The performance of CERES-Barley and CERES-Wheat under various soil conditions and tillage practices in Central Europe

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Das Verhalten der Ertragsmodelle CERES-Barley und CERES-Wheat bei verschiedenen Böden und unterschiedlicher Bodenbearbeitung in Mitteleuropa

1 Introduction

Crop growth models have been used since the 1960s and are regarded as important tools of interdisciplinary research. They were designed as system algorithms on various bases and have been widely used, e.g., for assessing the agricultural potential within selected regions (AGGARWAL, 2000) or for crop yield forecasting (VAN DIEPEN, 1992; PERDIGÃO and SUPPIT, 1999). Crop models can also provide useful estimates of the costs and benefits of agricultural practices, such as the sowing date, nitrogen fertilization time and amount, etc. (e.g., RINALDI, 2004). If weather data, based

Zusammenfassung

Wachstums- und Ertragsmodelle für Nutzpflanzen sind anerkannte Hilfsmittel zur Abschätzung des Pflanzenproduktionspotentials, zur Bestimmung des Klimawandeleinflusses und zur Analyse von Anpassungsmaßnahmen in der landwirtschaftlichen Pflanzenproduktion. Änderungen in der Produktionstechnik und in der Bodenbearbeitung zur Steigerung der Wasserversorgung der Nutzpflanzen gehören in diesem Zusammenhang zu den wichtigsten Anpassungsmaßnahmen in trockenen Regionen. Das Hauptziel dieser Studie war es, das Verhalten der validierten CERES (Crop-Environment Resource Synthesis) Wachstums- und Ertragsmodelle für Weizen und Gerste (CERES-Wheat und CERES-Barley) hinsichtlich des simulierten Ertrages und Bodenwassergehaltes mit konventioneller Bodenbearbeitung (Pflug) und Minimalbodenbearbeitung an zwei Standorten in Österreich und Tschechien im Vergleich zu Feldexperimenten zu testen. Zusätzlich wurden unter Einbeziehung von zwei weiteren Versuchstandorten verschiedene Stickstoffdüngungsstufen mitberücksichtigt. Insbesondere auf Böden ohne Grundwassereinfluss wurden Ertrag, Korngewicht, Blüh- und Reifezeitpunkt zufriedenstellend simuliert (der mittlere Fehler (rMBE) lag beim simulierten Ertrag im Bereich von –19,6 % bis 13,4 %, beim Korngewicht zwischen 5,4 % bis 13,0 %, beim Blühzeitpunkt zwischen 0,8 % bis 3,0 % und beim Reifezeitpunkt zwischen –3,3 % bis 2,0 %). Die Biomasseakkumulation wurde an allen Standorten sehr gut simuliert (der Index der Simulationseffizienz lag zwischen 0,92 und 0,83). Beim Bodenwassergehalt lag rMBE zwischen –28,5 % und 0 % und die mittlere quadratische Abweichung (rRMSE) zwischen 9,0 % und 31,2 % auf allen Standorten. Hier ist eine größere Schwankungsbreite erkennbar, der sich aus dem vereinfachten Bodenwassersimulationsansatz der CERES-Modelle ergibt und die eine zufriedenstellende Funktionalität auf die eher frei dränenden Böden beschränkt. Zusammenfassend zeigen die Ergebnisse standortabhängige (bzw. bodenspezifische) Unterschiede hinsichtlich des Einflusses unterschiedlicher Bodenbearbeitung, wobei zur Bewertung von Anpassungsmaßnahmen hinsichtlich der Bodenbearbeitung aber standortabhängige Unsicherheiten auftreten. Bezüglich der Bodenwasserhaushaltsmessungen und -simulationen lässt sich ableiten dass Minimalbodenbearbeitung auf den leichteren Böden (sandiger Lehm bzw. Löß des Marchfeldes) die Bodenwasserspeicherung durch dichtere Lagerung erhöht, während auf tonigen, dicht lagernden Böden (Fluvisol in Žabčice) eine Bodenlockerung durch den Pflug eine höhere Wasserspeicherung ermöglicht als Minimalbodenbearbeitung (allerdings nur unter Berücksichtigung der kurzfristigen mechanischen Wirkung).

Schlagworte: Minimalbodenbearbeitung, Pflügen, Anpassung an den Klimawandel.

Summary

Crop growth models are regarded as particularly useful tools for assessing plant production potentials, estimating the impact of climate change and analyzing the available adaptation options in agricultural crop production. Changes in management practices and tillage techniques that save water in the soil are among most frequently proposed adaptation measures in semi-arid areas. The main objective of the submitted study was to evaluate ability of two CERES (crop-environment resource synthesis) models (CERES-Barley and CERES-Wheat) to mimic the yields and soil water course under conventional (with ploughing) and minimum (without ploughing) tillage practices at two different locations (in the Czech Republic and Austria). Moreover, the behavior of the models under various management approaches (e.g., the fertilization level) and soil and climatic conditions within four sites in Central Europe was evaluated. Winter wheat and spring barley, the most important European cereal crops, were included. The yield level was successfully estimated (especially for soils without groundwater impact to the rooting zone) and the relative mean bias error (rMBE) varied from –19.6 % to 13.4 %. Consequently, the rMBE for the estimated seed weight varied from 5.4 % to 13.0 %, the time of flowering from 0.8 % to 3.0 % and the time of maturity from –3.3 % to 2.0 %. The soil water dynamics were also simulated and the rMBE varied from –28.5 % to 0.0 % and the relative root mean square error (rRMSE) varied from 9.0 % to 31.2 % in all of the experiments. The above ground biomass accumulation was estimated quite well with a simulation efficiency index from 0.92 to 0.83. On the basis of achieved results it could be concluded that tested models provided reasonable estimates of included parameters but they could be used for analysis of adaptation measures (such as tillage approach) only with certain caution. From the soil water measurements and simulations, it could be concluded that minimum tillage leads to an increase of the soil water on the Chernozem of Raasdorf. On the other side, ploughing seems to provide slightly larger soil water reserves on the fluvisol of Žabčice compared to the applied reduced soil cultivation (where potential long term effects are still not established), probably as a consequence of the higher soil compaction in minimum tillage on clay soil.

Key words: Minimum tillage, ploughing, climate change adaptation.

on future climate scenarios, are available, then growth models can be employed for a climate change impact assessment (e.g., Wolf et al., 1996; Alexandrov and Hoggenboom, 2000; Izaurralde et al., 2003). In spite of their rather complex structure, these models represent only a simplified version of reality.

According to recent studies, Central Europe will most likely be confronted with more arid conditions as a consequence of the changing climate (e.g., Hlavinka et al., 2007; Dubrovský et al., 2009). To mitigate the negative effects of drought within plant production (Quiring and Papakryiakou, 2003; Trnka et al., 2007; Hlavinka et al., 2009), appropriate adaptation measures, such as plant-breeding, irrigation or different crop rotation schemes, will have to be taken. The increasing probability of drought within the growing season has been one of the major concerns of the farming community in Central Europe during the last decade, so more suitable soil tillage and production methods have been a focus of research. In particular, the effects of soil cultivation on the soil water balance and crop growth are critical under increasing drought conditions.

According to H la et al. (2008), the conventional tillage (with ploughing) and minimum tillage (without ploughing) approaches could be considered as an acceptable classification for the contemporary soil tillage approaches. Furthermore, the minimum tillage approach includes many variants with different depths, intensities and methods of loosening (e.g., shallow loosening or direct sowing without antecedent tillage). Minimum tillage methods have been intensively investigated worldwide since 1960. The research is oriented mainly towards the effects on the soil properties, crop development or economic aspects (Sijtsma et al., 1998). Generally, minimum tillage leads to the conservation of soil moisture (e.g., Cantero-Martinez et al., 2007; Šíp et al., 2009) due to the residues of the previous crop on the surface (mulch), higher occurrence of capillary pores and retention capacity. Moreover the tillage influences soil biological activity, bulk density, soil compaction, soil temperature and erosion.

The monitoring of key canopy parameters in the early developmental stages could also be useful. If the status of the crop is closely monitored, then an appropriate management response can be taken (fertilization and/or irrigation operation) and the adverse effects of weather conditions due to the lack in the key yield formation factors within each crop could be reduced. Even though field experiments are an indispensable research tool, crop models could be used to test some of the scenarios at a much lower cost.

The main aim of this study was to evaluate the ability of two CERES (crop-environment resource synthesis) models (CERES-Barley and CERES-Wheat) to estimate the grain yield under different tillage techniques (the conventional approach with ploughing versus minimum tillage without ploughing) and management (fertilization level) at selected locations in Central Europe. The ability of the models to mimic the tillage effects on soil water dynamics (as the underlying cause for the growth/yield) was also analyzed. Moreover, selected parameters of key importance, such as the seed weight, time of flowering and maturity, were modeled and measured across a range of sites. Attention was also paid to the above-ground biomass dynamics estimates that have not been tested thus far for selected regional conditions and cultivars of winter wheat and spring barley.

2 Methodology

The performance of two CERES models, namely CERES-Barley (OTTER-NACKE et al., 1991) and CERES-Wheat (GODWIN et al., 1989), was examined in this study. They are regarded as appropriate and widely used tools for the simulation of the yield components, water balance, and other parameters within the crop-soil-atmosphere system (e.g., JONES et al., 2003; EITZINGER et al., 2004). The evaluated models are from the process-oriented variety of crop models and operate within a DSSAT v4.0 framework (Decision Support System for Agrotechnology Transfer). To run the simulation successfully, the models require information about the experiment itself (initial soil conditions, sowing details, fertilizers used, irrigation, organic residues, etc.), the daily weather (maximum and minimum temperature, solar radiation and precipitation, at least), the soil (chemical and physical properties for determined layers, etc.) and the cultivar specification (RINALDI, 2004). The models have a detailed soil water balance module and have

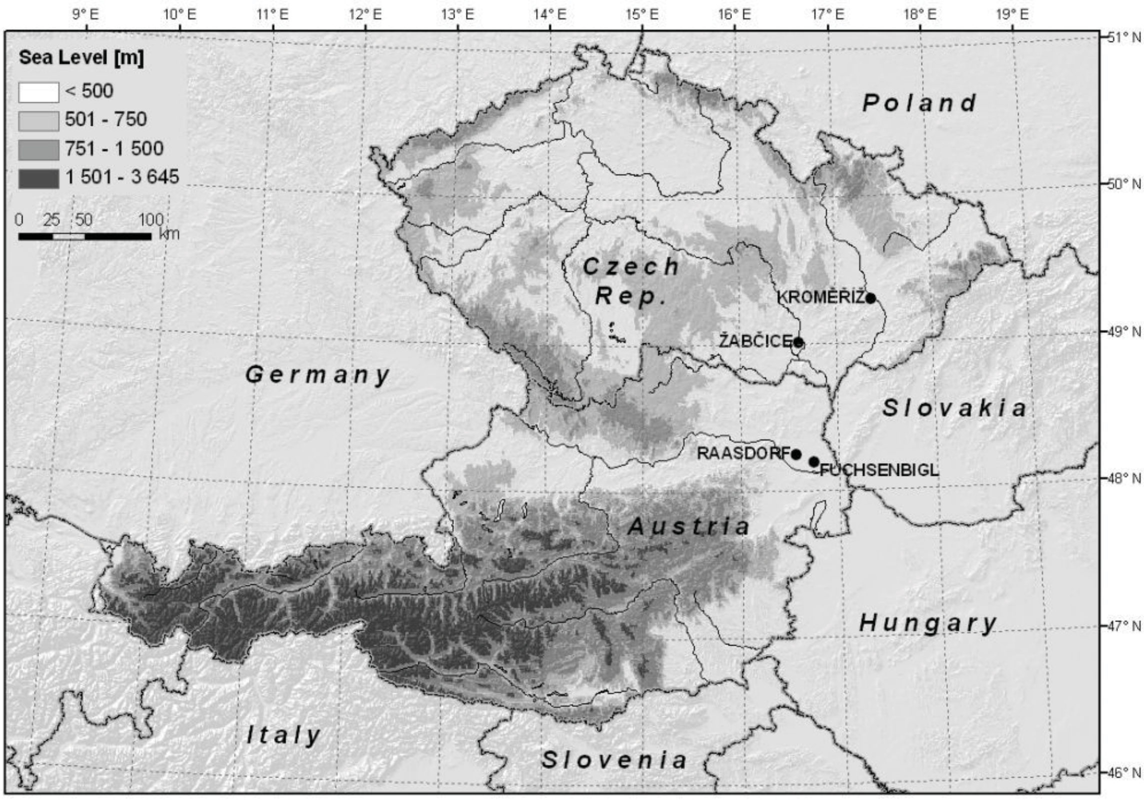

Figure 1: The location of four experimental sites included in the evaluation of the CERES-Barley and CERES-Wheat models. The altitude of the analyzed territories is also shown in the picture (darker grey indicates higher altitudes).

Abbildung 1: Die Standorte der Feldexperimente zur Evaluierung des CERES-Wheat-/CERES-Barley-Modells. Die Seehöhe der jeweiligen Regionen ist durch die Graustufen gekennzeichnet (dunkler bedeutet größere Seehöhe).

been previously used for Central European conditions (e.g., EITZINGER et al., 2004). More details about CERES models construction and functioning could be found in literature e.g. within JONES and KINIRY (1986), RITCHIE et al. (1998) or TSUJI et al. (1998) (Figure 1).

The experimental data used for the evaluation of the models were derived from four experimental sites in the Czech Republic and Austria (see Figure 1), where the field trials were located. The overall climate of the area included in the study is influenced by the penetration and mingling of ocean and continental effects. It is characterized by prevailing westerly and northwesterly winds, intensive cyclonal activity causing frequent alterations of air masses and comparatively high precipitation. Kroměříž (lat. 49.30°, long. 17.38°, elev. 204 m above sea level (a.s.l.)) is located in the fertile region in the middle of Moravia. For this area, the deep soil is typically based on huge loess. The soil type is chernozem with a 155 cm effective soil depth. The average annual temperature is 8.6 °C and the average precipitation is 599 mm. The winter wheat and spring barley field experiments (each with two fertilization levels) during three years (2005–2007) were included within the modeling study. During these experiments, the yields, the weight of one thousand seeds (TGW), the time of maturity and flowering and the above-ground biomass dynamics were observed and consequently simulated by the CERES-Wheat and CERES-Barley models. Žabčice (lat. 49.02°, long. 16.62°, 179 m a.s.l.) is located within southern Moravia. There is heavy soil, namely Gley Fluvisol, with a 105 cm effective soil depth and an occasional rise of groundwater to the rooting zone. The average temperature is 9.2 °C and the average precipitation is 480 mm. The spring barley yields, the time of flowering and maturity and the soil water content under two tillage regimes (with ploughing and minimum tillage) from 2004 to 2005 were measured and modeled. Fuchsenbigl (lat. 48.32°, long. 17.00°, elev. 149 m a.s.l.) is located in the Marchfeld region, which is one of the major field crop production areas in Austria. This region, located in the northeastern part of the country, is influenced by a semi-arid climate. The annual average temperature is around 9.8 °C, and the annual precipitation average is 550 mm. The soil type in the area of Fuchsenbigl is classified as Calcic chernozem. Explicitly, it is described as chernozem on fine calcareous sediments over gravel and sand. The soil type at this site is a loamy sand and sandy silt loam with a very deep groundwater table (> 6 m), which is typical of the Marchfeld region (EITZINGER et al., 2003). The upper soil layer has a thickness of around 150 cm above the C-horizon of sand and gravel. The data (yields, time of flowering and maturity) for winter wheat from 1989 to 2005 (except 2000) and for spring barley during the period from 1989 to 1995 were used within the study. Raasdorf (48.23°, long. 16.55°, elev. 156 m a.s.l.) is also located within Marchfeld region, approximately 13 kilometers northwest from Fuchsenbigl. The soil is Chernozem with 150 cm of effective depth. The yields and soil water course within winter wheat cultivated by conventional and minimum tillage during the year 2002 were included. An overview of the field trial periods, cultivated plants, and tillage and fertilizer levels is provided in Table 1, where the examined parameters are listed.

Table 1: An overview of the experiments and measured parameters included within the study (Abbreviations: WW – winter wheat, SB – spring barley, Pl – ploughing, Min – minimum tillage, N-l – low-nitrogen fertilization, N-m – medium-nitrogen fert., N-h – higher-nitrogen fert., MAT – maturity date, FLOW – flowering date, TGW – weight of one thousand seeds)

Tabelle 1: Übersicht der in der Studie verwendeten Feldexperimente und gemessenen Parameter (Abkürzungen: WW – Winterweizen, SB – Sommergerste, Pl – Pflugbearbeitung, Min –Minimalbodenbearbeitung, N-1 – geringe N-Düngung, N-m – mittlere N-Düngung, N-h – hohe N-Düngung, MAT – Reifedatum, FLOW – Blühzeitpunkt, TGW – Tausendkorngewicht)

Locality:	Soil:	Crop:	Tech:	Experiment duration																			Observed characteristics
				1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	
Fuchsenbigl	Calcic chernozem	WW	Pl; N-h	■	■	■	■	■	■	■	■	■	■	■		■	■	■	■	■			Yields, MAT, FLOW
		SB	Pl; N-h	■	■	■	■	■	■	■													
Raasdorf	Chernozem	WW	Pl; N-h														■						Soil water, Yields
		WW	Min; N-h														■						
Žabčice	Gley Fluvisoil	SB	Pl; N-m																■	■			Soil water, Yields, MAT, FLOW
		SB	Min; N-m																■	■			
Kroměříž	Chernozem	WW	Pl; N-m																	■	■	■	Soil water, Yields, MAT, FLOW, biomass, TGW
		WW	Pl; N-h																	■	■	■	
		SB	Pl; N-l																	■	■	■	
		SB	Pl; N-m																	■	■	■	

There were two basic tillage approaches within the experiments: i) field trials under conventional tillage with medium-depth ploughing (depth 0.18–0.24 m), abbreviated as "Pl", and ii) the minimum tillage approach, marked as "Min". Minimum tillage in Raasdorf was carried out by the direct sowing into non-prepared soil; in Žabčice, it was characterized by the soil loosening of up to 15 cm depth (without ploughing) performed within experimental plots continuously from the year 2003. Three basic fertilization levels were utilized throughout the experiments: "N-l" was a very low or zero nitrogen application, "N-m" was a medium nitrogen application within the range of 40–60 kg/ha, and "N-h" was a higher nitrogen application within the range of 120–160 kg/ha.

To determine the above-ground biomass accumulation, the plants (the portion above ground) from a square of 0.5 × 0.5 m were cut and dried (a heat air oven with a temperature of 80 °C was used up to a constant weight) at the Kroměříž experimental site. Consequently, the dry material was weighed and recalculated for the corresponding area. The above-ground biomass was measured several times (four times for the winter wheat and three times for the spring barley) per vegetation season.

The soil water content was measured continuously by time domain reflectometry (TDR) probes at 0.2 m, 0.4 m and 0.6 m depth intervals in Raasdorf and at depths of 0.1 m, 0.3 m and 0.5 m in Žabčice.

All of the CERES-Wheat and CERES-Barley runs assumed a 350 ppm concentration of CO_2 in the atmosphere. For the analyses within Kroměříž and Žabčice, the model cultivars "Akcent" (spring barley) and "Hana" (Winter wheat) were adopted as calibrated by Trnka et al. (2004 a, b). The winter wheat cultivar "Capo" and spring barley cultivar "Magda" were used within the Austrian experiments as calibrated by Rischbeck (2007).

The cultivar Akcent for CERES-Barley model was properly calibrated and successfully verified by Trnka et al. (2004 a) for the conditions in Central Europe. Within these processes the basic observed characteristics (about the crop canopies) were used (e.g., key phenological stages, grain dry matter, weight of a single kernel, number of productive tillers and N content at maturity), while a range of others (e.g., LAI (Leaf Area Index), above-ground biomass or soil moisture dynamics) were not included in the evaluation process. The study showed that the model performed quite well and was able to explain 83 % of the experimental yield variability. The estimated time of flowering and maturity were also verified and 80 % of their inter-seasonal variability was explained. Trnka et al. (2004 b) applied an analogous procedure for the CERES-Wheat calibration and evaluation. In this case, the winter wheat was represented by the cultivar Hana. The evaluation database originated from a range of field experiments throughout the Czech Republic and the model was able to explain over 53 % of the yield variability and 65 % of the inter-seasonal variability of observed phenological stages. In 71 out of 83 seasons, the difference between the simulated and observed grain yields was smaller than 20 %.

Rischbeck (2007) calibrated the winter wheat cultivar "Capo" and spring barley cultivar "Magda" using phenological and yield data series from the Fuchsenbigl experimental site. The difference between the simulated and observed dates of anthesis and physiological maturity of winter wheat for the calibration varied between 0 to 4 d. The simulated grain yields mostly agreed with the measured data ($R^2 = 0.61$; RMSE = 591 kg ha^{-1}) and the deviation in the annual yield predictions was below 20 %. The spring barley was calibrated in the same way. The difference between the simulated and observed anthesis as well as physiological maturity varied between 0 and 7 d; the simulated yield was within 20 % of the measured values for each year ($R^2 = 0.57$; RMSE = 623 kg ha^{-1}).

The different tillage approaches were defined by modifying the soil properties (water contents at field capacity and wilting point, bulk density and root weighting factor) in the upper layers (Castrignanò et al., 1997; Osunbitan et al., 2005) based on measurements or estimations. The relative changes of water contents at wilting point and field capacity for minimum tillage (against ploughing) used as input for models are listed in Table 2. The mentioned parameters were defined within the CERES-Wheat and CERES-Barley soil files. In addition, these models use the hydraulic conductivity for each defined layer as input. Unfortunately this para-

Table 2: The relative changes (in %) of water contents at wilting point (WP) and field capacity (FC) for minimum tillage (against ploughing) used as input for CERES models

Tabelle 2: Der relative Unterschied (in %) der Bodenwassergehalte am Welkepunkt (WP) und an der Feldkapazität (FK) der Minimalbodenbearbeitungsvariante zur Pflugvariante als Eingabeparameter in die CERES-Modelle

	Žabčice 2004		Žabčice 2005		Raasdorf 2002	
Depth in cm	WP	FC	WP	FC	WP	FC
0–30	–9.3	+1.4	–7.0	+3.0	+22.7	+25.5
30–90	–0.9	+2.7	+8.4	+7.9	0.0	+15.1
90–105 (90–150 for Raasdorf)	0.0	0.0	0.0	0.0	0.0	0.0

meter wasn't measured within the included experiments so it was defined as unknown. Moreover, the tillage depths (0.22 m for ploughing and 0.15 m for soil loosening) were defined in the CERES-Wheat and CERES-Barley experimental setup. The chisel plow setting was used within the simulations (both for ploughing and soil loosening) because no effect of the various tillage implements proposed by CERES models within simulated variables (e.g. actual evapotranspiration, soil moisture or biomass accumulation) was detected.

All of the evaluated parameters were examined with the help of descriptive statistics and by using Pearson correlation coefficients (r). The root mean square error (RMSE) as a parameter of random error and mean bias error (MBE) as an indicator of systematic error (DAVIES and MCKAY 1989) were employed. Its relative values (rMBE and rRMSE in %) were determined as the ratio of the appropriate value of the MBE or RMSE and the mean of measured parameter during the given time period. Within the biomass accumulation and soil water content simulations, the modeling efficiency index (MEI) according to WILMOT (1982) was used. This index results in a number between 0 and 1 (higher values indicate a better fit between the model and field observations). The MEI refers to the accuracy of predictions, where accuracy is regarded as the degree to which model predictions approach the magnitude of their observed counterparts.

3 Results and Discussion

3.1 Grain yield, time of flowering and maturity, above-ground biomass

Generally the yields of spring barley were simulated successfully and the results of the CERES-Barley reflected the differences across the stations and years well (see Figure 2a). The rMBE varied from –19.6 % to 37.0 % and the rRMSE varied from 6.3 % to 37.5 % (see Figure 7, 8). There was a slight overestimation within the Kroměříž station (when a medium amount of nitrogen was used as fertilizer). This is in agreement with the widely accepted fact that crop models do not account for a range of some stress factors (e.g., lodging, pest and diseases) and they generally overestimate the production. The highest bias was obtained for Žabčice, where the model significantly underestimated the real spring barley yields (both for experiments with ploughing and minimum tillage). This could be explained by the occasional presence of groundwater in the rooting zone during vegetation, which mitigated water stress and was not considered by the model.

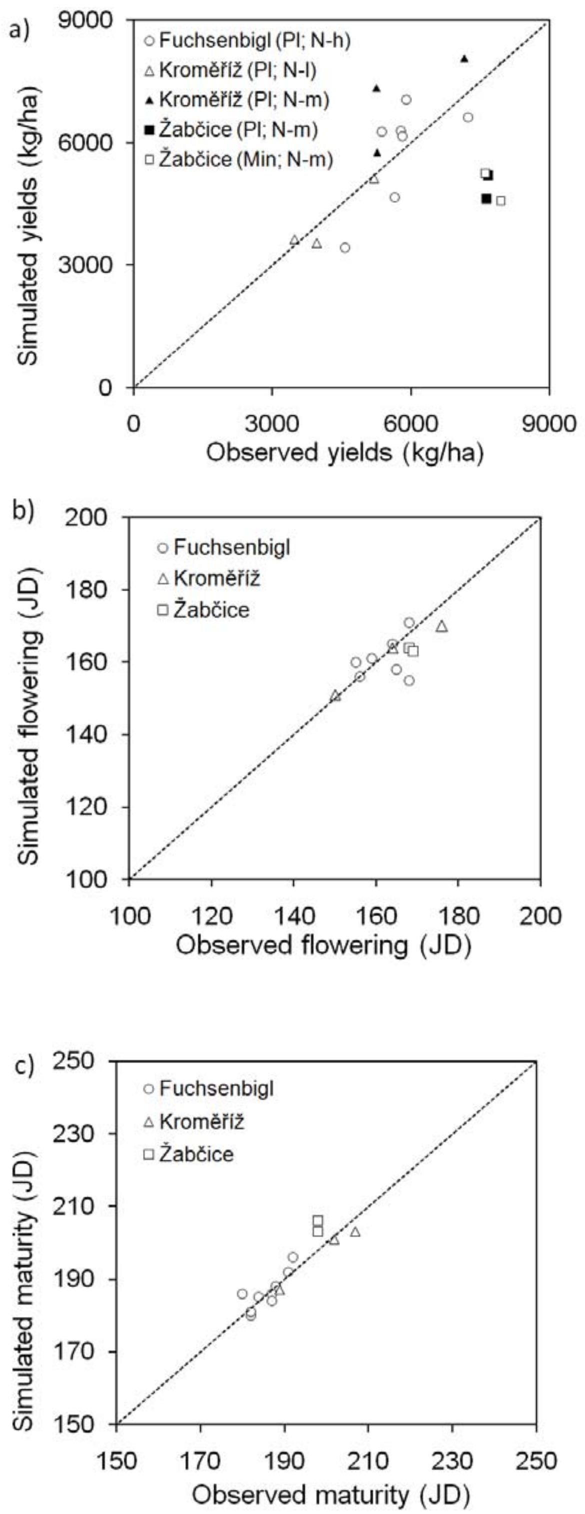

Figure 2: The evaluation of the CERES-Barley model's ability to simulate the (a) yields, (b) time of flowering and (c) maturity. The dotted line expresses the 1:1 trend.

Abbildung 2: Evaluierung des CERES-Barley-Modells hinsichtlich simulierter (a) Erträge, (b) Blühzeitpunkte und (c) Reifezeitpunkte. Die punktierte Linie zeigt das 1:1-Verhältnis.

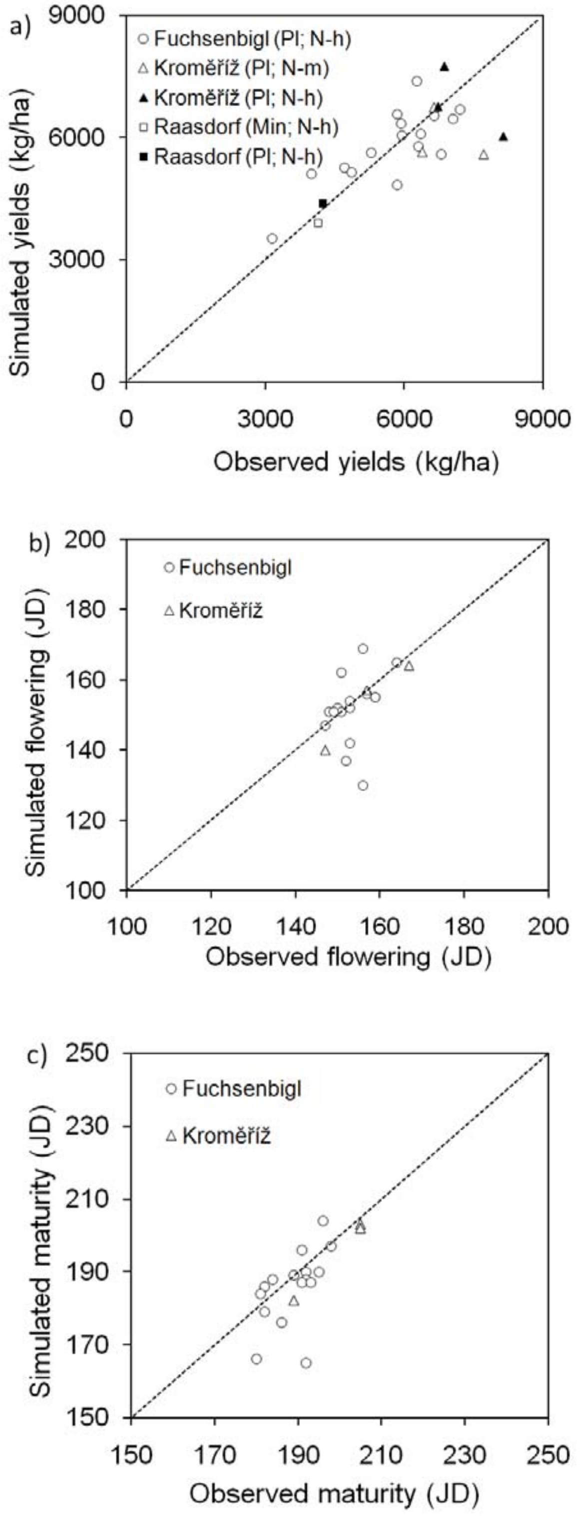

Figure 3: The validation of the CERES-Wheat model's ability to simulate the (a) yields, (b) time of flowering and (c) maturity. The dotted line expresses the 1:1 trend.

Abbildung 3: Evaluierung des CERES-Wheat-Modells hinsichtlich simulierter (a) Erträge, (b) Blühzeitpunkte und (c) Reifezeitpunkte. Die punktierte Linie zeigt das 1:1-Verhältnis.

The CERES-Wheat provided rather reliable estimates of the grain yields through all of the included experiments (rMBE varied from –3.0 % to 13.4 % and the rRMSE varied from 3.0 % to 18.8 %), as presented within Figure 3a. There was a higher scatter and a slight tendency to underestimate the production at Kroměříž (especially within N-m fertilization level). The CERES-Wheat also successfully reproduced the winter wheat yields after the different tillage used at Raasdorf during the year 2002. The higher yield was measured after ploughing (4,243 kg/ha) against the yield after the minimum tillage (4,139 kg/ha). The same trend was reproduced by the tested model (4,371 kg/ha after ploughing and 3,890 kg/ha after minimum tillage).

On the other hand, the CERES-Barley model was not able to reproduce the yield differences of the spring barley after different tillage at Žabčice. The observed yield after minimum tillage (7,940 kg/ha) was higher than the yield measured after ploughing (7,630 kg/ha) during 2004 and a slightly higher yield was observed after ploughing (7,670 kg/ha) compared to the yield measured after the minimum tillage (7,620 kg/ha) during 2005. The CERES-Barley model did not reproduce these trends within the analyzed years (for more detail see Figure 2a and Table 3). This could be caused by the minimal differences in the properties of soil after the ploughing and minimum tillage.

The dates of flowering and maturity were modeled with very satisfactory results for both plants (see Figure 2b–c and Figure 3b–c) within all the experiments of studied (the rMBE varied from –3.3 % to 3.0 % and the rRMSE varied from 1.3 % to 6 %). This high accuracy of the CERES-Wheat and CERES-Barley models has already been established by previous works (e.g., Trnka et al. 2004 a, b).

Consequently, the above-ground biomass measurements were compared with the CERES-Wheat and CERES-Barley estimates that have not been tested so far for selected regional conditions and cultivars. Both models provided very satisfactory results through the various fertilization levels, as is apparent from Figure 4a–d. The MEI in all cases varied from 0.92 to 0.83 and the r varied from 0.97 to 0.99. The rMBE varied from –22.4 % to 11.7 % and rRMSE varied from 20.3 % to 35.9 %. The relatively large bias in terms of the rRMSE parameter is a consequence of its construction in connection with amplitude of evaluated parameter.

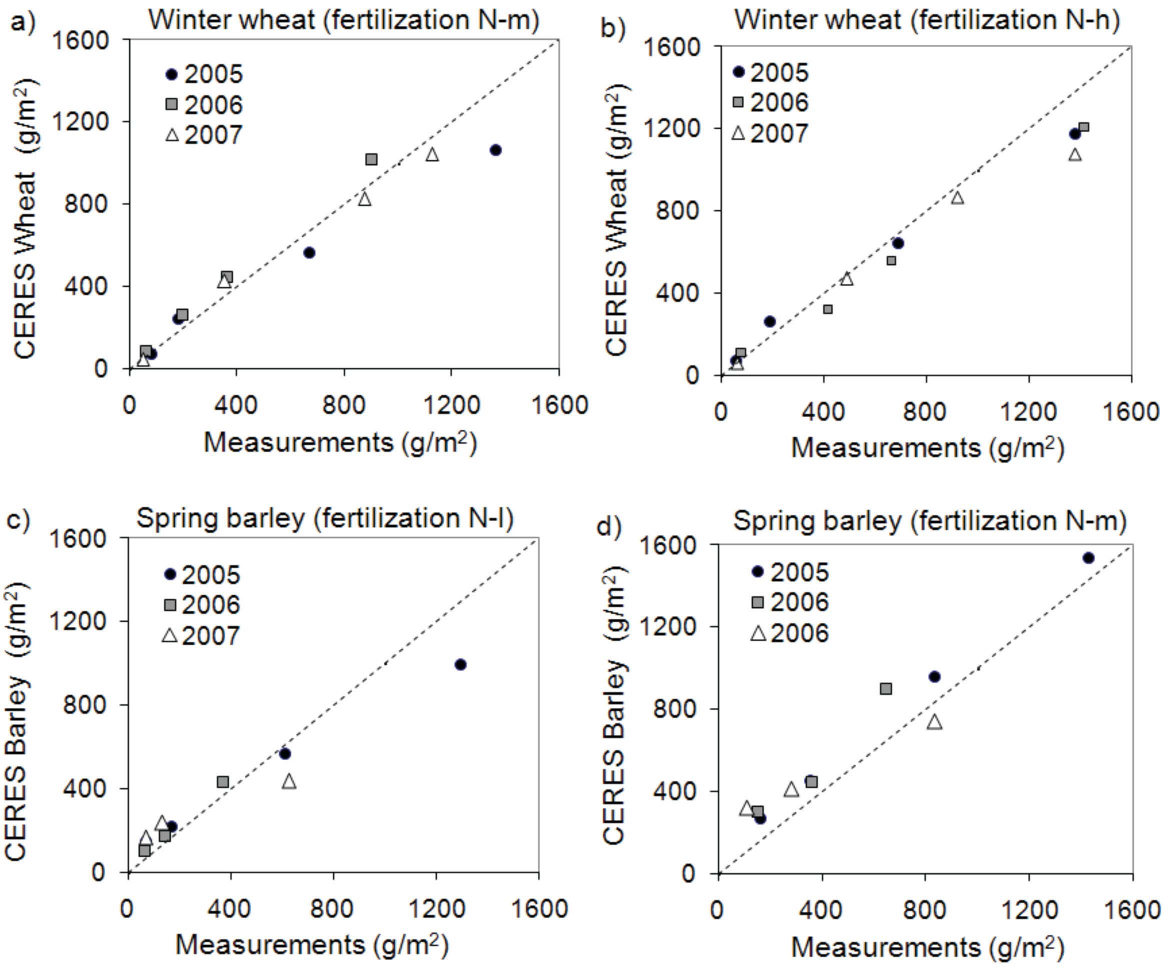

Figure 4: The evaluation of the CERES-Wheat and CERES-Barley models' ability to simulate the above-ground biomass of winter wheat (a, b) and spring barley (c, d) in Kroměříž where medium (a, d), high (b) and low (c) nitrogen fertilization levels were used. The above-ground biomass was analyzed three or four times during the vegetation season. The results for the years 2005, 2006 and 2007 are distinguished within the chart. The dotted line expresses the 1:1 trend.

Abbildung 4: Evaluierung des CERES-Wheat-/CERES-Barley-Modells hinsichtlich simulierter überirdischer Trockenmasse bei Winterweizen (a,b) und Sommergerste (c, d) in Kroměříž unter Berücksichtigung von mittlerer (a,d), hoher (b) und geringer (c) N-Düngung. Die oberirdische Trockenmasse wurde drei- bis viermal in der Vegetationsperiode erhoben. Die Ergebnisse der Jahre 2005, 2006 und 2007 sind in der Abbildung unterschiedlich dargestellt. Die punktierte Linie zeigt das 1:1-Verhältnis.

3.2 Simulation of soil water content

The evaluation of the soil water content estimates was conducted at Žabčice (during 2004 and 2005) and within the Raasdorf station (during 2002), where TDR (Time Domain Reflectometry) measurements were taken under the conventional and minimum tillage. The modeled and measured day-by-day soil water contents within the upper soil layers are depicted in Figures 5a–b and Figure 6. The investigated soil layers experienced substantial variation in time, but the models were able to cope with it fairly well at Žabčice (plough: MEI = 0.90, rMBE = –1.64 %, rRMSE = 9.03 %; minimum tillage: MEI = 0.88, rMBE = –0.02 %, rRMSE = 9.87 %). Eitzinger et al. (2004), however, revealed a higher accuracy for this particular crop model with the rRMSE for the spring barley ranging between 0.71 % and 4.67 %. The results for the winter wheat at Raasdorf (cultivated during the 2002) showed a much higher level of systematic bias (plough: MEI = 0.51, rMBE = –28.54 %, rRMSE = 31.20 %; minimum tillage MEI = 0.11, rMBE = –17.12 %, rRMSE = 23.30 %). Also, the temporal variability between the ploughing and sowing into non-prepared soil could play some role there. Eitzinger et al. (2004) also achieved considerably worse results for the winter wheat than for the spring barley. Compared to the mentioned work, the model presented within the current study did not show a tendency to underestimate the soil water content of the top layers. Differences in the case of the winter wheat simulations can be explained by significant variations in simulating the rooting depth, which is influenced by the root-weighting factor defined by user for each soil layer (ranking from 0 to 1 and characterizing the suitability for root growth), the default crop-specific coefficients and the actual soil water distribution. The results could be improved mainly by more detailed input data, especially regarding the soil structure and permeability, rooting depth and by the proper parameterization of the potential evapotranspiration for the given conditions. There are also the general limits of the CERES-Wheat and CERES-Barley models connected with the cascading principle, which calculates the soil water flux as long as the field capacity is surpassed and no flux is possible when the soil water content is below the field capacity. Moreover, the used models suppose the absolutely homogenous properties through the defined layers and capillary rise is neglected.

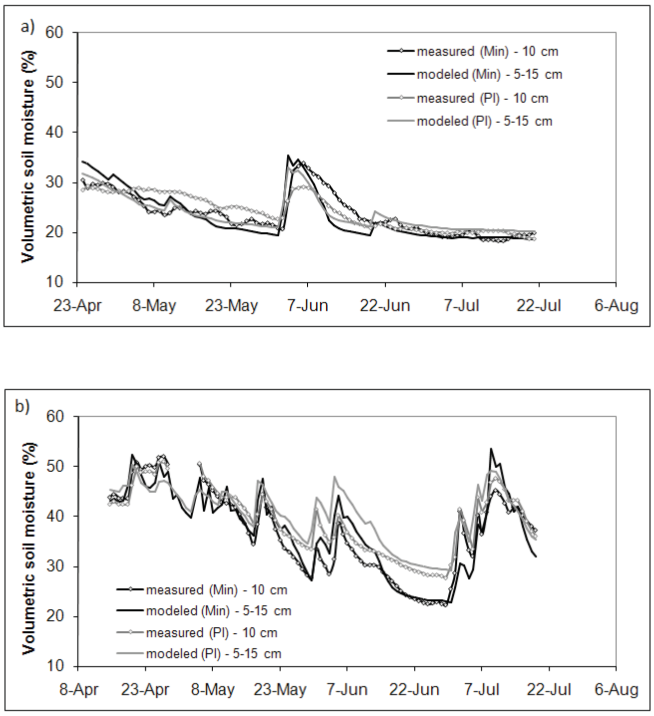

Figure 5: A comparison of the ploughing (Pl) and minimum (Min) tillage approaches within the Žabčice field trials on the basis of the volumetric soil moisture under spring barley during the years (a) 2004 and (b) 2005

Abbildung 5: Vergleich der Pflug- (Pl) und Minimalbodenbearbeitungsvariante (Min) der Feldexperimente in Žabčice hinsichtlich der gemessenen und simulierten Bodenwassergehalte (%Vol.) bei Sommergerste in (a) 2004 und (b) 2005

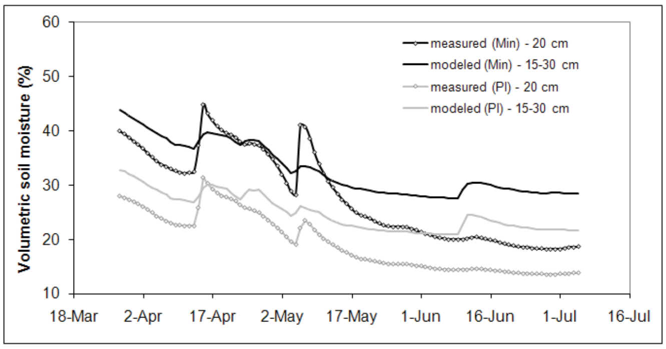

Figure 6: The comparison of the ploughing (Pl) and minimum (Min) tillage approaches within the Raasdorf field trials on the basis of the volumetric soil moisture under winter wheat cover during the year 2002

Abbildung 6: Vergleich der Pflug- (Pl) und Minimalbodenbearbeitungsvariante (Min) der Feldexperimente in Raasdorf hinsichtlich der gemessenen und simulierten Bodenwassergehalte (%Vol.) bei Winterweizen im Jahr der Ernte 2002

From Figure 5 it is apparent that slight differences between ploughing and minimum tillage at Žabčice are hardly distinguishable by the employed model. According to the Wilcoxon test ($\alpha = 0.01$), there was no statistically significant difference between the measured soil water course under ploughing and minimum tillage during the year 2004, but there was a significant difference during 2005. Also, the simulated soil water (after ploughing and minimum tillage) did not differ significantly in 2004 but did differ during 2005. The soil water content with ploughing in Žabčice was equal to or even slightly higher (mainly in 2005) than that observed with minimum tillage. This could be explained by the lower water infiltration in the upper soil layers in the minimum tillage treatment due to soil compaction on clay soil, by higher plant water uptake or by cracks bypassing the water flow of the upper soil layer. Generally, small differences could also be caused by only a slight disparity within the soil properties as a consequence of the short period with the unchanged minimum tillage at the experimental plots (from 2003). Some of the soil properties (e.g., organic matter changes, soil-moisture constants or worm activity) could be considerably altered as long-term effects of such cultivation. Some of the deviation within the soil moisture measurements could be connected with the TDR probes, which are sensitive to soil cracks (which often take place within the heavy Grey Fluvisoil at Žabčice). The Raasdorf TDR measurements provided results with statistically significant differences (according to Wilcoxon and = 0.01) between the experiments and the higher soil water content was observed after the minimum tillage. Although

Table 3: The water balance components according to the CERES-Wheat and CERES-Barley models for the different tillage methods and sites. Moreover, the measured and estimated yields after ploughing and minimum tillage are listed.

Tabelle 3: Simulierte Wasserbilanzkomponenten des CERES-Wheat-/CERES-Barley-Modells für die unterschiedlichen Bodenbearbeitungsvarianten und Standorte. Zusätzlich sind die gemessenen und simulierten Erträge der Varianten angegeben.

	Žabčice				Raasdorf	
	Plough 2004	**Mini 2004**	**Plough 2005**	**Mini 2005**	**Plough 2002**	**Mini 2002**
Start of water balance analysis	2004/082	2004/082	2005/089	2005/089	2001/273	2001/273
End of water balance analysis	2004/204	2004/204	2005/200	2005/200	2002/201	2002/201
Water content at the beginning (mm)	325.7	335.4	452.7	461.0	296.7	305.7
Water content at the end (mm)	286.4	276.5	342.8	353.2	319.3	328.9
Precipitation (mm)	205.7	205.7	254.7	254.7	388.9	388.9
Drainage (mm)	0.0	0.0	0.0	0.0	0.0	0.0
Runoff (mm)	6.8	8.9	5.5	4.4	14.25	21.0
Soil Evaporation (mm)	125.9	103.2	112.2	104.4	173.1	170.9
Transpiration (mm)	112.3	152.5	246.9	253.7	178.9	173.9
Potential ET (mm)	453.6	448.8	438.9	438.5	489.8	490.8
Measured yield (kg/ha)	7630	7940	7670	7620	4243	4139
Estimated yield (kg/ha)	4622	4568	5208	5237	4371	3890

the CERES-Wheat model estimated a lower amplitude and lower soil water depletion (see Figure 6), it reasonably reproduced the main trends. Also, the estimated soil water course statistically differed for both of the investigated tillage approaches.

The detailed overview of the simulated soil water balance components and yields (observed and estimated) within different tillage at Žabčice and Raasdorf stations is listed within Table 3. An overview of all of the results achieved within the current study is presented in Figures 7 and 8.

The simulations (using CERES-Wheat) executed by CASTRIGNANÒ et al. (1997) show some differences among four various tillage treatments for silty-clay soil in Southern Italy, but on the other hand, the simulated plant extractable soil water did not differ significantly for the conventional mould board ploughing and minimum tillage. Consequently, minimum tillage was recommended for the investigated environment, since it allows greater savings in time, energy and human work, without causing appreciable losses in the yield there. Within the cited study, the soil water content was successfully modeled for both of the mentioned treatments, while the r^2 varied from 0.98 to 0.99 and the regression slope varied from 0.86 to 0.93.

rMBE (%)	Fuchsenbigl		Raasdorf		Žabčice		Kroměříž			
	WW	SB	WW	WW	SB	SB	WW	WW	SB	SB
Characteristics:	Pl; N-h	Pl; N-h	Pl; N-h	Min; N-h	Pl; N-m	Min; N-m	Pl; N-m	Pl; N-h	Pl; N-l	Pl; N-m
Yields	-0.8	-0.4	-3.0	6.0	35.8	37.0	13.4	5.5	2.9	-19.6
Maturity	1.7	-0.3			-3.3	-3.3	2.0	2.0	1.2	1.2
Flowering	1.2	0.8			3.0	3.0	2.1	2.1	1.0	1.0
Soil water dynamics			-28.5	-17.1	-1.6	0.0				
TGW							13.0	8.4	5.4	6.7
Biomass dynamics							2.0	11.7	2.2	-22.4

Figure 7: The detailed comparison between the model estimates and reality based on a set of crop parameters. The rMBE parameter was used for the model simulation assessment, and the grey cells represent the locality-parameter combinations that were not analyzed. (Abbreviations: WW – winter wheat, SB – spring barley, Pl – ploughing, Min – minimum tillage, N-l – low-nitrogen fertilization, N-m – medium-nitrogen fert., N-h – higher-nitrogen fert., MAT – maturity date, FLOW – flowering date, TGW – weight of one thousand seeds)

Abbildung 7: Detaillierter Vergleich verschiedener simulierter Parameter der verschiedenen Varianten hinsichtlich ihrer Abweichungen zu den gemessenen Werten. Angegeben ist der statistische Parameter rMBE (mittlerer Fehler), die Kombinationen der grauen Zellen wurden nicht analysiert. (Abkürzungen: WW – Winterweizen, SB – Sommergerste, Pl – Pflugbearbeitung, Min – Minimalbodenbearbeitung, N-1 – geringe N-Düngung, N-m – mittlere N-Düngung, N-h – hohe N-Düngung, MAT – Reifedatum, FLOW – Blühzeitpunkt, TGW – Tausendkorngewicht)

rRMSE (%)	Fuchsenbigl		Raasdorf		Žabčice		Kroměříž			
	WW	SB	WW	WW	SB	SB	WW	WW	SB	SB
Characteristics:	Pl; N-h	Pl; N-h	Pl; N-h	Min; N-h	Pl; N-m	Min; N-m	Pl; N-m	Pl; N-h	Pl; N-l	Pl; N-m
Yields	11.7	15.0	3.0	6.0	35.9	37.5	18.8	18.2	6.3	22.7
Maturity	4.7	1.5			3.4	3.4	2.3	2.3	1.3	1.3
Flowering	6.0	3.7			3.0	3.0	2.8	2.8	2.2	2.2
Soil water dynamics			31.2	23.3	9.0	9.9				
TGW							14.6	11.1	7.3	7.1
Biomass dynamics							21.3	20.3	35.9	28.0

Figure 8: The detailed comparison between the model estimates and reality based on a set of crop parameters. The rRMSE parameter was used for the model simulation assessment, and the grey cells represent the locality-parameter combinations, which were not analyzed. (Abbreviations: WW – winter wheat, SB – spring barley, Pl – ploughing, Min – minimum tillage, N-l – low-nitrogen fertilization, N-m – medium-nitrogen fert., N-h – higher-nitrogen fert., MAT – maturity date, FLOW – flowering date, TGW – weight of one thousand seeds)

Abbildung 8: Detaillierter Vergleich verschiedener simulierter Parameter der verschiedenen Varianten hinsichtlich ihrer Abweichungen zu den gemessenen Werten. Angegeben ist der statistische Parameter rRMSE (mittlere quadratische Abweichung), die Kombinationen der grauen Zellen wurden nicht analysiert. (Abkürzungen: WW – Winterweizen, SB – Sommergerste, Pl – Pflugbearbeitung, Min – Minimalbodenbearbeitung, N-1 – geringe N-Düngung, N-m – mittlere N-Düngung, N-h – hohe N-Düngung, MAT – Reifedatum, FLOW – Blühzeitpunkt, TGW – Tausendkorngewicht)

4 Conclusions

The results of the present study confirmed that the CERES-Barley and CERES-Wheat models are able to provide relatively reliable estimates of the development, yields, above ground biomass accumulation and soil water dynamics across a range of different conditions (stations with different soils and climate).

The ability of the CERES-Wheat and CERES-Barley models to distinguish different tillage (ploughing vs. minimum tillage) was also assessed. The different tillage approaches were identified (within mentioned models) through the tillage date and depth, changed bulk density, field capacity, wilting point and root-weighting factor of the upper layers. The submodel of soil water provided good results within the Žabčice locality (MEI = 0.90–0.88), but it was difficult to pick up the small differences between the conventional and minimum tillage. In Raasdorf, the soil water content was simulated with a lower accuracy (MEI = 0.51 to 0.11), but the model detected the magnitude and trends of the differences between the tillage techniques well. From the results of the soil water measurements and simulations, it could be concluded that minimum tillage leads to an increase of the soil water that is available to the plant in Raasdorf. Ploughing, however, seems to provide slightly larger soil water reserves on the fluvisol of Žabčice (where potential long term effects are still not established), probably as a consequence of the higher soil compaction in minimum tillage on clay soil. Despite of mentioned results there was observed lower yield of spring barley after ploughing in 2004 and almost identical yields (for both tillage approaches) in 2005. For example CASTRIGNANÓ et al. (1997) revealed that soil water content did not differ significantly after the mould board ploughing and minimum tillage within silty-clay soil in Southern Italy and recommended minimum tillage for investigated conditions because it allows saving in time, energy and human work.

These results suggest that both models can be used only with caution to estimate the effect of adaptation measures such as tillage intensity and to optimize the crop production under the current and future climate conditions.

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