EFFECTS OF CLIMATE CHANGE ON GRASSLAND PRODUCTION IN SWITZERLAND

J. Fuhrer and M. Riedo
Swiss Federal Research Station for Agroecology and Agriculture Institute of Environmental Protection and Agriculture (IUL Liebefeld)
CH-3003 Bern, Switzerland

ABSTRACT

A mechanistic model for productive grassland was used to simulate annual dry matter yield in relation to fluxes of C, N, and water, and to test the sensitivity to climate change and to elevated [CO_2] (2xCO_2). Local weather scenarios were derived from the results of two General Circulation Models (GCM) by statistical down-scaling. Annual yield increased by a maximum of 10% without 2xCO_2 effects, by 1-16% in response to 2xCO_2, and by 6-24% with the combination of climate change and 2xCO_2. Decreased evapotranspiration and increased water use efficiency in response to 2xCO_2 were partially offset by climate change. The simulations indicated that productivity of grassland is sensitive to changes in climate and elevated [CO_2], and that the effects of CO_2 are modified by climate change, and hence depend on local soil conditions.

KEYWORDS

climate change, elevated [CO_2], grassland, productivity, evapotranspiration

INTRODUCTION

Grasslands cover a major portion of the agricultural land in Switzerland. Structural and functional changes in grasslands due to future climate change and elevated [CO_2] may thus have important effects on the country's forage production, but also on the energy balance of the non-forested land area. With the aid of models, the sensitivity of grassland to climate change scenarios (CC) can be assessed singly and in combination with elevated [CO_2] (2xCO_2). At the global scale, simulations for temperate grasslands revealed small potential increases in productivity in response to CC, but larger changes caused by doubled [CO_2] (Melillo et al. 1993, Parton et al., 1995). The aim of the present study was to assess the sensitivity of productive pastures to CC and elevated [CO_2] under the conditions of the Swiss Central Plateau, by using a mechanistic ecosystem model driven by hourly local weather data.

MODEL DESCRIPTION

The model integrates the dynamics of carbon (C), nitrogen (N), and water in a permanent grassland ecosystem. It is composed of submodels for vegetation, microclimate, soil physics, and soil biology. Hourly data for radiation, temperature, vapour pressure, wind speed, and precipitation are used as the driving variables. These data were obtained from meteorological stations (present climate), or by a statistical down-scaling procedure using results from General Circulation Model (GCM) simulations (Gyalistras et al., 1994) (climate change, CC). Management options include mineral fertilisation and cutting. Site specific model parameters include the fractional clover content, the depth of the main rooting zone, and several soil physical parameters. The time step is one hour, and the time scale covers one growing season. The model accounts for reproductive and vegetative growth stages of grasses and allows for the dynamic change in the fractional N content of plant structural dry matter. Plant dry matter is divided into structural dry matter, plant C substrate, and plant N substrate. Leaf photosynthetic rate, P_1 (mmol m^{-2} s^{-1}), is given by the solution of the equation for a nonrectangular hyperbola,

$$\theta_p P_1(I)^2 - (\alpha I + P_m)P_1(I) + \alpha I P_m = 0 \,, \quad (1)$$

where I is the leaf incident PAR radiation (W m^{-2}), q_p is the curvature parameter, a is the photosynthetic quantum efficiency (mmol J^{-1}), and Pm is the light-saturated leaf photosynthetic rate (mmol m^{-2} s^{-1}) which depends on the developmental stage, leaf temperature, and plant nitrogen concentration. Also, a factor $P_{m,CO2T}$ determines the temperature dependent effect of [CO_2] on leaf photosynthesis:

$$P_{mCO2T} = V_{cmax,\ acclim} A_{max} / A_{max,\ 350} \,, \quad (2)$$

where A_{max} is the light saturated rate according to the Farquhar & von Caemmerer (1982) leaf photosynthesis model, and $A_{max,350}$ is the value of A_{max} for the 'current' atmospheric CO_2 concentration of 350 mmol mol^{-1}. $V_{cmax,adap}$ is a parameter with values between 0 and 1 which accounts for a reduction in V_{cmax} [eqn (4)] due to the acclimation of leaf photosynthesis to elevated [CO_2]. $P_{m,CO2T}$ is calculated in such a way that at all temperatures its value is equal to 1 for Ca = 350 mmol mol^{-1} for all temperatures. The microclimate sub-model is used to calculate the canopy interception of short-wave radiation, and to calculate canopy and soil energy balance. The soil biology sub-model is used to calculate the concentrations of NO_3^- and NH_4^+ in the soil. The soil physics sub-model calculates the water content and temperature in different soil layers. Most of the model parameters were derived from the literature, and some from field measurements. A more detailed description of the model is given elsewhere (Riedo, 1996).

The model was tested by comparing the simulation results with measured data obtained in two consecutive years at sites differing in altitude. The comparison revealed satisfactory agreement for annual dry matter production (yield), N-yield, and seasonal evapotranspiration (ET) (not shown).

RESULTS AND DISCUSSION

Simulations were carried for three sites (Payerne, Bern, La-Chaux-de-Fonds) differing in altitude and soil conditions. Table 1 summarises the data for yield, ET and water use efficiency (WUE) calculated for present climatic conditions and current [CO_2] (350 ppm). The data are means for 1981-1994. With weather scenarios for each site, changes in response to CC, 2x[CO_2] with or without plant acclimation to elevated [CO_2] (CO_2), and all possible combinations of CC and CO_2 options were calculated. The results are shown in Fig. 1.

According to the down-scaling procedure, the change in local climate during the growing season is characterised by increased mean temperature (1.8-2.8^{o}C), increased vapour pressure deficit, reduced precipitation, and increased wind speed (not shown). With CC, annual yield tended to be higher compared to the reference. Reduced yield was possible for sites with unfavourable soil conditions (low water holding capacity). Seasonal ET clearly increased with CC, whereas WUE declined. With elevated [CO_2], gains in productivity depended on assumptions about acclimation of plants to elevated CO_2, but higher productivity can be expected with a concomitant decrease in ET and increased WUE. The positive effect of CO_2 on yield declined with altitude, possibly due to the decrease in $P_{m,CO2T}$. Yield increase was largest with the combination of CC and CO_2. The data for WUE suggest that with 2xCO_2 in combination with CC higher productivity is accompanied in most cases by increased resource use efficiency.

In conclusion, these simulations for Swiss grasslands between 500 and 1000 m a.s.l. indicate that forage production is sensitive to assumptions about climate change and elevated [CO_2], and that except for sites with less favourable soil conditions with respect to water retention, significant increases in productivity are obtained with the given scenarios.

REFERENCES

Farquhar G.D. and S. von Caemmerer. 1982. Modelling of photosynthetic responses to environmental conditions. In: *Physiological Plant Ecology II. Encyclopedia of Plant Physiology, New Series*, Vol 12B (Lange OL, Nobel PS, Osmond CB and H. Ziegler H eds.), Springer Verlag, Berlin, pp. 549-587.

Gyalistras D., von Storch H., Fischlin A. and M. Beniston. 1994. Linking GCM-simulated climatic changes to ecosystem models: case studies of statistical downscaling in the Alps. Clim. Res. **4**: 167-189.

Mellilo, J.M.,McGuire, A.D., Kicklighter, D.W., Moore, B. III, Vorosmarty, C.J. and A.L. Schloss. 1993. Global climate change and terrestrial net primary productivity. Nature **363:** 234-240.

Parton, W.J., Scurlock, J.M.O., Ojima, D.S., Schimel, D.S., Hall, D.O. and Scopegram Group Members. 1995. Impact of climate change on grassland production and soil carbon worldwide. Global Change Biol. **1**: 13-22.

Parton, W.J., Schimel, D.S., Cole, C.V. and D.S. Ojima. 1987: Analysis of factors controlling soil organic matter levels in Great Plains grasslands. Soil Sci. Soc. Am. J. **51**: 1173-1179**.**

Riedo, M. 1996. Sensitivität des Ökosystems Dauergrünland auf Klimaänderung und erhöhte atmsophärische CO_2-Konzentration - Entwicklung, Test und Anwendung eines Modells. PhD Dissertation, University of Bern, Switzerland, 129pp.

Table 1
Mean of annual dry matter yield (*Y*), seasonal evapotranspiration (*ET*), and water use efficiency (*WUE*) for three sites during 1981-94 with current [CO_2] (reference scenario) (altitude in m above sea level).

Sites	Payerne	Bern	La Chaux-de-Fonds
	490 m	565 m	1018 m
Y , kg m^{-2}	1.367	1.383	1.157
ET , mm	549.6	535.8	487.2
WUE , g kg^{-1}	2.49	2.59	2.39

Figure 1
Changes in dry matter yield (*a*), evapotranspiration (*b*), and water use efficiency (*c*) of productive grassland at different Swiss sites in response to different climate change scenarios (CC), elevated [CO_2] with or without plant acclimation (CO_2), or combinations of CC and CO_2 (CC+CO_2), relative to 1981-1994. The median of all simulation results is shown inside the box indicating the 25th and 75th percentiles, capped bars and filled circles indicate the 10th and the 90th, and the 5th and 95th percentiles, respectively.