A comparison of models for simulating harvest time of silage maize (*Zea mays* L.)

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Abstract

The determination of harvest time in silage maize is a prerequisite for minimizing losses during silage storage and the feedout phase, and for exploiting the yield and forage quality potential of hybrids. With respect to harvest time prediction, models can provide useful tools. The objectives of the present study therefore were to test the suitability of three models for predicting contents of dry matter (DM) and starch: two growing degree (GDD) approaches and the dynamic *FOMAQ* model, which was originally developed for grass growth and forage quality, and is driven by temperature, solar radiation, and soil water. Model calibration, which was based on a multi-year, multi-site experiment, showed a generally satisfactory agreement between observed and calculated values. The consideration of radiation and soil water availability in the *FOMAQ* model could improve model fit considerably compared to the GDD models.

Media Summary

Three models, two GDD approaches and the dynamic *FOMAQ* model, were evaluated for predicting contents of dry matter and starch of silage maize.

Key Words

Silage maize, modeling, dry matter content, starch content, whole crop, ear

Introduction

The optimal harvest time for forage crops is of vital concern for ruminant nutrition since crop maturity at harvest affects both roughage yield and quality. Environmental conditions, particularly temperature and soil water supply play a key role in the dynamics of growth and quality. The maturation of silage maize, especially the differences in maturation between ear and stover caused by the impact of genotype, are extensively discussed in Germany at present. Points of particular interest with respect to the optimization of feed value are the determination of the optimum harvest date and the possibilities to predict maturation. Therefore a project was initiated aiming at the development of a tool for a regional harvest time prediction. The suitability of three models for forecasting contents of DM and starch of the whole crop and ear DM content was investigated: (i) the growing degree-day concept, which uses a base temperature of 6 ?C (GDD-6), and has been applied in France since several years for predicting harvest time (Bloc et al. 1983, AGPM 2000) (ii) a modified ‘French method’, using a base temperature of 8 ?C (GDD-8), and (iii) the mechanistic *FOMAQ* model originally developed for forage grasses (Kornher et al. 1991; Herrmann et al. 2004).

Methods

Data base

Model calibration was based on data collected in a 4-year experiment (2000-2003) on more than 20 sites throughout Germany. Data for model validation will be acquired in 2004. The experimental layout was a split-plot design with two replications, where eight hybrids were assigned to the main plots and sampling dates to the split-plots. The hybrids covered a wide maturity class range (early to mid-late) relevant for Germany, including different maturation types (normal, dry-down and stay-green; low to high harvest index), see table 1. Maize was sown between end of April and beginning of May in rows 0.75 m apart. The final plant density was 7 to 10 plants m^{-2} depending on site and variety involved. The amount of nitrogen fertilizer applied was adjusted to local growth conditions in order to allow maximum production, but was limited to 150 kg N ha^{-1} maximum. Plant protection, phosphorus and potassium fertilization was applied according to the codes of ‘Good Agricultural Practice in Plant Protection and Fertilization’.

The sampling schedule comprised to record crop phenology on each sampling date and the occurrence of key growth stages, e.g. tasseling and silking, and to collect plant samples for yield and quality determination. Samples of 30 consecutive plants, randomly assigned to a row section bordered by un-harvested rows, were taken 7 times throughout the vegetation period, with 2 samplings before and 5 after silking. Twenty out of 30 plants were fractionated into ear and stover, weighed, and chopped. A representative sub-sample was oven-dried at 105 ?C to determine dry matter content. The remaining 10 plants were weighed and chopped as whole crop on each sampling date. A sub-sample was oven-dried at 65 ?C to constant weight for forage quality analysis. After drying, the samples were ground to pass through a 1 mm sieve. Forage quality was determined using near infrared reflectance spectroscopy (NIRS). Starch content of calibration and validation samples was determined polarimetrically as described in Naumann et al. (1997).

Table 1. Forage maize cultivars used in the experiments.

Hybrid	Maturity rating[?]		Maturity group	Maturation type
	S	K		
Arsenal	210	210	early	normal
Oldham	220	-	early	normal
Symphony	220	210	early	(stay green)
Probat	230	240	mid-early	(dry down)
Attribut	240	250	mid-early	(dry down)
Fuego	250	220	mid-early	stay green
Clarica	270	280	mid-late	(dry down)
Benicia	280	250	mid-late	stay green

[?] German maturity rating system developed from the FAO system in 1998: silage maize cultivars to be released in Germany receive two rating numbers, based on the DM content of the whole crop (S) and the grain (K).

Model description

FOMAQ (Forage Maize Quality) is one of few models that not only predicts biomass but also provides a comprehensive simulation of various forage quality parameters. Growth calculations are based on weather data as well as on plant and soil characteristics. The model requires daily data on average air temperature [?C], precipitation [mm], potential rates of evapotranspiration [mm] and incident global radiation [J cm^{-2} d^{-1}]. It consists of two dynamically interacting sub-models for dry matter production and quality development driven by plant and soil characteristics and environmental conditions such as temperature, radiation, and soil water availability. Growth is simulated in daily steps as a function of the current amount of biomass and the relative growth rate, which is a product of the growth potential of the young crop and an AGE index describing the impact of crop ageing on growth potential. A growth index GI summarizes the weather influence on growth and reduces the potential rate to an actual growth rate. The sub-model for quality prediction assumes the existence of different levels of quality over the entire growing period, with changes from one level to another occurring gradually. The present model, however, allows only for two such levels. The changes in quality and levels depend on genetical, but also on management and environmental input. Environmental factors like temperature, radiation and plant-available soil water are converted into corresponding change rates based on proper functions, implemented as exponential or negative exponential. *FOMAQ* provides a intrinsic parameter optimization module, which minimizes the deviation between simulated and experimental data in terms of the sum of squared residuals. Model parameters were optimized for each cultivar separately. For the GDD models, we assumed 2^{nd} degree polynomials to describe the relationship between GDD units and contents of starch and DM of the ear, and a 3-parameter exponential function to best quantify the relationship between GDD and DM content of the whole crop. The goodness of the model predictions was assessed by the root mean square error (RMSE) and the coefficient of determination.

Results

Three modeling options were investigated, namely starting calculations (i) at sowing, (ii) at silking using observed silking dates, and (iii) at silking using simulated silking dates. The first two options did not show pronounced differences with respect to model fit. The estimation of silking dates based on temperature sums, however, resulted in large deviations between observed and calculated data and is therefore not considered as a suitable approach for implementing the prognosis tool into practical agriculture. Results presented include the sowing-version for DM content and the silking-version (observed dates) for starch content. The *FOMAQ* model calibration required initially the optimization of the yield sub-model in order to calculate soil-water availability, which represents a driving variable for simulating DM and starch content in the quality part.

Tab. 2. Results of *FOMAQ* model calibration for dry matter yield (g DM m^{-2}), years 2000-2003.

		FOMAQ	
hybrid	n	r?	RMSE
Arsenal	379	0.94	181.9
Oldham	378	0.93	198.1
Symphony	379	0.92	201.8

Probat	378	0.94	186.0
Attribut	380	0.93	214.4
Fuego	379	0.93	182.1
Clarica	274	0.93	211.7
Benicia	274	0.93	207.4

The *FOMAQ* model comprises 54 parameters in total, with 28 originating from the growth part and 26 from the quality part of the model. We assigned hybrid-specific values to 3 of the growth parameters. Model optimization of forage quality traits resulted in 6 parameters that differed between hybrids for DM and starch content, respectively, while the remaining parameters were identical for all hybrids and locations. The adaptation from grassland to forage maize required no modifications with respect to the model algorithms. Dry matter yield was well simulated for all hybrids, with RMSE values ranging between 10 and 15% of final DM yield, although climatic and soil conditions varied substantially among sites and years, see table 2.

Tab. 3. Results of model calibration for DM and starch content of the whole crop and ear DM content, given as number of observations, coefficient of determination and RMSE for each hybrid. Calibration of starch content includes only years 2000 to 2002.

			FOMAQ		GDD-6		GDD-8	
	hybrid	n	r?	RMSE	r?	RMSE	r?	RMSE
Whole crop DM content (g kg^{-1} FM)	Arsenal	391	0.90	36.2	0.87	40.8	0.87	40.7
	Oldham	391	0.90	34.0	0.87	39.3	0.87	38.3
	Symphony	391	0.92	30.7	0.87	37.8	0.88	36.4
	Probat	391	0.91	31.9	0.88	36.6	0.88	35.8
	Attribut	391	0.91	30.4	0.88	35.4	0.89	33.2
	Fuego	391	0.90	30.6	0.87	34.4	0.88	33.4
	Clarica	280	0.88	33.3	0.85	36.9	0.87	33.7
	Benicia	281	0.88	31.2	0.86	34.1	0.87	32.0

Starch content (g kg^{-1} DM)	Arsenal	154	0.77	28.7	0.73	30.7	0.70	31.9
	Oldham	154	0.74	28.4	0.72	29.7	0.69	31.2
	Symphony	154	0.74	28.0	0.65	32.8	0.65	35.5
	Probat	154	0.81	31.1	0.77	34.2	0.75	35.7
	Attribut	156	0.71	38.1	0.75	35.2	0.71	37.6
	Fuego	154	0.77	30.1	0.73	32.5	0.71	33.9
	Clarica	103	0.84	32.3	0.82	33.2	0.82	33.8
	Benicia	103	0.87	30.1	0.84	33.8	0.83	34.7
Ear DM content (g kg^{-1} FM)	Arsenal	267	0.94	32.2	0.94	32.4	0.93	33.4
	Oldham	267	0.92	35.7	0.91	39.4	0.91	39.0
	Symphony	267	0.91	36.4	0.90	38.5	0.89	39.0
	Probat	267	0.95	31.9	0.92	39.2	0.91	40.2
	Attribut	266	0.95	32.2	0.94	32.8	0.94	33.7
	Fuego	266	0.92	37.5	0.92	35.8	0.92	37.6
	Clarica	198	0.93	36.4	0.93	36.9	0.94	35.9
	Benicia	198	0.94	36.0	0.93	36.1	0.93	36.7

For the DM content of the whole crop and the ear, results of model optimization resulted in a generally good agreement for the *FOMAQ* and the GDD-6 model, see table 3. The consideration of radiation and plant available soil water in *FOMAQ* resulted in an improvement of prediction accuracy compared to the GDD-8 model, reducing the prediction error on average by 9% for whole crop DM content and 6 percent for ear DM content. Especially the 2003 data contributed valuable information with respect to the impact of soil water availability on DM content changes, because growing conditions were characterized by severe water shortage on various experimental sites. A comparison of the two GDD models showed a better agreement for whole crop DM content when using 8 ?C base temperature, while for ear DM content GDD-6 resulted in lower errors. Simulated whole crop starch content correlated satisfactorily with observations for the *FOMAQ* model, whereas the GDD simulations showed slightly inferior model fit. Using *FOMAQ* reduced prediction error by 6% and 10%, compared to GDD-6 and GDD-8, respectively.

We expect the 2003 data (not yet available), which were effected by drought conditions, to contribute to a further differentiation with respect to model suitability.

Although results of model calibration are quite promising, especially for *FOMAQ*, further model refinement might improve model fit. Various studies have indicated that using soil temperature instead of air temperature in early growth stages will provide greater accuracy for predicting crop phenology and growth (Jamieson et al. 1995; Bollero et al. 1996). CERES Maize, for instance, uses soil temperature for growth stages up to the tenth leaf or tassel initiation, when the shoot apex still is near soil surface (Jones and Kiniry 1986). In contrast, McMaster and Wilhelm (1998), testing soil versus air temperature as a basis for GDD calculation of various phenological stages of winter wheat, could not find any significant improvement. Another weakness refers to the response functions calculated for temperature, radiation, and plant-available soil water. Model agreement might be enhanced by differentiating with respect to developmental phases, as for instance the vegetative and reproductive stages. The latter one might even be subdivided into flowering (pre-pollination to end of lag phase) and later grain filling stage. Findings in literature, however, are not unambiguous. Growth models like CERES Maize and CropSyst (Jones and Kiniry 1986; St?ckle et al. 1994) use a common base and optimal temperature for predicting crop phenology during the whole growth cycle from emergence to physiological maturity. In contrast, the study of Stewart et al. (1998) on the phenological temperature response of maize found substantial differences between the vegetative and reproductive growth stages, with a lower sensitivity in the 0 to 12 ?C temperature range for the silking to maturity period.

Conclusion

The results of model calibration demonstrated the superiority of the *FOMAQ* model over the GDD approaches, which can be attributed primarily to the consideration of water availability and irradiation on crop growth and development. Further model development is in progress and amongst other modifications will include the differentiation of the crop? s response with respect to environmental responses.

References

AGPM (2000) Besoins en degr?s-jours des vari?t?s de mais. Reactualisation 2000. Info No. 266. Association G?n?rale des Producteurs de Mais, Montardon, France.

Bloc D, Gay, J-P and Gouet JP (1983) Influence de la temp?rature sur le d?veloppement du mais. Bulletin OEPP 13, 163-169.

Kornher A, Nyman P and Taube F (1991) A computer model for simulation of quality herbage of grass swards based on meteorological data. Das wirtschtseigene Futter 37, 232-248, (in German with English summary).

Herrmann A, Kelm M, Kornher A and Taube F (2004) Performance of grassland under different cutting regimes as affected by sward composition, nitrogen input, soil conditions and weather – a simulation study using the *FOPROQ* model. European Journal of Agronomy (accepted).

Naumann K, Bassler R, Seibold, R and Barth C (1997) Methodenbuch III. Die chemische Analyse von Futtermitteln. VDLUFA Verlag, Darmstadt.

Jamieson PD, Brooking IR, Porter JR and Wilson DR (1995) Prediction of leaf appearance in wheat: A question of temperature. Field Crops Research 41, 35-44.

Bollero GA, Bullock DG and Hollinger SE (1996) Soil temperature and planting date effects on corn yield, leaf area, and plant development. Agronomy Journal 88, 385-390.

Jones CA and Kiniry JR (1986) CERES-Maize. A simulation model of maize growth and development. Texas A&M University Press.

McMaster GS and Wilhelm WW (1998) Is soil temperature better than air temperature for predicting winter wheat phenology?. Agronomy Journal 90, 602-607.

St?ckle CO, Martin S and Campbell GS (1994) CropSyst, a cropping systems model: water/nitrogen budgets and crop yield. Agricultural Systems 46, 335-359.

Stewart DW, Dwyer LM and Carrigan LL (1998) Phenological temperature response of maize. Agronomy Journal 90, 73-79.