WEATHER AND EXPECTED CLIMATE CHANGE IMPACT ON PERMANENT GRASSLANDS IN MESOHYGROPHYTIC LOCALITY*

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Paper presents an evaluation of weather impact (precipitation, temperature, Lang factor and evapotranspiration balance) on permanent grassland yields in two research mesophytic to mesohygrophytic localities (Černíkovice near Benešov, 363 m a.s.l., mean annual temperature 8.1 °C, annual precipitation 600 mm; Senožaty near Humpolec, 485 m a.s.l., 7.7 °C, 662 mm) in the Czech Republic. Consequently, also the potential climate change impact on the permanent grassland was researched for target year 2050 and 2080 based on two different climate change scenarios of Hadley Center global circulation model and stochastic weather generator LARS-WG. Results showed no direct yield dependency on weather, however extreme climate conditions could be the limiting factor especially in summer. That is more significant for nutrition-donated treatments. There were proved some dependencies of the yield on the Lang factor (Pearson test for Lang factor for June to August: $P = 2.056$, $F = 2.294$, $\alpha = 0.05$ for CGE), the correlation coefficients are generally not satisfactory. Climate change simulation proved expected increase in occurrence of extreme summer climate condition. The probability of extreme condition repeating in consecutive years will increase significantly during 21st century as well. Based on the results average yields reduction by 5 to 50% estimated depending on climate change scenario and N nutrition of the grassland were made.

permanent grassland; climate change; yield; climate; fertilization, weather

INTRODUCTION

As a climate change we understand statistically significant variations of the mean state of the climate or of its variability, typically persisting for decades or longer. Human activities, water management, agriculture and forestry especially, are vulnerable to expected climate change. The vulnerability is space-time dependent and may differ significantly as agreed many authors (e.g. Riedo et al., 1999; Arnell et al., 1999a, b). Kalvová et al. (2002) researched the potential climate change impact on water resources, agriculture, forestry and health for the area of the Czech Republic including the evaluation of different climate change scenarios relevance for the Czech Republic.

The climate change impact on the grassland ecosystems could be made in regional or global scale as grassland-forest boundary change (McGuire et al., 1995), or in the local scale as the climate change effect on production or biodiversity of grassland. Some climate change (CC) research studies used heating, rain-shelters and watering system for CC simulation (Jamieson et al., 1998) but majority of studies uses simulation of Global Circulation Models based on different CO_2 projections.

Not only the change in temperature and precipitation has to be taken into account, but also increased CO_2 concentration will cause changes in biomass production (Parton et al., 1995). While both factors could act in opposite way. Riedo et al. (1999) expect positive biomass production response to $2xCO_2$ increase, while the effect of temperature and precipitation change will be negative. Combination of both factors resulted in small but positive change of production. Hunt et al. (1991) found that precipitation and CO_2 increase accounted for the most of the variation among climate change treatment responses of soil, plants and microbes, while temperature depressed photosynthesis in the summer but extended vegetation season.

The purpose of this paper is to examine the weather effect on the permanent wet grassland yields in the Czech Republic including the impact of climate change as a possible limiting factor for continuous development of grasslands.

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MATERIAL AND METHODS

Černíkovice grassland experiment (CGE) was founded on mesophytic to mesohygrophytic meadow about 35 km south of Prague in 1966. Soil type was fluvisol – gleysol with loamy texture, $pH_{(KCl)}$ 5.0. Depth of underground water table oscillates between 0.1–0.7 m during the vegetation season. Senožaty grassland experiment (SGE) started on a mesophytic plain meadow in the highland of central part of the Czech Republic in 1976. Soil type was pseudogley with sandy-loam texture, $pH_{(KCl)}$ 5.1. Depth of underground water table oscillates between 0.3–1.0 m during the vegetation season (Mrkvička, Veselá, 2002).

Time series of meteorological data (temperature, precipitation, air pressure, humidity, sunshine duration and wind speed) were computed using data of near meteorological stations for both study areas. Time series covering the period 1961–2005 were reconstructed taking into account the distance of rain gauge for computing precipitation time series, while for temperature and air pressure the elevation correction was made (Table 1). Yield time series for different level of nutrition (N_{100}PK, N_{200}PK and no nutrition) were available for 1986–2005 (SGE) or for 1967–2005 (CGE), respectively.

Table 1. Study sites characteristics

	Latitude	Longitude	Altitude	Mean annual temperature*	Mean annual precipitation*
Senožaty (SGE)	49° 34’ N	15° 12’ E	485 m a.s.l.	7.7 °C	662 mm
Černíkovice (CGE)	49° 47’ N	14° 36’ E	363 m a.s.l.	8.1 °C	600 mm

* based on 1961–2005 period

Climate change projection

Kalvová et al. (2002) have find Hadley Centre Global Circulation Model (HADCM3) to provide reliable outputs for the area of the Czech Republic. Two basic HADCM3 scenarios (SRESA2, SRESB2) were used (IPCC-TGICA, 2007). SRESA2 scenario represents more pessimistic outlook of population and greenhouse gasses concentration growth, while SRESB2 scenario supposes moderate population growth and some towards in environmental protection. Target years 2050 and 2080 were taken into account (Table 2).

Downscalling using LARS-WG stochastic weather generator was applied (Semenov et al., 2002). LARS-WG provides outputs in the form of daily time-series for a suite of climate variables, namely precipitation (mm), maximum and minimum temperature (°C) and solar radiation ($MJ.m^{-2}.day^{-1}$). Two hundreds year time series of precipitation and temperature (to receive a sufficient number of realization for statistical evaluation) were generated for SRESA2 and SRESB2 scenario for target year 2050 and 2080 for both studied locations. The current climate conditions time series were also simulated.

Data was processed using STATISTICA 6.0 (Tukey HSD test) and CANOCO (RDA analysis) statistical packages and MS Excel.

Evapotranspiration model

Evapotranspiration (ET) balance is probably the most critical parameter affecting the growing conditions of forage. The Pennman-Monteith ET model (Monteith, 1965) as presented in FAO guidelines (Allen et al., 1998) was used in a statistical model based on approach introduced by Trnka et al. (2006). Model compares the potential and actual evapotranspiration to express the long-term (W_L) and short-term (W_S) water availability.

Long-term water availability is defined as follows:

$$W_L = t_{CL} \frac{ET_{aSE}}{ET_{rSE}} \tag{1}$$

Where ET_{aSE} is actual ET accumulation (in mm) from the start of the growing season, and ET_{rSE} is the corresponding reference ET value. Parameter t_{CL} representing the threshold of long-term water availability was set to 4.0 for CGE and 3.0 for SGE. Parameter defines that the reduction of biomass production appears when $ET_{aSE} < 25\%$ ET_{rSE} ($< 33\%$ ET_{rSE} respectively). Used t_{CL} values are relatively high if compared to those applied by Trnka et al. (2006), what is the response to good availability of underground water.

Table 2. Selected climate change characteristics

	SRESA2				SRESB2			
Target year	2050		2080		2050		2080	
Month	precipitation change (%)	temperature change (°C)	precipitation change (%)	temperature change (°C)	precipitation change (%)	temperature change (°C)	precipitation change (%)	temperature change (°C)
January	+10	+1	+25	+3.2	+10	+2.2	+20	+2.6
April	+40	+0.3	+47	+2.3	+34	+0.3	+21	+1.5
July	+9	+2.3	–19	+4.2	–11	+2.1	+3	+3.2
October	–16	+2.2	–25	+3.5	–11	+2.1	–20	+2.7

The start of the growing season was supposed to be the 81st day of the year.

Short-term water availability is defined as:

$$W_S = t_{CS}\frac{ET_{aW}}{ET_{rW}} \tag{2}$$

Where ET_{aW} and ET_{rW} are actual and potential evapotranspiration accumulated in previous 6 days. Parameter t_{CS} was set to 3.0.

Synthesis of both computed long and short time water availability factors is the total water availability factor:

$$W_A = \left[CW_L^M + (1-C)W_S^M\right]^{1/M} \tag{3}$$

Where C and M are model coefficients dependent on site characteristics (CGE $C = 0.6$, $M = 2$; SGE $C = 0.8$, $M = 3$).

The maximal and average values of W_A reached during the vegetation season were correlated to yield data.

Other climate statistics

Yield dependency on precipitation, temperature and Lang factor (eq. 4) was also examined.

$$L_F = \frac{P}{T} \tag{4}$$

Where P is precipitation total and T is average temperature for the selected period of time (month, vegetation season etc.).

RESULTS

Statistical Wilcox test ($P = 3.662$, $F = 4.244$, $\alpha = 0.05$) proved that CGE yields time series had a significant decreasing trend during 1967–1976, caused probably by succession of originally seeded sward. Therefore later evaluation was limited to 1976–2005 periods for CGE. Although that some dependencies of the yield on the Lang factor were proved (Pearson test for Lang factor for June to August: $P = 2.056$, $F = 2.294$, $\alpha = 0.05$ for CGE), the correlation coefficients are generally not satisfactory. In conclusion, there is no direct effect of common climatological criteria (temperature, precipitation or Lang factor) on yield for both study sites and all studied variants of nutrition. Nevertheless, the second cutting yield (made in September) is more connected to the climate characteristic than the first cutting (in June). A closer dependency on Lang factor (VI–VIII) was examined for N fertilized variants, if only years of low Lang factor values ($L_F < 3.5$ for SGE, $L_F < 3.0$ for CGE) were taken into account (Fig. 1). One can assume that only hot and dry summer means the limiting weather condition on wet grassland stands. Computed W_A (Figs 2 and 3) identified the driest years occurred in 1976–2005 period: 1976, 1990, 1996 and 2003 for CGE; 1992, 1993, 1994, 1998, 2000, 2003 and 2005 for SGE. But no dependency of summer yields on W_A was proved.

All the results suggest that in the case of 2003 the weather was the limiting factor of the yield. Therefore the characteristics of August 2003 were taken as a threshold to be compared to weather change simulation results (Fig. 4). It is obvious that summer of 2003 was extraordinary dry and hot comparing to the weather conditions of reference period 1961–1990. Although some lower precipitation amounts for summer months were simulated, the combination of high temperature and low precipitation was exceptional in August 2003. However, this should be partly caused by a slide tendency of underestimation of high temperatures by LARS-WG.

Simulated time series were sought through for the Augusts with lower precipitation total and higher average temperature than August 2003. There is sudden increase of the occurrence of extreme years with weather change. While there had been occurring no such a year in the base weather simulation, 2–6% of years suit to the criterion for target year 2050. The number of extreme years increased up to 27–39% for target year 2080 and SRESA2 scenario (Table 3). Increasing percentage of the extremely dry and hot summers will lead also to higher occurrence of consecutive years of extreme weather conditions.

Quantitative estimation of climate change impact on grassland yields could be only concerned as the approximate guess of possible development under changed climate. Supposing the same botanical composition of sward, the same biomass production during not limiting climate conditions period and founded regression for $L_F < 3.0$ (CGE), $L_F < 3.5$ (SGE), respectively, the following assumptions could be made:

- Decrease of number of years, in which L_F is not the limiting factor of yield ($L_F > 3.0$ for CGE, $L_F > 3.5$ for SGE) from 76% nowadays to 48–57% (SRESB2, and SRESA2 in 2050), respectively to 15–20% (SRESA2 in 2080), respectively;

Table 3. Occurrence of extremely dry and hot August according to climate change conditions

	CGE					SGE				
	base climate	SRESA2 2050	SRESB2 2050	SRESA2 2080	SRESB2 2080	base climate	SRESA2 2050	SRESB2 2050	SRESA2 2080	SRESB2 2080
Number of years	0	8	12	77	15	0	4	6	54	7
Occurrence (%)	0	4	6	38.5	7.5	0	2	3	27	3.5
Average dry spell duration (years)	0.00	1.00	1.09	1.65	1.08	0.00	1.00	1.00	1.24	1.00
Longest dry spell (years)	0	1	2	4	2	0	1	1	3	1

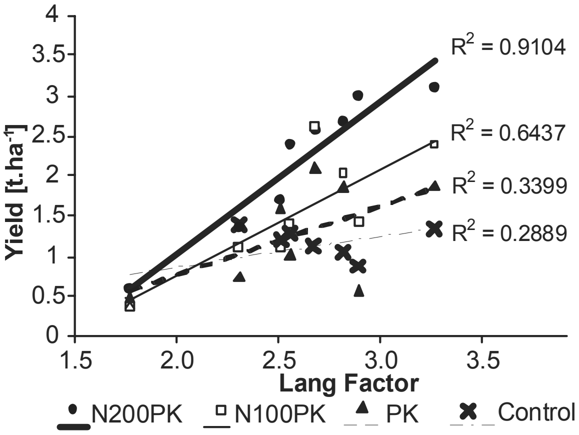

Fig. 1. Lang factor (L_F < 3.5) dependency for SGE

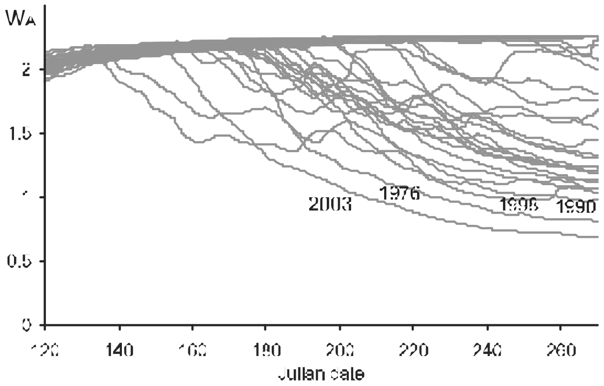

Fig. 2. Evapotranspiration model outputs for CGE

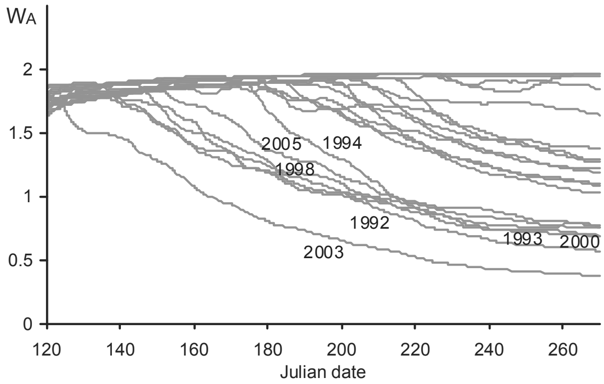

Fig. 3. Evapotranspiration model outputs for SGE

- Decrease of average yield for the years when L_F is limiting by 10 to 30% (according to found dependencies – Fig. 1);
- Consequent decrease of overall average yield for CGE non-nutrient treatment by 20% (0.77 $t.ha^{-1}$) for SRESA2 in 2080 and about 5% (0.2 $t.ha^{-1}$) for other scenarios and target years;
- Decrease of overall average yield for CGE high-nutrient treatment by 40% (2.8 $t.ha^{-1}$) for SRESA2 in 2080 and about 8–12% (0.6–0.9 $t.ha^{-1}$) for other scenarios and target years;
- Decrease of overall average yield for SGE non-nutrient treatment by 12% (0.12 $t.ha^{-1}$) for SRESA2 in 2080 and approximately the same yield in other scenarios (however, used regression is very week in this case);
- Decrease of overall average yield for SGE high-nutrient treatment by 15% (0.3 $t.ha^{-1}$) for SRESA2 in 2050, by 50% (1.15 $t.ha^{-1}$) for SRESA2 in 2080, and by 10% (0.2 $t.ha^{-1}$) for SRESB2 in both time horizons.

DISCUSSION

The evaluation of weather impact on wet grassland biomass production proved that there is no significant direct correlation between weather characteristics and yield at study sites during the whole evaluated period. Reason should be the different response of particular species to temperature and precipitation as found Alward et al. (1999) for the grassland ecosystem in Colorado, USA. Their research proved negative correlation of minimal temperature and the presence of dominant grass *Boutloua gracilis*, while f.e. exotic herbs were correlated positively. Nevertheless, some responses should be secondary result of changed competition interactions. The permanent grassland is a complicated ecosystem and its interaction to weather is not so clear as in the case of monocultures (Long, Hutchin, 1991). Missing data of botanical composition before 2004 did not enable the research of particular species response to the weather for studied grassland experiments.

Anderson (1991) states that a short-term response in soil processes are more predictable in well-drained grassland soils. Results of this study support this idea, as the yield dependency on weather was not significant in majority of cases. The lack of dependency is caused by the sufficient source of the underground water (water table is usually in the depth of 0.3–1.0 m). Therefore the grassland does not suffer by water stress even in dry years with high evapotranspiration demands and low precipitation. The only exception was the extraordinary hot and dry summer of 2003 with too high water stress even in study sites. It is very difficult to try to evaluate possible impact of weather change on underground water regime in both localities. Taking into account that majority of permanent grassland in the Czech Republic covers well drained slopes; one can assume the higher and sooner negative impact of stressing climate condition under the climate change on grasslands than in studied wet stands.

However, extreme weather characteristic such as hot and dry summer season affects the yields in the meaning of it decrease as documented for the year 2003. Such extreme years mean stressing of the grassland ecosystem, which results in the small yield but potentially also could lead to decrease of ecosystem quality in the meaning of biodiversity and species composition (to more xerophilous species) etc. This corresponds to the results of White et al. (2000), who proved the changes in species composition after extreme heat and precipitation stress. They also found no persistence effect of single extreme "climate"

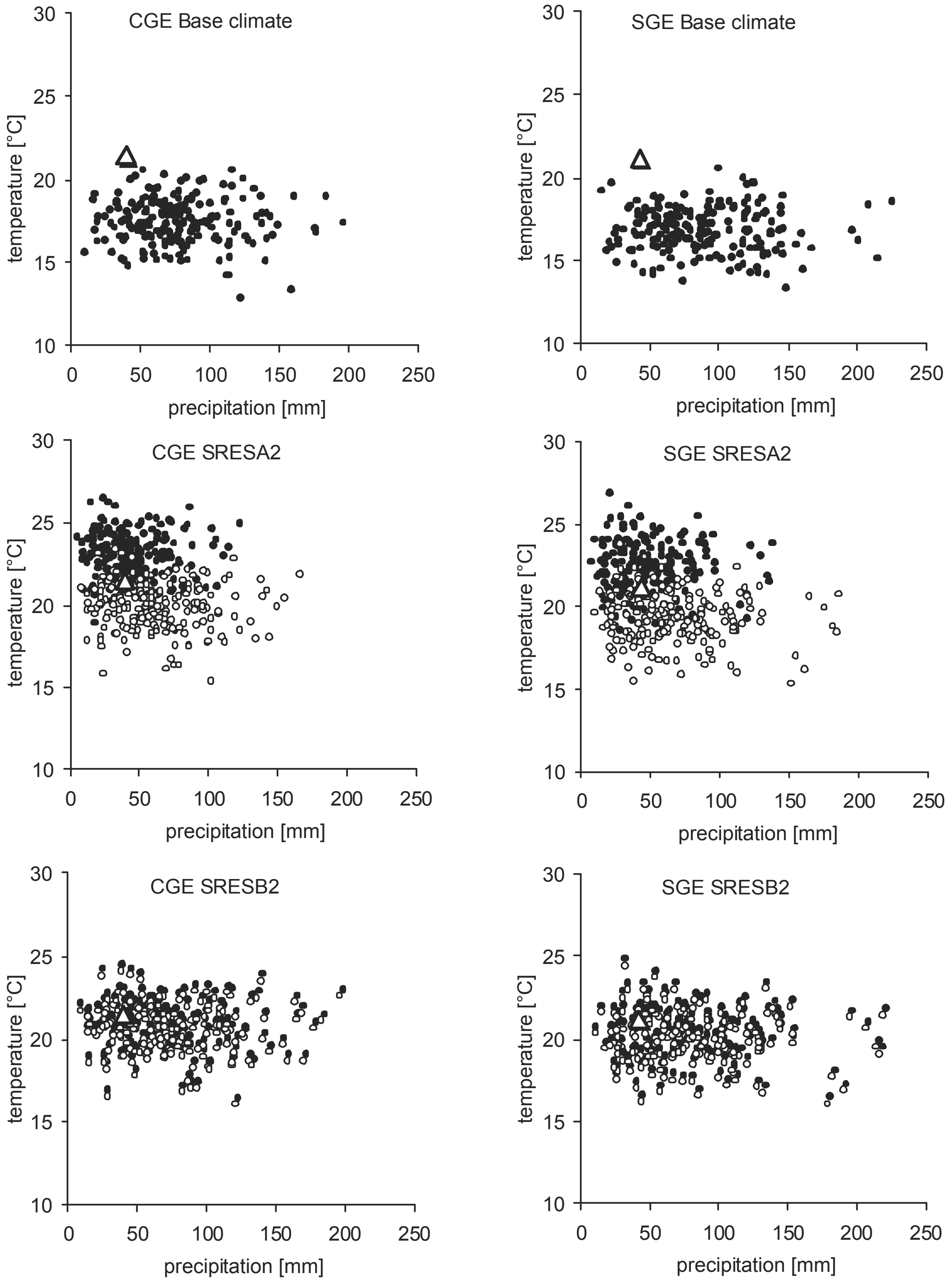

Fig. 4. Simulated August characteristics for CGE and SGE after the climate change compared to August 2003 characteristics (triangle), white dots = year 2050, black dots = year 2080

event on community composition or soil nitrogen in next year. However the question of the effect of consecutive years of weather stressing conditions, as simulated in this study, is not satisfactory answered yet. In later work, White et al. (2001) expect the increasing invasions of fast growing annuals species. It could be supposed that increasing weather stress would result in botanic composition changes preferring more steppe species.

In accordance to expectation the more climate dependency was found for N fertilized variants, as the N cycle in the soil is highly dependent on free water availability in the zone of aeration of the soil. The same found Gough and Hobbie (2003) in arctic tundra environment, where increasing temperature did not lead to increase of yield or change in species richness itself, but the nutrition was the main factor in biomass production and biodiversity. Underground water, available in study sites, satisfies the evapotranspiration demands of plant as absorption is made the though deep root system, but does not interact with the soil and added N fertilizers. This is in conform with Grime et al. (2000) conclusions that more fertile, early succession grassland is much more responsive to climate change, and in general artificial landscape patterns may prove more vulnerable to climate change than traditional landscape patterns.

Simulation of climate change impact on the plants in the meaning of biodiversity change etc. has to take into account not only change the of the climate but also changed CO_2 as simulated by Thornley and Cannell (1997) or Riedo et al. (1999).

CONCLUSION

Two study sites of permanent grassland were researched from the point of view of weather impact on yields. Although results did not prove the direct and clear weather impact on yields (because of availability of underground water on the study locations), the role of extreme weather condition as a limiting parameter for grassland development and production was proved. Simulation of the changed weather condition shows that the number of years of limiting climate condition is going to increase significantly during the 21st century. That will probably affect the grassland ecosystems in many ways. Decrease of yield by 5 to 50% could be the result of changed weather. In addition, more frequent stressing weather conditions would probably reflect not only in the landscape function of permanent grasslands and meadows but also in its flood protection function that is stressed in last years as one of the most important structural measure in flood prevention system.

Results show the need of more research in the field of weather impact on the grassland in dry localities, where the dependency on weather is more significant. Future research should focus also on the possible biodiversity composition change in changed weather conditions. Adaptation to weather change could include nutrient management of permanent grassland to ensure its demanded environmental functions.

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Vliv očekávané klimatické změny na výnosy trvalých travních porostů.

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Cílem studie bylo posouzení vlivu počasí, včetně očekávané klimatické změny, na výnosy trvalých travních porostů. Hodnocení bylo provedeno na dvou dlouhodobých pokusech katedry pícninářství a trávníkářství ČZU v Praze: v Černíkovicích (okr. Benešov, mezofytní až mezohygrofytní stanoviště, 363 m n. m.) a Senožatech (okr. Pelhřimov, mezofytní stanoviště, 485 m n. m.). Data byla zpracována pro období 1976–2005 (Černíkovice), resp. 1986–2005 (Senožaty). Posuzován byl rovněž vliv různé úrovně hnojení NPK ve srovnání s nehnojenou kontrolní variantou. Dopad klimatické změny byl hodnocen na základě dvou vybraných klimatických scénářů HADCM3 SRESA2 (pesimističtější varianta vývoje) a SRESB2 (optimističtější varianta vývoje). Pro ně byly stochastickým generátorem počasí LARS-WG vytvořeny 200leté řady teplot a srážek odpovídající současnému a změněnému klimatu k roku 2050 a 2080. Z výsledků vyplývá, že na hodnocených stanovištích nebyl prokázán jednoznačný vliv počasí (evapotranspirační bilance, srážky, teploty, Langův faktor) na výnosy, což lze vysvětlit dostatečným zásobením stanoviště podzemní vodou po celé vegetační období a rozdílnou reakcí jednotlivých rostlinných druhů na klimatické podmínky. Hnojené varianty reagovaly výrazněji na množství srážek potřebných k mobilizaci a zpřístupnění živin pro rostliny. Bylo prokázáno, že extrémní počasí v letním období (sucho a vysoké teploty, např. v roce 2003) jsou limitujícím faktorem pro produkci trvalého travního porostu a simulace klimatické změny potvrzuje významný, mnohonásobný nárůst extrémních let odpovídajících podmínkám roku 2003 v průběhu 21. století. To pravděpodobně ovlivní trvalé travní porosty ve smyslu jejich botanického složení i funkce.

trvalé travní porosty; klimatická změna; výnos; klima; hnojení

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