CALIBRATION OF THE CERES–MAIZE MODEL FOR SIMULATING SITE–SPECIFIC CROP DEVELOPMENT AND YIELD ON CLAYPAN SOILS

C. W. Fraisse, K. A. Sudduth, N. R. Kitchen

ABSTRACT. *Crop simulation models have historically been used to predict field average crop development and yield under alternative management and weather scenarios. The objective of this research was to calibrate and test a new version of the CERES–Maize model, modified to improve the simulation of site–specific crop development and yield. Seven sites within a field located in central Missouri were selected based on landscape position, elevation, depth to a claypan soil horizon, and past yield history. Detailed monitoring of crop development and soil moisture during the 1997 season provided data for calibration and evaluation of model performance at each site. Mid–season water stress caused a large variation in measured yield with values ranging from 2.6 Mg ha^{-1} in the eroded side–slope areas to 10.1 Mg ha^{-1} in the deeper soils located in the low areas of the field. The model was calibrated against measured data for root zone soil moisture content, leaf area index, and grain yield. The results demonstrated that modifications included in the model to simulate root growth and development are important in soils with a high–clay restrictive layer such as the claypan soils. Although the model performed well in simulating yield variability, simulated leaf area indices were below measured values at five out of seven monitoring sites, suggesting a need for model improvements. Results showed that accurate simulation of crop growth and development for areas of the study field that receive run–on or subsurface flow contributions from upland areas will require enhancement of the model to account for the effects of these processes.*

Keywords. *Crop Models, Site–specific, Yields, Maize.*

In recent years, farmers and researchers alike have shown considerable interest in the crop management system known as precision agriculture or site–specific management, causing a surge in the collection of such geospatial data as crop yield and soil properties. Although the collection of some geospatial data has become relatively easy, it is more difficult to know how to most effectively use that data in making crop management decisions (Sudduth et al., 1998). Several researchers have used statistical analysis to better understand the functional relationship of crop yield to other spatial factors (Pierce et al., 1995; Mallarino, 1996; Sudduth et al., 1996). However, crop production is a function not only of spatial factors but also of temporal variability. Year–to–year climate variability may often affect crop yields more than spatial variability. In fact, the impact of spatial variability on crop yield may be negligible in some years (Mulla and Schepers, 1997). Crop models, when well calibrated and validated, are able to integrate soil and weather conditions and management decisions to predict crop development and yield under alternative scenarios. This ability is important in precision agriculture, where it is necessary to extrapolate spatially dense but temporally sparse datasets across a range of climate years to answer the question, "Will this precision agriculture system work for me?" Crop models might also be used to predict the specifics of crop growth and development for the rest of a particular growing season on the basis of inputs describing the season to date. Bouma (1997) discussed the use of simulation models in this sort of "proactive" management approach to anticipate occurrences of crop stress, in contrast to the "reactive" approach where crop scouting, perhaps coupled with remote sensing, is used to identify stress after it has occurred.

OBJECTIVES

The overall objective of this research project was to evaluate the use of crop models as decision aids under a precision agriculture management approach. This first study focuses on the testing and evaluation of a modified version of the CERES–Maize model for simulating site–specific crop development and yield. Model calibration and observation of the model behavior under different growing conditions were the first phase of the study and are reported here.

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MATERIALS AND METHODS

Data for this study were collected during the 1997 cropping season in a 36–ha field located near Centralia in central Missouri. The field was managed in a high yield goal, high input, minimum till corn (*Zea mays* L.) and soybean (*Glycine max.* [L.] Merr) rotation. The corn hybrid Northup King RX790 was planted in the 1997 cropping season with a target population of 62,000 plants ha^{-1}. Fertilizer and chemical inputs were applied uniformly over the entire field. The growing season was characterized by a wet spring followed by drought stress during the pollination period (only 0.5 cm of precipitation occurred during the first two weeks of July) that caused yields to be reduced in those areas of the field with eroded, shallow topsoil.

SITE DESCRIPTION

The soils of the study field are characterized as claypan soils (fine, montmorillonotic, mesic, Udollic Ocharaqualfs, and Albaquic Hapludalfs). These soils are poorly drained and have a restrictive, high–clay layer (the claypan) occurring below the topsoil. Figure 1 shows the elevation and aspect maps of the field. Field elevation, determined by a topographic survey, ranges from 261.9 m at the drainage outlet along the north edge of the field to 265.8 m at the southeast corner. Topographic aspect was calculated using the TAPES–G (Terrain Analysis Program for the Environmental Sciences – Grid version; Gallant and Wilson, 1996) model. Surface and subsurface water flows from the west and east sides of the field to a central natural drainage channel that carries the water to an outlet located along the north side of the field (fig. 1).

A detailed first–order soil survey of this field established the presence of three distinct soils – Adco silt loam, Mexico silty clay loam (eroded), and Mexico silt loam (overwashed phase) (fig. 2). Based on previous work (Doolittle et al., 1994; Sudduth et al., 1995; Kitchen et al., 1999), topsoil depth above the claypan was estimated from soil electrical conductivity measured using a commercial electromagnetic induction sensor (fig. 2). Yield in the study field has been monitored and mapped since 1992. During that time, yield variability has generally followed landscape patterns during dry or wet years with a more uniform distribution of yield during years with well–distributed rainfall.

The selection of within–field monitoring sites for this study was based on this existing information for the study area. The main goal was to select enough sites to adequately characterize the yield variability measured in the field. Site selection was primarily based on topography, topsoil depth, and previous yield patterns. Topsoil depth and topography are field features affecting water storage and flow within the field and have a direct effect on yield but are properties that can not necessarily be altered. Although the field was previously sampled on a 30–m grid for soil properties such as phosphorus, potassium, pH, organic matter, calcium, and magnesium, this information was not used in the site selection because soil fertility factors other than nitrogen (N) are not taken into account by the model and could not be properly simulated. Seven monitoring sites were selected to represent the range of variability present in the field (table 1; figs. 1 and 2).

DATA ACQUISITION

Soil samples were obtained before planting at each site to a depth of 120 cm for profile characterization and mineral N analysis. Soil horizons were determined by a combination of visual and tactile inspection of the soil cores. The amount of surface residue from the previous crop was measured at each monitoring site. Neutron probe tubes were installed for root zone soil moisture monitoring during the growing season. Neutron probe readings were obtained every week at 15–, 30–, 45–, 60–, 80–, 100–, and 120–cm depths. Weather data required by the model, including rainfall, maximum and minimum daily air temperature, and incoming solar radiation, were collected on site by an automated weather station located at the west side of the field.

Soil textural composition and other soil physical and chemical properties required by the model (table 2) were based on the results of a first–order soil survey conducted by the USDA–NRCS (Natural Resources Conservation Service). The lower limit (LL) and the drained upper limit

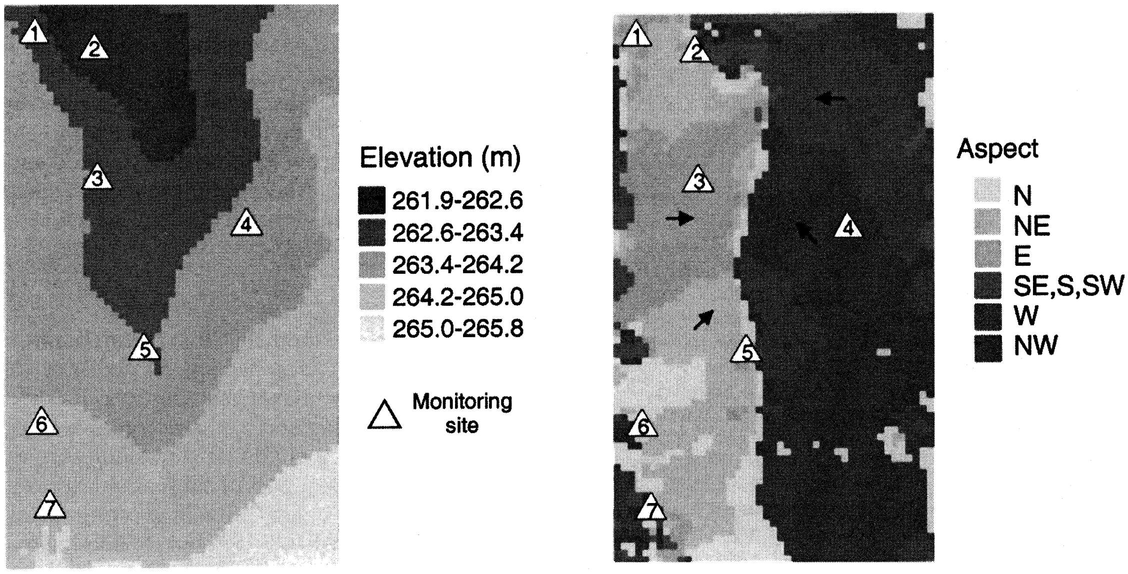

Figure 1. Elevation (left) and aspect classes (right) of the study area.

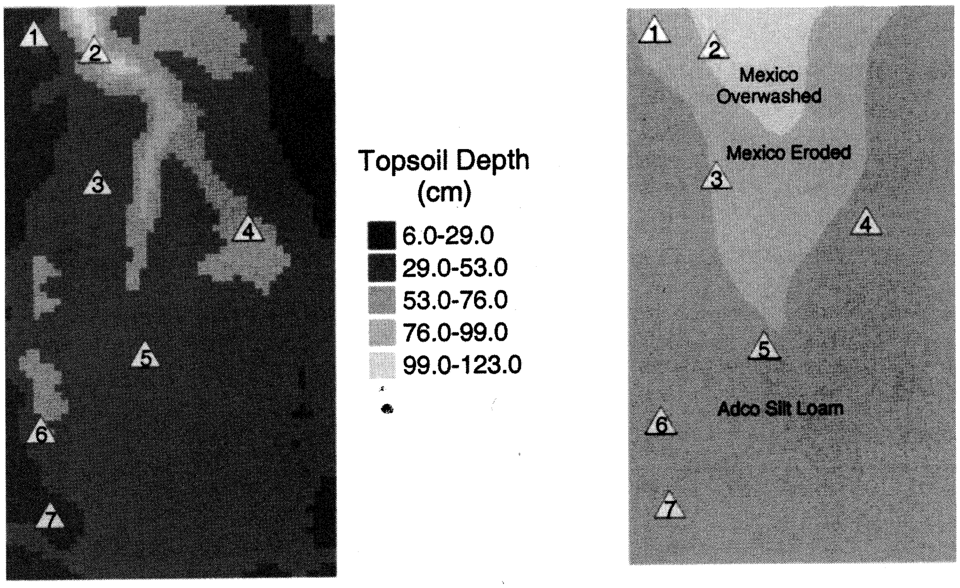

Figure 2. Topsoil depth (left) and soil types (right) of the study area.

(DUL) of available soil water were based upon the reported volumetric water contents corresponding with soil matric potentials of –1500 and –33 kPa, respectively. Saturated hydraulic conductivity (K_{sat}) values were not available from the NRCS survey and were estimated based on the method of Rawls et al. (1982). In this method, representative K_{sat} values are given for each soil textural class.

Each monitoring site consisted of a rectangular area of approximately 12 m^2 (3.8 × 3.0 m) with the neutron probe tube located at the center of the area. A buffer zone of 2 m was established around each site. Destructive biomass sampling for characterization of crop development was carried out beyond the buffer zone at different crop developmental phases. A 1–m stake was used to select a row section for harvesting. The stake was moved down the row at the sampling location until each end of the stake fell midway between two plants. At the beginning of the season, all plants within the sampled row section were transported to the laboratory for measurement of leaf area and dry biomass. Later in the season only one plant representing the average conditions at the site (neither the largest, nor the smallest) was used for leaf area and dry biomass measurements. However, the fresh weight of the entire sample was used to back–calculate the total dry biomass. Leaf area was determined by direct measurement using a LI–COR leaf area meter (LI–3100, LI–COR, Lincoln, Nebr.), in which the projected image of a leaf sample traveling under a fluorescent light source is reflected by a system of mirrors to a solid–state scanning camera. Measurement error with this type of area meter is generally less than 2% (Hatfield et al., 1976). In some cases, leaves tend to fold and wrinkle as they pass under the light source causing some differences in the total area measured. However, these errors are small compared to other sources of variation (Daughtry and Hollinger, 1984).

Table 1. Monitoring site characteristics.

Site	Elevation (m)	Topsoil Depth (cm)	Slope (%)	Aspect (deg.)
1	263.1	25	1.25	67
2	262.1	100	0.53	35
3	263.3	15	0.56	87
4	263.6	44	0.37	315
5	263.5	36	0.26	12
6	264.4	30	0.32	12
7	264.9	32	0.10	304

MODEL DESCRIPTION

The generic CERES (Crop–Environment–Resource–Synthesis) model simulates growth and development of wheat, maize, sorghum, pearl millet, and barley under adequate and limited soil water. For this study, the CERES Maize model (Jones and Kiniry, 1986) was selected because it is a process–oriented model capable of simulating water balance, nitrogen balance, growth, and development of a corn crop, while maintaining reasonable input requirements that would not prevent it from being used by crop consultants and farmers. The model operates on a daily time step and computes the state variables on each day of a year or growing season. It has been extensively tested on different soil types and for a range of climatic conditions and with various corn hybrids (Hodges et al., 1987; Carberry et al., 1989; Cooter, 1990; Jagtap et al., 1993, Pang et al., 1998). Pang et al. 1998, evaluated the model for characterizing nitrate leaching potential in various soil types and concluded that the CERES–Maize model can be used as a tool for soil specific nitrogen leaching characterization.

MODEL MODIFICATIONS

The version used in this study was CERES–3.1, a modification of the CERES–3.0 version (DSSAT v3, Decision Support System for Agrotechnology Transfer; Tsuji et al., 1994). Several new features were added in CERES–3.1 to improve model performance under a site–specific crop management approach (Garrison, 1998; Batchelor and Ritchie, 1998). The modifications made by the developers in this version included: 1) consideration of the effects of limited soil aeration on crop growth and development; 2) the previous concept of using a root distribution weighting factor to estimate the relative root growth in all soil layers was replaced by a layer–specific root hospitality factor; 3) roots

Table 2. Soil properties required by the model for each monitoring site.

Site	Soil Horizon	LL[a] (cm^3/cm^3)	DUL (cm^3/cm^3)	SSAT (cm^3/cm^3)	KSAT (cm/day)	SDBM (g/cm^3)	CLAY (%)	SILT (%)
Site 1	Ap	0.13	0.35	0.48	24.4	1.2	17.3	80.2
	BE	0.16	0.33	0.49	10.3	1.32	24	69.4
	Bt_1	0.31	0.45	0.52	1.44	1.32	60.1	38.3
	Bt_2	0.29	0.45	0.53	1.44	1.52	60.1	38.3
	BTg	0.2	0.4	0.43	2.16	1.48	46.9	51.1
	BCg	0.17	0.4	0.44	3.6	1.42	33.7	59.3
Site 2	Ap	0.12	0.35	0.48	24	1.3	18.9	78.7
	A	0.13	0.39	0.46	16.3	1.34	18.9	78.2
	AB	0.19	0.37	0.5	16	1.32	22.8	73.5
	EB	0.25	0.39	0.44	2.16	1.32	41.8	53
	Bt	0.3	0.4	0.45	1.44	1.37	51.2	43.6
	BtgB1	0.27	0.4	0.45	2.16	1.38	43.9	50.5
	BtgB2	0.3	0.4	0.45	3.6	1.38	38.1	43.9
Site 3	Ap	0.13	0.34	0.43	24	1.4	24.5	61
	Bt	0.27	0.4	0.52	1.44	1.2	65.1	34
	Btg	0.24	0.41	0.47	3.6	1.43	38.6	58.7
	BCg	0.23	0.39	0.44	16.3	1.48	25.9	67.1
Site 4	Ap	0.13	0.35	0.46	24	1.38	17.3	80.2
	Ap/E	0.13	0.35	0.46	24	1.41	17.3	80.2
	E	0.15	0.36	0.44	24	1.45	16.2	75.7
	Bt	0.31	0.48	0.53	1.44	1.25	59.4	39.2
	Btg	0.25	0.39	0.47	2.16	1.29	46.9	51.1
	BCg	0.17	0.33	0.45	3.6	1.4	33.7	59.3
Site 5	Ap	0.13	0.35	0.41	16.3	1.3	17.3	80.2
	E	0.15	0.35	0.45	20.3	1.38	16	75.7
	Bt	0.31	0.5	0.53	1.44	1.3	59.4	39.2
	Btg	0.25	0.36	0.42	2.16	1.45	46.9	51.1
	BCg	0.17	0.33	0.45	3.6	1.4	33.7	59.3
Site 6	Ap	0.13	0.35	0.45	16.3	1.39	17.3	80.2
	Ap/E	0.12	0.38	0.46	24	1.48	16.2	75.7
	E	0.22	0.4	0.5	16.3	1.43	16.2	75.7
	Bt	0.25	0.45	0.49	1.44	1.35	59.4	39.2
	Btg	0.23	0.36	0.45	3.6	1.46	39.1	60.3
	BCg	0.17	0.33	0.45	3.6	1.46	33.7	59.3
Site 7	Ap	0.13	0.35	0.46	16.3	1.38	17.3	80.2
	E	0.12	0.35	0.45	24.4	1.45	16.2	75.7
	Bt	0.28	0.44	0.51	1.44	1.22	59.4	39.2
	Btg	0.23	0.35	0.45	2.16	1.29	46.9	51.1
	BCg	0.17	0.33	0.45	3.6	1.4	33.7	59.3

[a] LL = Lower limit, DUL = Drained upper limit, SSAT = Upper limit saturated, KSAT = Saturated hydraulic conductivity, SDBM = Bulk density, CLAY = Clay textural fraction, SILT = Silt textural fraction.

were not allowed to extend into saturated layers, and root senescence was increased if a soil layer became saturated to account for poor respiration under oxygen depleted conditions; 4) a "hardpan" factor was included to slow down root penetration through a hardpan; 5) a tile drainage routine was added to better simulate water table dynamics and root interactions under tile drainage conditions; and 6) leaf and stem expansion and photosynthesis were reduced under water–logged conditions.

In this modification of the model, the routine that calculated root growth (ROOTGR) was modified to include the calculation of a relative saturation factor ($SWWET_L$) for each soil layer (eq. 1). The saturation factor will affect root growth and senescence under low aeration conditions.

$$SWWET_L = 1.0 - EXP\ (-100.0 \times (SAT_L - SW_L) \quad (1)$$

where

SAT_L = saturated soil water content for layer L (cm^3/cm^3)

SW_L = soil water content for layer L (cm^3/cm^3)

The original model used three factors to calculate root growth in each layer: (1) a soil water deficit factor (SWDRY); (2) a factor describing mineral N availability (RNFAC); and (3) a root growth weighting factor (WR). The modified version included the saturation factor and replaced the root growth–weighting factor with a root hospitality factor (RHFAC) that defines the ability of roots to penetrate and explore a soil layer. An additional factor, the hardpan factor (HPF), is used to characterize a layer with additional restrictions on downward root development, including restrictive layers such as a compaction pan or claypan, layers with the presence of rock fragments, or layers exhibiting aluminum toxicity. The hardpan factor is only applied to the layer(s) specified. The rate of root depth increase in a given layer (RRD_L) is given by the following equation:

$$RRD_L = 0.2 \times \min(SWDRY, SWWET, \min(RHFAC, HPF)) \quad (2)$$

In the original model, potential root water uptake for each layer was a function of available water, given by the difference between the actual and the lower limit of plant–extractable soil water contents, and the root length density factor, estimated based on the root growth weighting factor. In the modified model, potential root water uptake from each soil layer is calculated from the fraction of available soil water, but root length density for each layer can be affected by the root hospitality and hardpan factors. The potential root water uptake from the profile (TWRU) is calculated by summing the root water uptake for all soil layers. If transpiration (EP) is less or equal to TWRU, the zero–to–unity soil water deficit factor (SWDF) used in the maize growth routine is calculated by equation 3.

$$SWDF = TRWU / EP \quad (3)$$

Results and Discussion

Model Calibration

The CERES–Maize model was calibrated against measured data for root zone soil moisture content, leaf area index (LAI), and grain yield. The calibration procedure involved first adjusting the soil water lower and upper limits, K_{sat}, root hospitality, and hardpan factors so that simulated soil moisture values closely matched the measured values. The hardpan (also called soil impedance factor) and hospitality factors are empirical rather than physical and, therefore, cannot be measured. They were adjusted iteratively so that the predicted data fit the measured data as closely as possible. Second, calibration of the genetic coefficients and additional adjustments of the root hospitality and hardpan factors were done to allow a closer match of the simulated and measured leaf area index and yield. In soils with a high–clay restrictive layer such as the claypan soils, root development is an important factor in determining yield, especially in the case of mid–season drought stress. The hardpan and root hospitality factors were, therefore, key in calibrating the model for measured yield on these soils. Table 2 shows the site–specific calibrated values for the following soil properties: soil moisture lower limit (LL), soil moisture upper limit drained (DUL), soil moisture upper limit saturated (SSAT), and saturated hydraulic conductivity (KSAT). Bulk density (SDBM) and clay (CLAY) and silt (SILT) textural fractions for each site, as obtained from the USDA–NRCS first–order soil survey, are also included in table 2. Phenological development of the crop was reported during field trips for biomass sampling or occasionally during neutron probe readings. This information was used to ensure the correspondence of simulated and observed growth stages. No attempt was made to record the exact dates of changing growth stages. According to information provided by the seed company, the corn hybrid planted requires 2580 heat units to reach maturity or approximately 114–115 days. The genetic coefficients required by the model include the thermal time (growing degree days) from seedling emergence to the end of juvenile stage (P_1), the photoperiod sensitivity coefficient (P_2), the thermal time from silking to physiological maturity or black layer (P_5), the maximum kernel number per plant (G_2), the potential kernel growth rate (G_3, mg/day), and the interval in thermal time (degree days) between successive leaf tip appearances, "phyllochron" interval, (PHINT, hard–coded to 38.9° days in CERES–3.1). It is important to notice that the crop cultivar planted was the same in all monitoring sites and, therefore, the calibrated values for the genetic coefficients used in the model must be the same for all sites. This is particularly difficult since transition between growth stages in the model is primarily a function of growing degree days, and differences in development due to water stress are not accounted for. Initially, the values suggested by Jones and Kiniry (1986) for the genetic coefficients of cultivars planted in central Missouri were used. Adjustments were made to better match the simulated and observed crop development, yield, number of kernels per ear, and weight of individual kernels. Table 3 shows the calibrated values for the genetic coefficients.

In the CERES–Maize model, potential dry matter production is a linear function of intercepted photosynthetically active radiation. The actual rate is calculated by multiplying the potential dry matter production by the most limiting of three stress factors – temperature, deficient soil water, and excess soil water. The actual dry matter production is then partitioned among the different plant organs growing in any phenological stage. Plant leaf area growth is affected by the most limiting of three factors, the soil water deficit factor (SWDF), the mineral N availability factor (RNFAC), and the water saturation factor (SEWET). The water deficit factor is a function of potential root water uptake and plant transpiration, and the saturation factor accounts for soil water saturation conditions in the root zone. In the model, water stress can also cause leaf area loss as the ratio of actual root water uptake to potential climatic transpiration declines from its maximum value of 1.0. This simulated reduction in leaf area could be observed in the data for most sites during the water stress period that started approximately 60 days after planting.

Monitoring Site Results

Figures 3 through 9 compare simulated and measured values of volumetric soil water content at three different depths and simulated and measured leaf area index for the monitoring sites. Correspondence between simulated and measured data for both the soil moisture content and leaf area index was best at the sites where the upper edge of the claypan layer was found from 25 to 40 cm below the soil surface (sites 1, 5, 6, and 7). The zero–to–unity hardpan factor, introduced in the model to slow down root penetration through a claypan, ranged from 0.35 at site 2 where the upper edge of the claypan layer was 100 cm from the soil surface to 0.09 at site 3 where it was 15 cm from the soil surface.

Table 3. Calibrated values for genetic coefficients.

Genetic Coefficient	Calibrated Value
P1 (degree days)	240
P2 (days)	0.6
P5 (degree days)	700
G2	800
G3 (mg/day)	8.5
PHINT (degree days)	38.9

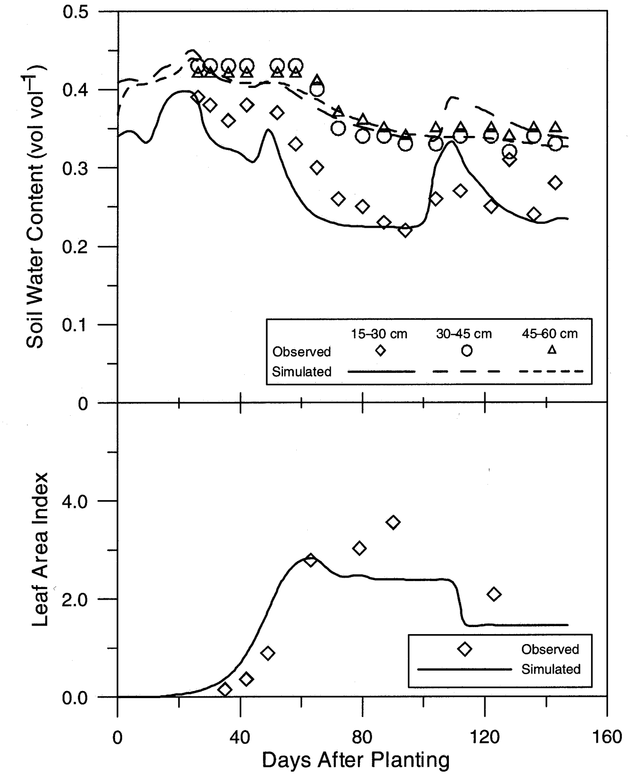

Figure 3. Simulated and observed volumetric soil water content and leaf area index for monitoring site 1.

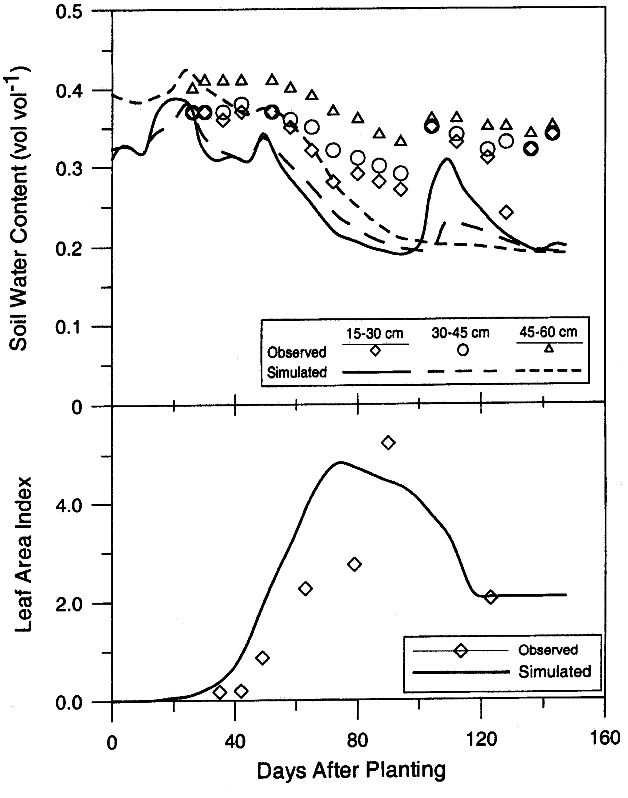

Figure 4. Simulated and observed volumetric soil water content and leaf area index for monitoring site 2.

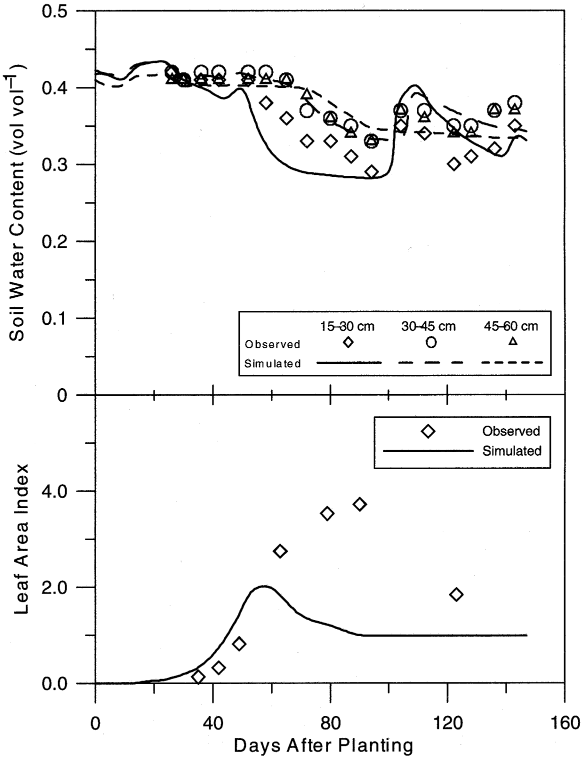

Figure 5. Simulated and observed volumetric soil water content and leaf area index for monitoring site 3.

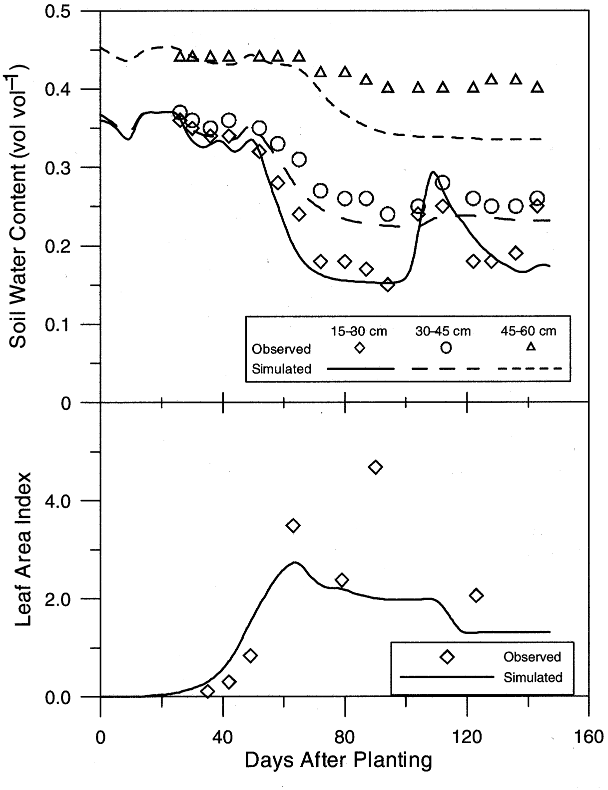

Figure 6. Simulated and observed volumetric soil water content and leaf area index for monitoring site 4.

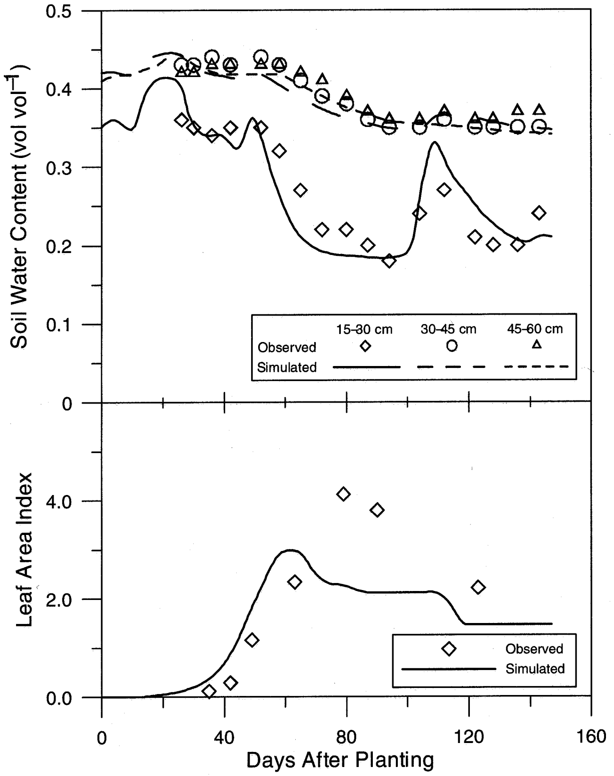

Figure 7. Simulated and observed volumetric soil water content and leaf area index for monitoring site 5.

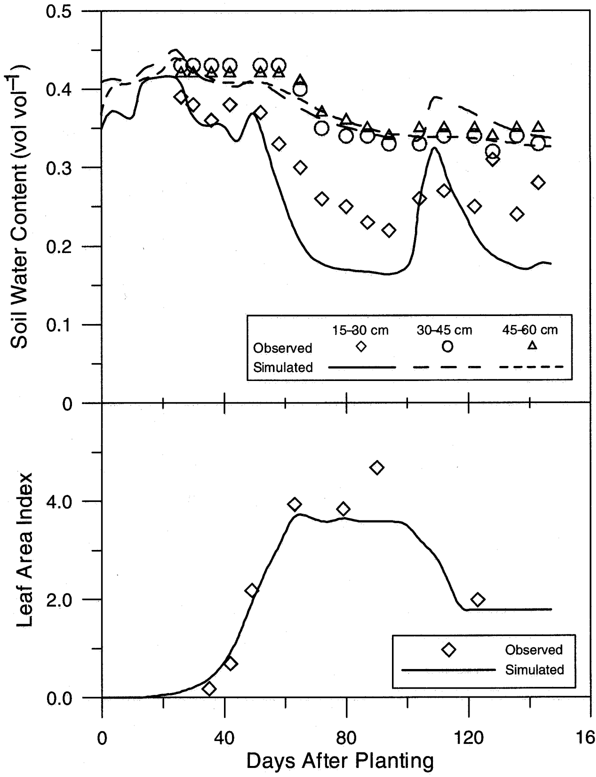

Figure 9. Simulated and observed volumetric soil water content and leaf area index for monitoring site 7.

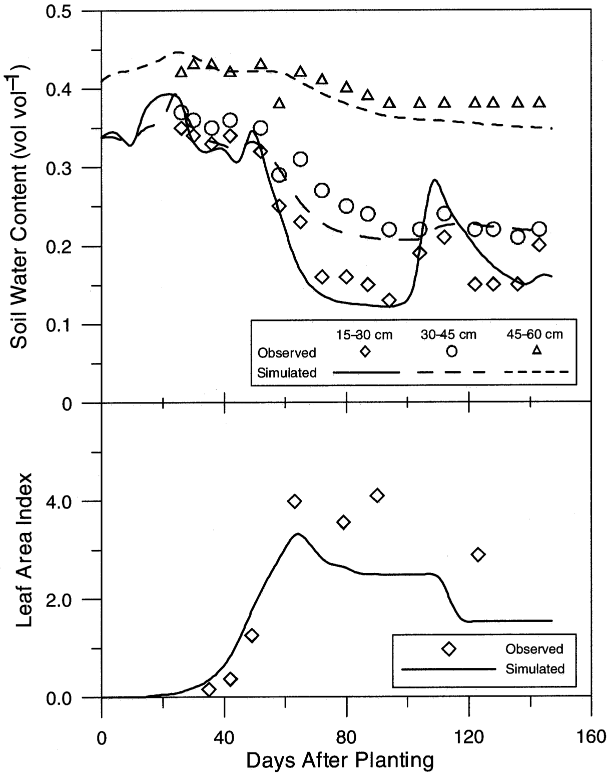

Figure 8. Simulated and observed volumetric soil water content and leaf area index for monitoring site 6.

Site 1

The upper edge of the high clay layer (B_t or claypan horizon) at site 1 (fig. 3) was located at 25 cm from the soil surface. Minor adjustments in the lower and upper soil water limits and the root hospitality factors were required for good calibration of soil water content at this site. The calibrated value for the hardpan factor at this site was 0.20. Simulated leaf area indexes during the reproductive stages were lower than the measured values. A better correspondence could be obtained by increasing the hardpan factor and decreasing the water stress during that period. However, this modification would have caused the model to over predict yield at this site.

Sites 2 and 4

Site 2 (fig. 4) had deeper topsoil above the B_t horizon (100 cm), and the hardpan factor was calibrated to 0.35 in order to facilitate root penetration through the soil layers. Root hospitality factors were set to 1.0 for all layers in order to facilitate root development and water uptake throughout the profile, and to increase simulated yield. Simulated soil water contents were consistently lower than measured soil water contents across all root zone depths. Site 2 was located in a low area of the field near the field water outlet (fig. 1). Not only was the topsoil deeper than at the other sites, facilitating greater root development, but this site also received surface and, probably, subsurface water contributions from the upland areas of the field. Since the water balance in the model does not account for run–on or lateral subsurface water contributions, the model could not be properly calibrated in this case.

This same problem may have occurred at site 4 (fig. 6), where simulated soil water contents agreed well with measured soil water contents in the upper soil layers but were lower in the 30– to 45– and 45– to 60–cm layers. Like site 2, site 4 also had deeper topsoil (44 cm) and received water contributions from adjacent areas due to its location along a secondary drainage channel in the field. The calibrated hardpan factor for this site was considerably lower, 0.13, in order to simulate the measured yield of 5.8 Mg ha^{-1}. It is important to note that site 4 was under considerable weed pressure that is not taken into account by the model.

Site 3

Monitoring site 3 (fig. 5) had shallow topsoil, with the B_t horizon found at 15 cm from the soil surface. The ranges of measured and simulated soil moisture contents were narrower at this site than at the other sites, and less water was available for plant growth. The calibrated value for the hardpan factor at site 3 was low (0.09), in order to better represent the low yield (in the range of 2.6 Mg ha^{-1}) measured for this site. As a consequence, simulated leaf area indexes during water deficient periods were lower than observed values. The simulated zero–to–unity soil water deficit factor (*SWDF*) for this site was considerably higher and more persistent than the SWDF simulated for other sites. Figure 10 illustrates a comparison of simulated water stress for sites 1, 3, and 7. Soil water deficit stress appears at site 3 within 40 days after planting, while stress at the other deeper topsoil sites did not occur until approximately 60 days after planting. The fact that the claypan layer is found at shallow depth at site 3 causes the crop to experience water stress for longer periods of time and at higher intensities during the season.

Sites 5, 6, and 7

Simulated and observed soil moisture contents for site 5 (fig. 7) matched well. The claypan horizon at this site was 36 cm from the soil surface and the calibrated hardpan factor used here was 0.15. Simulated leaf area index was lower than measured leaf area index during the period with water deficit stress. In the case of sites 6 and 7 (figs. 8 and 9), the simulated soil moisture contents at the 45– to 60–cm layer were, in general, lower than the measured soil moisture, although good correspondence was obtained at the shallower depths. The calibrated hardpan factors for these sites were 0.15 and 0.25, respectively, which reflect the lower yield measured at site 6. Observed and simulated leaf area indexes matched well early in the growing season, although simulated values for sites 5 and 6 were lower than the measured values during the period starting 60 days after planting.

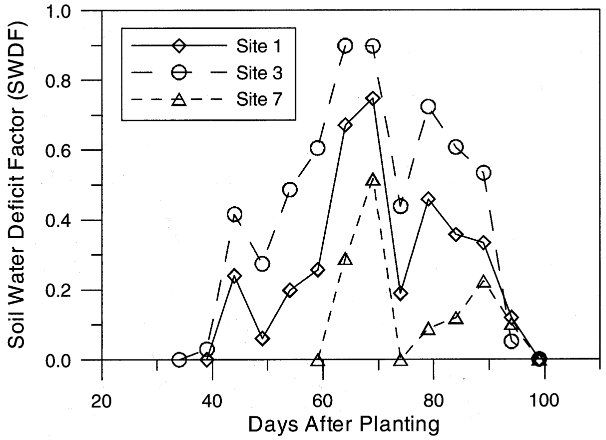

Figure 10. Comparison of simulated soil water deficit factors for monitoring sites 1, 3, and 7.

For best model performance, the calibration process must ensure that all simulated parameters, including yield, total biomass, and soil water content, are in good agreement with observed parameters. Although satisfactory results were obtained for some monitoring sites, a good calibration for all parameters could not be obtained for most sites. For example, excessive simulated water stress at site 3 caused the simulated leaf area index to be lower than observed leaf area index during water–deficient periods of the cropping season. In fact, LAI was underestimated by the model for all sites except 2 and 7.

There was also difficulty in calibrating soil water contents at sites subject to water flow accumulation. Figure 11 compares simulated and observed soil water content for monitoring sites at three distinct landscape positions. Site 2 was located in an area of run–on and water accumulation, and exhibited deep topsoil. Site 3 was on a side slope, runoff area and had shallow topsoil. Site 6 was on a broad, flat summit position and had intermediate topsoil depth. Simulated soil water content followed observed data well for both sites 3 and 6. However, soil water was greatly underestimated for site 2, suggesting water accumulation from surface and possibly subsurface flow as a possible explanation for model errors at this location as well as at site 4. Even though LAI and soil moisture were underestimated at several sites, the generally good calibration of the model for yield at the monitoring sites demonstrated that the modifications were helpful in characterizing the growing conditions found in the study area.

GRAIN YIELD

Figure 12 shows simulated and observed grain yield values for the monitoring sites. Yield predictions for sites 1, 4, 5, 6, and 7 were within 3% of observed values. The yield predicted for site 3 was 3.4 Mg ha^{-1}, approximately 0.8 Mg ha^{-1} or 33% higher than the observed yield.

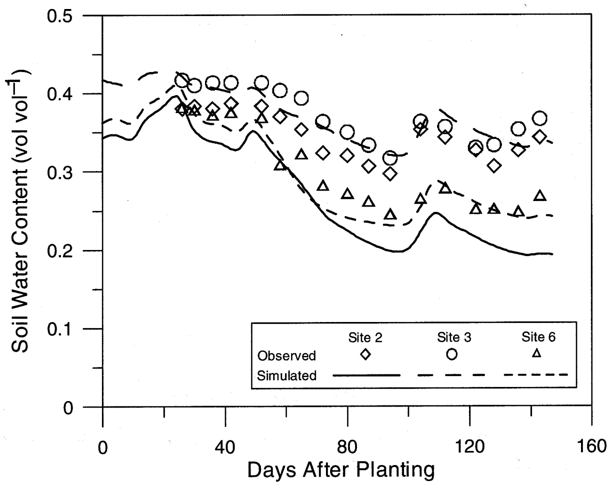

Figure 11. Simulated and observed profile volumetric water content (15–60cm) for monitoring sites 2, 3, and 6.

Yield predicted for site 2 was 8.9 Mg ha^{-1}, 12% lower than the observed value of 10.1 Mg ha^{-1}. Calibrating the model to simulate a higher yield could be achieved in several ways, such as by eliminating water deficit, water saturation, and nitrogen stress during the growing season or by modifying the genetic coefficients. In the case of site 2, there was no simulated water deficit or nitrogen stress during the growing season and a very minor water saturation stress during the initial stages of development. Consequently, the alternative option to simulate a higher yield would be to modify the crop genetic coefficients such as P2, P5, G2, or G3. However, modifying the calibration values used (table 3) to create a simulated yield increase at site 2 would result in over–prediction of yield at the other monitoring sites. Since the revised genetic coefficients would raise the overall yield, further adjustments at the other monitoring sites would be necessary. The adjustments would need to increase water stress at the other sites to reduce the simulated yields to match the observed yields. As a consequence of additional stress, simulated leaf area would be further decreased. Since simulated leaf area index at several of the monitoring sites was already lower than observed leaf area index, no modification of the genetic coefficients was introduced to further increase the simulated yield at site 2. The problems encountered in simulating the yield at site 2 suggest that the model may be under–predicting leaf area expansion or over–predicting leaf senescence under water stress conditions.

CONCLUSIONS

The modifications included in this version of the CERES–Maize model allowed a better characterization of site–specific crop development conditions for claypan soils. The root hospitality and hardpan factors were important parameters in calibrating the model for measured yield variability, but measured leaf area index was underestimated at five out of the seven monitored sites even after calibration. The mid–season water stress that occurred during the 1997 cropping season enhanced the importance of proper simulation of root development. In claypan soils, the location and thickness of the high–clay layer are important factors for accurately simulating root density and water uptake at the various depths. The claypan was characterized by a lower root hospitality factor allowing the model to simulate the difficulty of the root system to expand in high clay layers. The ability to use the hardpan factor to characterize slower rates of downward root development due to the presence of restrictive layers was also important in claypan soils.

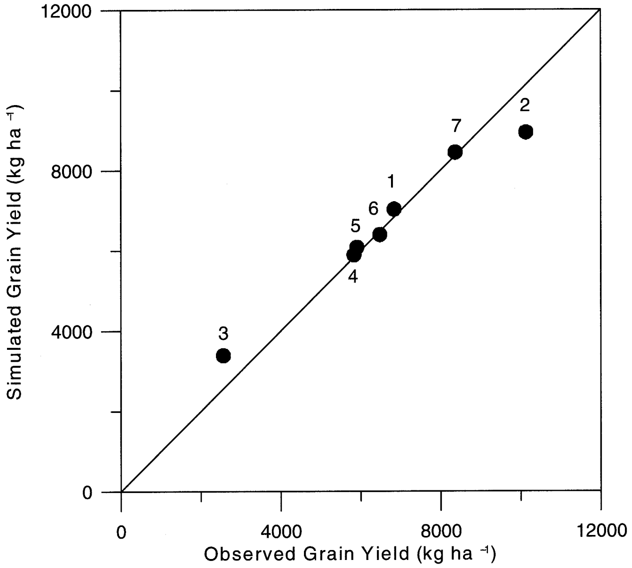

Figure 12. Comparison of simulated and observed grain yield for the seven monitoring sites in the study area.

The yield results obtained for most monitoring sites were in good agreement with measured values. However, extreme yield values, either low or high, created additional difficulties in the calibration process. In the case of low yields such as measured for site 3, the calibrated value for the hardpan factor had to be low in order to simulate the measured yield. As a consequence, simulated leaf area expansion was reduced due to water stress conditions, and simulated leaf area index during water deficient periods was lower than measured leaf area index. In the case of high measured yields such as for site 2, the hardpan and root hospitality factors were increased, and the lack of water stress conditions caused the simulated leaf area expansion to be higher than that observed in the field.

Soil cores extracted from each monitoring site at the end of the 1997 season were used for determination of root density at the various depths. The results obtained are currently being analyzed and will provide additional information for evaluation and calibration of the root hospitality and hardpan factors.

Areas that receive run–on or subsurface flow contributions from upland areas of the field are difficult to simulate with the current modeling approach. The coupling of hydrologic models with crop models seems to be the best way to properly simulate the water balance in these areas. However, this might increase the complexity and input requirements of the combined model to a level that would prevent its adoption as a management tool. A potential alternative is the use of terrain analysis models to allow the quantification of topographic attributes of landscapes and the determination of hydrologic "homogeneous" zones within the field. Areas that receive run–on or subsurface flow contributions from upland areas of the field would be characterized by high root hospitality factors, reducing the possibility of water stress during the simulation process.

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