An enhanced approach for estimating grassland yield potential under various cutting regimes

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Abstract
The study introduces a GIS (Geographic Information System) tool that assesses the potential biomass yield of grassland based on data for 6-cut management yield measurements from two long-term grassland field trials with multiple fertilization schemes. Therefore, a two-step approach is developed and implemented in GIS. First, a dynamic daily soil water balance model is applied and its outputs are then used to estimate biomass production. The grassland yield model is based on the statistical model, which takes as predictors accumulated temperature, global radiation and water stress, as well as cutting and fertilization to estimate grassland production. The daily meteorological data are interpolated over the domain using very high resolution. These data are then processed by the water balance model (WBM) in each grid in combination with grid-specific information about soil, growing dynamics and cutting regime frequency in order to obtain grid-specific water stress factors. The result is used by GRAssland statistical Model (GRAM) and combined with the seasonal sum of temperature and global radiation. The major innovation of this approach is the focus on spatial aspects of production potential through incorporation of the model algorithms into GIS.

Keywords: grassland yield potential, biomass production, water balance model, GIS

Introduction
Over the past years there has been an intensive search for alternative uses of agriculture land to provide sustainable sources of renewable energy. One of the more recent options is the utilization of grassland biomass for energy purposes, and thus there is a need to assess the production potential of grassland under various cutting regimes as well as its stability under various weather conditions. As grasslands of different types cover an area of 1.61 million hectares in Austria, which is more than 50% of the agricultural land, the potential benefit is obvious. The scheme could be also viable in other regions where sufficient biomass production could be achieved and where excess land is available due to decline in animal husbandry (e.g. in Czech Republic). The alternative use of grasslands might require up to six cuts per year (compared with 2-4 cuts in conventional systems) for which relatively few experimental data exist. Therefore, the study introduces a concept that would allow assessment of the potential yield of biomass and its variability under present climatic conditions, as well as to pin-point areas having the highest production potential.

Materials and methods
The key procedure of the water balance model (WBM) is the calculation of the daily reference evapotranspiration as the main soil water balance driver. It is calculated from daily values of temperature, wind, relative humidity, and global radiation and radiation balance respectively, according to FAO Penman-Monteith (Allen *et al.*, 1998; 2005). In order to adjust reference evapotranspiration (which represents the conditions over a well-watered grass sward of 12 cm

height) to represent cultivated grassland fields with various cutting regimes, the crop-specific evapotranspiration has to be calculated. Therefore, crop coefficient dependent on growth stages is used to adjust the value of daily reference evapotranspiration. The WBM calculation for the first growth is initiated at the beginning of the thermal growing season, defined as continuous period with mean air temperature above 5 °C at 2 m height. In the next step, actual evapotranspiration is derived for each day based on crop evapotranspiration (which represents the water atmospheric demand) and water available to the crop (which represents the supply side of the WBM). Available soil water is determined by actual soil water content that is driven by water balance during previous day and precipitation on the given day. Soil water content is calculated for a model profile that assumes two soil layers each of 20 cm depth, and water transfer is allowed between the layers as well as percolation to the sub-root zone. The ratio of crop evapotranspiration and actual evapotranspiration indicates the level of water stress. If water stress occurs the growth supporting factor will be reduced due to the intensity of stress. The factor effects the summation of daily temperature and global radiation over the period of each growth through a complex function described by Trnka *et al.* (2006). For example, during drought periods temperature and radiation sum acquired are reduced (assuming that plants cannot utilize solar radiation when lacking sufficient amount of available water), which is translated to lower grassland yield estimates in the GRAM procedure.
The first challenge when developing a spatially oriented system that would be suitable for the complex terrain where most of the grasslands are to be found is the availability of high quality data. As the primary source of energy in the system is global radiation, it needs to be represented with the highest precision possible. This requires taking into account slope and aspect of the terrain, as grasslands are frequently situated either on the slopes or in the deep valleys where solar radiation values are quite different from unobstructed horizontal plain used for measuring global radiation values. Therefore, the ArcGIS tool 'Solar Radiation' calculates the astronomically possible amount of radiation with respect to slope, aspect, and topographical shadowing for each raster cell of a study region. From this result a factor can be derived, which represents only the topographic-dependent variability of radiation. This radiation factor improves the interpolated surface of global radiation because it takes into account both the actual weather (e.g. cloud cover) and the geometric component of radiation caused by sun angle and the position of irradiated surface. The observed temperature at weather stations is interpolated geostatistically by using a Digital Elevation Model (elevation-detrended ordinary kriging). The other main climate parameter for GRAM input, the global radiation, is also needed as a spatial surface for each day. It is generated from the values of observation stations by an ordinary kriging interpolation.

Temperature and global radiation are not used directly as predictors for the statistical model of yield estimation, but are combined with and changed according to the day-specific value of growth supporting factor. For the spatial application the growth supporting factor also has to be available as a continuous surface, like daily temperature and radiation. Therefore, the reference evapotranspiration is calculated at the weather stations and then interpolated by elevation-detrended ordinary kriging like temperature. The interpolated reference evapotranspiration can be improved by using the radiation factor which represents the topographic variability. For the next step, i.e. the transformation from reference to crop evapotranspiration, it is necessary to specify management aspects of grassland production. A spatial model of cut dates and growth duration respectively is challenging and has to be determined approximately by using regional studies and/or elevation-dependent temperature models. The spatial version of actual evapotranspiration needs the information about soil quality (field capacity) and the precipitation values as a geodata layer with an adequate accuracy. The continuous surface of precipitation can be interpolated from measurements at weather stations by ordinary kriging or taken from weather radar datasets.

Results and discussion

The GRAM model is applied after preparing raster datasets for the individual predictors. The statistical model is developed based on high quality field experiments. This model relates the yield of each growth to fertilization, duration of growth, and the temperature and radiation sum adjusted by the growth supporting factor. The resulting multiple regression function can be used for station-based analysis of grassland yields as well as for a spatial approach. For this study, long-term trial data for multiple cut regimes (including six cuts) with multiple fertilization management at two Austrian sites were used. These included Gumpenstein, for which data from a continuous trial between 1970 and 2003 are available, and Piber with data available for the period 1970-1993. The results of the model validation for the 6-cut regimes at Gumpenstein and Piber indicate that the model is able to explain up to 80% of yield variability caused by seasonal weather variability, differing fertilization regimes and by the effect of local conditions. It tends to perform better for experiments with higher doses of nitrogen fertilization and at sites (years) when water is a limiting factor.

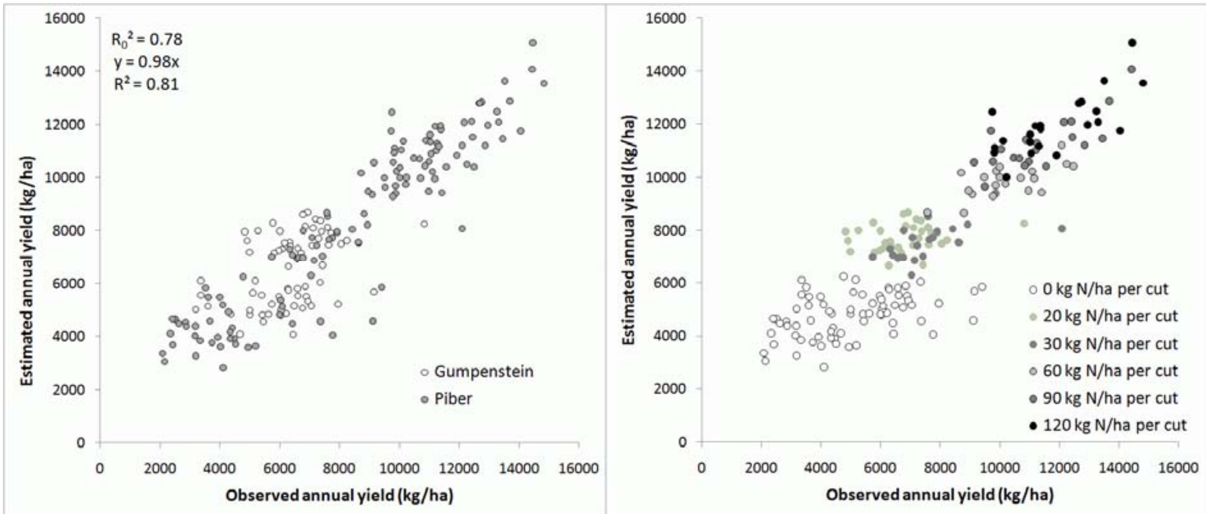

Figure 1. Performance of the statistical model (verification by the independent dataset) at the trial sites Gumpenstein and Piber.

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