ADAPTATION OF CROP-WEATHER MODELS IN AUSTRIA AND BULGARIA

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1. Introduction

Year-to-year fluctuations in weather causes large variations in crop yields. Uncertainty in weather creates a risky environment for agricultural production. During the last decades the application of simulation and system analysis in agricultural research has increased considerably. The simulation model is one of the most complex method among the approaches used to describe the soil-plant-atmosphere system.

Numerous crop growth and yield models have been developed for a wide range of purposes in recent years (e.g. Hoogenboom, 2000). These models range in complexity from the most sophisticated simulators of plant growth, primarily intended for research into plant physiological interactions, to multiple regression models using only a few monthly weather variables to forecast regional crop yields. Generally, plant-process yield models have been developed to predict yield at the level of an average plant in a specified field. Thus the input data required by these models include plant parameters specific to the variety or hybrid planted in some field and soils parameters describing the soil in that field. The prediction of crop development is an important aspect of crop growth modelling. Crop models that use daily weather, soil and plant data in simulating crop yields have the potential for being used to assess the risk of producing a given crop in a particular soil-climate regime and for assisting in management decisions that minimize the risk of crop production (e.g., Tsuji et al., 1998).

Current algorithmic models are frequently inaccurate when they are applied to locations other than that where developed. According to Hoogenboom et al. (1999) before using a crop model for a particular production region, it is important that a minimum amount of crop phenological and yield data should be applied to allow estimation of the model performance for that region’s cultivar types and for calibration of specific parameters. That is why the objective of this study was to adapt (including calibration and verification) crop simulation models for specific environmental conditions in Austria and Bulgaria.

Crop models, in general, integrate current knowledge from various disciplines, including meteorology, soil physics, soil chemistry, crop physiology, plant breeding, and agronomy, into a set of mathematical equations to predict growth, development and yield (e.g. Hoogenboom, 2000). Baier (1979) provided some interesting background and terminology for what he called “crop–weather models”. This term was assumed to be also used in this study.
2. Method and experimental material

The following crop-weather models were adapted for the environmental conditions in selected regions in Austria and Bulgaria:

The CERES generic grain cereal and CROPGRO grain legume models of the Decision Support System for Agrotechnology Transfer (DSSAT) (e.g. Tsuji et al., 1998) were used to simulate crop growth, development and yield formation of important agricultural crops such as winter wheat, maize, barley and soybean. These crop models are designed to use a minimum set of soil, weather, genetic and management information. The models are daily incrementing and require daily weather data, consisting of maximum and minimum temperature, solar radiation and precipitation as input. They calculate crop phasic and morphological development using temperature, daylength, genetic characteristics and vernalization, where appropriate. Leaf expansion, leaf growth and plant population provide information for determining the amount of light intercepted, which is assumed to be proportional to biomass production. The biomass is partitioned into various growing organs in the plant using a priority system. A water and nitrogen balance sub-model provides feedback that influences various growth and development processes. A new soil water model was completed, which contains improved infiltration, redistribution and root uptake calculations. Restrictions to percolation are included in soil inputs so that perched water tables can be simulated along with oxygen stress effects on root and crop growth processes. An option has been added to compute potential evapotranspiration using the Penman equation, which uses humidity and wind speed as input if these data are available (e.g. Hoogenboom et al., 1999; Tsuji et al., 1994).

The crop-weather models of DSSAT have been distributed to many national and international scientists at research, educational and private institutions and organizations, as well as to many other individuals across the world. The generic grain cereal model CERES and grain legume model CROPGRO have been extensively tested in North and South America, Africa, Asia and Europe (e.g. IBSNAT, 1993; Tsuji et al., 1994). Normally, these crop models are run on a “point” basis, i.e., input data in terms of soil and weather conditions are assumed to relate to one location, e.g., a field or plot where an experiment was conducted (e.g. Hoogenboom et al., 1999).

The WOFOST (WOrld FOod STudies) explanatory and dynamic crop model (e.g. Supit et al., 1994; Van Diepen et al., 1989) Ver. 7.1 was also used in the study. This model was developed by the DLO-Winand Staring Centre and Research Institute for Agrobiology and Soil Fertility in Wageningen (e.g. Boogaard et al. 1998). WOFOST is a member of the family of models developed in Wageningen by the school of C.T. de Wit. It is designed to simulate the growth and development of annual field crops and grass during the growing season, from sowing to maturity or harvest in daily increments. It simulates a cropping system defined by crop, the weather conditions and the soil parameters, including the plant and soil water balance. Outside the crop-growing period the soil water balance can be calculated for bare soil conditions. The major processes taken into account are phenological development, assimilation, respiration and evapotranspiration. WOFOST uses parameters and functions describing the effects of temperature, radiation and water stress on important physiological crop processes as a function of the development stage and crop status. For example, the photosynthesis response curve is limited by a maximum leaf CO$_2$ assimilation rate and initial light use efficiency of a single leaf. These parameters are further related to temperature at a specified carbon dioxide concentration. Biomass partitioning is a function of the development stage of the crop, while temperature determines the development rate of the crop.

The WOFOST model is designed for simulation of three production levels. The potential yield production level is limited only by temperature, solar radiation and the specific
physiological plant characteristics. Such conditions are possible in greenhouses or in very intensive agricultural production systems (e.g., under field conditions with optimum irrigation and nutrition). At the water-limited production level, the soil and plant water balance is also included in the simulation of crop growth with the interactions between transpiration, stomata opening, CO₂ assimilation and water uptake being considered. The third production level is also limited by nutrients.

Crop model validation is accomplished by imputing the user's minimum data set, running the model and comparing outputs. To validate crop-weather models researches compare simulated outcomes with measured results obtained from the experiments. Prior to evaluating the models, the genetic coefficients for the varieties used are estimated. Usually calibration consists of determining sets of model parameters/coefficients for the studied locations to adjust timing of growth stages and yield components. Generally, calibration is done by running crop-weather models and adjusting the coefficients to correct unreasonable results and running the model again, repeatedly (e.g., Penning de Vries et al., 1989). Before validation of crop-weather models a procedure of model calibration is strongly recommended. That is why the strategy of crop-weather model adaptation, applied in this study, assumed both calibration and verification/validation procedures.

Model parameters/coefficients may be determined either in controlled environments or under field conditions, but since we are model users, who do not have access to controlled environment facilities, most determinations will be made using field data. To help with this we developed a subroutine which enables to estimate genetic coefficients from field data sets that relate to environment, dates of phenological events, and various growth aspects by means of an optimization procedure, suggested by Rozenbrok (e.g., Himeblau, 1975). In the purposed subroutine, the coefficients for a crop cultivar were estimated by running the appropriate model with approximate coefficients, comparing the model output (e.g., dates of predicted events such as flowering and maturity dates, kernel numbers per ear and grain biomass accumulation for each of the experiments) to actual data, and then altering the genetic coefficient until the predicted values and measured values match (i.e., by running several iterations). The coefficients were determined in a preset sequence, with those that relate to phenological aspects being determined first.

The above crop-weather models require daily weather data, agrometeorological and soil information as input. Agrotechnological (e.g., phenological development, yield, agrotechnology applied), weather and soil data from some locations in Upper Austria, Lower Austria (Marchfeld) and south-eastern Austria (Fig. 1a) were incorporated within the study. Soil characteristics such as horizon designation, percentages of clay, silt, coarse fractions, organic carbon, saturated hydraulic conductivity, total nitrogen, aluminum saturation, bulk density, pH in water and buffer for every given soil layer were used in order to create appropriate soil data profiles in the selected Austrian regions.

Data from crop experiments, conducted during the last two decades in Austria were used. The Austrian registered winter wheat cultivar “Perlo” was used for Lower Austria. “Perlo” is a well established cultivar, especially adapted for dry and warm regions such as the region of Marchfeld. Agrotechnological, “Perlo” phenological and yield data, as well as weather data from Grossenzersdorf (Marchfeld, Lower Austria) for the period 1985-1999 were gathered for the simulation study. Agrotechnological, phenological and yield data of two additional winter wheat cultivars (“Renan” and “Silvius”) grown in Upper Austria and south-eastern Austria for the period 1991-2000 were also used. For the same period and regions crop data of two spring barley cultivars (namely “Meltan” and “Elisa”) were collected. Soybean data (“Ceresia” and “Apache” cultivars) from field experiments, carried out in Grossenzersdorf from 1992 to 1999 were also collected.
The CERES crop-weather model for maize and winter wheat was calibrated and verified at 21 experimental variety stations in North and South Bulgaria (Fig. 1b) using field experiments conducted during the period 1980-1993. The Bulgarian maize hybrid "Kneja 611" and winter wheat bread variety "Sadovo 1" were used. The phenological and yield data were obtained from the Bulgarian National Variety Commission of the Ministry of Agriculture. Daily weather data, including precipitation, maximum and minimum temperature, and solar radiation, were collected for the same period for the nearest weather stations, which are members of the weather network of the Bulgarian National Institute of Meteorology and Hydrology. Different soil types (e.g., typical chernozems; leached chernozem-smolnitza; grey forest, moderately loamy; leached cinnamonic forest; delluvial-meadow, sandy; alluvial, clayey-sandy; etc.) were taken into account in the study.
3. Results and discussion

3.1. Austria

3.1.1. Winter wheat (CERES and WOFOST models)

The CERES model for winter wheat was calibrated using planting and maturity dates and yields of the wheat cultivar “Perlo” from 1985 to 1999 at station Grossenzersdorf (Lower Austria). The calibration consisted of determining sets of five cultivar coefficients to adjust timing of growth stages and yield components. This was done by running the model and adjusting the coefficients to correct unreasonable results and running the model again, repeatedly. After each run coefficients controlling flowering date and maturity date were readjusted automatically. When the estimated growth stage dates were reasonable for a given year, the coefficients controlling grain number and grain weight were adjusted to set estimated yields at a reasonable level. The CERES model adequately simulates the winter wheat growth stages duration as influenced by cultivar, planting date (day-length, temperature) and delay due to transplanting. The difference between simulated and observed dates of flowering and physiological maturity varies between 0 and 7 days (Fig. 2). The simulated grain yields are in most cases in accord with the measured data, with predicted yield results mainly within acceptable (e.g. Chirkov, 1969; Procerov and Ulanova, 1961) limits of ±17% of measured yields (Fig. 3). In year 1993 where some drought periods caused plant water stress, there is 42% difference between the simulated and measured winter yield. The highest deviation (83%) between the simulated and measured wheat yield occurs for 1996. It is a result a growth limitation (e.g. Aggarwal et al., 1994), not considered by the CERES model.

![Fig. 2. Comparison between simulated and observed flowering and maturity of winter wheat, cultivar “Perlo” in Grossenzersdorf (1985-1999) (CERES model)](image)

The CERES model for winter wheat was also calibrated for the wheat cultivars “Renan” and “Silvius”, cultivated intensively in Upper Austria and south-eastern Austria during the last decade. The “Renan” wheat cultivar is representative for Eastern Austria, while the “Silvius” cultivar is grown especially in Upper Austria. A comparison between the simulated and observed flowering dates both for “Renan” and “Silvius” wheat cultivars is presented in Figure 4.
The difference between the simulated and observed wheat flowering dates in all selected stations and years is less than 1 week. Even for the “Silvius” wheat cultivar grown in Freistadt (Upper Austria) the above deviation from 1993 to 2000 is not higher than 1 day (Fig. 5). The simulation error for wheat maturity is between 0 and 7 days which is considered as a good result (Fig. 6). In Freisdadt the maximum deviation between the simulated and observed physiological maturity of winter wheat is 3 days in 1996 and 2000 (Fig. 5). It is obviously that the variations of the simulated phenological stages by the CERES model are following the variations of the observed ones.

Fig. 3. Variations of simulated and observed winter grain yield (cultivar “Perlo”) in Grossenzersdorf

Fig. 4. Comparison between simulated and observed flowering date of winter wheat (“Renan” and “Silvius” cultivars) at the stations in Upper Austria and south-eastern Austria (1991-2000)
Fig. 5. Variations of simulated and observed flowering and maturity of winter wheat (“Silvius” cultivar) in Freistadt

Fig. 6. Comparison between simulated and observed maturity date of winter wheat (“Renan” and “Silvius” cultivars) at the stations in Upper Austria and south-eastern Austria (1991-2000)

The CERES model parameters impacting wheat growth and yield formation were calibrated using the “Renan” cultivar data from Lambach (Upper Austria). Figure 7a compares the variations of the simulated and measured winter yield between 1991 and 2000. Only in 2 years the deviation between the simulated and measured wheat grain yield is above 20%. It should be noted that these 2 years are characterized with very high measured wheat grain yield – near 9000 kg/ha. The simulation error for wheat grain yield is less or equal to 10% from 1993 to 1999 (Fig. 7a).
For verification, crop models are used to simulate crop responses under specific experimental conditions for which observed data are available. Usually, verification refers to the testing of the model on an independent data set. When this is done, we have an empirical indication as to the model's applicability to years and/or locations other than those for which it was fitted or calibrated. Figure 7b represents, for example, a verification of the calibrated CERES model parameters from Lambach on a neighboring station (Wartberg, Upper Austria). The deviation between the simulated and measured yield from 1994 to 2000 in Wartberg exceeds the ±20% interval only in 1995. It is necessary to point out that the measured winter wheat grain yield was very low in this year (Table 1) at the most stations used in the study, although weather conditions were favorable for normal crop growth (at least without water stress). It should be also specified that the eventual impact of pest and diseases on crop growth, development and yield formation was not account within the study.

Fig. 7. Variations of simulated and measured winter wheat (cultivar “Renan”) yield in Lambach (a) and Wartberg (b)
Table 1. Deviation between simulated and measured winter wheat grain yield in 1995

<table>
<thead>
<tr>
<th>Station</th>
<th>Wheat cultivar “Renan”</th>
<th>Wheat cultivar “Silvius”</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Simulated (kg/ha)</td>
<td>Measured (kg/ha)</td>
</tr>
<tr>
<td>Lambach</td>
<td>7035</td>
<td>6560</td>
</tr>
<tr>
<td>Wartberg</td>
<td>7059</td>
<td>5260</td>
</tr>
<tr>
<td>Freistadt</td>
<td>6662</td>
<td>5440</td>
</tr>
<tr>
<td>Gleisdorf</td>
<td>8593</td>
<td>9020</td>
</tr>
<tr>
<td>Eltendorf</td>
<td><strong>8502</strong></td>
<td><strong>4720</strong></td>
</tr>
</tbody>
</table>

* - not in Fig. 8

The low measured winter wheat grain yield in Upper and south-eastern Austria in 1995 versus the relatively simulated high wheat yield caused most of the significant deviations beyond the ±20% error interval presented in Figure 8. The comparison of the simulated and measured yields in this figure indicates satisfactory performance of the CERES model for the selected regions.

![Comparison between simulated and measured winter wheat (“Renan” and “Silvius” cultivars) grain yields at the stations in Upper Austria and south-eastern Austria (1991-2000)](image)

Calibration of the WOFOST model for Austrian environment conditions (Grossenzersdorf, Lower Austria) had been initiated by Eitzinger et al. (2000). The simulated crop-growing duration of the “Perlo” winter cultivar from 1985 to 1999 correlated well with the observed data, although in some years (i.e. 1986, 1992 and 1993) larger differences (11-14 days) were also noted. Nevertheless, the mean difference between the simulated and observed crop-growing season was only 1 day and on acceptable range from 0 to 8 days, excluding the above three years (Eitzinger et al., 2000).

The WOFOST simulation model was also calibrated for the winter wheat cultivars “Renan” and “Silvius” for the selected locations in Upper Austria and south-eastern Austria. Some results, obtained for station “Lambach (Upper Austria) are presented in Figures 9-10.
Generally, the variations of the simulated and observed phenological stages (including flowering and physiological maturity) of the “Renan” winter wheat cultivar are similar during the investigated period (Fig. 9). The difference between the simulated flowering and maturity dates is not higher than 1 week, except in 1994 for flowering (8 days). The obtained deviations of the simulated winter wheat yield, relative to the observed one is less than 20% from 1991 to 1999. A comparison between the results presented in Figures 7a and 10 shows that the WOFOST model also simulates not well the higher yields in 1992 and 2000. It should be noted that the effect of fertilizers on the crop growth and final yield formation was not account for the crops in Upper Austria and south-eastern Austria. It might be a reason for the simulated underestimation of the winter wheat yield in these two years (Fig. 10).

![Fig. 9. Variations of simulated and observed flowering and maturity of winter wheat (“Renan” cultivar) in Lambach; WOFOST model](image1)

![Fig. 10. Variations of simulated and measured winter wheat (cultivar “Renan”) yield in Lambach; WOFOST model](image2)
3.1.2. Spring barley (CERES model)

In a similar way the CERES model was calibrated and verified for spring barley (“Meltan” and “Elisa” cultivars) at some locations in Upper and south-eastern Austria. Some of the obtained results are presented in Figures 11-14. The simulated by the CERES model phenological stages are compared with the observed flowering and maturity dates in Figures 11 and 12.

![Fig. 11. Comparison between simulated and observed flowering date of spring barley (“Meltan” and “Elisa” cultivars) at the stations in Upper Austria and south-eastern Austria (1992-2000)](image1)

![Fig. 12 Comparison between simulated and observed maturity date of spring barley (“Meltan” and “Elisa” cultivars) at the stations in Upper Austria and south-eastern Austria (1992-2000)](image2)
The deviation of the simulated flowering dates from the observed ones varies between 0 and 9 days. The difference between the simulated and observed maturity dates of spring barley also is not higher than 9 days except 2000 in Freisdat (Upper Austria). The 2000 simulated maturity date of the “Elisa” cultivar is 12 days later than the observed physiological maturity date. Nevertheless, it might be expected that the CERES model would simulate spring barley maturity dates that are not later or earlier than 10 days in comparison to the observed/real ones.

Fig. 13. Variations of simulated and measured spring barley (“Meltan” cultivar) yield in Lambach (a), Wartberg (b) and Gleisdorf (c)
The calibrated CERES model parameters optimized for station Lambach (Upper Austria) were applied for verification in stations Wartberg and Gleisdorf (Fig. 13). Generally, the variations in simulated spring barley grain yield follow the variations of the measured yield, especially from 1992 to 1996. The observed yield decreases in 1992, 1993, 1994 and 1995 are well simulated by the crop model. A difference of 33% between the simulated and measured barley yield is seen for 1997 in Gleisdorf (south-eastern Austria). The measured yield in that year was very high in comparison to the yield of the rest years and stations – above 8000 kg/ha. It seems that the CERES model can not account great positive variations of crop yield due to model limitations themselves and/or input data limitations. The comparison between the simulated and measured spring barley grain yield of the “Meltan” cultivar as well as the “Elisa” cultivar for 3 stations are also presented in Figure 14.

![Graph comparing simulated and measured wheat yield (kg/ha)](image)

Fig. 14. Comparison between simulated and measured spring barley (“Meltan” and “Elisa” cultivars) grain yields at stations Lambach, Wartberg and Gleisdorf

### 3.1.3. Soybean (CROPGRO model)

The CROPGRO model was calibrated and verified for two soybean cultivars (“Ceresia” and “Apache”) using agrometeorological data from Grossenzersdorf (Lower Austria) for the period 1992-1999. The model simulates flowering and physiological maturity dates well for each cultivar in all considered years, used for model calibration (1995-1999) as well as for model verification (1992-1994). The difference between the simulated and measured dates of these two phenological stages varies from 0 up to 5 (Fig. 15). The deviation between the simulated and measured soybean yield by the cultivar "Ceresia" varies in most years between 1% (1994) and 20% (1997, 1999) (Fig. 16a). The difference between measured and simulated yield by the cultivar "Apache" varies between 6 and 20 % except in 1994 (Fig. 16b). The highest differences between the simulated and measured yield in 1994 for both two cultivars (53 and 54%, respectively) are caused due to simulated insufficient soil moisture during the crop-growing season. It should be noted that the CROPGRO model is very sensitive to water stress. 1994 was a very dry year, with dry spells during the summer season. The model simulates very well the variations of measured soybean yield during the studied period (Fig. 16), which is a precondition for a good model performance in the selected region.
Fig. 15. Comparison between simulated and observed phenological stages of soybean ("Ceresia" and "Apache" cultivars) in Grossenzersdorf (1993-1999)

Fig. 16. Variations of simulated and measured seed yield of soybean cultivars "Ceresia (a) and Apache (b), in Grossenzersdorf (Lower Austria)
3.2. Bulgaria

3.2.1. Maize (CERES model)

As a first step, the CERES model parameters determining maize development and phenological stage occurrence were calibrated. Figure 17 represents a comparison between the simulated and observed silking and maturity dates of maize for the investigated 21 experimental crop variety stations across the country. The difference between the simulated and observed silking dates during the period of calibration (1984-1990) in most cases (108 cases from total 112 field experiments) is up to 1 week. The deviation of the simulated maturity dates, relative to the observed ones is less than 2 weeks, except 2 cases. A better view for the distribution of the simulation error regarding these two phenological stages can be obtained in Figure 18.

![Figure 17. Comparison between simulated and observed silking and maturity dates of maize in Bulgaria during the periods of calibration (1984-1990) and verification (1991-1993)](image1)

![Figure 18. Number of deviations (\(\Delta n\)) between simulated and observed silking and maturity dates of maize in Bulgaria during the period of calibration (1984-1990).](image2)
After identification of the CERES model parameters, characterizing the vegetative and reproductive periods of maize crop, the model parameters related to maize yield formation were optimized. The biological meanings of these parameters are related to the maximum grain number for one crop and the rate of grain filling. Within 78.8% of the total maize field experiments the error of the simulated number of grains/m², relative to the measured one is less than 20%, whereas the deviation of the simulated maize grain weight from the measured weight is higher than 20% only in 6 cases (Fig. 19).

![Diagram](a) ![Diagram](b)

**Legend:**
- A - 0% ≤ Δ ≤ 10%,
- B - 10% < Δ ≤ 20%,
- C - 20% < Δ ≤ 25%,
- D - 25% < Δ ≤ 30%,
- E - 30% < Δ ≤ 40%,
- F - 40% < Δ ≤ 50%

Fig. 19. Deviation (Δ) between simulated and measured number of grains/m² (a) and grain weight (b) of maize in Bulgaria (1984-1990)

The deviation between the simulated maize grain yield and the measured one is less than 10% for more than 1/3 (44%) of all field experiments and it is less than 20% for 73% of all cases (Fig. 20 ands 21). The difference from 25 and 50% is observed for 21 field experiments (from total 112).

![Graph](Fig. 20. Comparison between simulated and measured maize grain yield in Bulgaria during the periods of calibration (1984-1990) and verification (1991-1993))
Fig. 21. Deviation ($\Delta$) between simulated and measured maize grain yield in Bulgaria (1984-1990)

It is necessary to specify again that up to 20% deviation of the simulated crop yield, relative to the observed one is considered as a good result in this study, following for example Chirkov, (1969), Procerov and Ulanova (1961), Slavov and Vitanov (1977).

In order to validate the calibrated CERES model parameters for maize, the model was verified on independent agrometeorological data set including the periods 1980-1983 and especially 1991-1993. The differences between the simulated and observed silking and maturity dates of maize are above 7 and 14 days, respectively only in 6 cases from 1991 to 1993 (from total 50 field experiments) (Fig. 17). The deviation between the simulated and observed maturity dates varies up to 1 week in 1/3 of the experiments, used for model verification. The simulation error, related to the number of grains/m² and grain weight is less than 20% within 60 and 84% of the cases, respectively. As a result, the deviation between the simulated and measured maize grain yield is on the interval 0-25% for 33 field experiments (66% of the total), carried out during the period 1991-1993 (Fig. 20). The agrometeorological data from 1980 to 1983, available for some of the experimental crop variety stations, were also used for model verification. For example, the variations of the simulated and measured yield of maize at station Kojnare (North Bulgaria) are presented in Figure 22.

3.2.2. Winter wheat (CERES model)

The CERES model for winter wheat was also adapted for the environmental conditions in Bulgaria by applying crop, weather and agrotechnological data from 1980 to 1993. The years from 1984 to 1990 were used for calibration of the model parameters and the rest years were left for model verification. The obtained results are presented in Figures 23-28.

Legend: A - 0% ≤ $\Delta$ ≤ 10%, B - 10% < $\Delta$ ≤ 20%, C - 20% < $\Delta$ ≤ 25%, D - 25% < $\Delta$ ≤ 30%, E - 30% < $\Delta$ ≤ 40%, F - 40% < $\Delta$ ≤ 50%
Fig. 22. Variations of simulated and measured grain yield of maize at station Kojnare (North Bulgaria) during the periods of calibration (1984-1990) and verification (1980-1983 and 1991-1993).

Fig. 23. Comparison between simulated and observed flowering and maturity dates of winter wheat in Bulgaria during the periods of calibration (1984-1990) and verification (1991-1993).

The departure of the simulated dates of winter wheat flowering and maturity, relative to the observed ones is less than 3 days in 80 and 68%, respectively for all 132 field experiments executed from 1983 to 1990. This difference is higher than 1 week only for 4 and 6 cases (from total 58 field experiments), respectively in the years of model verification from 1991 to 1993 (Fig. 23 and 24). The model simulation error for the number of wheat grains/m² and grain weight is less than 20% for 74 and 93%, respectively of the field experiments, carried out from 1983 to 1990 (Fig. 25).
As a result of the above good model results, the deviation between the simulated and measured grain yield of winter wheat is also considered as a satisfactory performance of the CERES model (Fig. 26-28). The simulation error for the main periods of calibration (1984-1990) and verification (1991-1993) is beyond the ±20% interval only for 28% of the considered all 190 field experiments. In a similar way, as it was done for maize crop, agrometeorological data from 1980 to 1983, when available, were also applied for additional model verification (Fig. 28).
Simulated wheat yield (kg/ha) vs. Measured wheat yield (kg/ha)

Fig. 26. Comparison between simulated and measured grain yield of winter yield in Bulgaria during the periods of calibration (1984-1990) and verification (1991-1993)

Legend: A - 0% ≤ ∆ ≤ 10%, B - 10% < ∆ ≤ 20%, C - 20% < ∆ ≤ 25%, D - 25% < ∆ ≤ 30%, E - 30% < ∆ ≤ 40%, F - 40% < ∆ ≤ 50%

Fig. 27. Deviation (Δ) between simulated and measured grain yield of winter wheat in Bulgaria (1984-1990)

4. Conclusions

There was found good agreement between real phenological stages and yield of important crops in Austria and Bulgaria and phenology and yield, estimated with the CERES, CROPGRO and WOFOST models. Overall, the model test results were very good. The results obtained indicated a satisfactory performance of the applied simulation models for winter wheat, spring barley, maize and soybean in the selected environments.

It is necessary to emphasize, however, that the above crop-weather models embody a number of simplifications and limitations. For example, many physiological processes and
their response to diurnal weather conditions are not simulated on hourly base but using daily time step input weather data. The impacts of weeds, diseases, and insect pests on crop growth, development and final yield formation were also not assumed within the study. These limitations might be related to some of the high deviations between the model crop simulations and real measured crop data.

Crop-weather models can play an important role at different levels of applications, ranging from decision support for crop management at a farm level to advancing understanding of sciences at a research level. The main goal of most applications is to predict final yield in the form of either grain yield, fruit yield, root or tuber yield, biomass yield for fodder, or any other harvestable product (Hoogenboom, 2000). Certain applications link the price of the harvestable product with the cost of inputs and production to determine economic returns.

According to Hoogenboom (2000), the management applications of crop-weather models can be defined as strategic applications, tactical applications, and forecasting applications. In strategic applications, the crop models are run prior to planting of a crop to evaluate alternative management strategies. In tactical applications, the crop models are run before planting or during the actual growing season. Both strategic and tactical applications provide information for decision making by either a farmer, consultant, policy maker, or other person involved directly with agricultural management and production. Forecasting applications can be conducted either prior to planting of a crop or during the growing season. The main objective is to predict yield; this information can be used at a farm-level for marketing decisions or at a government level for policy issues and food security decisions.

The models applied within the study can be used for within-year crop decisions, multi-year risk analysis for strategic planning, crop yield prediction, basic economic assessments of agricultural cereal production and definition of research needs in Austria and Bulgaria and surrounding countries in Central and Eastern Europe. For example, these models have potential for generating forecasts of environmental yields in advance of harvest or maturity, as well as at the time of harvest. In this case, online assessments of current agrometeorological conditions and expected yield can be done. Expected crop yields can be predicted some time
before harvest by using climate or expected weather data. Because long-range weather forecasts are not yet reliable, predicting weather is not yet very exact. However, using a range of reasonable weather patterns, a “fork” of yield expectations can be determined. Such estimates will be of value to growers seeking to sell their crops, to the transportation industry in planning to move the crop, and to national governments estimating the effects of production on future prices.

Once the CERES, CROPGRO and WOFOST crop-weather models have been adapted for the environmental conditions in the selected regions in Austria and Bulgaria, numerous computer experiments can be run. These experiments can involve an assessment and comparison of new and traditional varieties and their response to different fertilizer and irrigation regimes, to different soil types and climatic conditions (e.g. climate change impacts). The major goal of these simulations will be determination of the optimum crop management practices, necessary to obtain high crop yields and gains.

References


