Improved estimation of mountain grassland production by using local input data in a crop model

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Abstract

The STICS crop model has been successfully tested in France to predict production of different crops and, since 2000, has also been used for grasslands at the regional scale by the French Ministry of Agriculture. Overestimation of grass production in highland conditions may be due to model functions or model parameters (using a 'mean' species in a multi-species community), or input data. The aim of this study was to explain this overestimation. Simulated aboveground biomass was compared with estimates made with field estimations over a seven-year period in the Vosges mountains (NE France, altitude: 250 to 1,300 m).
However, the use of accurate climatic data instead of regional values as input data in the STICS crop model still did not completely eliminate the overestimation. Introduction of the characteristics of the main species present, based on analysis of the species according to their functional traits, could enable better estimation of DM production of mountain grasslands. This result now needs to be confirmed especially by comparing it with the possible effects of other factors, like run-off, that influence the water balance and that may have been neglected up to now.

Keywords: grassland, crop model, mountain climate, functional traits, production

Introduction

The STICS crop model has been successfully tested in France to predict production of different crops and has also been used at regional level for grasslands by the French Ministry of Agriculture. Overestimation of grass production in highland conditions could be due to uncertainties in climatic variables (= driving variables), or to model parameters (using a 'mean' species in a multi-species community), or to inadequate model functions. In this paper, we evaluate possible improvements to be obtained by using climatic variables and plant features as parameters in the model. Both climatic input data and several species-specific plant parameters that affect plant production are of great concern.

Materials and methods

Plant parameters from the STICS model (Brisson *et al.*, 1998) were adapted for grassland cut at any stage of growth. A mean grass parameter set was used which was derived for intensive grass crops in lowland experiments (Ruget *et al.*, 2006). In addition to plant parameters, the model requires information on climate, soil and agricultural practices. The observed dataset contains field estimations made over a period of five years (2000 to 2004) in the main stock-breeding areas in the Vosges mountains (NE France, altitude: 250 to 1300 m). Estimates of aboveground biomass were based on observations of the number and weight of bales, or on estimates of how much the cattle consumed based on grazing duration and the mean daily dry matter eaten by a dairy cow. Permanent information on soil, climate and practices was collected as environmental patch features. These data were either not the same as those used in the model, or not at the same time scale as the input data required by the crop model. It was thus necessary to derive suitable data from measured data. Available water, pH and the C/N ratio were observed, and field capacity, wilting point, depth and organic nitrogen are required for soil. In the same way year-to-year monthly mean values of climate variables (temperature, precipitation, global radiation, and potential evapotranspiration. ETP) were collected, and yearly daily values are needed. Year-to-year mean practices were collected (mean dates of first cut, number of cuts or mean fertilization amounts) and used as they were. Botanical composition was observed in each patch. As all French grassland species can be classified in four plant functional types (PFT), A, B, C and D, the patches were also classified in four PFTs as a function of the proportion of each species. The growth features of the PFT are well known (Table 1, Cruz *et al.*, 2003). The values of the Ellenberg indices (Ellenberg, 1991) were assigned for each species.

Table 1. Main features of the four functional types.

	Max prod.	Date of max prod.	Leaf life span	Digestibility	SLA and water content	Phenology
A	H	E	s	h	h	e
B	H	L	lg	m	h	
C	Low	L	lg	low	low	l
D	Low	Vl	vlg	very low	low	

Prod: production, h: high, , e: early, l: late, vl: very late, s: short, lg: long, vlg: very long, m: medium.

A number of alternative daily climate datasets were derived from the available information (Table 2). The first used the climate at a single location (Colmar, series 1), the second (series 2) used the local and daily values known for each patch, obtained with correction factors from mean monthly values of the Aurelhy interpolation method (Benichou and Le Breton, 1986). The third (series 3) used classical meteorological relations (temperature with height, ETP with formulas and precipitation at the nearest stations to eight nearby locations), and for the fourth and final (series 4), we used a combination of the best estimation for each variable. Global radiation was the same in all datasets because of the low variations between values at locations caused by the Aurelhy method. To evaluate the methods, we compared the results of six input sets, using only statistical criteria (RMSE, root mean square errors and its systematic and unsystematic components).

Table 2. Composition of the 4 meteorological datasets as a function of the origin of the meteorological data.

Variable	'Unique' 1	Aurelhy interpolation 2	STICS calc and local measure 3	STICS calc and Aurelhy 4
T	Colmar	monthly Aurelhy diff	STICS calc with altitude	STICS calc with altitude
ETP	Colmar	Colmar	calc using simple formulas	calc using simple formulas
RR	Colmar	monthly Aurelhy diff	near stations	monthly Aurelhy diff
Rg	Colmar	Colmar	Colmar	Colmar

(T: temperature, ETP: potential evapotranspiration, RR: precipitation, Rg: solar radiation, calc: calculation, diff: differences, measure: measurements).

Results and discussion

Classifying species using Ellenberg indices or plant functional types (PFT) gives approximately the same results. The good agreement between the classification of species obtained with PFT typology and Ellenberg indices (AFC) is one of the main results of our study: most of the species are grouped together in the same groups (classes). Moreover, there is an altitudinal distribution of the species and PFT, with A and B species at low altitudes, C and D at high altitudes. The features of both main species present in the Vosges mountains (B and D), led us to give new values to two parameters, driving the leaf growth rate and the crop production through light use efficiency. We thus constructed two plant files, one featuring species with a high leaf growth rate and high production (two parameters) and the other with half values for both parameters.

Climatic series differed considerably for rain between rain shadow valley values, station values and Aurelhy values (higher maximal values at high altitudes). The ETP values differed when they were estimated using simple formulas introducing the effect of altitude on temperature, instead of unique or Aurelhy values (more or less similar).
Combining some among the four climatic series with both plant parameter files led to six main simulation sets, whose results are reported below in Table 3.

Table 3. Statistical results of tested combinations of plant features and climate calculations.

Climate	1	4	1	2	3	4
Plant features	prairie	prairie	BD	BD	BD	BD
RMSE	1.6	2.57	1.31	1.52	1.58	1.34
RMSEs	0.83	2.06	0.82	1.2	1.13	1.00
RMSEu	1.37	1.54	1.02	0.92	1.11	0.90

Prairie: the unique original plant file, BD, two plant files, i.e. consideration of plant functional types.
1 to 4: the numbers of climatic sets (table 1).

The best results came from the use of the plant files featuring the PFT and as climate data, either unique climate, or climate using Aurelhy rain and altitudinal variations in temperature and ETP. Paradoxically, the correct value of statistical criteria in the configuration of a unique lowland climate (1) is probably due to the serious water stress that occurs with the rain shadow climate. The last simulation (climate 4 and plant BD) gave the lowest dispersion (RMSEu) and can be regarded as the best configuration.
The main conclusion is the interest of taking plant functional types into account. Moreover, the quality of estimations is highly dependent on the water balance. This means that, in such conditions, both rain and ETP must be well assigned.

Conclusion

The classification of species obtained using Ellenberg indices (without correspondence with the model parameters) and with the PFT (with correspondence) led to the same groups of plants. This meant the species could be gathered in two main groups and the plant parameters could be attributed for each existing group (B and D). The introduction of the characteristics of the main species present, based on analysis of the species according to their functional traits, enabled better estimation of DM production of mountain grasslands. However, only one trial was conducted that showed the ability of the model to represent functional types, but we did not study either all the functional types or all the plant parameters involved. Climate also has a major effect on production. The construction of a daily climate database using different methods for estimating each variable gave the best series when using each method in their best domain: Aurelhy for rain, and altitudinal calculation for temperature and ETP.

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