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The effects of landscape structures on microclimatic crop growth conditions and their potential to adapt to climate change.

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Abstract. Knowledge about small scale spatial climate variations which are mostly caused by landscape structures and soil conditions, is important for assessing potential adaptation measures for agriculture, e.g., to compensate for negative climate change impacts on crops. To detect spatial climate variations at different scales (e.g., from the field scale to the regional scale in agriculture), a number of methods can be applied. For example, transect measurements of different climatic parameters within a certain terrain can be used. Two case studies in Austria are presented that address the detection and use of spatial climatic variations in various agricultural environments to assess or simulate local climate impacts on agriculture. Further the assessment of adaptation measures to compensate for negative climate change impacts on crops is discussed related to small spatial scales.

Introduction

Agricultural production conditions are determined largely by local climatic conditions, the parameters of which can vary significantly over various spatial dimensions and time scales, depending on the orography, the landscape structures, the soil, the canopy and the surface conditions. Due to climate change significant shifts in local climate conditions are expected (similar to the shifts in climatic zones on a larger spatial scale), and estimation methods for detecting the relevant spatial gradients of various climatic parameters are becoming more and more important for climate change impact studies (Trnka et al., 2009). Spatial climatic variations and their effects on crops can be detected and investigated over various spatial and temporal scales. For example, the knowledge about spatial gradients in climatic parameters related to a defined time scale can serve as a basis and as input for agrometeorological assessments of related climate shifts or climate change impacts on crops at various spatial scales (Eitzinger et al., 2008). However, for decision making at the farm level (e.g., for precision farming, land-use planning or for adaptation to the changing climate), knowledge about the local spatial variability of the natural resources important for crop growth (especially soil and climatic conditions) is crucial (Basso et al., 2007; Baethgen, 2010). The objective of this study was to analyse the relevance of spatial climate gradients over different scales for climate change impact studies in agriculture, using selected case studies carried out in Austria. Specifically, the study addressed the consequences and potentials of developing adaptation measures for agricultural crop production for various climate change projections related to the different spatial scales applied.

Data and methods

Two case studies in different regions in Austria with different climatic and soil conditions and land use patterns were analysed. The first case study region comprised the Marchfeld (a relatively flat region of about 900 km²), which is located in the northeastern part of Austria. It is the main arable crop production area in Austria, with a semihumid climate and water-limiting growth conditions for crops during the summer. The region is characterised by flat terrain with windbreaks as main landscape structures, high evapotranspiration rates during the summer due to high temperatures and winds, and it is one of the driest regions in Austria. In this case study the effect of hedgerows (windbreaks) on microclimatic conditions were investigated. The other case study site in eastern Austria that is located south of the Marchfeld region is a wine-growing area with hilly terrain and similar climatic conditions (Göttlesbrunn, Prellenkirchen). The aim of this study was to analyse the climatic terroir for wine-growing conditions and to map microclimatic parameters based on (locally measured) statistical relationships to orography. For both case studies experimental microclimatic transect measurements were carried out to detect local climatic effects and phenomena caused by landscape structures (orography and hedgerows), especially related to wind conditions, evapotranspiration potential, air temperature and humidity. For detecting evapotranspiration potential manual ceramic spherical atmometers were used for the transect measurements. As potential evapotranspiration is determined by integrating a number of meteorological parameters, it can be effectively used for microclimatic analyses of local climate phenomena with some additional meteorological measurements. Additional meteorological measurements in the presented case studies (wind, air temperature, air humidity, global radiation) were carried out by automated agrometeorological stations with different electronic sensors. For the first case study, the crop model CERES-Wheat (Jones and Kiniry, 1986; Godwin et al., 1989) was applied to analyse climate change effects on crop yield potential. Crop model input data (soil, weather, crop management) were obtained from experimental field measurements at this site. The validated crop model was applied to compare the impact of hedgerow effects (microclimatic scenarios) on winter wheat yield for a single year (2005) and for climate scenarios without hedgerow effects. For the climate scenarios the monthly climate change signals of the GCMs HadCM3 and ECHAM5 for different emission scenarios (SRES) such as A2 and A1B of the future periods of 2025-2045 (further named as 2035s) and 2040-2060 (further named as 2050s) were used to derive the daily weather input data. As reference period the daily data of a representative weather station of the period 1971-2000 were used.

Results and disscussion

For the first case study (Marchfeld region) the hedgerow effects (with microclimatic scenarios) on winter wheat yield for 2005 were measured and simulated as follows: The winter wheat growing season of 2004/2005 was well representative for the mean long term weather conditions of that region, with prevailing crop water deficits during spring and summer. The simulated yield at a distance of 80 m (2193 kg/ha) showed good agreement with the actual measured yield (2270 kg/ha). The maximum actual yield was measured at a distance of 8 m (3220 kg/ha). Simulations were carried out using different microclimatic scenarios, taking into account different wind speed reduction and snow accumulation effects. A range of yields from 2983 kg/ha to 3653 kg/ha, depending on the reduction of the wind speed and snow accumulation effects, were simulated. According to the results a reduced wind speed by 50% had the most significant positive effect on the simulated winter wheat yield for 2005. The simulated results for the soil-water balance parameters also showed a positive effect on soil water content at distances closer to the hedgerow (as indicated by higher total actual evapotranspiration and lower crop water stress), which had a significant, positive effect on crop yield. The scenario with wind speed reduction of 50% and a snow accumulation effect shows the lowest water stress value. The wind shading effect of the hedgerow and the resulting reduction of wind speed and evapotranspiration, combined with a higher soil water content (indicated by a low water stress factor) at the beginning of the vegetation period, resulted in the highest yields. The effect of melting snow banks was limited to only a few meters distance from the hedgerow, but the simulation showed a positive effect on soil water content for about two months, covering most of the growing period of winter wheat.

As shown above, for crop yields near hedgerows, the soil-water balance and the snow cover thickness in winter near the hedgerow play an important role. These effects were further considered as part of a long-term assessment of the impact of a hedgerow under climate scenarios. Therefore, we compared the above-discussed hedgerow effects in this region on winter wheat yields with simulated yields (CERES-Wheat model) under climate scenarios for an open area. The applied climate scenarios for the 2035s and 2050s show a warming trend and decreasing summer precipitation for that region. The results show that hedgerows could more or less compensate for the negative impacts on winter wheat yields caused by increasing water stress conditions under the climate scenarios. The effect, however, depends on the applied climate scenario and the distance from the hedgerow. For example, for a distance of 80 m, the mean positive yield effect of the hedgerow would account for approximately 8%, whereas the most negative yield effects under the climate change scenario A1B-2035s (emission scenario A1B for the 2035s of two global climate models) would range from -11 to -15% for this case study site. For the climate scenarios of the 2050s, the model simulated slightly increasing yields due to the positive direct CO2 effect on photosynthesis from the increased atmospheric CO2 concentration. In that case, this yield increase would be even higher close to the hedgerows.

In the second case study the climatic terroir of a wine-growing region was analysed in order to design high spatial resolution maps for support of vineyard management (including in view to adaptations to climate change). In this study area orography effects on plant stands, such as those induced by mountains or hills, including field slope and aspect, play an additional important role in modifying local climates compared with flat areas. Here, complex interactions such as the modification of the surface energy balance and the mass transfer of water related to wind direction and wind speed can change the local climatic conditions, including soil and air temperature, air humidity and evapotranspiration, which are critical for wine growth conditions, quality potential or pest and desease developement within vineyards. For example, the HUGLIN index (a growing degree day index for wine) is mapped including a line for potential radiation frost risk (depending on sea level) in this vinyard area showing considerable small scale variations (below 1 km distances) within the area. Other examples of maps of monthly extreme temperatures withing the vineyard canopy and mean air humidiry conditions over the terrain show similar spatial variations, depending strongly on orography.

Conclusions

On the small scale, several adaptation measures can be developed based on high-resolution information, such as was demonstrated for the hedgerow effects. One of these adaptation measures involves planning the distances between hedgerows or mixed crop farming to maximise wind-breaking effects and minimise unproductive evapotranspiration for the relevant crop (increasing crop water productivity). Other options include precision farming techniques such as adapting irrigation, soil cultivation and fertilisation to the spatial variations of the soil conditions. Further, the timing of field work could be changed to minimise soil water losses at vulnerable locations or sites (e.g., timing of mulching, crop rotation, crop selection). For medium scales, which include orography and land-use effects in addition to small-scale effects, adaptation measures can be identified for land-use planning or crop selection. Mapping the local climatic conditions can help to optimise cultivar selection and location (e.g. in vineyards) or identify risky sites with extreme climate impacts (e.g., cold-air lakes, sites with high wind speed, dry and wet locations) or increased risks for diseases related to air humidity.

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