-growing season is projected to decrease due to the GCM simulated decrease of precipitation and because of shortening the actual crop-growing season caused also by expected warming. Figure 18 represents the projected decrease (in days) of the duration of maize growing season at the investigated experimental crop variety stations under the ECHAM4 climate change scenarios for the 2050s. It can be seen that in the middle of the 21st century the ECHAM model simulates a decrease of the above growing season between 2 weeks and a month.

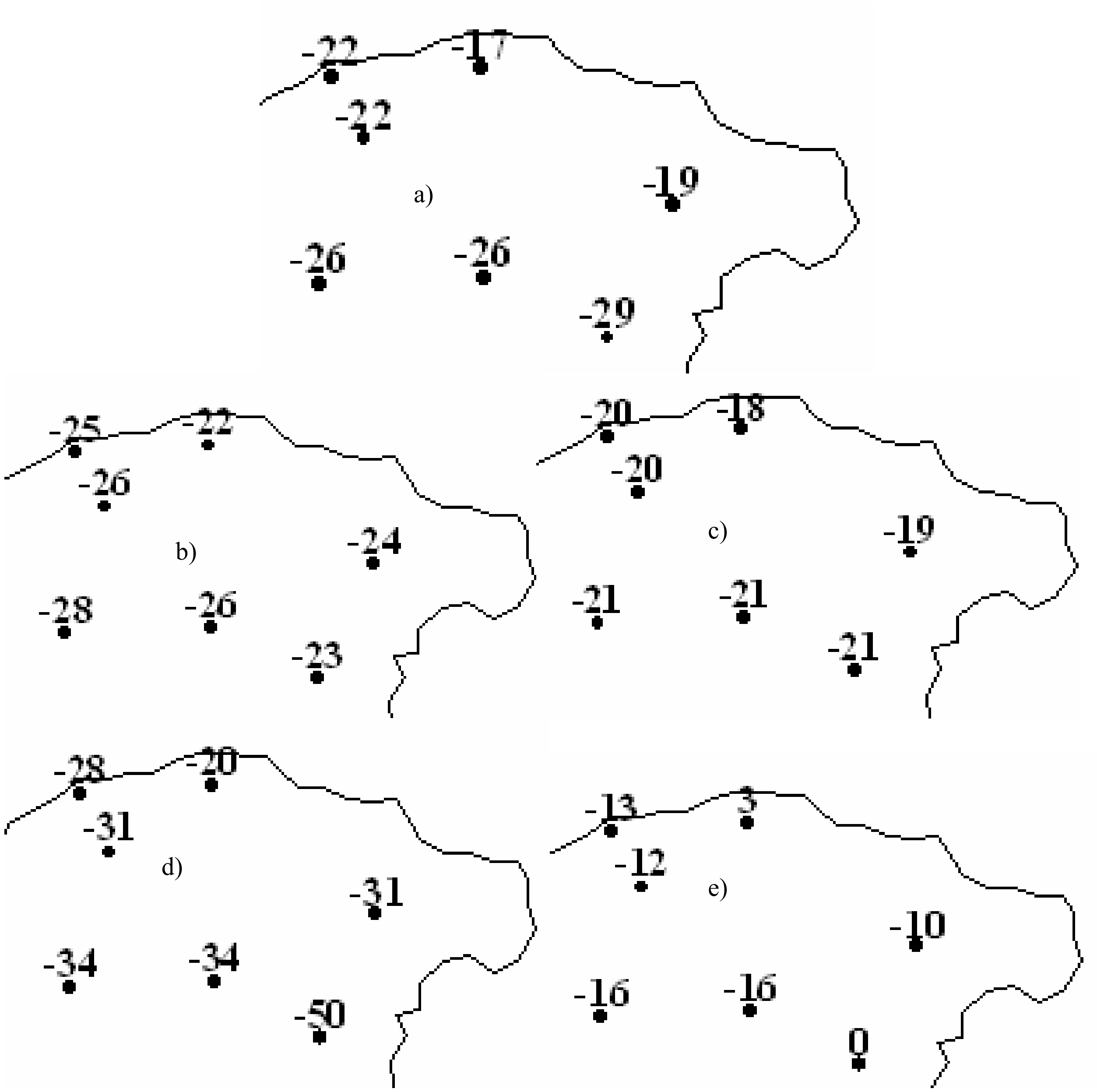


Fig. 37. Changes of the duration of maize growing season (a), irrigation (b), evapotranspiration (c), runoff (d) and drainage (e) under the ECHAM4 scenarios for the 2050s

The other parameters of the water balance such as seasonal evapotranspiration, runoff, drainage and soil moisture at maturity were also simulated under expected climate change (Fig. 37). As a result of the irrigation decreasing and shortening of the growing season, seasonal evapotranspiration is also expecting to decrease at the 2050s up to about 20 %.

The DSSAT Seasonal Analysis program was again 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 tested treatments of the irrigated numerical experiment were the same like these in Table 5. Some statistics of the simulated harvest yield of maize calculated by means of the Seasonal Analysis program under the HadcM3 climate change scenario are presented in Table 8.

In the same way, the economic analysis of the Seasonal Analysis computer program calculated means, standard deviations, maximum and minimum of the economic returns, and plots these as box plots, cumulative function plots, or mean-variance diagrams. 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. These results were obtained using the relevant plots in Fig. 38 and 39. According to the Seasonal Analysis program the Gini dominant treatment was again the 5th treatment (40 mm water applied per every day of irrigation).

Table 8 Simulated harvest yield of maize in Carev brod under HadcM3 climate.

Treat-ment	Mean [kg/ha]	St.Dev. [kg]	Min [kg/ha]	Max [kg/ha]
1	7107	1768	3356	9735
2	7876	1278	5059	10286
3	7967	1268	5194	10136
4	8494	943	6403	10525
5	8683	766	7081	10525
6	8794	738	7301	10525

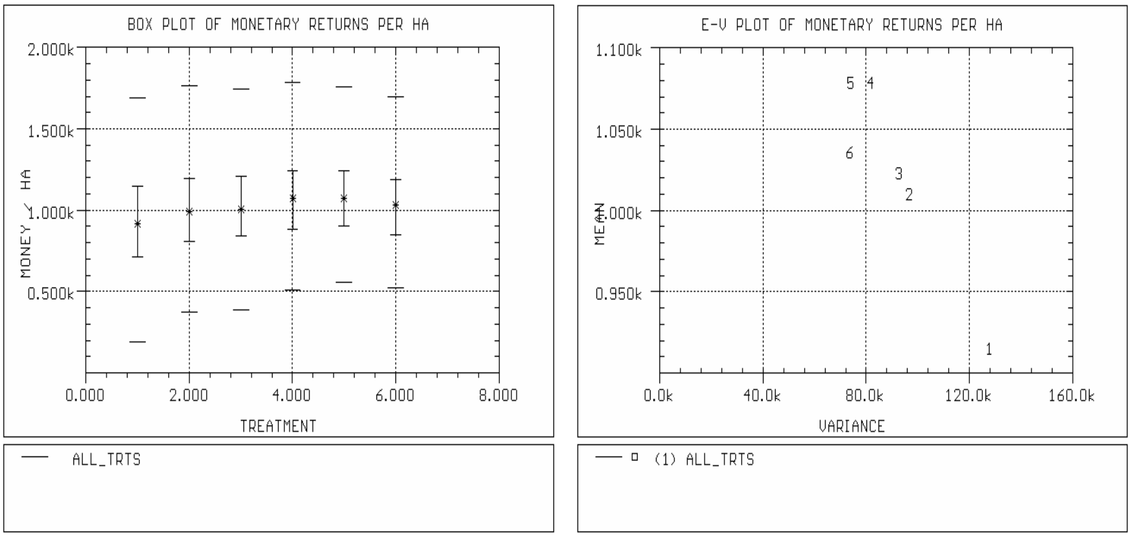


Fig. 38 Box (left) and mean-variance plot of monetary returns per hectare under HadcM3 climate.

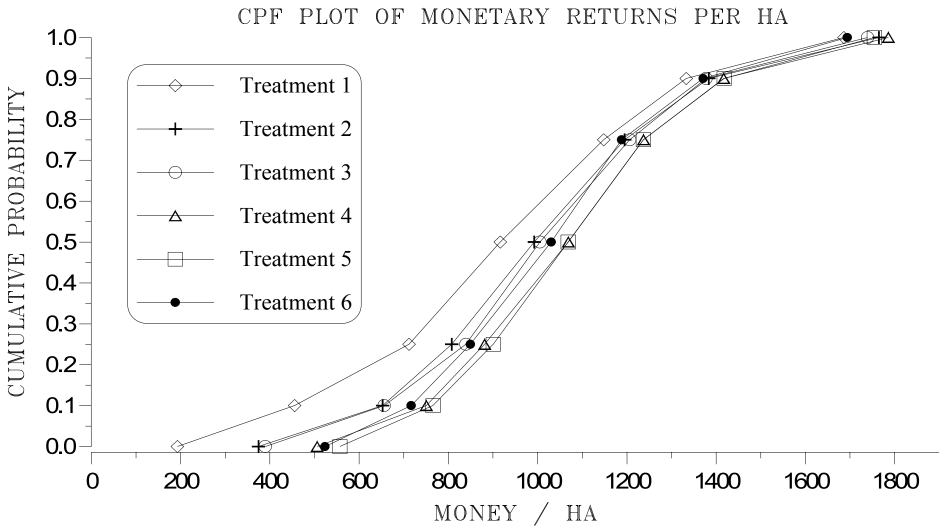


Fig. 39. Cumulative probability function plot of monetary returns per hectare under HadcM3 climate.

Summary

The DSSAT could be used by individual farmers, governmental or private organizations to determine an irrigation strategy for particular soil and climatic conditions in North Bulgaria. The DSSAT could be also used by researchers to determine an irrigation strategy for maize crop under expected climate change in Bulgaria.

One should be careful in interpreting the DSSAT strategy evaluation outputs, as the assumptions may not always be valid. They are, however, a useful tool for helping decision-makers to "pre-screen" a wide variety of options and identifying those options or treatments that merit further investigation. Further analyses outside the confines of the DSSAT will always be required before much can be said about the feasibility of particular situation.

Romania (NMA) VULNERABILITY TO DROUGHT OF ROMANIAN AGRICULTURAL REGIONS AND IMPACT ON CROP PRODUCTION – PRESENT CONDITIONS AND PERSPECTIVES IN THE CONTEXT OF CLIMATE CHANGE

Introduction

Accurate diagnose of agro-meteorological conditions is a crucial process needed for understanding the risks caused by extreme weather events and for decision making and sustainable development actions. Drought periods and heat waves are of particular interest, the main agricultural crops in Romania, winter wheat and maize, being considerably affected by the occurrence of these two phenomena. In addition, high vulnerability of large agricultural areas to drought and desertification in the context of climate change is a constant concern of scientists and decision makers. Due to different crop water requirements and initial soil water storage at the beginning of the growing season, it is not sufficient to look at the precipitation amount only. The dynamics of soil water balance is specific to each agricultural field and crop, due to differences in precipitation, evapo-transpiration, and soil water retention capacity. In the recent years, the intensity, duration and effects of drought phenomenon were increased, showing already the potential effects of a changing climate.

According to United Nations Convention to Combat Desertification, **drought** is defined as *"*the naturally occurring phenomenon that exist when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems".

Mitigating the effects of drought means activities related to the prediction of drought and intended to reduce the vulnerability of society and natural systems to drought as it relates to combating desertification.

Drought can be expressed in terms of:

- **intensity** – extreme, severe, moderate
- **duration** or **persistence** – months, years
- **spatial extent** – local, sub-regional and regional level
- **frequency** – number of months and years for a given period

The negative effects of meteorological extreme events on crop production require specific monitoring and modeling methods in order to forecast the evolution of risk factors. Spatial variability of weather, climate, and soil across a region or sub-region, limit the correct assessment of natural phenomena impact on agriculture. Moreover, as climate is changing, the interactions between weather and agricultural crops become more complex. It is yet unknown how will be affected/changed the periods with maximum crop water requirements compared with the periods of most abundant precipitation during the growing season, how phenological phases of each crop will be "shifted" or modified in duration, or how much the length of growing season will be affected by the climatic changes. In particular, it is still unclear how dramatic will be the change in yield production, due to the combined effects of climatic changes and increase in atmospheric CO_2 concentration.

Regional and local conditions

In Romania, forty-eight percent of the arable area is affected by drought, the south-eastern and eastern parts of the country being the most affected areas. The drought phenomenon, although without a strict cyclical character, generally shows repeatability at 15-25 years intervals. Within such cycles there are extremely dry years, but also short term interruptions of about 1-3 years with rainfalls above the normal amounts. These interruptions do not modify the general features of the droughty period from the point of view of the severe climate characteristics, as well as of the water resources in the soil and in the groundwater and in the surface and hydro-graphic network. Average yields of various crops in droughty cycles are only 35-60 percent of the potential yields.

The drought phenomenon on Romanian territory is specific characteristic related to the continental influences of the temperature climate, with rather large deviations from one year to another as compared with the normal values of climatic, agro-climatic and hydrological parameters (Vranceanu et al., 1998). In the south and south-eastern area of Romania, where CECILIA target area is located, the complex agricultural drought is a climatic hazard phenomenon inducing the worst consequences ever occurred in agriculture. The intensity, duration, frequency and persistence-related characteristics record maximum values especially in the southern part of the Romanian Plain and Dobrogea, the extreme droughts prevailing (30,0%- 35,0%) followed by the droughty cases (15,0%-25,0%) and moderate droughty (15,0% -20,0%) in the sowing-springing period of the winter crops/ IX-X, and in the hoeing crops critical period / VII-VIII, the cases recording above normal values, varying between 40,0% and 60,0% at the level of the southern area of the Romanian Plain, reaching even 70,0% in the south of Dobrogea, followed by those droughty and moderate droughty, 20,0%-30,0%.

Drought periods and heat waves are of particular interest, the main agricultural crops in Romania, winter wheat and maize, being considerably affected by the occurrence of these two phenomena. Due to different crop water requirements and initial soil water storage at the beginning of the growing season, it is not sufficient to look at the precipitation amount only. The dynamics of soil water balance is specific to each agricultural field and crop, due to differences in precipitation, evapotranspiration, and soil water retention capacity.

Drought in the context of climate change

Precipitation and soil water content

First, we consider the amount of precipitation cumulated during the agricultural year (September-August) and during the intervals with maximum plant water requirement (May and June for winter wheat and July and August for maize). It is important to note that while reduced amounts of precipitation indicate a limitation to the crop development, a normal or above normal sum of precipitation doesn't necessarily guarantee the normal crop evolution, the risk of drought occurrence being still high if other meteorological parameters are increasing the water use of plants. High temperatures, especially the prolonged and intense heat waves may change dramatically the soil water balance by increasing the evapotranspiration thus reducing the soil available water and favoring the apparition of pedological drought. In addition, heat waves produce thermal stress to plants even if water is not limited.

The yearly precipitation amount for agricultural years was **extremely low in 1999-2000**, **low** in **2000-2001**, **2001-2002**, and **2002-2003**, (Fig. 40). Mapping of total precipitation amounts during agricultural years 1999 to 2003, presented in Fig. 1, shows that most of the country areas were in deficit, and only few and limited regions of no interest for agriculture were relatively wet. The absolute extremes of yearly precipitation regime were recorded during the years 1999-2000 and 2002-2003, which were extremely dry years:

- 1999-2000 / **minimum** precipitation amount / **163,3 mm / Sulina**
- 2002-2003 / **minimum** precipitation amount / **260,0 mm / Harsova**

During the extremely droughty year 1999-2000 record low precipitation amounts resulted in one of the most severe and prolonged drought of the last century. Precipitation deficits as high as 74% produced calamity of the crops on large cultivated surfaces, or extremely low yields – below 700 kg per hectare for maize. Where the winter wheat crops were in irrigated regime, the average yield was 2800 kg per hectare, about a third from the yield potential of the cultivated maize variety. This shows that even when water is no longer a limiting factor (in irrigated fields) thermal stress of the plants during heat waves determine low quality and quantity crop yields.

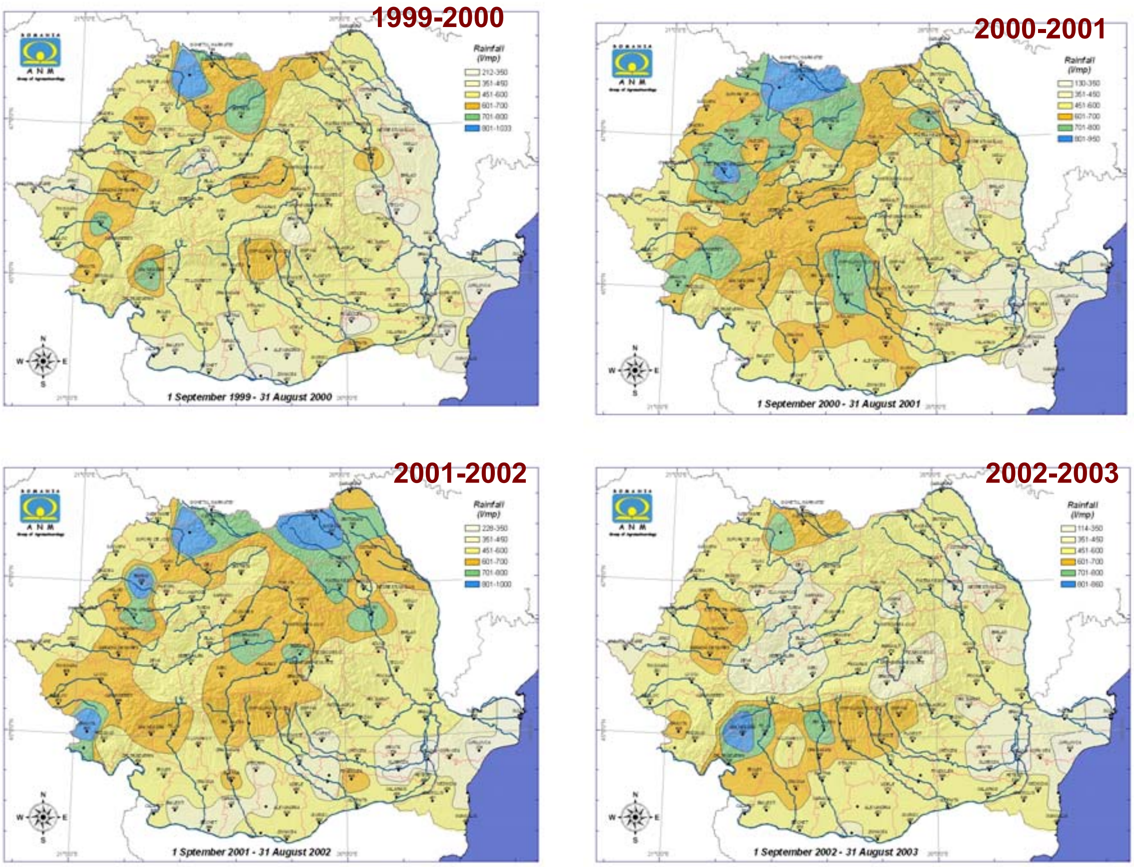


Fig. 40. Zoning of the annual precipitation in the period 1999-2003 / 4 consecutive droughty agricultural years

The precipitation regime during the agricultural year 2002-2003 also showed large deficits compared to the multi-annual average during the critical period of agricultural crops development (June-August). Extreme pedological drought progressively diminished crop quality and quantity affecting the vegetation stage. For winter wheat, production per hectare was only 800-1700 kg, and for maize 400-3300 kg, while in Dobrogea, the crops were completely destroyed.

Soil water available for winter wheat plants at the end of May, a critical period in crop development is presented in the dynamics of the 4 consecutive years analyzed in Fig. 41.

The precipitation deficits of extremely droughty years 2000 and 2003 culminated during the most important season for crop development (May-June) when plant water requirement was the highest, with disastrous effects for both winter wheat and maize in the non-irrigated fields. The spatial extents to most of Romanian territory of extremely low precipitation amounts during May-June interval of 2000 and 2003 are presented in Fig. 42a and Fig. 42d. In such conditions, corroborated with high water consumption during the whole season, soil water reserve was often down to the wilting point in large agricultural areas, for both winter wheat crop (Fig. 42b) and maize crop (Fig. 42c). High evapotranspiration rates during May 2003 resulted in extreme low water content in the soil in winter wheat cultivated soil at the end of the month (Fig. 42e), the wheat being harvested the following month. Similarly, maize crop high water consumption during June-August interval depleted the soil water reserves to extreme pedological drought conditions, extremely in South-East and West of the country (Fig. 42f).

Soil water balance is directly affected by the crop water requirement through evapotranspiration, which is dependent mainly on temperature and stage of vegetation. Crop water requirements depend on local weather conditions, soil and plants' characteristics and plant stage of growth. Agricultural or pedological drought occurs when root-zone soil moisture is insufficient to sustain crops between rainfall events.

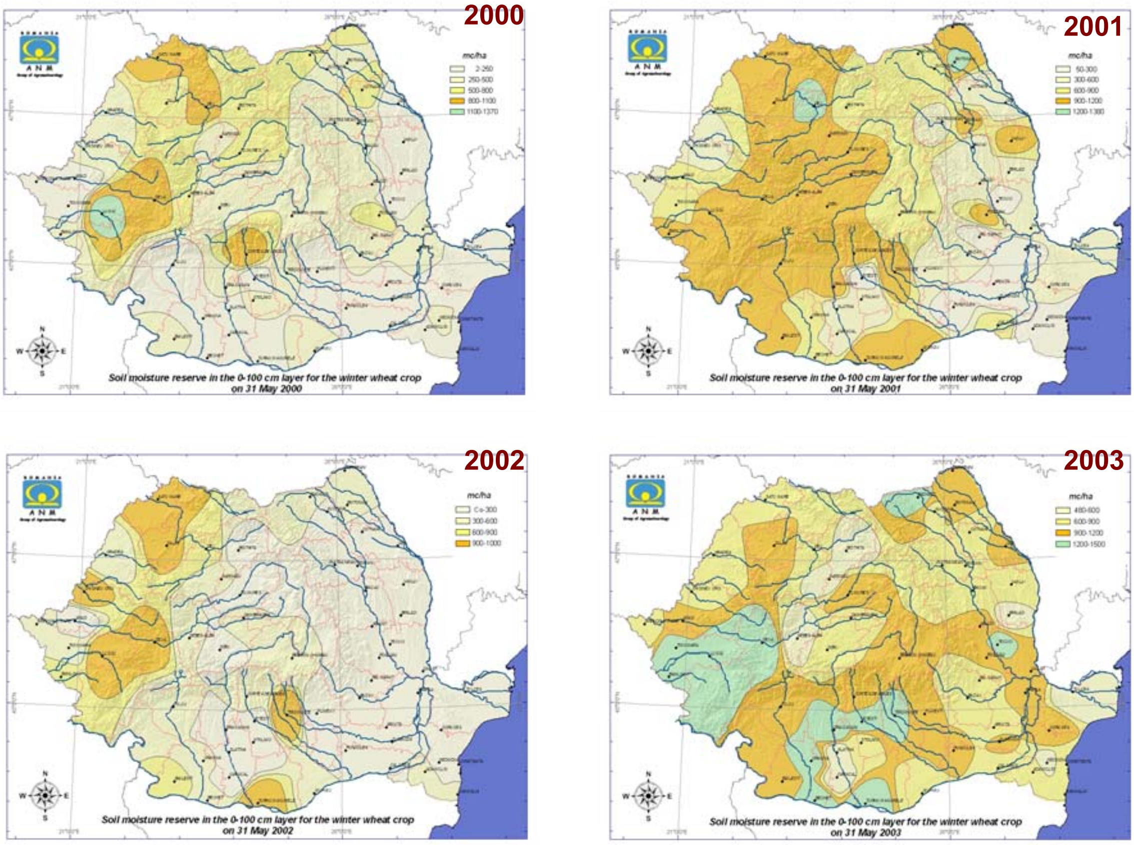


Fig. 41 Zoning of plant available soil moisture (m^3/ha) for the winter wheat crop/May

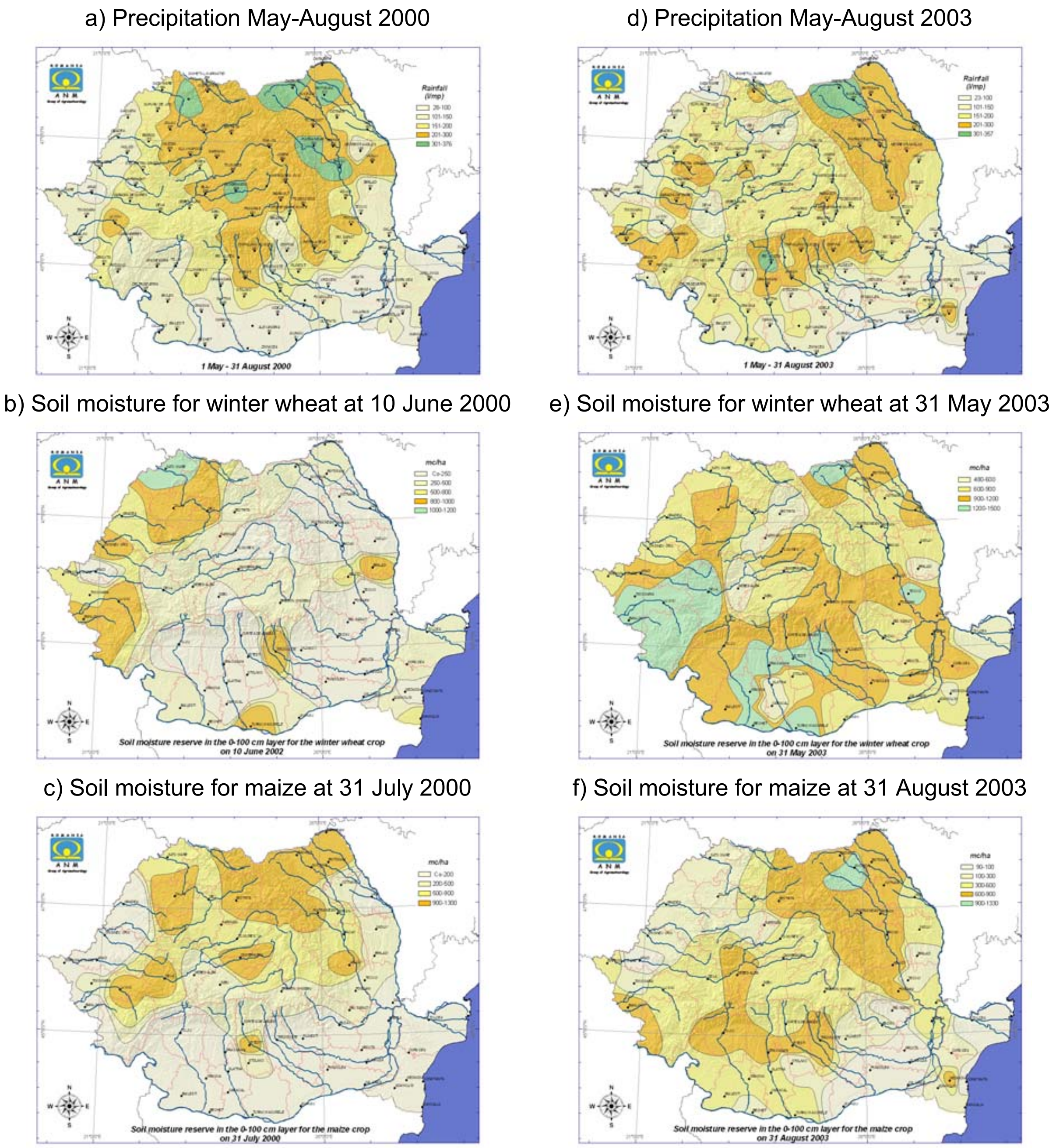


Fig. 42: Sum of precipitation amounts for May-August interval and soil water reserves at critical dates for crop development for winter wheat and maize, during the extremely droughty years 2000 and 2003

Temperature regime and heat waves

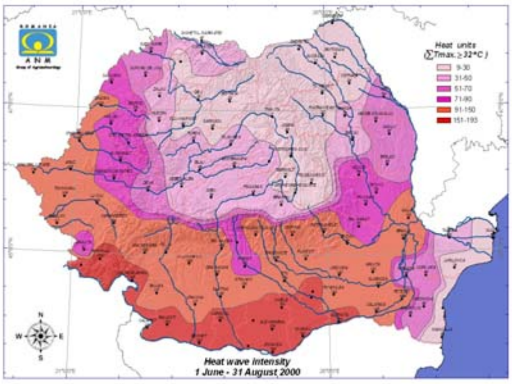
During the summer of 2000, extreme thermal stress conditions were recorded, with no less than 193,0 heat units in a total number of 48 days in the south of the country, at Bechet – the maximum value for intensity and duration of the heat wave. For the 2000-2004 period, the maximum values for heat waves intensity and duration recorded during summer are presented in Table 9.

Station	"Heat" units				"Heat"duration			
	2000	2001	2002	2003	2000	2001	2002	2003
Buzau	97.4	56	55.2	37.9	37	-	20	23
Calarasi	145.4	103	62.6	74.6	45	-	26	33
Braila	105.2	90	58.8	36.9	37	-	27	18
Ramnicu Sarat	77.6	46	54.7	29.0	31	-	19	17
Pitesti	77.9	7	27.6	26.2	29	-	15	17
Ploiesti	118.2	42	39.0	43.7	40	-	17	21
Giurgiu	191.2	90	76.4	117.3	46	-	31	49
Turnu Magurele	187.6	99	60.2	111.6	47	-	27	47

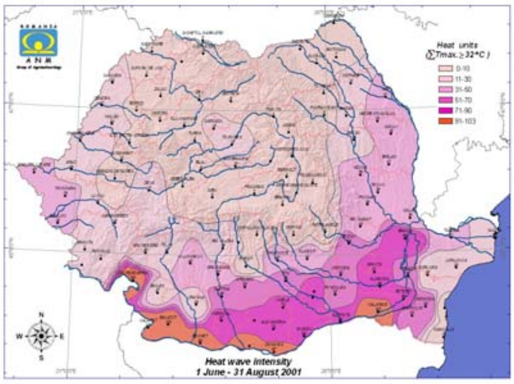
Table 9. Values for "heat intensity" and duration during 2000-2003 agricultural years, at stations from CECILIA target area.

The spatial extent of heat intensity according to total number of heat units recorded, is showed in Fig. 43. Generally, the South, South-East, and South-West regions of the country are affected by heat, but during the extreme year 2000, both the intensity and the spatial extent of very intense heat were much larger than in other years, with more than half of the country affected by heat waves cumulating over 50 units.

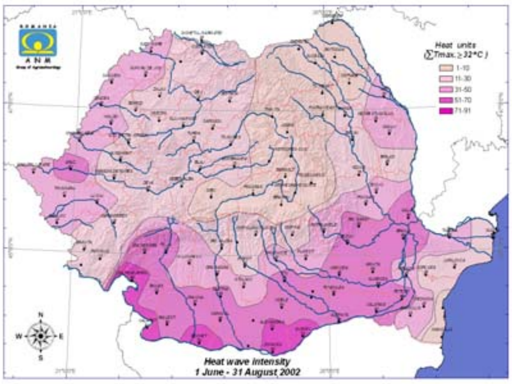
2000



2001



2002



2003

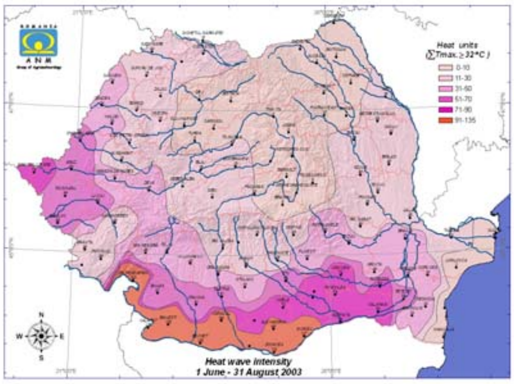


Fig. 43: Heat wave intensity during summer season of years 2000-2003.

Phenology and crop production

Heat and water stress combined, result in forcing of crop phenological phases, reducing the length of the growing season (number of days from sowing to harvest). This has a negative impact on quality and quantity of crop production. Available data of growing season length and yield production of winter wheat during the extreme years 1999-2003 is presented in table 10.

Station	Average length of the growing season	Length of growing season during droughty years	Yield (kg/hectare)
Calarasi	**270**	1999-2000 / 252 days	4250
		2000-2001 / 259 days	3200
		2001-2002 / 265 days	4500
		2002-2003 / 258 days	2600
Buzau	**277**	2000-2001 / 259 days	N/A
		2001-2002 / 269 days	3374
		2002-2003 / 257 days	1975
		2003-2004 / 256 days	N/A
Pitesti	**277**	1999-2000 / 264 days	3700
		2000-2001 / 247 days	3000
Turnu Magurele	**266**	2001-2002 / 254 days	4820
		2002-2003 / 252 days	2000
Giurgiu	**270**	2002-2003 / 256 days	2400
		2003-2004 / 261 days	2000
Braila	**274**	2000-2001 / 261 days	4110
		2001-2002 / 249 days	4000
		2002-2003 / 228 days	2800
		2003-2004 / 265 days	1250
Slobozia	**270**	2000-2001 / 247 days	3850
		2002-2003 / 228 days	850

Table 10. Length of growing season and yield, during 2000-2003 agricultural years, at stations from CECILIA target area, compared to the multi-annual average.

The degree of favorability for agricultural species of each agricultural year from 2000 to 2004 is described below, with focus on the most important crops in Romania, winter wheat and maize, respectively:

- 2000 / extremely droughty year, unfavorable for winter wheat and maize crops in almost of the cultivated surface, especially in the South and South-East of the country, where the combined effect of thermal and water stress determined complete loss of the production;
- 2001 / favorable for winter wheat crop in most of the agricultural regions, except Dobrogea, while for maize the year was not favorable in the South and East of the country, due to extreme pedological drought;
- 2002 / droughty year, unfavorable for winter wheat in most of the country and for maize in South and South-East;
- 2003 / extremely droughty year, with high water stress for plants; in most agricultural regions of the country, the conditions were unfavorable for both crops, winter wheat and maize.

Summary

Agricultural crops are exposed to risk from extreme meteorological events each agricultural year. The impact of severe weather phenomena varies with plant species and agricultural region geo-climatic characteristics and is directly related to the intensity, duration, and cumulative effects of the threats.

Extremely droughty years like 2000 may result in complete calamity of the crops if no mitigation actions are taken. Even in irrigated areas, crop yields are low in quantity and quality due to thermal stress that generally occurs in dry hot years.

During 2003, winter wheat and maize crops were highly affected by extreme pedological drought prolonged over the entire May-August interval, when water requirement of plants is highest.

Climate change has a major impact in agriculture by affecting the quantity and quality of yields and altering the soil water balance, plant water requirements, and length of vegetation period. However, the combined effects of changes in temperature and precipitation regimes in different climate change scenarios are not yet well understood, thus additional work is required for impact assessment at regional level. Down-scaling the predictions of Global Circulation models (GCM) and taking into account the local conditions of the area of interest will improve the accuracy of crop yield estimations in the new conditions of climate change.

Slovakia (FRI)

Introduction

Nowadays more than ever production of food depends on reasonable usage of natural resources. Today climatic conditions become the most important factor influencing variability of field crop yields in Slovakia.

During last century increase of annual air temperature by about 1°C was occurred on most of climatic stations in Slovakia. On the other hand annual precipitations decreased by about 10 % in conditions of Danubian and East-Slovakian lowlands. Precipitation totals varied also in mountainous regions, but no significant trend was found during last century. Temperature rise and shortage of precipitations influence also conditions for drought occurrence especially on lowlands of Slovakia. Droughts significantly reduced yields of field crops during last decade of years in Slovak republic several times (1992, 1995, 2000, 2002). Determining of reasonable growing strategy in condition of climate change can help to reduce lost on yields of field crops and have significant social economic effect.

Evapotranspiration as an important compound of water balance is frequently used for evaluation of drought conditions in Slovakia. Spatial distribution of potential evapotranspiration can define water need of ecosystems (Tomlain, 1997), actual evapotranspiration was correlated to yield of some field crops (Huzulák, Matejka, 1985, Vidovič, Novák, 1985).

Difference between potential evapotranspiration and precipitation totals during growing season was defined as climatic index of drought in condition of Slovak republic (Kurpelová, Coufal, Čulík, 1975, Tomlain, 1997). This index was also used for agro-climatic regionalization of Slovak republic in period of years 1961-1990.

During last decades of 20th century there was recorded the most significant increase of air temperature as well as changes in precipitation distribution in Slovakia (Lapin et al., 2001). Consequently the conditions for drought occurrence changed too. Therefore new spatial distributions of potential and actual evapotranspirations were recalculated.

Energy and water sufficiency (balance) were evaluated for growing seasons limited by daily mean air temperatures T>5,0 °C – *GS5* and T>10,0 °C – *GS10*). Defined growing seasons were charecterized by daily mean air temperature sums (*TS* in °C), precipitation totals (*R* in mm), potential evapotranspiration (E_0 in mm), actual evapotranspiration (*E* in mm) and climatic index of drought (E_0-*R* in mm). Potential of changing climate impact on plant production was evaluated according to meteorological data from years 1961 – 1990 and climate change scenarios CCCM20 (Lapin, 2001). Climatic data from database of SHMI in Bratislava were used in this report.

New actual agro-climatic regionalization (based on data from years 1961-1990) is proposed in the report. Effective adaptive measures to reduce lost on plant production in condition of climate change are analyzed too.

Regional and/or local conditions

Regional conditions of Slovak republic are influenced first of all by altitudinal profile of Slovakia. Temperature and water balance conditions are given in table 11.

Actual agro-climatic regionalization is evaluated according to meteorological data from years 1961-1990. Spatial distribution is given on fig. 44. Classification of macro regions and regions are the same as in work Kurpelová, et al. (1975). This classification is useful also from the point of view of defining of traditional agricultural production zones. Warm macro region cover conditions of maize and sugar beet agro regions, moderately warm macro region fit to potato agro region and cold macro region to mountainous production agro region.

Some details on present climate are given in next part, where comparison in context of climate change is given.

	Macro region	Region	*TS10*	*Eo-R*
1	Cold	-	< 2000	< 0
2	Moderately warm	-	2000 – 2400	0 – 50
3	Warm	Wet	2400 -2600	50 – 100
4		Wet – normal	2600 – 2800	100 – 150
5		Dominantly dry	2800 – 3000	150 – 200
6		Dry	> 3000	> 200

Table 11 Agro climatic regions of Slovak republic

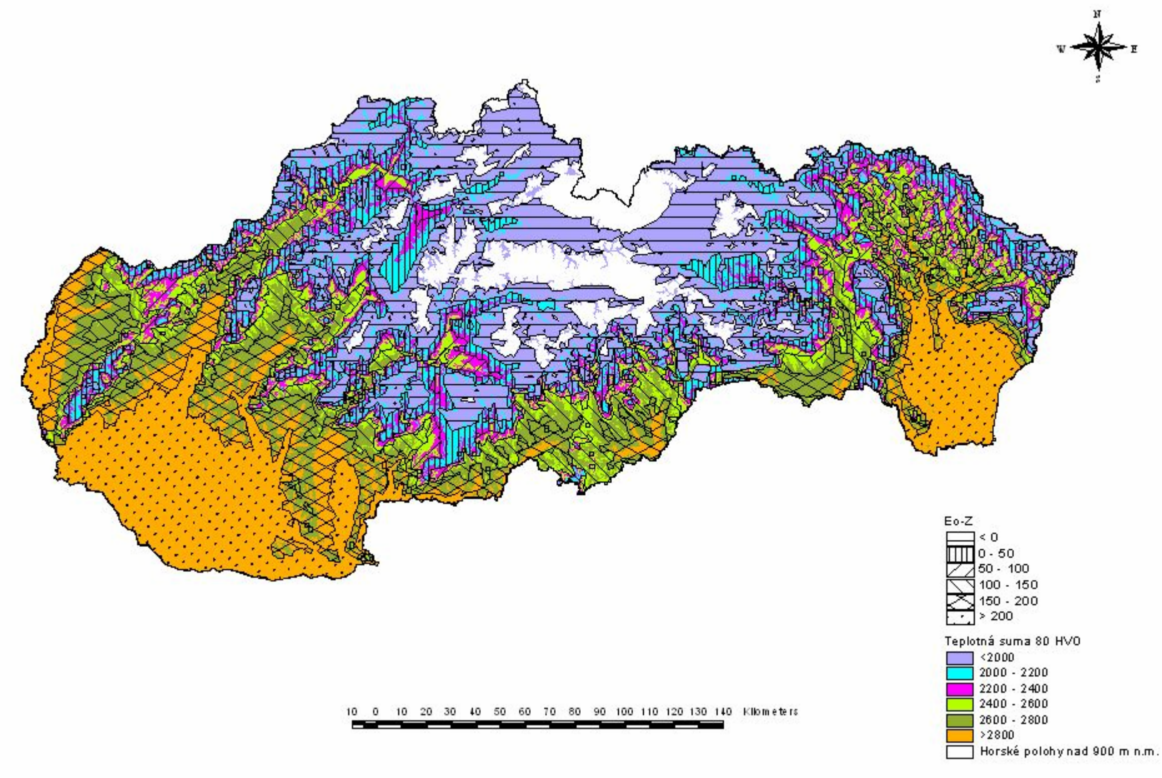


Fig. 44 Agroclimatic regionalization of Slovak republic

Drought and desertification in the context of climate change

Data and methods

Climatic data from database of SHMI in Bratislava were used for calculation in reference period of years (present climate - concentration $1xCO_2$), data referring to climate change conditions ($2xCO_2$) were generated according to scenarios (Lapin et al., 2001). Two periods of years related to concentration CO_2 in atmosphere were evaluated as given in table 12.

CO_2 concentration		Time horizons
$1xCO_2$	330 ppm	1961 – 1990

$2xCO_2$	660 ppm	2061 – 2090

Table 12

Phenological relations were evaluated for 2 growing seasons defined according to air temperatures: growing season limited by daily mean air temperature T≥5 °C – GS 5°C) and growing season limited by daily mean air temperature T≥10 °C – GS 10°C). The periods mentioned above were charecterized by daily mean air temperature sums (*TS* in °C), precipitation totals (*R* in mm), potential (E_0 in mm) and actual evapotranspiration (E_0 in mm) and climatic index of drought.

Climatic stations used for GIS analyses in this report were selected both from the point of view of altitude (up to 900 m a.s.l. – upper border of plant production) and spatial distribution. Evaluated acreage represents 45 000 km^2 – 90% of total area of Slovakia Selected stations represent 4 agro regions as given in tab. 13.

Agricultural regions (productive type)	Altitude v m n. m.	Climatic stations	Altitude V m n.m.
Maize	**<200**	**Somotor**	**100**
		Hurbanovo	**115**
		Nitra	**143**
		Piešťany	**165**
		Kamenica n/C.	**178**
Sugar beet	**200 – 350**	**Rimavská Sobota**	**214**
		Prievidza	**260**
		Košice	**230**
		Sliač	**330**
Potato	**300 – 650**	**Bardejov**	**304**
		Sliač	**330**
		Liptovský Hrádok	**640**
Mountainous	**>600**	**Liptovský Hrádok**	**640**

Tab. 13 Agricultural zones and related climatic stations

Spatial evaluation is realized in the raster model of geodata. Through the interpolation technique is calculated the spatial change of the individual average meteodata. It is used the regularized spline interpolation technique with tension and kriging. Resolution component will be comparison of both results interpolations and selection of the most suitable surface. By the interpolation created surface is than possible to divide by reclassification to the zones, those determinate spatially the specific range of values.

Results

Growing seasons

Duration of growing season is an important factor influencing energy and water balance conditions. From the point of view of regionalization of plant production of Slovak republic the growing season is usually defined according to air mean temperature:

1, growing season limited by daily mean air temperature T>5 °C – GS 5°C) and

2. growing season limited by daily mean air temperature T>10 °C – GS 10°C).

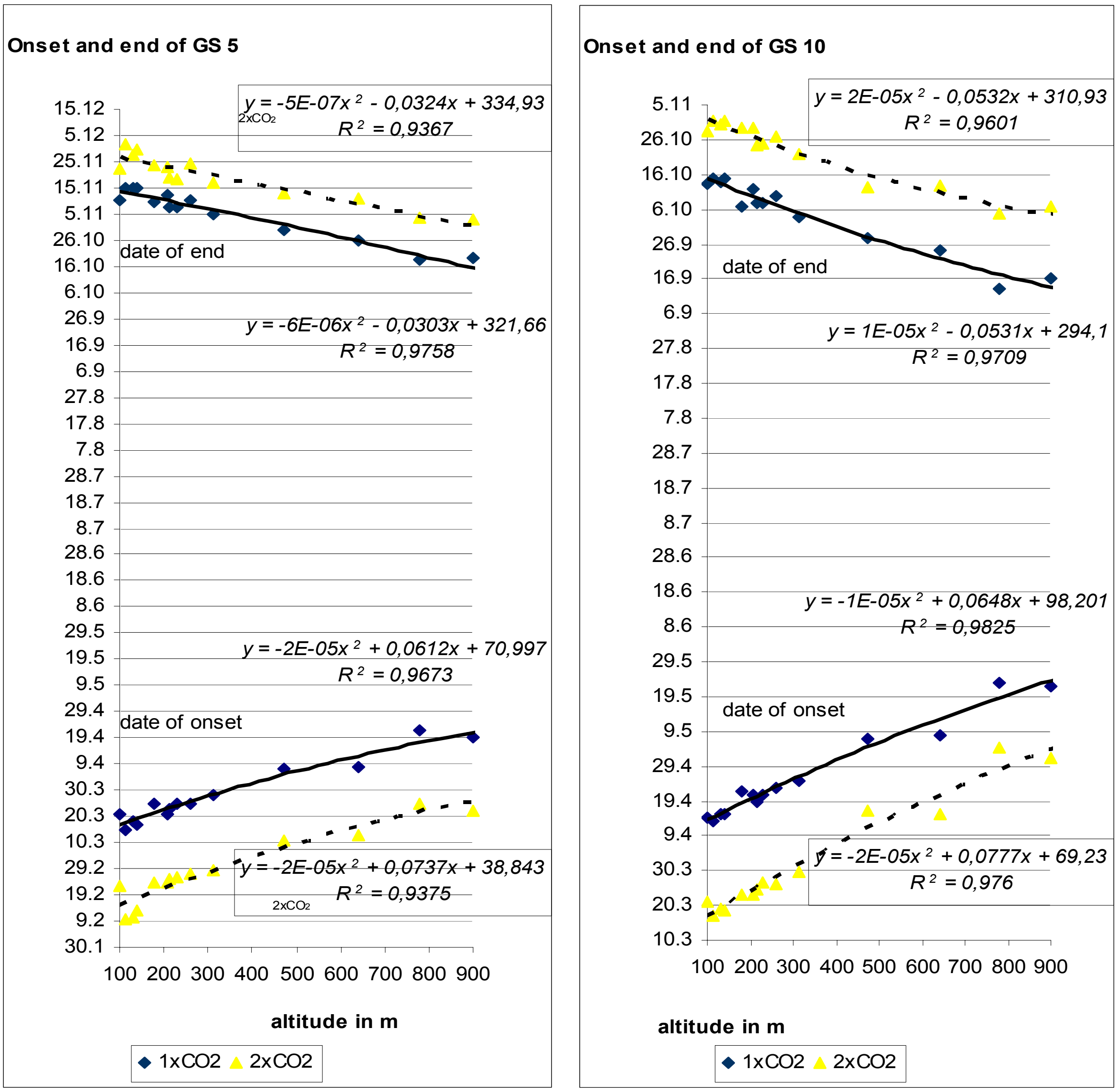


Fig. 45 Onset and end of growing seasons GS5 and GS10 in present climate (1xCO_2) and in condition of climate change (2xCO_2) in dependence on altitude in Slovakia

GS 5 is limited by biological temperature minimum of most crops grown in condition of SR. GS 5 cover season of grasslands, forage crops on arable soils, on temperature of less demanding fruit-trees and others permanent crops. Duration of GS5 also determine the wintering period of wheat (T<5, 0 °C).

GS 10 is limited by biological temperature minimum (by daily average air temperature T ≥ 10,0 °C). It is basically the period of biomass production of crops like maize (*Zea mays* L.), sugar beet (*Beta vulgaris* L.) and other plants of temperate zone.

Onset and end of GS5 and GS10 in altitudinal profile of SR are given on figure 45. From trend lines of onset and end of GS5 resulted, that the onset would accelerate significantly (by about 28 days) in climate conditions 2xCO_2 in the whole altitudinal profile.

This fact has serious effects on over-wintering field crops (winter wheat (*Triticum vulgare* L.), seed rape (*Brassica napus* L.). Growing season will be shift to the months with lower input of solar radiation, what has negative effects on their biomass production. Higher temperatures also influence evaporation and evapotranspiration and consequently droughts can occur earlier then in conditions of 1xCO_2 climate.

Duration of GS5 in maize agro region (34 % of total agricultural acreage in Slovakia) was 235 days during reference period 1xCO_2. Such conditions will occur practically on the whole the agriculture acreage of SR in climate conditions $2xCO_2$ and GS5 duration will over-reach at average 275 days on Danubian lowland, East Slovak lowland and Zahorie lowland.

Duration of GS 10 typical for maize agro region in present climate $1xCO_2$ is 175 days and more. Those conditions will occur on 80 % of total agricultural acreage in climate conditions $2xCO_2$ and duration of GS 10 can exceed 200 days on Danubian lowland, East Slovakian lowland and Zahorie lowland.

Temperature

Air temperature sums T≥5,0 °C (TS5) will increase by 22 % in southern – lower placed locality of Slovak republic in climate condition $2xCO_2$ (Station Hurbanovo – Danubian lowland), however TS5 increase and reach the rise about 45% towards higher located areas of Slovak republic.

Spatial changes and distribution of TS5 results from figure 3 in climate conditions $1xCO_2$ a $2xCO_2$. While the TS5>3200 °C was reached on the acreage of 12 880 km^2 (27 %) in climate conditions $1xCO_2$. TS5>3200 °C will occur on area bigger then 35 000 km^2 in climate conditions $2xCO_2$, what represent more then 80 % of evaluated area.

TS10 will increase by 23 % on lowlands of Slovakia in climate condition $2xCO_2$ (Station Hurbanovo), however relative increase of temperature in sub mountains regions would be about 45 %. While the TS10>2800 °C was found on the acreage of 11 136 km^2 (25 %) in climate conditions $1xCO_2$, this value can occur on the area bigger the 30 000 km^2 in climate conditions $2xCO_2$ (67 %).

It will allow grow crops demanding higher temperature totals not only in conditions of Danubian and East Slovakian lowlands, but also in sub mountainous uplands of Liptov and Turiec (up to 650 m). On the other hand water demand will rise too and drought can occur on bigger area too.

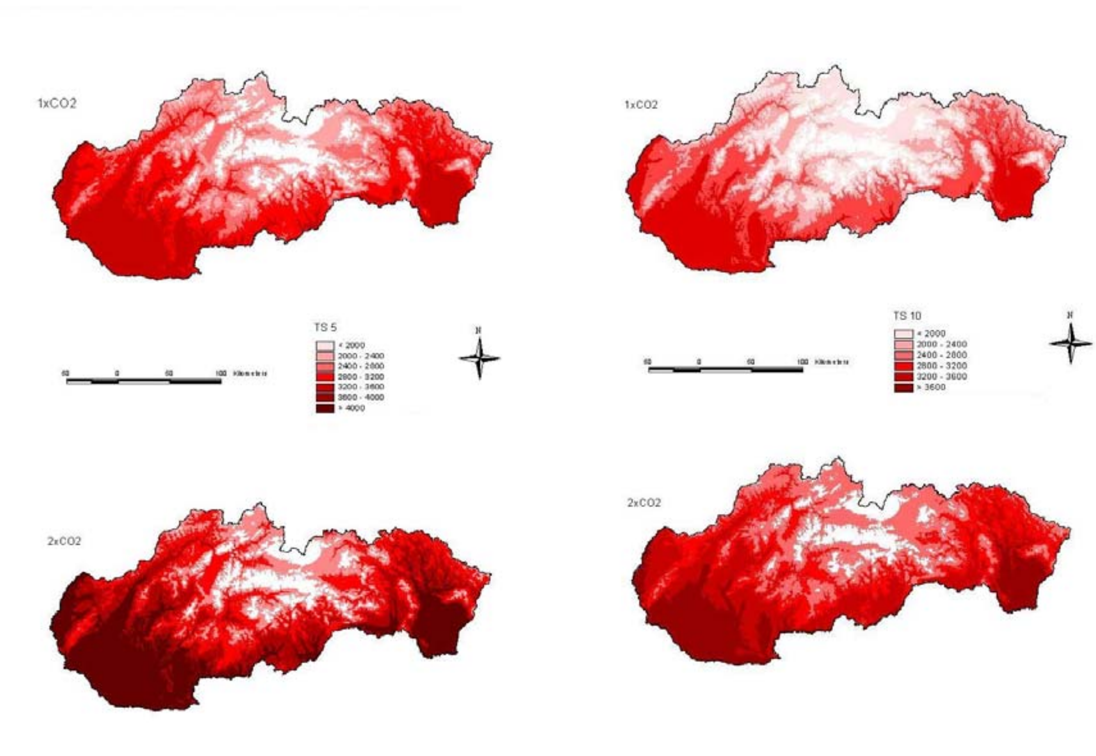


Fig. 46. Daily mean air temperature sums T≥5 °C – GS 5°C (left) and T≥10 °C – GS 10°C (right) in conditions of climate 1x CO_2 and 2x CO_2

Precipitation and evapotranspiration

Precipitation totals are influenced by altitudinal profile of Slovakia. Generally there is calculated an increase of R for climate conditions 2xCO_2: 65 - 80 mm (15 - 20 %) on lowlands of SR and increase by 65 - 128 mm (12 -20 %.) in northern part of Slovak republic. During GS5 all agro regions should receive rainfall R>480 mm in climate conditions 2xCO_2, or R>390 mm during GS10.

This fact should favorably influence a production potential of some crops especially in higher altitudes (e.g. winter wheat, spring barley, forage crops and grass-land). However the potential is also influenced by number and time distribution of rainfalls. As presented in some works (Špánik, Igaz, Čimo, 2006) the number of days with rainfall decrease and number of periods of droughts increases in condition of Danubian lowland (by about 4% in each decade of years since 1960). Except for it precipitation should be evaluated in context of evapotranspiration. Rainfall increase will not cover evapotranspiration demands of plants in hot conditions of lowlands.

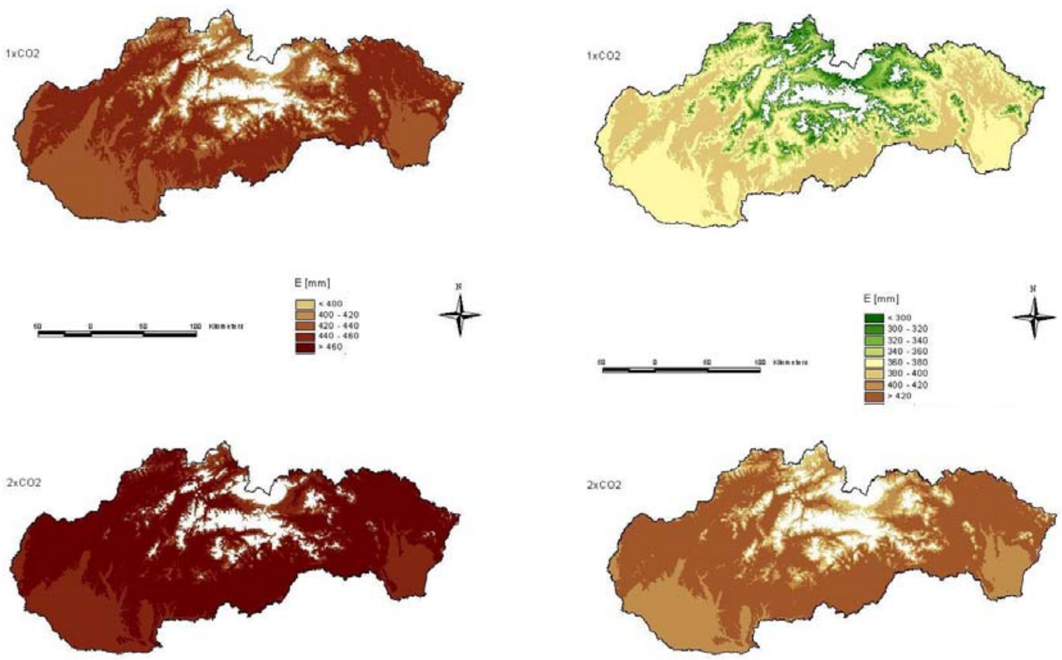


Fig. 47. Spatial distribution of actual evapotranspiration for GS5 (left) and GS10 (right) in conditions of 1x CO_2 and 2x CO_2

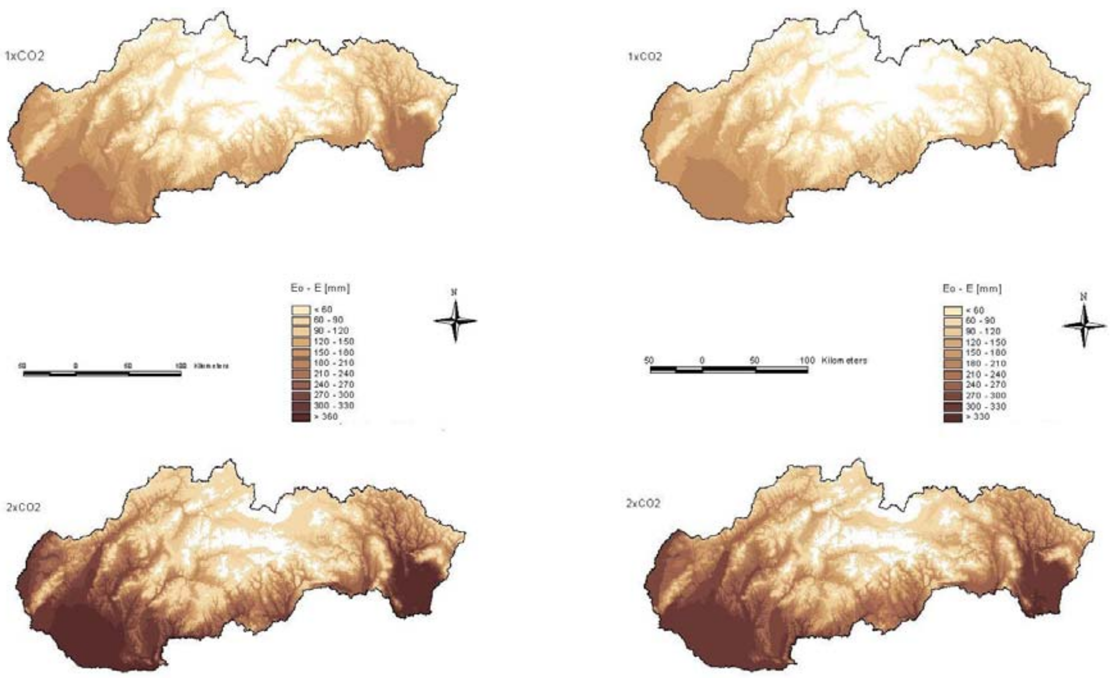


Fig.48. Spatial distribution of evapotranspiration deficit E_0-E for GS5 (left) and GS10 (right) in conditions of 1x CO_2 and 2x CO_2

Supposed air temperature increase during GS5 and GS10 will cause the increase of E_0 on the whole area of Slovak republic in climate conditions 2xCO_2. E_0 will increase during GS5 by 150 mm, i.e. 23 % on the south of Slovakia (Hurbanovo – Danubian lowland). E_0> 500mm can be expected on the whole agricultural used area and E_0 more then 800 mm can be expected on the hottest localities of Slovak republic (south of Danubian lowland and the lowermost localities of SR). Extremely high E_0 totals call for effective management of water resources and development of irrigation in the most area of SR to eliminate unfavorable effect of drought on the crop production.

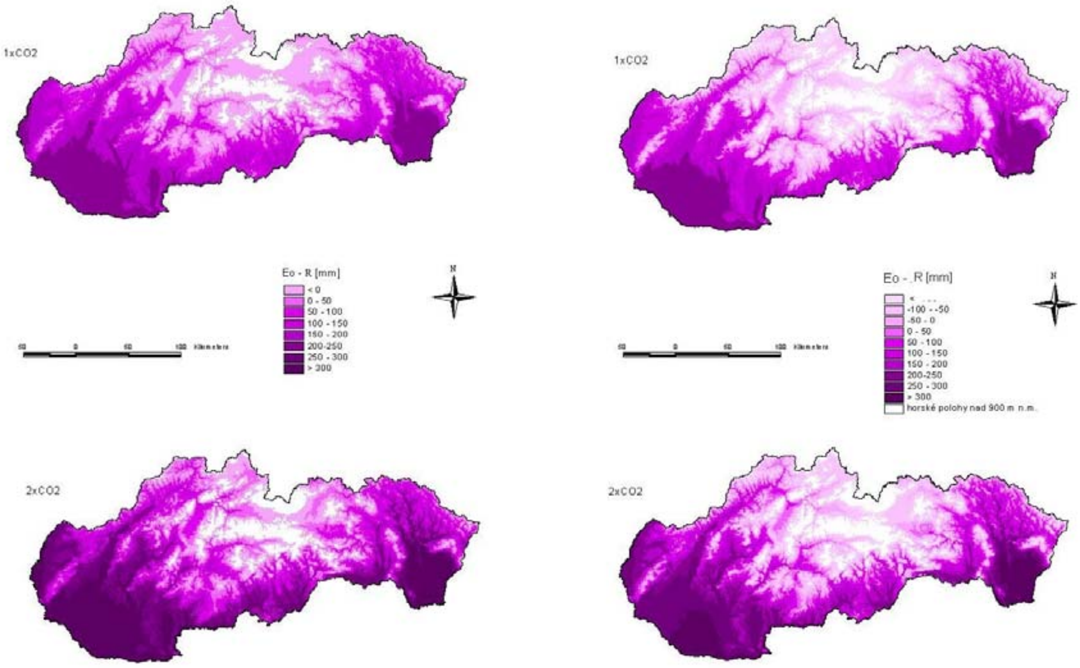


Fig. 49. Climatic index of drought (E_0-R) in mm for GS5 (left) and GS10 (right) in conditions in conditions of 1x CO_2 and 2x CO_2

Spatial distribution of climatic index of drought (E_0-R) in mm results from figure 5 during GS5 in Slovakia. Difference between potential evapotranspiration and rainfalls is significantly changing with changes of E_0 and R in the altitudinal profile. More significant changes of this index were calculated for lowland conditions of south Slovak (+30 %) in climate conditions 2xCO_2. Zero values of index will shift from altitude 550 to 650 high above see level. Changes of this index are even more significant for GS10 as compared with GS5. There was found increase of the index climate by 90 – 100 mm on lowlands (+32 - +45%) in condition of 2xCO_2. Zero values of the index will shift from altitudes 550 m to 700 m.

Conclusions: Adaptive measures

There are only four agro-technical measures, which can be applied as effective adaptation tools for mitigation of negative effects (droughts including) (ŠPÁNIK et al., 2000):

- change of crop
- change of variety
- modification of sowing date term
- irrigation
- change of crop

This step can help in sub mountain regions which will not be so short of water. Increasing of temperature comfort will unable growing the crops, which are nowadays typical for hottest Slovak regions. Strong representation of maize in crop rotations is supposed in future climate. Maize potential is able to overcome the period with lack of water during vegetative period.

- change of variety

Other cereals, which are dominating in plant production in Slovakia today, call for change of varieties. Current types of winter wheat varieties are not enough drought-resistant and could reach the maturity in climate change condition about 4 weeks earlier.

Season of wintering is likely to become a risk. Warm winter can cause that sudden decreases of temperatures will likely become more frequent during growing season and so damage caused by frost will have to be taken into account by selecting a new varieties.

- modification of sowing date term

According to results of modeling it can be concluded that the sowing term of spring barley is suitable to adapt to average day temperature T≥ 5°C in agro-climatic conditions of Slovakia.

- irrigation systems

Expansion of irrigation systems is currently one of the most frequently considered adaptive measures to mitigate drought effects. Using irrigation systems however require sufficient amount of water, and it is likely, that the need of field crops will be satisfied only partly.

Summary

Drought conditions were evaluated on the background of temperature and water balance conditions during growing seasons limited by daily mean air temperature T>15°C – *GS5 and* T>10 °C – *GS10*.

GS5 and GS5 were charecterized by daily mean air temperature sums (*TS* in °C), precipitation totals (*R* in mm), potential evapotranspiration (E_0 in mm) and climatic index of drought. Agroclimatic regionalization (zonation) was proposed according to meteorological data from years 1961 - 1990.

High totals of potential evapotranspiration during so short time period as GS10 period is (as compared with GS5 period), can evoke conditions when drought will appear on lowland of SR. This fact should be considered in future in selection of proper varieties of field crops. Effective management of water resources and irrigation can reduce negative effect of increased evapotranspiration on yield production.

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