MOŽNÉ TRENDY VÝNOSŮ PŠENICE OZIMNÉ V ZMĚNĚNÝCH KLIMATICKÝCH PODMÍNKACH

EXPECTED TRENDS OF WINTER WHEAT YIELD IN CLIMATE CHANGE CONDITIONS

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ABSTRACT: The crop model CERES-Wheat in combination with stochastic weather generator were used to quantify impacts of climate change scenarios on crop yields of the most important European cereal crop i.e. winter wheat. Seven experimental sites with high quality experimental data were selected in order to evaluate the selected crop model and also to carry out climate change impact analysis. The analysis was based on multi-year crop model simulations run with daily weather series obtained by stochastic weather generator and applying two emission scenario projections assuming CO_2 ambient air concentration 548 ppm (B1) and 826 ppm (A2). Seven global circulation models (GCMs) were used to derive individual climate change scenarios. Outputs of the seven GCMs were also averaged in order to derive average scenario (AVG). Time periods 2025, 2050 and 2100 were examined in the study. Simulated results show that wheat yields tend in general to increase (40 out of 42 applied scenarios) on most locations in range between 7.5-25.3% in all three time periods.

Keywords: CERES-Wheat, weather generator, GCM, crop modeling

INTRODUCTION

Earth's atmospheric CO_2 concentration increased about 30% during past 200 years, from near 280 to more than 360 ppm (Amthor, 1998). This ongoing change is of concern because increase of greenhouse gasses may be warming the Earth's surface and could alter temporal and spatial patterns of precipitation and evaporation (e.g. Houghton, 2001). In fact most of Europe has already experienced increases in surface air temperature during the 20th century, which amounts to 0.8°C in annual mean temperature over the entire continent (Beniston and Tol, 1998). The atmospheric CO_2, which is the primary source of carbon for the plants, is in its present concentration sub-optimal for C_3 type plants (Hall, 1979) and therefore the increased content of CO_2 in the air stimulates photosynthesis even though some experiments seem to suggest that the increase of the photosynthesis intensity vary during the phenological phases (e.g. Mitchell *et al.,* 1999). In the same time, higher ambient CO_2 allows to reduce the transpiration intensity through decreased stomatal conductance especially under higher temperatures (Bunce, 2000). This should lead to the improved water use efficiency (WUE) and thereby to a lower probability of the water stress occurrence (Kimball, 1983). The experiments made in controlled environment indicate that the winter wheat growth and biomass production might increase up to 33±6% (e.g. Cure and Ackock, 1986) at doubled ambient CO_2. Recent review of 156 experiments

(Amthor, 2001) with winter wheat that were carried out during years 1976-2001 supports these claims. Experiments that were undertaken in controlled environment either in laboratories or greenhouses show 12-14% yield increase per 100 ppm of additional CO_2 ambient concentration while in the field experiments the reported increase is only 8-8.6%. In this paper the effect of different climate change scenarios for three reference periods (2025, 2050 and 2100) on simulated winter wheat crop yields is evaluated.

MATERIALS AND METHODS

Field experiments

All test sites used in the study lay within the area of the Czech Republic, between 48°33´-51°03´N and 12°05´-18°51E. The climate of the Czech Republic is influenced by mutual penetration and mingling of ocean and continental effects. In order to carry out the crop modeling part of the study it was necessary to gather sufficiently large sample of experimental data. The database was based on the results of the long-term experiments at the seven test sites that were carefully selected out of thirty available. These sites (Tab 1) were chosen according to their climatic and soil representativness of the study area. For each of these sites all necessary input data i.e. results of field experiments, detail description of the field operations and soil conditions as well as weather data were collected and basic characteristics of each site are provided in Tab 1. The experimental database originally included in total 83 seasons, which were certified as acceptable for further processing by internal procedures of the State Institute for Agricultural Supervision and Testing (SIAST). The winter wheat (*Triticum aestivum L.*) cultivar Hana used in the study was chosen because it has been widely grown since 1985 and therefore available data series are sufficiently long and in the same time it still belongs among the most popular cultivars in the Czech Republic (Jurečka and Beneš, 2000).

Table 1. Characteristics of the seven experimental sites in the Czech Republic. Climatic characteristics relate to 1961-1990 period.

SITE	CZ_1	CZ_2	CZ_3	CZ_4	CZ_5	CZ_6	CZ_7
Name of the site	Lednice	Kroměříž	Sedlec	Chrastava	Staňkov	Domanínek	Kr. Údolí
Elevation (m a.s.l.)	170	204	300	345	370	565	647
Primary crop of the production region	maize	sugar-beet	sugar-beet	cereals	cereals	potatoes	forage
Soil type	Chernozem	Chernozem	Chernozem	Luvisol	Luvisol	Cambisol	Cambisol
Effective soil depth (cm)	140	155	150	150	180	130	135
Mean annual temperature (^oC)	9.5	9.1	8.2	7.6	8.2	6.8	6.4
Mean annual precipitation (mm)	488	571	510	816	526	591	604
Mean accumulated global radiation/ year (MJ m^{-2})	3955	3914	3706	3487	3790	3787	3634

Climate scenarios

The climate change scenarios applied in this paper are based on the transient simulations made by seven GCMs, which were available from the IPCC-DDC database (http://ipcc-ddc.cru.uea.ac.uk) in the beginning of 2001. These GCM simulations were made within the frame of the Coupled Model Intercomparison Project (CMIP, Covey et al. 2003).

Whilst mean values of individual weather elements were modified according to the appropriate GCM scenario the standard deviation parameters of Met&Roll were modified in such a way that it would reproduce weather series with temperature variability 12.5%, 25% and 50% lower than under present climatic conditions and also series with variability 12.5%, 25%, 50% and 100% higher than nowadays. These series were then used as inputs to the crop model and 99 simulation runs were performed for each combination of GCM scenario and temperature variability alteration. In the end the series were statistically evaluated using standardized Wilcoxon statistic for testing the hypothesis that the distribution of grain yields under a given temperature variability scenario does not differ from the reference distribution related to particular GCM scenario and unmodified temperature variability.

Table 2: Changes in global mean temperature for two emission scenarios and three time periods The changes are with respect to the baseline period (1961-1990) and were calculated by MAGICC (Model for the Assessment of Greenhouse-gas Induced Climate Change, Hulme *et al.* (2000)) with only effect of greenhouse gasses considered.

EMISSION SCENARIO		2025	2050	2100
SRES-B1	CO2 (ppm)	420	467	548
	ΔT_G (°C)	+0.49	+0.76	+1.17
SRES-A2	CO2 (ppm)	438	535	826
	ΔT_G (°C)	+1.10	+2.08	+4.29

Climate change impact assessment

In order to carry out climate change impact assessment the authors applied method originally developed by Porter and Semenov (1995) and adapted by Žalud and Dubrovský, (2002) for the conditions of the Czech Republic. The method is based on the comparison of the outputs from the multiple crop growth model runs with weather series representing the present vs. changed climates. The input to the crop model consists of the pedological, physiological and cultivation data taken from a single “representative” year and from the 99-year synthetic weather series created by the stochastic weather generator Met&Roll (Dubrovský, 1997). The representative year is defined by the set of 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 (Table 3). While the model input data based on the representative year remain the same, the new weather series is generated for each run. The parameters of the weather generator derived from the observed series (1961-1990) are used to generate weather series representing present climate. The parameters of the generator are modified in accordance with the selected climate change scenario to generate series representing the changed climate.

Table 3. Characteristics of representative years at seven test sites.

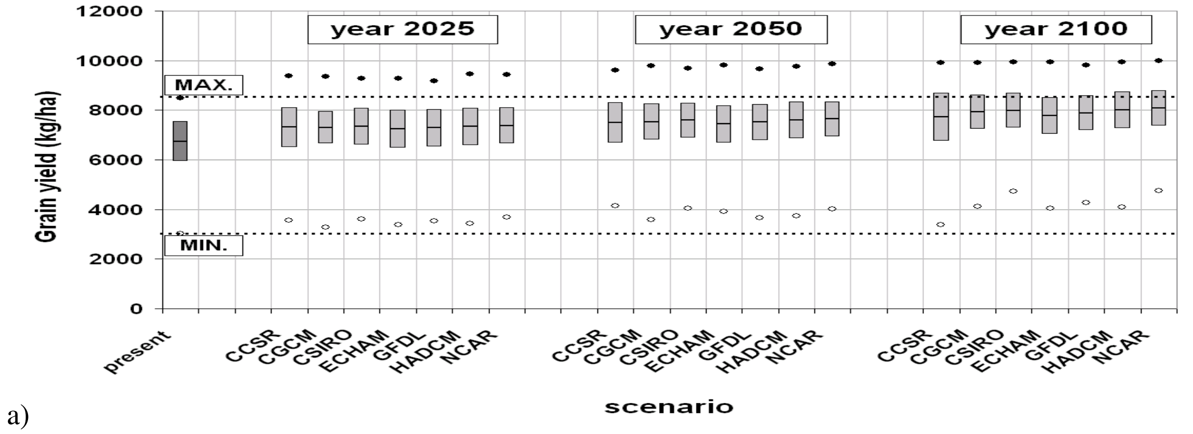
SITE	CZ_1	CZ_2	CZ_3	CZ_4	CZ_5	CZ_6	CZ_7
Representative year	1989	1996	1994	1992	1996	1993	1988
Sowing date	29th September	4th October	5th October	1st October	1st October	7th October	1st October
Harvest date	9th July	8th August	3rd August	28th July	1st August	17th August	19th August
Dose of N fertilizer (kg.ha^{-1})	90/3*	60/2*	75/2*	85/3*	100/3*	90/3*	60/2*
Initial available soil water in the soil profile (mm)	318	274	205	210	234	174	162
Sowing density (seeds.m^{-2})	500	400	400	400	400	500	500

* Number of applications

RESULTS AND DISCUSSION

Increase of temperature that is predicted by all scenarios would lead to shortening of the vegetation duration of winter wheat (interval from sowing till physiological maturity) by 4-71 days which is in accordance with results reported by number of similar studies (e.g. Tubiello *et al.* 2000 or Alexandrov and Eitzinger, 2002). The significance of this change clearly depends to a large extend on scenario used and reference time period because the differences in the predicted temperature increase between individual scenarios are great. The study confirmed that significant shift in the duration of the vegetation season is to be expected and by 2050-2100 (depending on the emission scenario used) the length of the winter wheat vegetation duration in the production areas with altitude over 600 m will equal to present values in lowlands (300 m and less). The change of the annual mean temperature expected according scenarios HadCM_B1_2050 and ECHAM_B1_2050 lays within interval 0.9-1.12°C and this would lead to shortening of the vegetation period by 2.3-3.5%. These findings correspond with the results of field experiments (e.g. Wolf *et al.*, 1998) with winter wheat cultivar Minaret at Clermont Ferrand (France) a Rothamsted (England) in temperature gradient tunnels. Increase of temperature during the grain filling period by 1.0°C lead to 2.6% shorter vegetation duration at Clermont Ferrand. The same temperature increment from sowing till maturity at Rothamsted caused the shortening of vegetation duration by 2.8%. With respect to different parameters of the used cultivar, its different vernalization requirements and also differences in the day length between these two sites and Czech conditions it can be stated that the simulated results correspond well with these field trials.

Impact of changed weather conditions on the winter wheat yields (not including CO_2 fertilization effect) would lead to yield depression, which would be the most severe in the lowland and midland sites. Applying ECHAM_A2_2050 and HadCM_A2_2050 resulted in yield reduction reaching up to 25%. Generally the sites in the regions with present low air temperatures would be the ones least affected by indirect effect of climatic change. The main reason for the yield reduction lays in temperature increase that



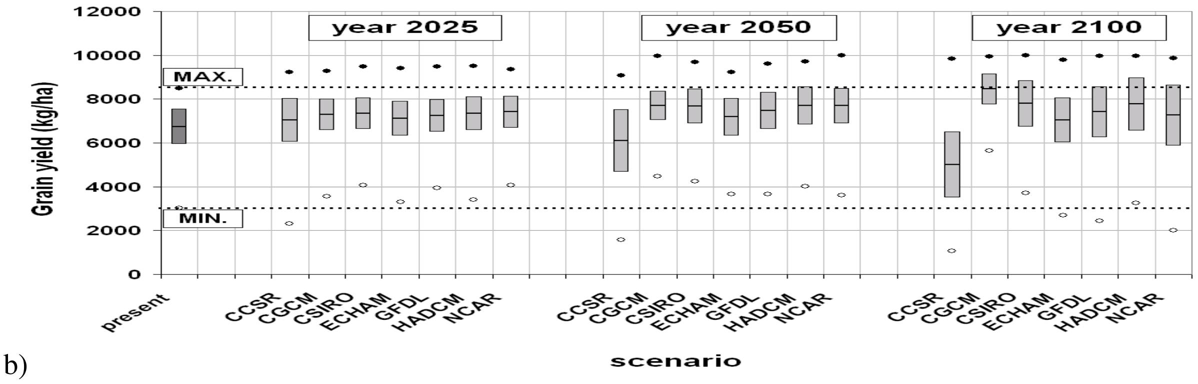


Fig. 1. Overview of simulated winter wheat yields both for present climatic conditions and combination of B1 emission scenario (a) and A2 emission scenario (b) with 7 GCM scenarios for three time periods. Each bar represents mean±std for 99 simulation runs performed at each of 7 test sites pooled together. White dots represent the lowest simulated yield attained out of all simulations (693 in total) for particular scenario, while black dot represent the absolute maximum of the simulated yields. Dotted lines parallel with x-axis represent the lowest and highest yields level under present climatic conditions

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besides shortening of the vegetation duration through speeding up developmental processes also influences respiration rates as well as assimilate partitioning. Generally lower amount of precipitation during some months is not sufficient to cover the increased evapotranspiration demand caused not only by higher temperatures but also by increased solar radiation sums. Simulated results presented in this study show yield reduction in interval 0-17% when scenarios HadCM_B1_2050 and ECHAM_B1_2050 were applied (estimated increase of annual mean temperature 0.9-1.2°C). Combination of the changed climatic conditions and increased CO_2 concentration on crop yields leads to inverse trends in grain yields than in the previous case. If the fertilizing effect is not included the yields would have reached 25-98% of present values while when the stimulating effect is accounted for yields might increase by as much as 25.3% by 2100 in comparison with the present conditions. The deviation could be easily explained by applying slightly different version of GCM and emission scenarios as well as by specific conditions of the region. Change of the grain yield depends on the used scenario and also on the locality (Fig. 1 and 2). Increase of grain yields under increased CO_2 level is influenced by the built in function of CERES-Wheat model that shows on average 9.5% yield increase per 100 ppm increase of CO_2 concentration under unchanged climatic conditions. This

Table 6: Deviations of the vegetation duration (period from sowing till maturity) and yield characteristics for individual scenarios in comparison with the present conditions (climate 1961-2000). Vegetation duration deviation is expressed in days, deviations of yield mean and STD deviations as the ratio of the yields and STD under changed conditions and present conditions. Deviations of the minimum and maximum yields are expressed as difference of the values simulated under changed and present climate. The values of first three characteristics in the table represent mean deviation for each scenario calculated from 99 simulations for each out of the 7 sites. Deviations of the minimum and maximum values are based on the lowest resp. the highest values on all seven sites both for the present and changed climate.

EMISSION SCENARIO TIME PERIOD	GLOBAL CIRCULATION MODELS						
	CCSR	CGCM	CSIRO	ECHAM	GFDL	HADCM	NCAR
DEVIATION OF THE VEGETATION DURATION [days]							
B1_2025	-10	-4	-6	-8	-7	-6	-6
A2_2025	-22	-8	-12	-16	-13	-11	-11
B1_2050	-15	-6	-9	-11	-10	-8	-8
A2_2050	-42	-13	-22	-29	-24	-20	-21
B1_2100	-23	-8	-13	-17	-14	-12	-12
A2_2100	-71	-25	-41	-56	-48	-41	-41
DEVIATION OF THE YIELD MEAN [%]							
B1_2025	+8.3	+8.3	+8.8	+7.3	+8.0	+8.7	+9.3
A2_2025	+4.3	+8.2	+8.9	+5.5	+7.3	+9.0	+10.0
B1_2050	+11.0	+11.6	+12.5	+10.3	+11.4	+12.6	+13.3
A2_2050	-9.6	+14.2	+13.8	+6.5	+10.9	+14.3	+14.0
B1_2100	+14.5	+17.4	+18.4	+15.2	+16.9	+18.8	+19.8
A2_2100	-25.8	+25.3	+15.5	+4.5	+9.8	+15.2	+7.5
DEVIATION OF THE YIELD STD [%]							
B1_2025	-1.3	-20.1	-9.3	-5.0	-7.7	-6.4	-10.1
A2_2025	+21.8	-12.1	-11.5	-2.8	-9.8	-5.5	-10.3
B1_2050	+0.7	-10.4	-12.9	-7.4	-10.8	-8.7	-13.2
A2_2050	+74.9	-17.1	-2.3	+5.2	+3.7	+6.7	-0.1
B1_2100	+20.1	-14.9	-14.5	-9.4	-14.0	-9.1	-13.5
A2_2100	+85.4	-12.7	+29.4	+25.3	+41.9	+49.6	+72.0
DEVIATION OF THE MINIMUM YIELD [kg.ha^{-1}]							
B1_2025	+514	+237	+585	+340	+496	+390	+657
A2_2025	-731	+514	+1027	+270	+910	+376	+1038
B1_2050	+1113	+539	+1008	+877	+630	+700	+992
A2_2050	-1457	+1428	+1207	+633	+639	+977	+573
B1_2100	+344	+1087	+1697	+1008	+1245	+1053	+1713
A2_2100	-1963	+2608	+681	-345	-593	+221	-1032
DEVIATION OF THE MAXIMUM YIELD [kg.ha^{-1}]							
B1_2025	+889	+851	+788	+780	+693	+960	+938
A2_2025	+738	+788	+978	+914	+1001	+1020	+869
B1_2050	+1115	+1292	+1190	+1324	+1178	+1258	+1374
A2_2050	+591	+1475	+1194	+726	+1113	+1207	+1486
B1_2100	+1428	+1423	+1440	+1437	+1329	+1452	+1503
A2_2100	+1347	+1443	+1505	+1298	+1463	+1461	+1361

value is in accordance with numerous experiments overviewed by Amthor (2001). Localities in the higher altitudes show the highest yield increase when the fertilizing effect of CO_2 is applied. The mechanism behind this fact seems to be optimization of temperature (and partly) precipitation regimes during the growing season. Under changed climatic conditions accompanied by increased CO_2 concentration it is reasonable to expect in the Czech Republic slight yield increase in the range of 4.3-10.0% by 2025, 6.5-14.3% by 2050 and 4.5-19.8% by 2100. However as it is apparent from Fig. 2b and Tab. 6 under the emission scenario A2 one scenario predicts mean yield decrease equaling to 9.6% and 25.8 by 2050 and 2100 respectively. It is necessary to add that besides the changes in climatic conditions and carbon dioxide concentration, change of no other parameters was considered in the presented study. Also eventual yield reductions due to weeds, pest, diseases or improper fertilization and soil management were not taken into account.

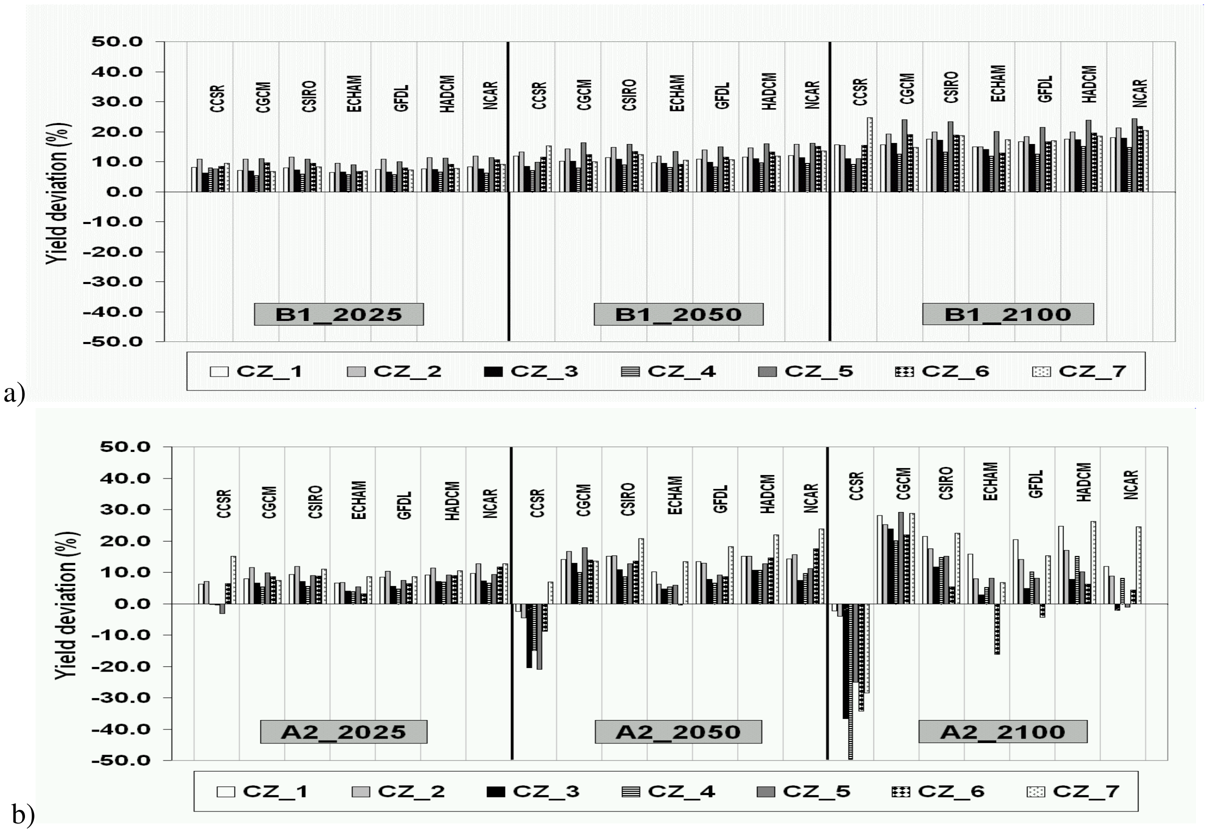

Fig. 2. Deviation of means yields expected under changed climatic conditions in comparison with the present (i.e. 1961-1990 climate based) yields for two applied emission scenarios B1 (a) and A2 (b), three time periods and seven GCM. Results were derived separately for each site as mean yield value out of 99 simulation runs for each site-scenario-time period combination.

CONCLUSIONS

Three conclusions can be drawn this study. Firstly wheat yields show on general increasing tendency (40 out of 42 applied scenarios) on most locations in range between 7.5-25.3% in all three time periods. In case of CSSR scenario that predicts the most severe increase of air temperature yield would be reduced by 9.6% in 2050 and by 25.8% if the A2 emission scenario would become reality. Differences between individual scenarios are large and statistically significant and especially for the more distant time periods may lead to doubts about the trend of the yield shift. Secondly site effect on the final quantity of climate change impact on winter wheat yield is caused by differences in the present soil and climatic conditions. Site effect increases with increasing severity of imposed climatic changes and culminates for emission scenario A2 and time period 2100. The sustained tendency benefiting the two warmest sites has been found as well as better response to the change climatic conditions of sites with deeper soil profiles than those with less suitable soil conditions. Thirdly temperature variability proved to be important factor and influenced both mean and standard deviation values of yields. Change of temperature variability by more than 25% leads to statistically significant changes in yield distribution however the effect of temperature variability decreases with increased values of mean temperature for latter time periods or A2 emission scenario. It is highly probable that similar effect will be found for other meteorological elements and therefore use of climate change scenarios accounting for possible changes in elements variability is highly desirable.

Souhrn: Nejistoty ve scénářích změny klimatu a jejich dopady na výnos pšenice ozimé byly analyzovány pomocí růstového modelu CERES-Wheat v kombinaci se stochastickým generátorem meteorologických dat. Růstový model byl evaluován na vybraných sedmi experimentálních místech a následně použit jako nástroj pro impaktovou analýzu založenou na vícenásobné simulaci a dvou emisních scénářích označených jako B1, kdy koncentrace CO_2 předpokládá pro rok 2100 hodnotu 548 ppm a A2 s předpokládanou koncentrací CO_2 826 ppm. Pro danou analýzu bylo využito sedm scénářů GCM s výstupy v časových hranicích 2025, 2050 a 2100. Simulované výsledky pro všechna tři testovaná období naznačují tendenci zvýšení výnosu (při 40 ze 42 použitých scénářů) v rozsahu mezi 7.5-25.3%.

Klíčová slova: růstový model, scénáře změny klimatu, emisní scénář, výnos**,**

Acknowledgement: This study was conducted with support of the Grant Agency of the Czech Republic, contract no. 521/02/0827.

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