ADAPTAČNÍ OPATŘENÍ PRO PĚSTOVÁNÍ JEČMENE JARNÍHO V PODMÍNKÁCH ZMĚNY KLIMATU

SPRING BARLEY – ADAPTATION MEASURES IN CLIMATE CHANGE CONDITIONS

Semerádová Daniela, Trnka Miroslav, Žalud Zdeněk

Mendel University of Agriculture and Forestry Brno

Abstract: The decrease of the mean yields due to the indirect effect of doubled CO_2 may be reduced, and might be even turned to increase, if the spring barley would be planted 45-60 days sooner (compared to the planting date of the representative year). Application of the earlier planting date would result in additional 15-22 % increase of the yields in $2\times CO_2$ conditions. Adaptation to climate change through changing the cultivar showed the close positive correlation between the length of vegetation period of the cultivar and the grain yield. The relationship between the two quantities might be quantified by 1.5% yield increase per one extra day of spring barley vegetation season. No more than 5-day increase of the vegetation period was considered owing to the fact that the difference between the standard and the latest cultivars commonly used in the Czech Republic is only 2 days. The initial water content in the soil water profile proved to be one of the key elements determining the spring barley yield under the rainfed conditions: the yield increases by 54-101 $kg.ha^{-1}$ per 1% increase of the available soil water content. The highest sensitivity was found at the locality with the lowest rainfall and vice versa. The issue of the proper soil water management will be therefore important for sustainable production of high spring barley yields, i.e. without a need of additional inputs under the changed climatic conditions.

Key words: planting date, cultivar change, soil moisture

1. Introduction

Spring barley is the second (after winter wheat) most significant cereal in the Czech Republic (as well as in the European Union) both in the acreage and production quantity. The total arable area in 2000 (CR) was 352 892 ha, i.e. 11.5% of the total acreage (www.czso.cz, 2001) with the average yield 3030 $kg.ha^{-1}$ meaning that the total annual production equals to 1.07 millions ton of grain making it important economical commodity. As majority of the agriculture crops in the country it is grown under rainfed conditions without possibility of irrigation. Therefore its yields are extensively influenced by weather variability and the degree of the weather dependency ought to be studied concentrating on introduction of the crop models and their applications. The long-term objective of our work is help to prepare ground for development of a system for spatial analysis and assessment of the cereal production on the national level coupled with the yield forecasting system. Such system should encompass detailed databases and wide variety of options so it could be used besides yield forecasting and climate change impact assessment also for optimizing technologies by minimizing inputs, space analysis of nitrogen balance or soil protection etc. The final step should include its combination with a socioeconomic model that would significantly extended number of potential users.

The main aim of the paper is the examination of the mitigation and adaptation strategies potential for spring barley in expected climatic conditions.

2. Material and Methods

2.1. Experimental sites

As it was already mentioned the study was based on the results of field experiments made in three experimental sites representing environmental conditions of three different production regions. These regions differ significantly in their climatic conditions as well as in prevailing soil types. The experimental site in Žabčice (49°01´ N, 16° 37´ E, 179 m a.s.l.) represents the main maize production region of the Czech Republic and it lays on heavy soils. The annual average air temperature equals to 9.2°C and the annual average precipitation is 480 mm. The experimental site in Kroměříž (49°18´ N, 17° 23´ E, 204 m a.s.l.) is situated in a sugar beet production region. The annual average air temperature is 8.6 °C, the annual average precipitation is 599 mm, and soil texture is classified as a typical loam. The experimental site in Domanínek (49°32´ N, 16°15´E, 560 m a.s.l.) belongs to the main potato production region of the Czech Republic. The annual average air temperature equals 6.5°C and the annual average precipitation is 651 mm. Soil is rather light and can be characterized as a loamy sand. Description of the climate for all regions is based on 1901-1950 long-term averages. Cultivar AKCENT, which is a two-row semi-late spring barley cultivar of the dwarfed type was used in this study. It is suitable to all spring barley growing altitudes and is characteristic by high yields and lodging resistance. The cultivar is sensitive to drought conditions as well as to *Rhynchosporium cerealis* and *Pyrenophora teres* (Jurečka and Beneš, 2000). The cultivar is suitable for malt production but it can be also grown under less favorable environmental conditions for feed grain.

2.2 Definition of the climate change scenarios

In developing climate change scenario, recent transient runs of general circulation models (GCM´s) were used (Dubrovský *et al.*, 2002). Seven GCMs available from the IPCC data distribution center (http://ipcc-ddc.cru.uea.ac.uk) were validated in detail to examine their performance for a territory of the Czech Republic. Based on the results obtained, three GCMs for construction 2xCO_2 weather were selected: ECHAM4, HadCM2 and NCAR-DOE. In addition, the scenario averaged over all 7 GCMs was developed (in following text these scenarios will be abbreviated as ECHAM, HAD, NCAR and AVG). The final scenarios were defined by the pattern scaling technique (Santer et al., 1990), which consists in multiplying the standardized scenario by the prognosed increment of the global average temperature, ΔT_G. The value of ΔT_G = 2.33 °C was estimated with use of the one-dimensional climate model MAGICC (Hulme et al., 2000) assuming IS92a emission scenario, doubled atmospheric CO_2, and the middle climate sensitivity. The standardized scenario is obtained by dividing

Table 1. Changes in annual climatic characteristics related to the four 2×CO_2 climate change scenarios for the Czech Republic.

Scenario	Abbreviation used in the text	Change of the mean annual temperature (°C)	Change of the global radiation (%)	Change of the annual precipitation (%)
ECHAM4	ECHAM	+3.6	+4.2	-4.0
HadCM2	HAD	+2.7	+1.3	-0.7
NCAR-DOE	NCAR	+2.6	+0.6	+10.0
Average scenario	AVG	+3.0	+1.8	+3.7

a climate change scenario for given area and given period by the increase in mean annual global surface temperature prognosed for that period. In this study, the standardized scenario was determined as a weighted average of the series of the scenarios for nine consecutive 10-year slices within the 2010-2099 run of given GCM. The final scenarios differ in magnitude of the changes of mean annual climate characteristics (Table 1) and in shape of the annual cycle of the changes. Scenarios, which were developed using the above-described method, were then coupled with the crop model in order to estimate the direct, indirect and combined effects of increased ambient CO_2.

In order to carry out climate change impact assessment the method developed and applied by Žalud and Dubrovský (2002) was used. The method as it is apparent from the fig.1 consists of several interrelated steps and includes the use of the crop growth model runs with multiple weather series representing both the present and changed climates. Based on the fact that the findings obtained by a comparison of model yields for the different climates have a statistical significance, multi-annual crop model simulations were run for each scenario (Table 1). The descriptive statistics, such as means, standard deviations, and quantile characteristics, were determined and used for the impact assessment. This approach is considered more decisive (in a statistical sense) than the use of single values related to individual years. Since the distribution of the yields may be asymmetric and far from normal, the use of quantiles might be more appropriate because of their robustness. The input to the crop model consists beside already mentioned pedological, physiological and cultivation data taken from a single "representative" year also from the 99-year synthetic weather series created by the stochastic weather generator Met&Roll (Dubrovský, 1997). The representative year is defined by the site-typical values of all non-meteorological parameters (including the planting date, soil profile and details on the fertilization regime) needed to run the model. The parameters of the weather generator derived from

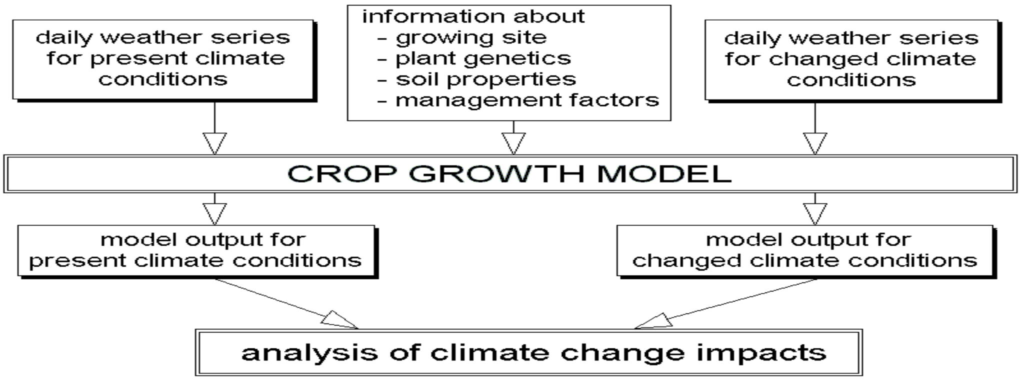


Fig.1: The scheme of the crop model experiments used in climate change impact studies (Žalud and Dubrovský, 2002).

the observed series are used to generate weather series representing the present climate. The parameters of the generator are modified in accordance with the climate change scenario to generate series representing the changed climate (Dubrovský *et al.*, 2000).

Both stressed and potential yields were calculated, and both direct and indirect effects of increased CO_2 were assessed. The last goal of the thesis was the investigation of possible means of adaptation to the changed climate as far as growing spring barley is concerned. Three mitigation strategies were examined: 1) shift in the sowing date, 2) change of the cultivar properties (preference of early or late ripening cultivars), 3) soil moisture conservation.

3. Results and Discussion

3.1. Shift in the sowing date

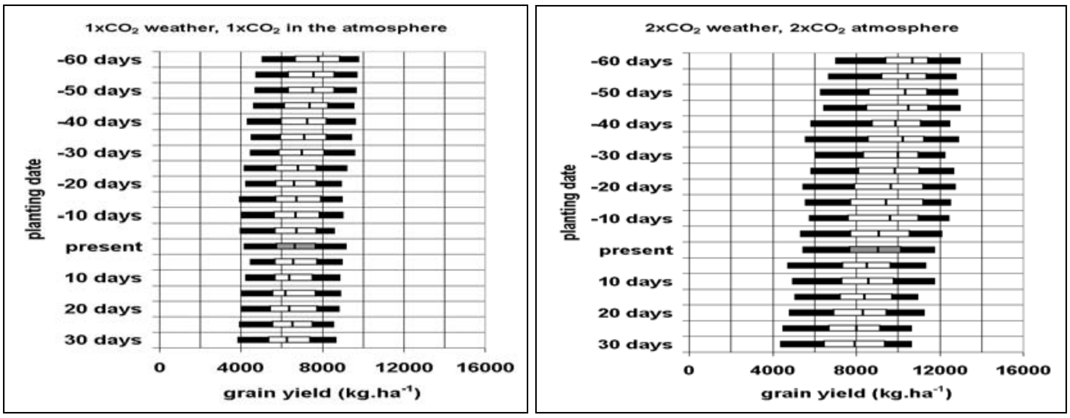
The 99-year crop model simulations were run for present conditions (present levels of CO_2 and present climate) and for changed climatic conditions (doubled CO_2 concentrations and $2\times CO_2$ climate according to AVG scenario) at water and nutrient limited conditions at three test regions. The value of the planting date (PD) varied within the interval (D_0 – 60 days, D_0 + 30 days), where D_0 is the planting date of the "representative year". It was assumed that the soil and weather conditions would allow for the field operation to be done on the selected date. The following conclusions were made:

(i) The model grain yields simulated in the present climate and ambient CO_2 concentration (Fig.2) are rather insensitive to small changes in PD. Specifically, the median of the yields remains nearly constant if PD varies within (D_0 – 10 days, D_0 + 10 days). In contrast with the similar study carried out for maize (Žalud and Dubrovský, 2002) the probability that the barley is damaged by a spring frost does not significantly increase in applying earlier planting date. The interpretation of the results should be carefully considered as the ability of the model reliably to simulate the frost damage is yet to be experimentally evaluated. On the other hand, if the planting date is delayed beyond D_0, the grain yields tend to decrease due to the shift of the vegetation period into months with higher temperatures and lower precipitation causing higher water stress during grain filling phase and a shortening of this phase. In the case of the planting date delayed by 1 month, the average grain yield decreases by 9.5 % at the all three test regions with significant change in the vegetation duration which shortens by 13 days at Žabčice and Kroměříž whereas the change at Domanínek only by 7 days.

(ii) The increase of the yields resulting from the changes in daily weather conditions in the 2× CO2 climates can be even enlarged by switching to an earlier planting terms (Fig.2b). It is also possible to reduce yield variability (under the changed climatic conditions) by shifting the PD. However, the mitigation is only partial, as the high temperatures occurring at the later phases of the crop development cannot be avoided by earlier planting and therefore will cause the adverse effect on the crop yield variability. For example in the case of the locality Kroměříž the simulated results suggest as the most suitable alternative the planting date shift by 45 days (from the 26th March to the 9th February). This change would lead to the prolongation of mean duration of the growing period from 116 days to 144 days (compare to 125 days in 1×CO_2 climate) and to the mean yields increase by 3300 kg/ha in comparison with the present ambient CO_2 (Fig.2a-b; note that the graphs display quartile characteristics but the magnitudes of the indirect effect are calculated from the means), and by 1100 kg/ha at doubled ambient CO_2 (Fig.2b). This means that the positive combined effect of doubled CO_2 manifested by a 40 % respectively 33% yield increase of the stressed yields simulated using AVG scenario with the present planting dates is even more pronounced equaling to 55% at the Regions 1 and 2. Also the 27% yield increase caused by the combined effect of the changed climatic conditions at the locality Domanínek might be increased up to 42% if the shift of the planting date is applied.

3.2. Use of a different cultivar

One of the most influential factors determining the yield quantity under the changed climatic conditions is thought to be increase of temperature. High temperatures generally speed up phenological development of the crop and therefore leave less time for the yield formation. Even though the above presented simulation results suggest that higher WUE together with direct effect of the carbon dioxide will more than eliminate this negative influence the search for maximum utilization of the climatic conditions in the sense of sustainable agriculture practices should continue. The length of the phenological stage is determine by number of degree days and therefore the most easiest way to encounter the shortening of the phenological phases due to the temperature increase is replacement of the currently used cultivars with those which need higher number of degree days to finish their phenological stages. Therefore, the genetic coefficients of the currently used and calibrated cultivar driving the phenological development were adjusted in such way that they would prolong (shorten) the vegetation period under current conditions by 2 (5 days respectively). Impact of the modification was than evaluated in three regions based on the simulations for the present and changed climatic conditions (using AVG scenario) with the following results:



a) b)

Fig.2. Adaptation to the climate change –through the shift in the planting date at the locality Kroměříž simulated by CERES-barley model. The shift is given in terms of the deviation (in days) from the representative year's planting date (26th March). The bars represent quantiles (5th, 25th, median, 75th, 95th) of the model yields obtained in the 99-year crop model simulations for present and changed climate. The changed climate is represented by AVG scenario. The shaded bars relate to the representative year's planting date.

i) The yields simulated in the present climate and ambient CO_2 concentration (Fig. 3) show change of yields depending on the length of the vegetation of the cultivar used, showing yield decrease per each day of shorter vegetation period approximately by 100 kg.ha^{-1}.day^{-1}. The opposite trend of the same magnitude was found when cultivars with longer vegetation period were used in the simulations. The yield variability (expressed in the terms of coefficient of variation) did not show any significant change. These results especially the negative influence of the shorter vegetation period corresponds in most cases with the results of the State Official Variety Tests (Jurečka and Beneš, 2000)

ii) The effect of the increasing length of the vegetation period remains positive also under the 2xCO_2 weather and 2xCO_2 ambient air concentration adding some momentum to the late and semi-late cultivars yield gains already caused by the direct CO2 fertilization effect and higher WUE efficiency. The magnitude of the change is the same as under the present conditions i.e. about 150 kg.ha^{-1}.day^{-1}.

3.3. Introduction of the soil water conserving practices

The water content in the soil water profile represents the largest storage entity of water in the agriculture system under the rainfed conditions. It acts both as source (for the crop) and the sink for (precipitation) and serves as buffer as it saves water from irregular rainfall events and transforms it into a continuous source for the plants. The amount of the water stored depends on physical soil properties (especially on the wilting point and field capacity), depth of the soil profile and, of course, on the precipitation regime in the rain dependent agriculture system. The model structure respects these experimentally verified facts and the water amount available in the start of each simulation in the soil is one of the key predictors influencing the crop growth. The careful and well-advised soil water management is therefore one of the key element in producing high crop yields without need of additional inputs (e.g. irrigation) under the present climate. The series of simulations were therefore

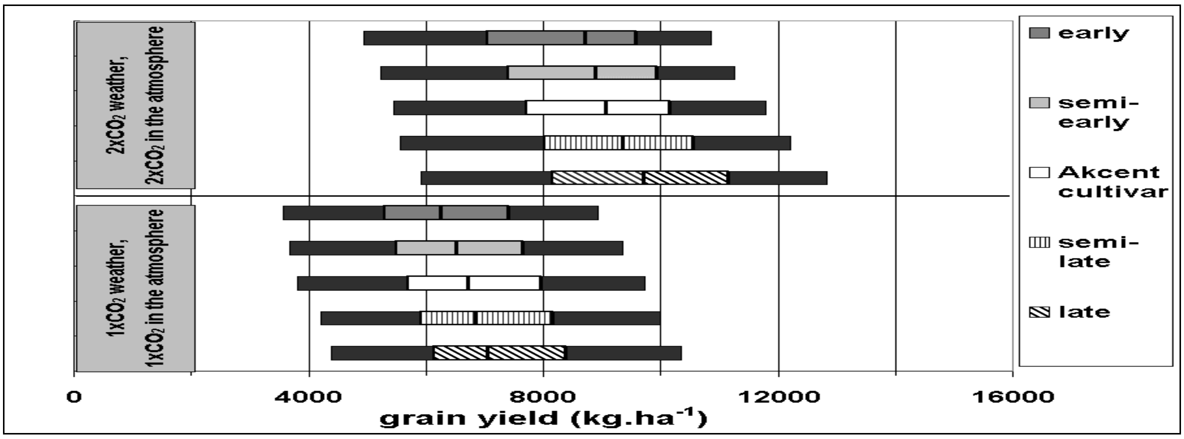


Fig. 3. Adaptation to the climate change through the use of cultivars with different length of vegetation simulated by CERES-barley model.. Early = 5 days shorter vegetation period than the presently used Akcent cultivar; semi-early = 2 days shorter; late = 5 days longer; semi-late = 2 days longer). The bars represent quantiles (5th, 25th, median, 75th, 95th) of the model yields obtained in the 99-year crop model simulations present and changed climate. The changed climate is represented by AVG scenario.

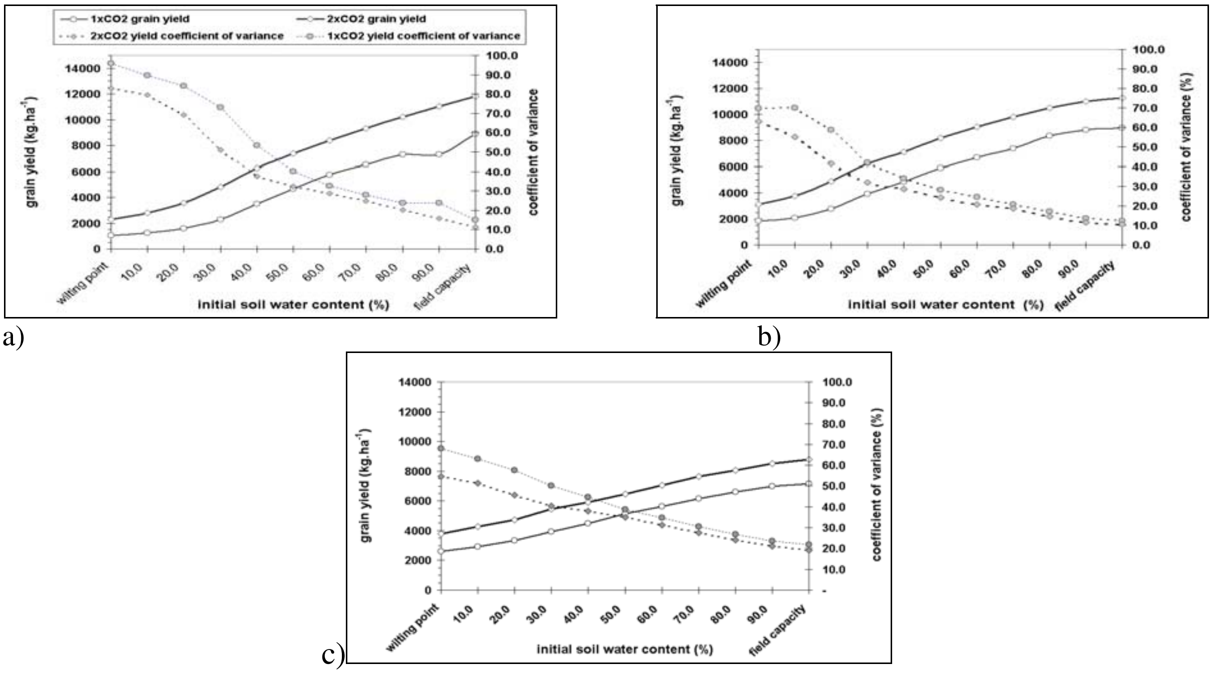


Fig.4. Sensitivity analysis of the water limited spring barley (cultivar Akcent) grain yield to different levels of initial available soil water (ISAW) simulated by CERES-barley model at a) Žabčice; b) Kroměříž and c) Domanínek under present and 2×CO_2 climatic conditions (only AVG scenario was considered). Each point represents 99-year simulation that is described by the mean and the value of the coefficient of variance.

carried out in order to quantify the impact of the initial soil water content on the grain yield under present and changed (using AVG scenario) climatic conditions (Fig.4.). The figure shows that the yield increase and their variability (represented by the coefficient of variance) decrease with increasing the initial soil water content value. These results are mainly due to the water stress reduction especially during initial developmental stages. Under the present CO_2 conditions, the yield increases by 101, 88 and 54 kg.ha^{-1} per 1% of additional initial soil water content (in the interval from 30-80% in which the relationship is more or less linear one at Žabčice, Kroměříž and Domanínek, respectively. Similar values of soil water relationship and yield were recorded for the changed climatic conditions, making it one of the key parts of any adaptation strategy. The soil water holding ability might increase by using proper soil tillage techniques for the given soil type and climatic conditions (Lampurlanés *et al.,* 2001), straw incorporation (Singh *et al.*, 1998) or mulching (Tolk *et al.*,1999). Higher soil water reserves can further enhance the production of spring cereals and in the same time eliminate to a certain degree risk coming from prolonged drought spells.

4. Conclusions

All three tested performances (shift in the sowing date, change of the cultivar properties, soil moisture conservation) seem to be promising as adaptation tool for expected climate conditions. Next studies will be done for more locations and cultivars in the future.

Souhrn: Pokles průměrného výnosu vzhledem změny klimatických podmínek může být redukován změnou termínu setí (o 45-60 dříve) ve srovnání s reprezentačním ročníkem. Existuje pozitivní korelace mezi délkou vegetačního období a výnosem ve smyslu jeho zvýšení o 1.5% na jeden "extra" den. Testován byl pouze 5 denní interval neboť rozdíl mezi standardními a velmi pozdními kultivary používanými v ČR jsou 2 dny. Klíčovým faktorem růstu a vývoje je množství vody v půdě. Podle modelových simulací se výnos zvyšuje o 54-101 kg.ha^{-1} na 1% zvýšení dostupné vody v půdě. Nejtěsnější závislost byla stanovena na lokalitě s nejnižšími srážkami.

Klíčová slova: doba setí, změna odrůdy, půdní vlhkost

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Corresponding author: Ing. Daniela Semerádová
MZLU Brno, Ústav krajinné ekologie
Zemedelska 1, 613 00 Brno
tel and fax: 00420545133083, dany12@tiscali.cz