CLIMATE CHANGE, STAND STRUCTURE AND THE GROWTH OF FOREST STANDS

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1 INTRODUCTION

Many studies in forest science deal with the responses of forests on environmental changes in climate and CO_2-concentration, most of them showing a rise of net primary production under higher CO_2-concentrations and elevated temperatures (e.g. Lewis et al. 2001, Hamilton et al. 2002). The influence of other environmental parameters as for example stand structure, level of stress, or management impact on growth in combination with climate change is, however, analysed insufficienly up to present. Physiological growth models are suitable tools for analysing these multiple influences on growth and their interactions (e.g. Sinoquet and Le Roux, 2000). In these model types the different physiological processes are described separately in response to environmental parameters, whereby the interactions lead to integrated results that are not previously parameterized. Thus, new combinations of environmental conditions can be investigated. In this study the impact of different climate change scenarios on the growth of forest stands was analysed taking different stand structure types into account.

2 METHODS

Values of South German level II plots form the database for this study. At these plots all necessary data for initialisation and validation of the model as well as the driving forces of growth (climate and deposition data) are available. A description of the plots can be found in www.lwf.bayern.de.
The physiological growth model BALANCE calculates the 3-dimensional development of individual trees or forest stands and estimates the consequences of environmental influences. As an individual tree model BALANCE simulates growth responses on the single tree level, which enables also an estimation of the influence of competition, stand structure, species mixture, and management impacts because tree development is described as a response to individual environmental conditions and environmental conditions change with each individual tree development. Dimensional tree growth is calculated once a year based on the biomass increase of the woody tissue that has been accumulated during the last year by each single tree. Biomass of an individual tree is calculated from the dimensional variables tree position, tree- and crown base height, diameter, and crown radii. The increase in biomass is the result of the interaction of several physiological processes which depend on the physical and chemical microenvironment that is itself influenced by the stand structure. The individual carbon-, water- and nutrient balances of the trees species beech, oak, spruce and pine are the fundamental processes for the simulation of growth. Each tree is structured in crown and root layers, which are in turn divided in up to 8 crown- and root sectors. For each layer resp. each sector micro climate and water balance are calculated by using temperature, radiation, precipitation, humidity and wind speed measurements from climate stations. While these calculations are computed daily, the physiological processes assimilation, respiration, nutrient uptake, growth, senescence and allocation are calculated in monthly or decadal time steps (= 10-day periods) from the aggregated driving variables. This way, CO_2-concentration, soil condition, competition between individuals, and stress factors, as for example air pollution and nutrition deficiency, can be considered besides the weather conditions. Based on the individual carbon balance, dimensional changes and mortality of a tree are computed annually. To depict the relationships between the environmental influences and growth the annual cycle of foliage development must be known. With the beginning of bud burst foliage, biomass and leaf area as well as light availability and radiation absorption change. Thus, the date of foliage emergence in a tree determines its assimilation and respiration rate but also affects the environmental conditions of the trees in its vicinity. In BALANCE the beginning of bud burst is modelled by using a temperature sum model (Rötzer et al. 2004), while foliage senescence is estimated in dependence on the respiration sum. Because tree development is described as a response to individual environmental conditions and environmental conditions change with the individual tree developments, environmental influences can be assessed in any kind of species mixture or stand structure. A more detailed description of the model can be obtained in Grote and Pretzsch (2002) resp. in Rötzer et al. (2005).

3 RESULTS

MODEL VALIDATION

In order to validate BALANCE simulated values were compared to measured ones (soil water content, bud burst and leaf colouring, diameter at breast height, tree height and crown density) at six level II plots. The validation results show that BALANCE simulates realistically the water cycle in forest stands. Figure 1 presents a comparison of simulated and measured soil water contents under a beech stand at the level II plot "Freising"

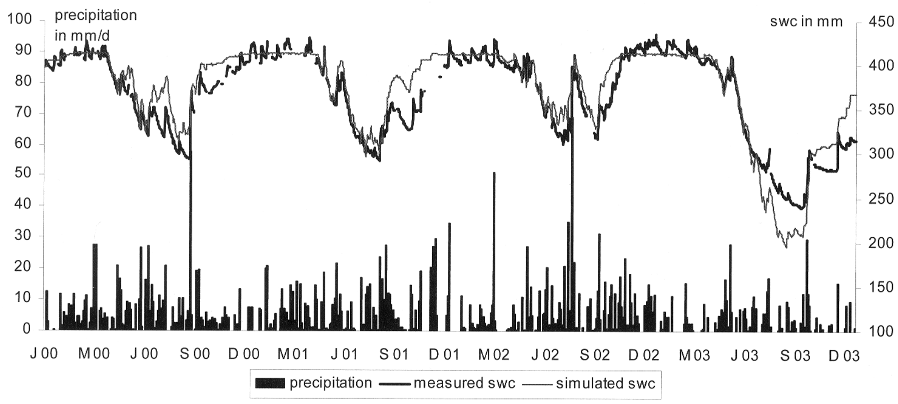

Fig. 1: Measured and simulated daily values of the soil water content *swc* for the beech stand at the level II plot 'Freising' (soil depth 120 cm) for the period 2000 - 2003

While the mean absolute error MAE of the soil water content at the plot 'Freising' was 3.5% (100%-basis: field capacity), the values for the other 5 plots range between 2.5% and 7.3%. When simulated and observed values of the annual start and end of the vegetation period expressed by bud burst and leaf colouring are compared, good accordance is apparent (Rötzer et al. 2005). The validation of the growth parameters showed that the differences between measured and simulated tree diameters (at breast height) were smaller than 1% for spruce, smaller than 6.5% for beech both after 7 years of simulation, and smaller than 1% for oak after 8 years of simulation. The simulations for pine trees, however, conform less with measurements (22.6% difference after 8 years). Compared to the diameter results the findings obtained for tree height were similar. Crown density values are also estimated in a sufficient way. The overall validation results show that for central European regions BALANCE simulates realistically the growth of forest stands, particularly for the tree species beech, oak and spruce, on the base of single tree modelling (Rötzer 2004, Rötzer et al. 2005).

SCENARIOS

In a first step the sensitivity of tree growth on climatological changes was examined. Temperature was increased gradually, whereas precipitation was decreased. Radiation was held constant at 110% for all simulations with a temperature increase. Initial data for the simulations were taken from the level II beech stand 'Freising'. The climate of the years 1994 - 2003 was used as control run. Fig. 2 shows the mean biomass increment of a beech stand within 10 years in dependence on rising temperatures and decreasing precipitation sums.

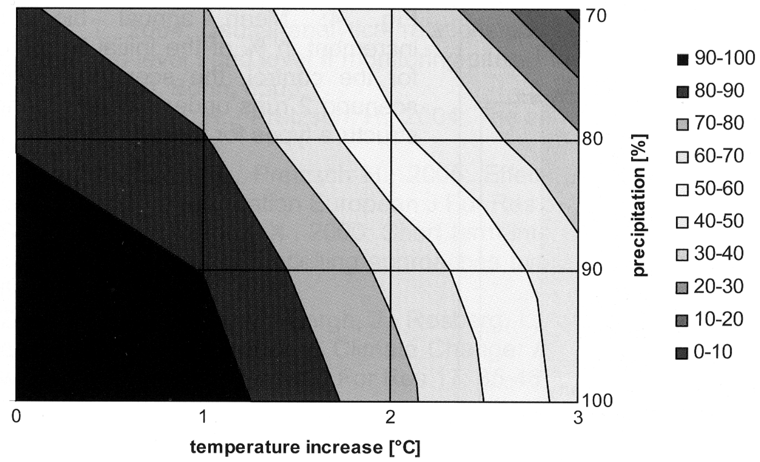

Fig. 2: Biomass gain of a beech stand [%] in dependence on temperature increase and precipitation decrease after 10 simulation years at the level II plot 'Freising' (100%-base: controll run at a temperature increase = 0°C and a precipitation = 100%)

It can be seen in Fig. 2 that with increasing temperature biomass gain is reduced up to 50% (temperature increase 3°C). If, additionally, precipitation is reduced to 70% of the control run, a 50% biomass reduction is obtained already at a temperature increase of 2°C. When precipitation is reduced to 70% and temperature is increased for 3°C, biomass increment shrinks to values lower than 10% compared to the control run.

For analysing the impact of further environmental changes on tree growth a temperature increase of 3°C, a radiation increase of 10% and a precipitation decrease of 20% was assumed for scenario 1. In addition to scenario 1, the CO_2-concentration was doubled for scenario 2. The course of the annual biomass gain of a beech stand at two different sites ('Freising' and 'Mitterfels') is shown in Fig. 3 for the control run, the scenario 1 and the scenario 2 runs.

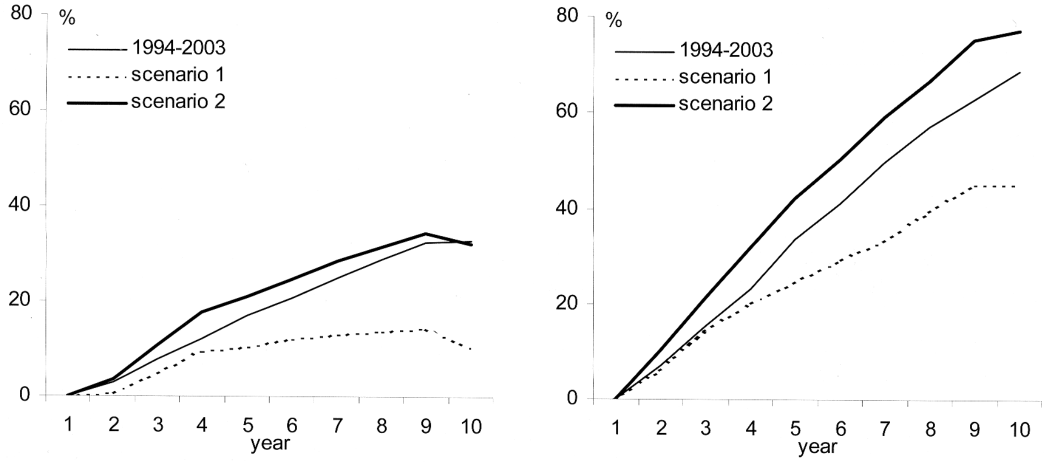

Fig. 3: Annual biomass increment of a beech stand in % of the initial values at the level II plots 'Freising' (left) and 'Mitterfels' (right) cumulated for 10 years of simulation

As expected for scenario 1 the growth of beech trees, i.e. the biomass increment, is distinctly smaller at both plots than the increment of the control run. The difference of the biomass gain between control and scenario 1 runs is almost equal at both plots. Compared to the control run the increment under scenario 2 conditions varies at the two plots. At the plot 'Mitterfels', which is situated in the Bavarian Forest at 1025 m asl., scenario 2 produces a clearly higher biomass increment, whereas at the plot 'Freising', situated in southern Bavaria at 508 m asl., biomass gain of the control and the scenario 2 runs are almost equal. The different gains of the single runs at the two plots are definitely based on the different stand conditions of both forest stands.

Besides a climate change and a doubling of the CO_2-concentration, in further simulation runs also species mixture and stand density were taken into account. For the level II plot 'Freising' tree growth was computed for the original beech stand, for a beech stand with a 20% reduction of stand density and for two mixed stands (beech with 20% oaks and beech with 20% spruces) under present climate (control run) and scenario 1 and 2 conditions. Fig. 4 shows the results for the mean annual biomass increment.

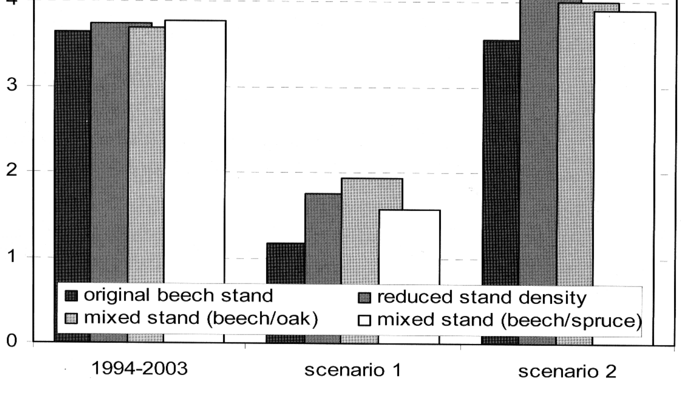

Fig. 4: Mean annual biomass increment in % of the initial biomass for the control, the scenario 1 and scenario 2 runs under different stand structure types for the plot 'Freising'

If the number of trees was reduced by app. 20%, which means less competition for light, water and nutrients, biomass rises every year by 3.7% for the control run, by 1.8% for scenario 1 and by 4.2% for scenario 2. If 20% of the trees are exchanged by oak resp. spruce, the annual biomass increment is 3.7% resp. 3.8% for the control run. Compared to the biomass gain of 1.2% per year for scenario 1, the percentages for the beech/oak stand resp. the beech/spruce stand are obviously higher with 1.9% resp. 1.6%. A clear difference in the biomass increment between the pure and mixed beech stands is also apparent for the scenario 2 run (pure stand: 3.6%, beech/oak stand: 4.0%, beech/spruce stand: 3.9%). Similar results can be found for other parameters which describe the growth of forest stands, e.g. diamater, tree height.

4 DISCUSSION AND CONCLUSION

BALANCE has been proved to be a powerful tool for the simulation of tree growth of central European forest stands. By calibrating and validating further sites, the area of application can be extended. The sensitivity of the model on environmental changes (e.g. climate and stand structure) and on combinations has been demonstrated. Causal analyses on the relationships of the site specific factors and growth are possible. Scenario studies with BALANCE show that climate changes have strong influences on the growth of forest stands. The extent to which climate and CO_2-concentration changes control the tree growth, strongly depends on the stand conditions as well as on the level of changes (see also Lewis et al. 2001; Zheng et al., 2002 ; Bergh et al., 2003; Mäkinen et al., 2003). A higher CO_2-concentration can increase growth or compensate growth reduction induced by climate change. Modified stand structure types can also influence tree growth. Already small changes in stand structure (20% reduction of stand density, 20% change of tree species) cause a clear change in the annual biomass increment. To analyse the multiple influences, interactions and feedbacks of changing environmental conditions on forest growth, further studies, e.g. at the free-air ozon- und CO_2-fumigation experiment Kranzberg/Germany, have to be done.

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