Potato Simulation Model and its Evaluation in Selected Central European Country

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Summary

The study was focused on evaluation of SUBSTOR – Potato model and its utilization in potato growing management in the Czech Republic. The experimental field used for the model evaluation was located in Žabčice – South Moravia region with altitude of 179 meters above the sea level. Tuber yield served as reference for the model evaluation. Nine years experimental data set (1994 – 2002) was used for the model validation. Rosara cultivar represented very early growing potato, Karin cultivar depicted early growing potato (*Solanum tuberosum* L.) in the experiment. Comparison between observed and simulated tuber yields presented the evaluation process of SUBSTOR – Potato model. Tuber yields simulated by the model showed excellent accuracy ($R^2 = 0.97$) for Rosara cultivar, but only for four of tested years (1997, 1998, 1999 and 2002). Karin cultivar matched lower value ($R^2 = 0.43$). The model tended to underestimate the tuber yield for non seasonable conditions (i.e. dry years – low amount of precipitation and its disordered distribution during the growing season or higher mean air temperature) and showed the sensitivity to selected cultivars. Study proved SUBSTOR – Potato model as suitable for utilization in potato management; however, potential differences might be expected while using the model under extreme weather conditions.

Key words

evaluation, program, sensitivity, *Solanum tuberosum* L., SUBSTOR, weather conditions

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Introduction

Potato is one of the important tuber crop in the EU. Almost 2% of the arable land area in the EU is used for potato production (Wolf, 2002). The growing demand for potato – as both a fresh and processed food – and a decreasing availability of land for area expansion mean that yield will have to be improved through some combination of germplasm enhancement, better crop protection and more efficient and productive management systems (Bowen et al., 1999). The average yield of 15.9 t ha^{-1} currently estimated at the global level is much below the yield of 30 − 50 t ha^{-1} commonly obtained across a range of environments and management systems, so it would seem that there is considerable scope for improvement (Allen and Scott, 1980; 1992). Development and innovative research push scientists active in potato research to use more and more sophisticated computer programs to evaluate complex situations that cannot be analyzed directly with other means.

The progress of dynamic crop growth models, which started more than thirty years ago, considerably improved analytic solution of problems in crop sciences. Those models are being used increasingly to study complex dynamic systems. Through the use of mathematical equations, researchers are better able to understand the development and improvement of these dynamic systems. 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, which 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; Thornton et al., 1991).

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 field management data over extensive time periods. The evaluation of the models normally includes their validation on independent data sets i.e. defining the usefulness and relevance of a model for a pre – defined purpose (Šťastná et al., 2002). This contribution represents experiences and results from assessment of SUBSTOR (Simulation of Underground Bulking Storage organs) Potato model (Ritchie et al., 1995) under different weather conditions during nine years experiment and two potato cultivars in the Czech Republic.

Material and methods

Main part of the study contained collection of required input data for SUBSTOR − Potato model calibration and evaluation at the experimental field in Žabčice (South Moravian region) of the Czech Republic with latitude 49° 01' N, longitude 16° 37' E and altitude 179 m. The long-term mean yearly precipitation shows 480 mm, the mean annual temperature is 9.2 °C. The calibration and evaluation process followed subsequent stages as *data collection* (observation or measurement) of the experimental data (planting, maturity dates and tuber yields), *calibration* of SUBSTOR – Potato model using experimental data; *evaluation* of the model by comparison of the observed and simulated data, *assessment* of the possibilities and limitations (simulation of potential yield). Various types of input data are required to prepare and run the model simulation. The minimum weather data set (comprising daily maximum and minimum temperatures, global radiation and precipitation) and management data were obtained from the field experiments.

Table 1. General description of the experimental field at Žabčice locality

Site	Žabčice
Latitude	49° 01' N
Longitude	16° 37' E
Elevation (m above sea level)	179
Primary crop	maize
Soil type	Fluvisol Gley
Mean annual temperature (°C)	9.2
Mean temperature (Apr – Sept) (°C)	15.7
Sum annual precipitation (mm)	480
Sum precipitation (Apr – Sept) (mm)	312
Range of annual accumulated global radiation ($MJ\ m^{-2}$)	3584 – 4312

Site description

Žabčice experimental site is situated in maize production region, which slightly differs in climatic as well as soil conditions from optimal potato production region. Complete set of meteorological, pedological, crop and management input data (Table 1) was collected. Experiments used for the model evaluation have been carried out during years 1994 − 2002. 'Rosara' and 'Karin' potato cultivars have been used for the model simulation (Table 2).

Soil description

The soil type at Žabčice experimental field belongs to Fluvisols Gley subgroup according to the Czech Soil Taxonomy (Němeček and Kozák, 2000). Water saturation comes up to 40 vol. %, field capacity 38 vol. % and wilting point 21 vol. % (Table 3). The soil type is deep grounded with a high (at about 1.7 m depth) groundwater level (continuous impact of groundwater on the rooting zone of crops). The soil depth considered for simulation of soil water balance was 1.5 m with similar soil water storage capacity (240 − 260 mm for the rooting depth of 1.5 m).

Table 2. Characteristics of 'Rosara' and 'Karin' potato cultivars used in the experiment (deu = Germany, csk = Czechoslovakia, Marker scores: 1 = fragment present, 0 = fragment absent, 2 = unclear or missing value, maturity: 1 (very late maturing) to 9 (very early maturing), resistence – Leaf blight and Tuber blight: 1 (very susceptible) to 9 (very resistant). Source: Gebhardt Ch. et al. (2003)

Cultivar	Origin	Year	Marker BA47f2 650 bp	Marker R1 1400 bp	Marker R1 1800 bp	Marker CosA 210 bp	Marker GP179 570 bp	Marker GP76 500 bp	Maturity	Leaf blight	Tuber blight
Rosara	deu	1990	2	2	0	0	0	1	9	6	7
Karin	csk	1980	0	0	1	0	0	0	7	5	8

Table 3. The main soil water characteristics in the soil profile used by SUBSTOR – Potato model

Soil depth (cm)	Clay loam			%		
	Wilting point (%)	Field capacity (%)	Soil saturation (%)	clay	sand	silt
25	21	39	40	32	21	47
75	21	38	40	34	27	39
150	21	39	40	29	37	34

SUBSTOR – Potato model

SUBSTOR is one of sixteen FORTRAN – based field crop models included in the DSSAT (Decision Support System for Agrotechnology Transfer) software (Hoogenboom et al., 1994) (version 3.5, later on version 4.0) developed by the IBSNAT (International Benchmark Sites Network for Agrotechnology Transfer) project. The explanatory and dynamic crop models of the SUBSTOR group are composed from several modules, which serve for data input, mathematical calculations of the growth and development processes and finally for presentation of the simulation outputs (Fig. 1). The model takes into account several processes simultaneously to provide a realistic description

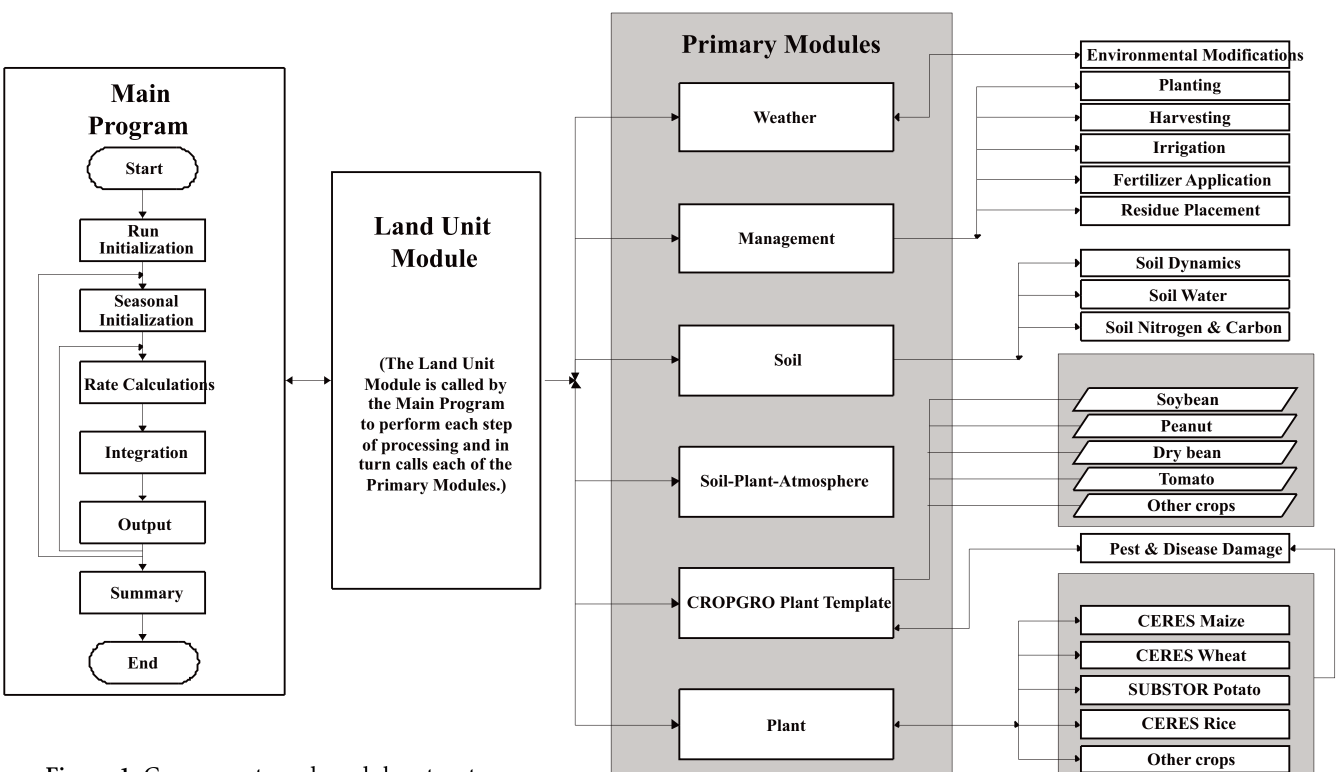

Figure 1. Components and modular structure of DSSAT including SUBSTOR – Potato model

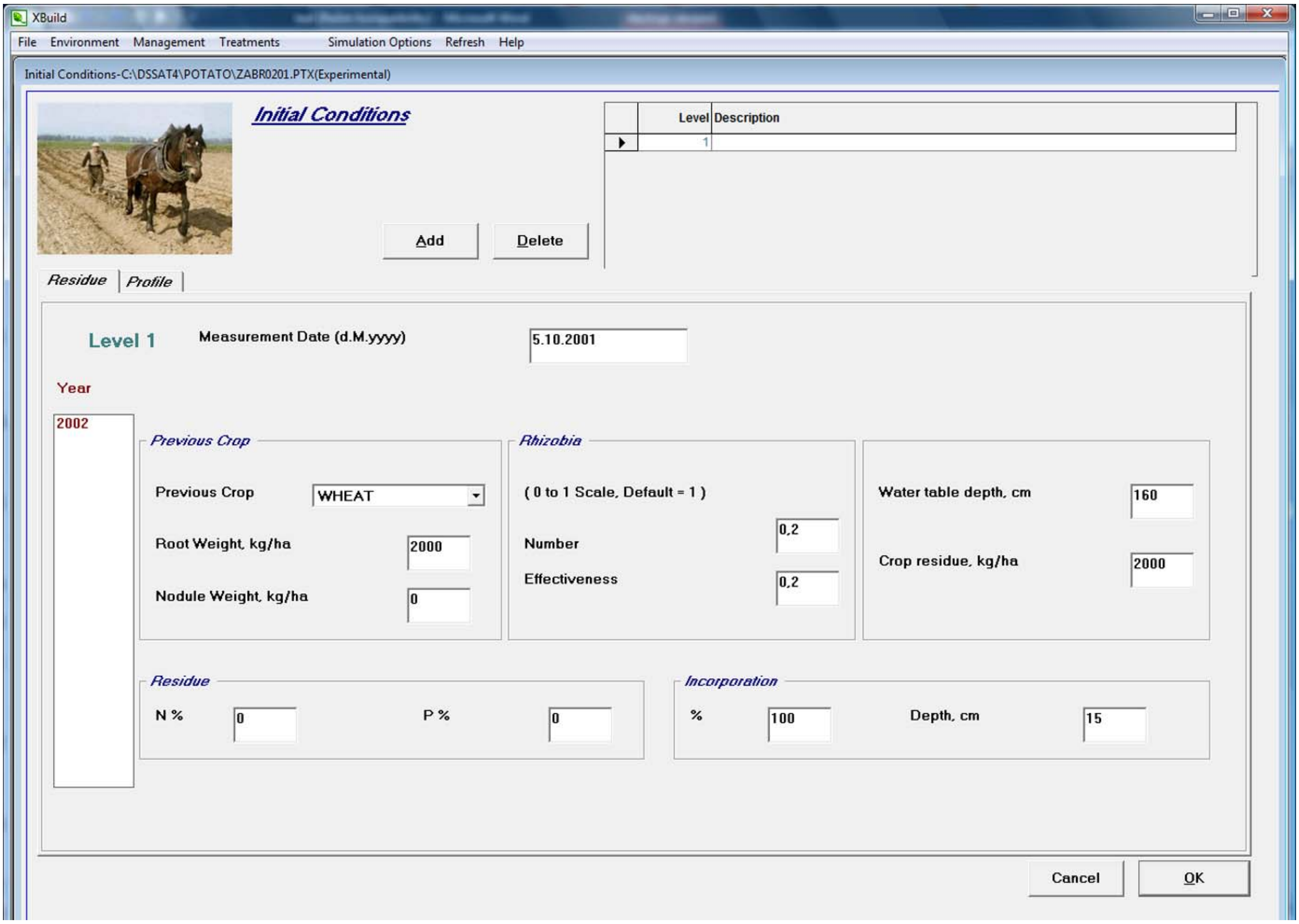

Figure 2. Design of XBuild program specifying any combination of management options

of the crop – soil – atmosphere system. Each simulation consists of the following steps:

— calculations of the phenological development
— formation of leaf, stem and root biomass and its partitioning
— available soil water and its utilization by the crop
— and the nitrogen balance and its distribution to crop organs.

Output data files provide a detailed description of the above ground biomass formation and the biomass nitrogen content as well as information about soil reserves of available water and nitrogen. A lot of additional and useful information is provided through the utilities of DSSAT (Fig. 2). Most of the crop simulations in DSSAT4 use the modular Cropping Systems Model (CSM). This model incorporates the previous CROPGRO, Ceres – Maize, Millet and Sorghum, Ceres – Rice and SUBSTOR – Potato models into a single system with shared soil and weather simulation routines.

Calibration of input data

Four groups of input data were required to prepare and run the model simulation. The minimum weather data set comprises daily maximum and minimum temperatures (°C), global radiation (MJ m^{-2}) and precipitation (mm). The meteorological stations (automatic or climatological) were used as a source of needed values. Genetic coefficients were derived mainly from literature sources (e.g. Vermeer, 1990) and partly from experimental data from test sites. Soil input data were derived from soil pits situated directly at the experimental site. Crop management data included information about planting, emergence and harvest dates as well as about used amount of nitrogen, potassium and phosphorus fertilizers and finally, data about tillage practices and previous crop were set into the model before the simulation started. Rosara – very early growing cultivar (vegetation period 90 – 100 days) and Karin – early growing cultivar (vegetation period 100 – 110 days) were chosen for the experiment.

The model is designed to be used for simulation of two production levels. The *potential yield production level* is limited only by temperature, solar radiation and the specific physiological plant characteristics. This level was also considered in our study. At the *water and nutrients – limited production level*, the soil and plant water balance together with available nutrients are included in the simulation of potato growth. SUBSTOR model is based on "black box approach" and therefore cannot be easily adapted or modified by user for local conditions as their source codes are not normally available. On the contrary some models enable such adaptation e.g. WOFOST (Supit et al., 1994).

The SUBSTOR model was calibrated for the mentioned experimental site by adapting soil, weather, management and crop model parameters into input files. Main characteristics – tuber yield and cultivars were used as evaluation parameters. This option was used in the study in order to obtain a more complete picture of the model accuracy. Nine years treatments consisted of trials included 'Rosara' and 'Karin' potato cultivars grown under annually different weather conditions. The purpose of this approach was to test whether the model can realistically reflect potato tuber yield production during the different weather conditions and to gain perspectives on the model accuracy and sensitivity.

Results and discussion

SUBSTOR – Potato evaluation

Evaluation is an important step in model verification. It involves a comparison between independent field measurements (data) and outputs created by the model. The model evaluation results were compared to observed data from Žabčice during years 1994 – 2002 (Fig. 3) for 'Rosara' and 'Karin' potato cultivars. Locality experimental data were taken from final reports of long – term potato experiments, which were conducted by several departments of Mendel University of Agriculture and Forestry, Brno. The model

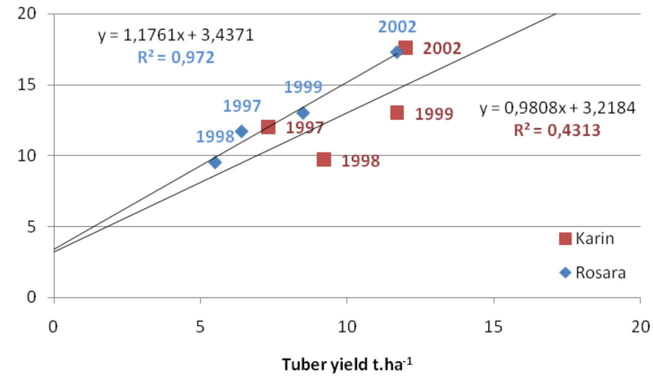

Figure 4. Evaluation of potato yield (dry matter) at Žabčice, cultivars 'Rosara' and 'Karin', years 1997, 1998, 1999 and 2002. The straight line in the figure represents the linear regression functions relating the observed and simulated tuber yields (t ha^{-1})

evaluation using tuber yield as the main parameter was very successful – see the coefficients of determination 0.97 in Žabčice (Fig. 4), but only for four of nine tested years (1997, 1998, 1999 and 2002) for Rosara cultivar. Most of those years are considered as above normal concerning precipitation amount (Fig. 7). Also Table 4, as well as Figs. 6 and 7, show that mentioned years were *extraordinary wet* from precipitation point of view or *warmer* than normal from the temperature point of view (Fig. 5). Similarly good result between observed and simulated values in normal ranges of tuber yields (R^2 = 0.915) in Argentina was published by Travasso et al. (1996).

As may be seen in Table 5, the model underestimated water limited tuber yield in years 1994, 1995, 1996 and 2000. Those years can be categorized as *extreme* years from the temperature point of view. Results showed that the model did not reach similar values as observed yields due to the significant increase of mean air temperature. The same

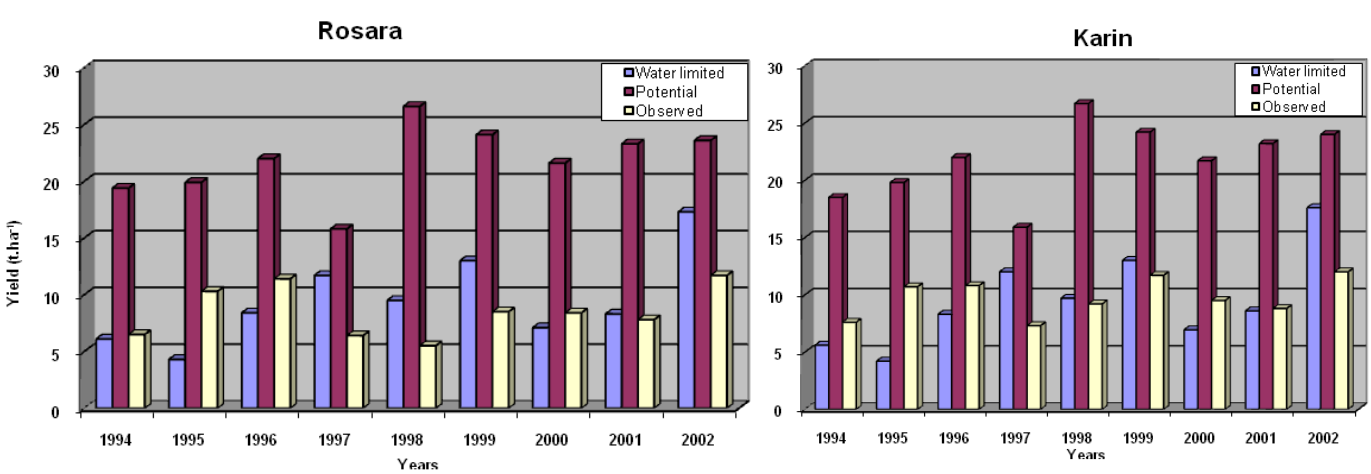

Figure 3. Yield differences – comparison between observed, water limited and potential tuber dry yield data (t ha^{-1}) for 'Rosara' and 'Karin' cultivars during 1994 – 2002

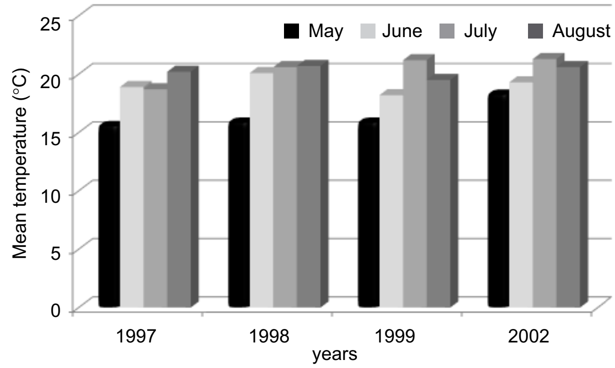

Figure 5. Mean air temperature values (°C) within four months (May – August) for selected years in Žabčice

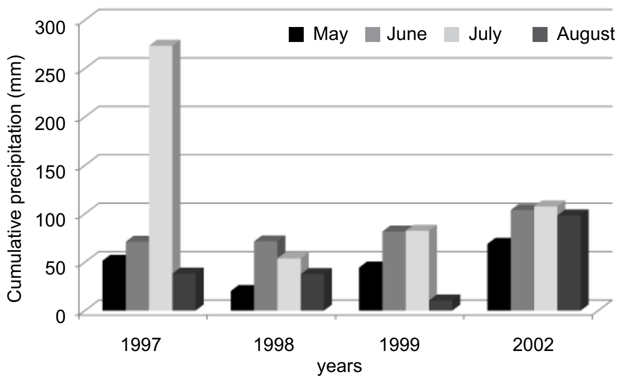

Figure 6. Precipitation values (mm) within four months (May – August) for selected years in Žabčice

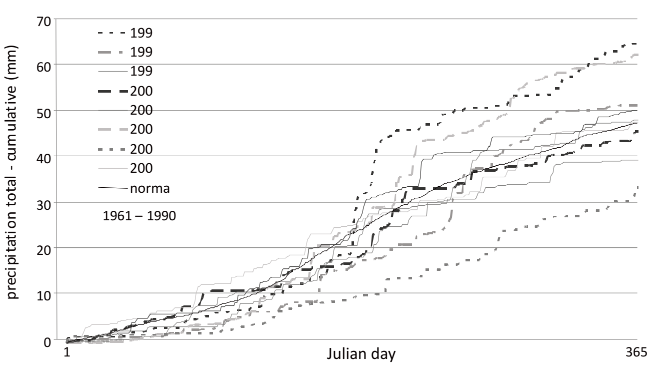

Figure 7. Cumulative precipitation total (mm) for selected years (1997 – 2004) in Žabčice

tendency confirms Klepper and Rouse (1991) for potato growth model and a series of observations on the growth of the Russet Burbank cultivar obtained from Wisconsin. Simulation with increased temperatures showed much lower the predicted yield and the larger relative uncertainty.

Sensitivity of the model was shown also on two selected cultivars. Better result was obtained for very early growing Rosara cultivar ($R^2 = 0.97$), while early growing Karin cultivar matched lower value ($R^2 = 0.43$). One of the explanations could be physiological differences projected into genetic parameters of the cultivar in the model.

Table 4. Categorization of selected years by deviations from normal (1961 – 1990) for mean annual air temperature (°C) and sum annual precipitation (mm) according to Kožnarová and Klabzuba, 2002

Year	Air Temperature (°C)		Precipitation (mm)	
1994	11.2	extraordinary warm	389	dry
1995	10	warm	490.4	normal
1996	8.3	very cold	511.2	normal
1997	9.2	normal	660.4	very wet
1998	10.2	warm	518.8	normal
1999	10.3	warm	399.6	dry
2000	11.3	extraordinary warm	434.3	normal
2001	10.0	warm	485.9	normal
2002	10.5	very warm	629.2	very wet
Normal 1961 – 1990	9.2		480	

Another reason of divergence could be the soil water storage. Experimental site Žabčice has much higher soil water storage in the rooting zone by the impact of groundwater, which can act as a buffer during dry periods. Total biomass accumulation and yield can be therefore significantly higher for rain – fed conditions as no water shortage occurred in spite of increased soil water use (Eitzinger et al., 2003).

The yield difference might be also caused by factors that were not described by the model (e.g. change in crop management and protection or in nutrient supply). These results correspond well with the conclusions from modelling studies for potatoes in Denmark (Olesen et al., 2000). First, crop growth model simulations could explain only to a limited extent the inter – annual yield variation from the inter – annual variation in weather conditions and, second, for most crop species in the EU a clear technology trend (i.e. yield increase over time due to improved crop varieties and crop management) was observed (Kabat et al., 1995).

There might be also other factors as harvest losses or pests and diseases that were the reason why the model did not satisfactorily assess such differences and which can influence the yield values. Those were not simulated during the experiment. Based on the results, it is possible to say that model was successfully validated at Žabčice for the shorter time period. However, results were not sufficiently precise for simulations in years with extremely high temperature values during the particular year. Some yield limiting factors were possibly not considered well by the model. That might limit reliability of the model in some cases.

Table 5. Validation of the SUBSTOR – Potato model for 'Rosara' and 'Karin' cultivars in Žabčice. Validation parameters: potato dry tuber yield (t ha-1) and cultivars

Year	Rosara			Karin		
	Water limited yield	Potential yield	Observed yield	Water limited yield	Potential yield	Observed yield
1994	6.1	19.4	6.5	5.6	18.5	7.6
1995	4.3	19.9	10.3	4.2	19.8	10.7
1996	8.4	22.0	11.4	8.3	22	10.8
1997	11.7	15.8	6.4	12	15.9	7.3
1998	9.5	26.6	5.5	9.7	26.7	9.2
1999	13	24.1	8.5	13	24.2	11.7
2000	7.1	21.6	8.4	6.94	21.7	9.5
2001	8.3	23.3	7.8	8.6	23.2	8.8
2002	17.3	23.6	11.7	17.6	24	12

Comparable model analyses of the sensitivity of potato production have been performed for Scotland (Peiris et al., 1996) and different states in the USA (Rosenzweig et al., 1996). In the cooler climate in Scotland temperature rise gave higher tuber yields because of the increased length of the growing season, whereas in the warmer climates in the USA, especially in the more southern states, temperature rise had a strongly negative effect on tuber yields (Kabat et al., 1995). These results correspond well with the sensitivity of tuber production to temperature in SUBSTOR – Potato in the Czech Republic.

Conclusions

The results of this study confirmed the possibility of the application of the SUBSTOR – Potato model in the Czech Republic conditions, especially South Moravian region. Model was successfully evaluated for four years (1997, 1998, 1999 and 2002) with similar weather conditions as far as the simulation of tuber yield is concerned. The model tended to underestimate the tuber yield for unsuitable conditions (i.e. dry years – low amount of precipitation and its disordered distribution during the growing season or higher mean air temperature – years 1994 – 1996 and 2000 – 2001). Further research in this area is therefore needed in order to improve model calibration and apply it as well for different soil conditions. Longer and more detailed historic data should be examined and further field trials should be carried out including e.g. continuous measurements of soil water. Such evaluation procedure can minimize the disadvantages of each method and improve our ability to test a model in more details. Only carefully calibrated and evaluated models can be used for purposes of dynamic tuber yield and harvest predictions, climate change impact studies, adaptation and sensitivity analyses, optimization of management performances (e.g. irrigation and fertilizing practices) and for other practical applications.

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