EVALUATION OF CROP MODEL STICS IN THE CONDITIONS OF THE CZECH REPUBLIC AND AUSTRIA

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Abstract:

Crop growth models have become indispensable tools of agrometeorological and plant production research during past forty years. Out of the wide range of available tools CERES, WOFOST, LINTUL, EPIC, MACROS, SWAP, STICS and APSIM belong to the most used and know. Even though the basic philosophy of all models remains the same they differ in number of key modules as well as design. It is also the case of crop model STICS that has been built with an intension of flexible architecture allowing easy incorporation of new crop species and model functionalities. Other specific feature of the model is its consistency and transparency as the required inputs are almost exclusively in form of directly „measurable" parameters without use of unit less semi-empirical coefficients. The presented study focuses on the model testing under the environmental conditions of Central Europe and its performance is being compared with other modeling tools that are presently used in the region. The main aim is to examine model capability to capture interannual variability of winter wheat and grassland yields over range of sites with varying climatic and soil conditions. In case of winter wheat models, the database includes field experiments at 5 representative sites (n = 62). The stations are spread over the whole altitudinal gradient within which winter wheat is growing in Central Europe i.e.(100-700 m a.s.l.). Grassland data originate from Austrian permanent meadow experiments and include long-term (40 years) trials at Gumpenstein experimental station (700 m a.s.l.). The results of the STICS model will be compared with those attained by CERES-Wheat (winter wheat) and GRAM (grasslands) models using the same datasets.

Key words: crop model, calibration, evaluation, grassland, winter wheat

Introduction

Crop growth models have become indispensable tools of agrometeorological and plant production research during past forty years. Out of the wide range of available tools CERES, WOFOST, LINTUL, EPIC, MACROS, SWAP, STICS and APSIM belong to the most used and know. Their development have started more than thirty years ago and considerably improved analytic solution of problems in crop sciences but new scientific problems arose in the same time. One of the main advantages of crop model application is the possibility to use them under various weather and soil conditions and under different environment in different regions of the world, this is not usually possible when models based on the statistical analysis are used. One of the important preconditions of the application of dynamic models is the evaluation of the model reliability in reproducing the real world processes at the given place and time (Addiscot et al. 1995; Penning de Vries 1977). The processes of evaluation of any crop model are relatively long and difficult because they require the collection of large data sets including weather, soil, crop and crop management data over extensive time periods. Most of the field experiments whose results are normally used in order to evaluate crop models were designed for other purposes, so they often do not contain the complete data set necessary for crop model inputs. These gaps have to be filled either by calculations (e.g. using Angström formula in order to calculate daily global radiation values or calculating initial available soil water content at planting time from available data) or approximation (as in case of crop residues of the previous crop or initial nitrogen content in the deeper soil layers). Some useful data as e.g. maximum LAI or total above-ground measurements are not available at all and cannot be calculated or estimated. The evaluation (sets i.e. defining the usefulness and relevance of the model for a pre-defined purpose) of STICS that belongs to the most recent generation of European crop models is the main objective of the presented study.

Material and methods

STICS model

The aims of STICS (Simulateur mulTIdisciplinaire pour les Cultures Standard) correspond to those of a large number of existing models (Whisler et al., 1986). It is a daily time-step crop model with input variables relating to climate, soil and the crop system. Its output variables relate to yield in terms of quantity and quality and to the environment in terms of drainage and nitrate leaching. The simulated object is the crop situation for which a physical medium and a crop management schedule can be determined (Brisson, 2003). The main simulated processes are crop growth and development as well as the water and nitrogen balances. STICS has been developed since 1996 at INRA (France) in collaboration with other research or professional institutes. Despite the renown and availability of existing models new models appear regularly in the literature that has been attributed to the fact that no one universal model can exist in the field of agricultural science and that it is necessary to adapt system definition, simulated processes and model formalizations to specific environments or to new problems (Sinclair and Seligman, 1996). These same authors insist on the heuristic potential of modeling, a determining element in the development of STICS. From a conceptual point of view, STICS is made up of a number of original parts relative to other crop models (e.g. simulation of crop temperature, simulation of many techniques) but most of the remaining parts are based on conventional formalizations or have been taken from existing models. Its strong points are the following (Brisson, 2003):

- its ‘crop’ generality: adaptability to various crops (wheat, maize, soybean, sorghum, flax, grassland, tomato, beetroot, sunflower, pea, rapeseed, banana, sugarcane, carrot, lettuce, etc.).
- its robustness: ability to simulate various soil climate conditions without considerable bias in the outputs (Brisson et al., 2002). This feature can jeopardize accuracy at a local scale.
- its ‘conceptual’ modularity: possibility of adding new modules or complementing the system description (e.g.: ammonia volatilization, symbiotic nitrogen fixation, plant mulch, stony soils, many organic residues, etc.). The purpose of such modularity is to facilitate subsequent developments.
- the external communication created by the model among the users and developers, which drives the model advancement.

Details about the STICS model formalism, structure and results might be find e.g. in Brisson *et al.,* 1998a; Brisson *et al.,* 1998b; Brisson *et al.,* 2002; Ruget *et al.*, 2002 or Brisson *et al.* 2003.

Experimental setup

The presented study focuses on the model testing under the environmental conditions of Central Europe and its performance is being compared with other modeling tools that are presently used in the region. The main aim is to examine model capability to capture interannual variability of winter wheat and grassland yields over range of sites with varying climatic and soil conditions. The capability of the STICS model to estimate onset of developmental stages was tested only in case of winter wheat as the cut timing at permanent meadows does not depend on the phenology, the proper simulation of development is irrelevant. In case of winter wheat models, the database includes field experiments at 5 representative sites that are described in Table 1. The stations are spread over the whole altitudinal gradient within which winter wheat is grown in Central Europe i.e.(100-700 m a.s.l.). Grassland data originate from Austrian permanent meadow experiments and include long-term (40 years) trials at

Gumpenstein experimental station (700 m a.s.l.) with three cuts per year. The trial was conducted with during period 1961-2000 at the same location (Photo 1). Besides comparing the estimated values of yield and developmental stages with experimental data we compared the results of the STICS model with those obtained by CERES-Wheat (Trnka *et al.*, 2004) and GRAM (Trnka *et al.*, 2006) models using the same datasets.

Table 1. Selected characteristics of five winter wheat experimental sites in the Czech Republic; climatic characteristics relate to 1961-1990 period.

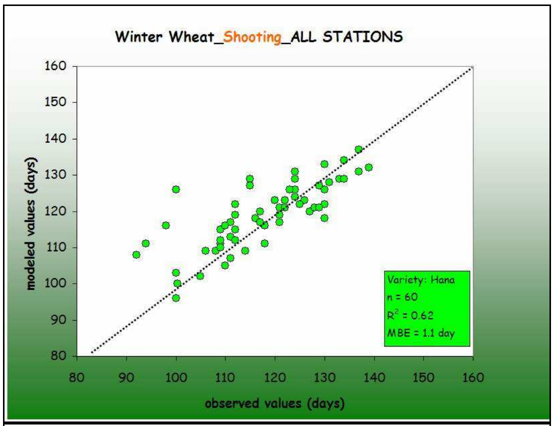
Name of the site	**Lednice**	**Sedlec**	**Chrastava**	**Staňkov**	**Kr. Údolí**
Elevation (m a.s.l.)	170	300	345	370	647
Primary crop of the production region	maize	sugar-beet	cereals	cereals	forage
Soil type	Chernozem	Chernozem	Luvisol	Luvisol	Cambisol
Effective soil depth (cm)	140	150	150	180	135
Mean annual temperature (^{o}C)	9.5	8.2	7.6	8.2	6.4
Mean annual precipitation (mm)	488	510	816	526	604
Mean accumulated global radiation per year (MJ m^{-2})	3955	3706	3487	3790	3634

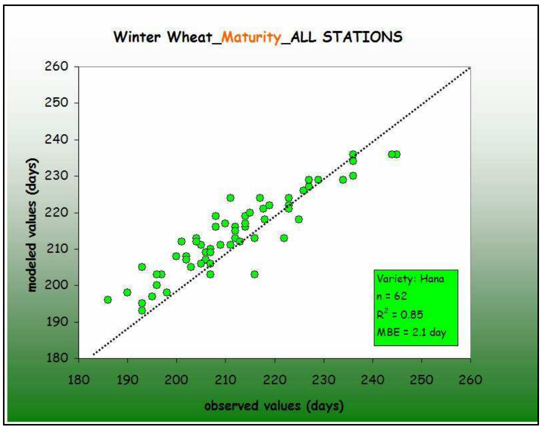
Results and discussion

Winter wheat

STICS model was at first calibrated in order to properly estimate development and production parameters of the winter wheat cultivar HANA. In order to fulfill this task the even years from all stations were used to calibrate the model whilst the remaining data (odd years) were left for model verification using independent data set. The overall performance of the model in terms of onset of the key stages is presented at the Fig. 1. In general the STICS successfully estimates dates of shooting, heading and maturity however in some seasons there is a bias of more than 20-30 days. Even though such bias can be avoided by applying a built-in option of fixed development dates (i.e. forcing the observed dates of developmental stages) it might limit practical use of the model in some types of studies (e.g. yield forecasting or climate change analysis). However two key developmental dates (i.e. heading and maturity) were reproduced with high degree of accuracy and are comparable with results of CERES-model.

Accuracy of the yield prediction was tested in particular at locations Lednice and Sedlec and STICS performed with satisfactory precision (Fig. 2) especially in case of Lednice experimental station. The main reason behind the better performance at this site is the higher degree of water stress that is well depicted by the model. It should be noted that results at Sedlec are promising and that model was able to diagnose all low yielding years.





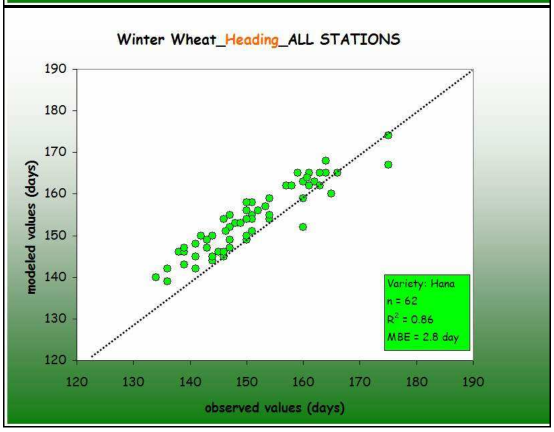


Figure 1: Comparison of three developmental stages as observed at 5 experimental locations of Institute for Agriculture Supervision and Testing (Lednice, Sedlec, Chrastava, Staňkov and Krásné Údolí) for winter wheat cultivar HANA. The systematic error is expressed in terms of Mean Bias Error (MBE). The onset of shooting was not recorded in 2 cases.

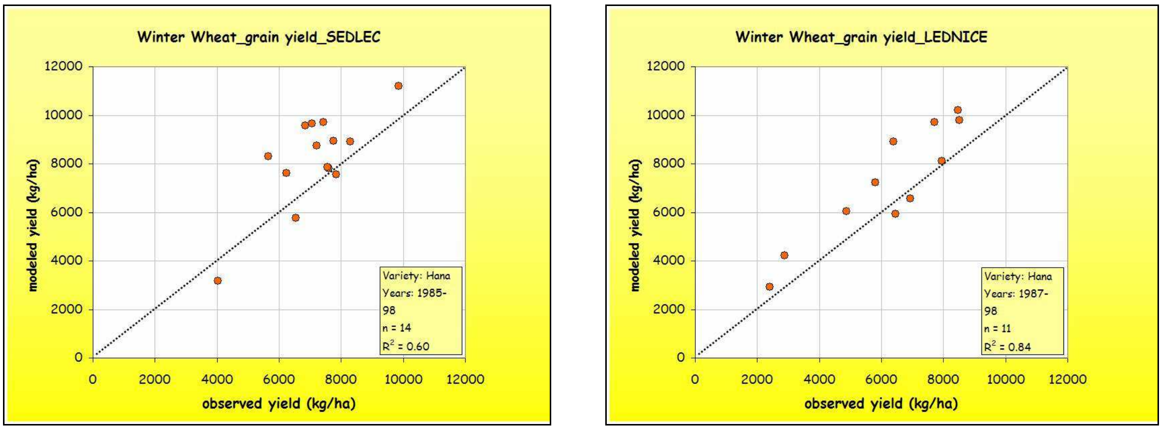


Fig. 2. Comparison of observed and estimated winter wheat yields (cultivar HANA).

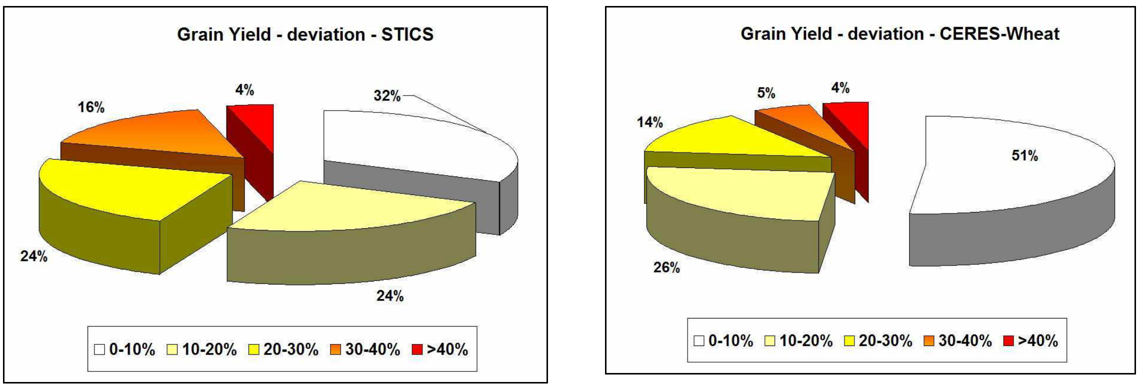


Fig. 3. Deviation of observed yields and those simulated by STICS and CERES-Wheat crop models respectively.

The comparison with the performance of the CERES-Wheat model (Fig 3) indicates higher bias in STICS based estimates. Still in large majority of seasons the yield is predicted with error lower than 30%. Much more problematic seem to be STICS results at “wet” locations (Chrastava, Staňkov and Krásné Údolí) that does not suffer from significant water stress and tend to have low interannual yield variability. At these locations STICS shows unrealistically high yields and altered patterns of interseasonal variability compared to the observations. This phenomena might be caused either by imperfect representation of other stress factors (e.g. overwintering or annoxia) or through underestimating effect of suboptimal temperatures and global radiation on growth and development. Less than optimal simulation of nitrogen balance might be another contributing factor.

Permanent meadows

Permanent grasslands used either for forage production (meadows) or as pastures make up a significant portion of Austrian territory (22 per cent), constitute an important segment of the landscapes and are part of the agriculture production system. Austrian managed grasslands are mostly located in humid regions and are thus not irrigated. At the same time, the grasslands in the Alpine and near-Alpine regions are distributed over a large range of altitudes (200 to 2000 m) and are strongly affected by significant climate variability as most rain-fed grasslands over Europe. Owing to the climatic factors during individual years and the growing seasons grassland production varies considerably. This is of major importance to dairy farmers not only in Austria but through out Europe since the whole farming system must allow for the risk of unfavorable weather conditions. Therefore understanding to the underlying causes of the yield variability in meadows is of major interest.

Photo 1. Overview of the long-term meadow experiment at Gumpenstein (Austria).

The application of the STICS at the Gumpenstein site (Photo 1) brought along challenges in form of the range of input parameters. As some parameters (LAI, nitrogen content of the soil, temperature requirements etc.) were not available at the experimental site they had to be estimated based on the French experiments or through expert judgment. As Fig. 4a indicates the STICS model is able to encapture part of inter-cut variability but the effect of the individual seasons on the yields were not mimicked by the model. Whilst for the first cut STICS estimates are unrealistically high dry matter production the last cut biomass is

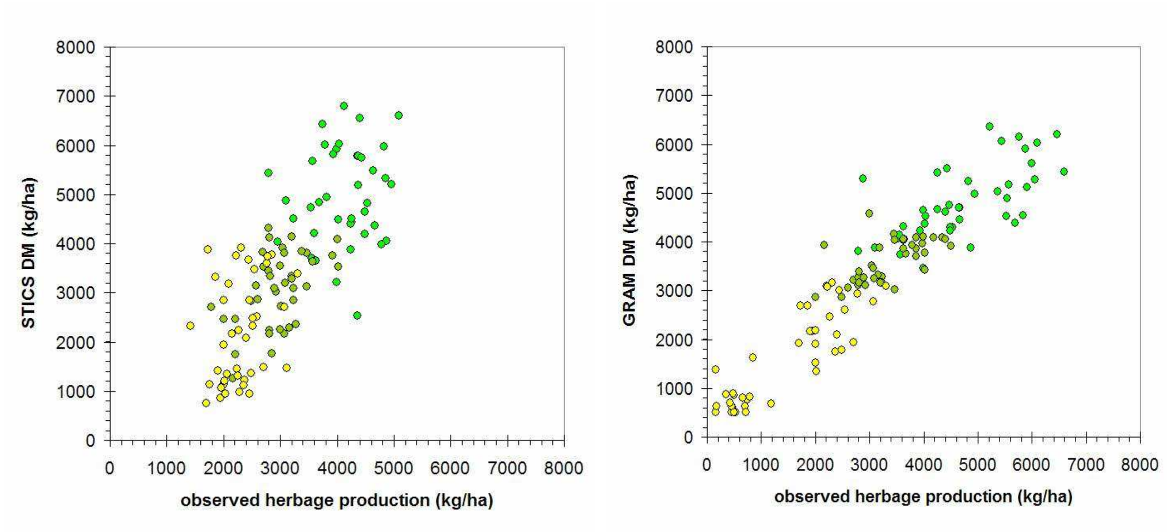


Fig. 4. Comparison of the observed dry matter (DM) herbage production of the individual cuts and STICS estimates (4a – left) and GRAM estimates (4b – right). The bright green dots represent the 1st cut, green the 2nd cut and yellow color the 3rd cut yields during 1961-2000 period.

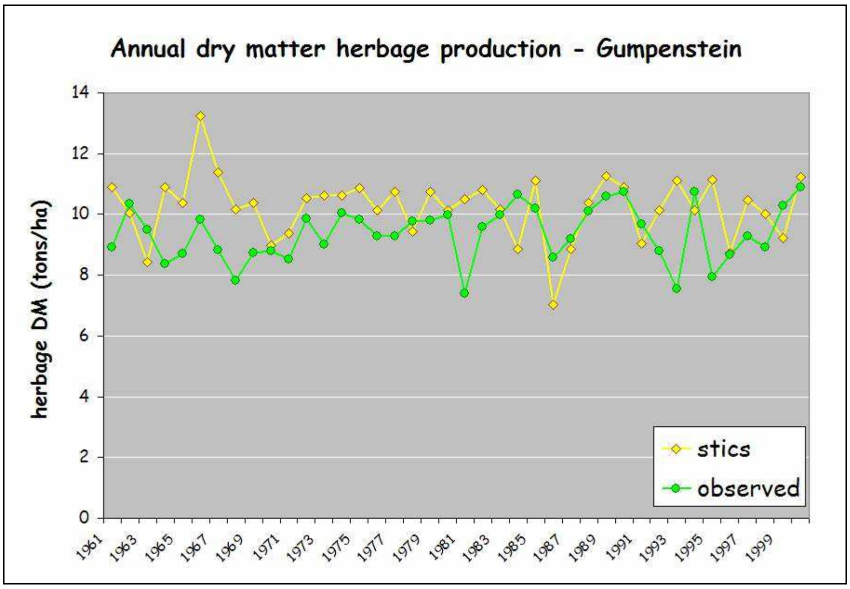


Fig. 5. Comparison of the observed annual dry matter (DM) herbage production and STICS estimates (during 1961-2000 period).

underestimated. This then transforms into the improper representation of interannual yield variability as might be seen at the Fig. 5. The same figure however demonstrates that after all STICS is able to reproduce overall yield level (production potential) of the site. Comparison with the semi-empirical GRAM model (Fig 4b) shows that the statistical model (although partly process based) gives at the site level more accurate results than the general dynamic model (i.e. STICS). This phenomena was discussed e.g. by Brisson *et al.* (2003) that attributes such shortcomings to the model robustness that lead into lower model sensitivity to local influences. In this particular case the main reasons behind the misrepresentation of STICS yield variability might be either improper setting of the input data and/or lack of pronounced drought stress that seems to be one of the main controlling mechanisms under the French climatic conditions.

Conclusions

The results of the study demonstrate that STICS model can be effectively used at least at some of the Central European locations. Even though it does not provide the same accuracy of the results of other models (CERES-Wheat and GRAM) it seems to be able to at least partly reproduce key biological process. Because of its robustness and versatility it might be used as parallel instrument to the mentioned models e.g. in climate change impact studies.

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