Reprinted from *Agronomy Journal*
Vol. 90, No. 5

Maize and Sorghum Simulation in Diverse Texas Environments

James R. Kiniry* and Anton J. Bockholt

ABSTRACT

Crop models for decision making should accurately simulate grain yields across a wide range of soils and climate regimes. This study was designed to evaluate two models' ability to simulate plot grain yields under diverse weather conditions and soils in Texas. The objective was to compare measured grain yields of maize (*Zea mays* L.) and sorghum [*Sorghum bicolor* (L.) Moench] with grain yields simulated by the ALMANAC (Agricultural Land Management Alternatives with Numerical Assessment Criteria) model and to compare measured maize yields with grain yields simulated by a new version of the CERES-Maize (Crop-Environment Resource Synthesis) model. Using yield performance trials, both models were tested for their ability to simulate the mean yield for five years at each location and their ability to describe year-to-year variability in measured yields. Both models were tested at nine locations for maize and ALMANAC was tested at eight locations for sorghum. Model inputs included parameters for the soil type, planting dates, planting rates, and locally measured weather data. Mean simulated grain yield for each site was within 10% of the mean measured grain yield for all cases, except for CERES at Thrall, where mean simulated yield was 13% lower than mean measured yield. When the models did not account for a significant amount of the year-to-year variability in measured grain yield at a site, it was usually due to the narrow range of measured grain yields. The soils, weather, and crop parameter data sets developed here can be useful starting points for deriving data at similar sites, giving model users examples of realistic input data.

PRODUCERS AND PUBLIC POLICY ADMINISTRATORS can benefit from simulation tools providing accurate grain yield predictions of crops for different soil types, different climatic conditions, and different amounts of rain and irrigation. Before investing money in seed, fertilizer, and other expenses, a crop model could calculate probabilities of grain yield levels of maize or sorghum for a given soil type based on fall and winter rain and probabilities of various climatic conditions for the upcoming season. Facing delays in planting or replanting, producers could further benefit from knowing expected maize or sorghum grain yields predicted by models. Policy administrators need to know the impact of various agricultural programs on crop yields and yield stability. All such activities require accurate crop simulation.

Texas, with its high risk of drought, high air temperatures during flowering and grain growth, and uncertainties for late spring freezing, is a state where sorghum and maize producers are especially vulnerable. The extremes in air temperature, relative humidity, and soils offer an excellent range of environmental conditions for testing crop simulation. Models capable of accurately simulating maize and sorghum grain yields across sites will be valuable for risk assessment, maturity-type optimization, decisions regarding whether to and what to replant following early stand reduction, and plant-density optimization.

Two models designed for these applications are the maize model CERES-Maize (Jones and Kiniry, 1986) and the more general crop model ALMANAC (Kiniry et al., 1992b). Recent work at several U.S. locations has shown the value of both for maize simulation (Kiniry et al., 1997). However, simulated grain yields in central Texas tended to exceed reported county average yields when the standard value of harvest index of 0.53 was used for ALMANAC and when the standard value of 500 seeds per plant was used as the potential for CERES-Maize. Low values of 0.30 for harvest index in ALMANAC and 450 seeds per plant in CERES-Maize were needed to accurately simulate measured grain yields at the site in Texas. More model testing in Texas was needed, using plot grain yields instead of county average yields. Use of plots yields avoids the variability in amounts of rain across a county, which complicates simulation of county average yields. In this study, the objective was to evaluate the yield simulation capability of CERES-Maize and ALMANAC in Texas, using diverse sites and plot grain yields of maize and sorghum for five years. These models were evaluated at sites with diverse soils and climate in the state.

MODEL DESCRIPTIONS

While having similar components for evapotranspiration, soil water balance, and plant dry matter growth, the approach to simulating grain yield differs between ALMANAC and CERES. ALMANAC simulates grain yield based on harvest

Abbreviations and variables: ALMANAC, Agricultural Land Management Alternatives with Numerical Assessment Criteria [model]; CERES, Crop-Environment Resource Synthesis [model]; GROWTH, plant growth rate, g $plant^{-1}$ d^{-1}; HI, harvest index; LAI, leaf area index; PAW, plant-available water or the difference between the drained upper limit and the lower limit for the soil profile; RMSE, root mean square error; RUE, radiation-use efficiency; SEEDS, number of seeds $plant^{-1}$; VPD, vapor pressure deficit, kPa. *CERES crop parameters:* G2, the potential number of seeds per plant; G3, the potential kernel growth rate in mg $seed^{-1}$ d^{-1}; P1, degree days during the juvenile stage, base 8°C; P2, the photoperiod sensitivity coefficient; P5, the degree days from silking to physiological maturity, base 8°C. *ALMANAC crop parameters:* DLAI, fraction of the season when leaf area begins to decline, PHU, degree days from planting to maturity, base 8°C.

J.R. Kiniry, USDA-ARS, 808 E. Blackland Rd., Temple, TX 76502; A.J. Bockholt, Soil and Crop Sciences Dep., Texas A&M University, College Station, TX. Received 7 Apr. 1997. *Corresponding author (kiniry@brc.tamus.edu).

Published in Agron. J. 90:682–687 (1998).

Table 1. Texas yield data sets for maize (M) and sorghum (S) used in simulations for 1991 to 1995.

Town	County	Geographical coordinates	Weather station	Mean planting dates† Maize	Mean planting dates† Sorghum	Mean annual rainfall	Irrig. or dryland	Crop
						mm		
Dumas	Moore	35°52′ N, 101°58′ W	Borger	22 Apr.	24 May	462	irrig.	M, S
McKinney	Collin	33°12′ N, 96°35′ W	Sherman	17 Mar.‡	29 Mar.‡	1136	dry	M, S
Bardwell	Ellis	32°33′ N, 96°48′ W	Kaufman	14 Mar.	—	1038	dry	M, S
Thrall	Williamson	30°58′ N, 97°06′ W	Granger	25 Feb.§	6 Mar.§	1026	dry	M, S
College Station	Brazos	30°40′ N, 96°22′ W	College Station	28 Feb.	21 Mar.	1262	irrig.	M, S
Wharton	Wharton	29°19′ N, 96°06′ W	Thompson	19 Mar.	19 Mar.	1515	dry	M, S
Castroville	Medina	29°33′ N, 100°30′ W	Hondo	9 Mar.	11 Mar.	747	irrig.	M, S
Corpus Christi	Nueces (San Patricio)¶	27°48′ N, 97°24′ W	Corpus Christi	16 Mar.	5 Mar.	849	dry	M
Weslaco	Hidalgo	26°10′ N, 97°59′ W	McCook	17 Feb.	20 Feb.	540	irrig.	S

† Except as noted, planting dates are means for 1991–1995.
‡ Did not include the 1 May planting in 1995.
§ Did not include the 13 Mar. maize planting in 1992 or the 7 May sorghum planting in 1992.
¶ County in parenthesis is for sorghum, where different from maize.

index (HI). Potential grain yield is computed as a percentage of the aboveground dry matter at maturity. Drought near anthesis reduces simulated HI in ALMANAC. Cessation of growth before maturity due to cold temperatures or drought also reduces simulated grain yield. CERES simulates the number of seeds per plant based on growth per plant from silking to the beginning of the effective filling period of grain. The model simulates average mass per seed from a potential seed growth rate, a degree-day sum required for grain filling, and the amount of assimilate available for grain growth.

CERES-Maize

Since publication of the model in 1986, three studies have provided basic information about maize growth relationships described in the model. Improvements in the model based on these studies were described previously (Kiniry et al., 1997). The first change is that radiation-use efficiency (RUE) is now reduced as mean daily vapor pressure deficit (VPD) exceeds 1.0 kPa (Stockle and Kiniry, 1990). Maize RUE is 4.33 g MJ^{-1} of intercepted photosynthetically active radiation for mean daily VPD less than 1.0 kPa and is reduced by mean daily VPD > 1.0:

$$\text{RUE} = 5.05 - 0.72\ \text{VPD} \qquad [1]$$

The second change is that only 0.26 g of grain is produced for each gram of carbohydrate lost from the stem and leaves (Kiniry et al., 1992a). Respiration, efficiency of conversion of glucose into grain, and translocation costs presumably are responsible for this being less than 1.0. Thirdly, seed number is now a linear function of plant growth rate (GROWTH). The slope of this function and the potential seed number are genotype-specific (Kiniry and Knievel, 1995). For this study, number of seeds per plant (SEEDS) is calculated from GROWTH (g $plant^{-1}$ d^{-1}) from silking to the beginning of grain growth as

$$\text{SEEDS} = 165 + 58.7\ \text{GROWTH} \qquad [2]$$

SEEDS is constrained to not exceed a genotype-specific potential number of seeds per plant (G2).

ALMANAC

ALMANAC simulates plant growth using leaf area index (LAI) and, as in CERES, RUE is sensitive to VPD. For maize, the response of RUE to VPD is identical to that in CERES. For sorghum the equation equivalent to Eq. (1) is:

$$\text{RUE} = 4.66 - 0.94\ \text{VPD} \qquad [3]$$

with RUE equal to 3.72 for VPD less than 1.0 kPa. This was derived from the values of Stockle and Kiniry (1990), assuming that 10% of the biomass is in roots at anthesis. The model simulates population density by adjusting potential LAI. Maximum potential simulated LAI at high planting densities is 6.0 for maize and 5.0 for sorghum. Simulated potential LAI for the planting densities at the different locations varied from 4.1 to 4.6 for sorghum and from 3.5 to 4.4 for maize.

ALMANAC uses a modified harvest index (HI) approach to simulating grain yield. For maize, we use a HI value of 0.53 and assume that stress reduces HI only slightly. Values for HI reported for temperate regions usually were between 0.46 and 0.58 and the mean was 0.52 (Kiniry et al., 1997). While severe drought treatments have been shown to reduce maize HI to as low as 0.27 to 0.31 (Sobriano and Ginzo, 1975; Griffin, 1980; Costa et al., 1988), use of such a low value for plant stress

Table 2. Soils and selected soil parameters for demonstration data sets in Texas.

Town	Soil type	Soil depth	PAW†	Runoff curve number‡
		m	cm	
Dumas§	Pullman clay loam (Torrertic Paleustoll)	2.0	26	78
McKinney	Houston Black clay (Udic Haplusterts)	1.3	18	86
Bardwell	Burleson clay (Udic Haplusterts)	1.7	24	86
Thrall	Burleson clay (Udic Haplusterts)	2.0	22	86
College Station	Ships clay (Chromic Hapluderts)	2.0	26	81
Wharton (maize)	Asa silty clay loam (Fluventic Hapludolls)	2.2	25	75
Wharton (sorghum)	Lake Charles clay (Typic Hapluderts)	2.0	19	75
Castroville§	Knippa clay (Vertic Calciustolls)	1.5	22	72
Corpus Christi	Victoria clay (Udic Pellusterts)	1.6	18	75
Weslaco	Hidalgo sandy clay (Typic Calciustolls)	1.4	18	78

† PAW, plant-available water (the difference between the drained upper limit and the lower limit for the profile).
‡ Runoff curve numbers are based on soil hydrologic groups.
§ Simulated with the water balance turned off for CERES (assumed no drought stress) to simulate irrigated conditions at these sites.

Table 3. Maize measured and simulated grain yields and coefficients of variation (CV) for nine Texas locations for 1991 to 1995. Measured grain yields were from performance tests each year.

Town	Measured		ALMANAC		CERES	
	Mean	CV	Mean	CV	Mean	CV
	Mg ha^{-1}	%	Mg ha^{-1}	%	Mg ha^{-1}	%
Dumas	11.4	6	10.3	4	11.3	9
McKinney	6.5	32	7.1	21	6.0	37
Bardwell	6.9	27	7.1	21	6.7	31
Thrall	8.5	17	8.5	20	7.4	42
College Station	10.2	4	10.0	9	9.5	11
Wharton	8.4	15	8.5	8	8.4	4
Castroville	9.3	5	9.4	10	9.5	5
Corpus Christi	6.4	18	6.8	18	6.0	39
Weslaco	7.8	26	8.4	12	7.5	12

in this study caused greater errors in grain yield simulation by ALMANAC. For sorghum, the simulated HI value was 0.45, based on the results of Prihar and Stewart (1990). We assumed that sorghum HI is reduced only slightly by stress. At Dumas, sorghum HI was set to 0.53 because, under intense irrigation management, Prihar and Stewart (1991) found values greater than 0.5 in the High Plains of Texas.

MODEL EVALUATION

Data Sets

We tested both models at nine locations for maize and tested ALMANAC at eight locations for sorghum (Table 1). Four locations were irrigated as needed; the other five sites were dryland. Simulated grain yields were compared with the mean of the five highest yielding hybrids measured each year at each location in the annual maize and sorghum performance tests in Texas (Pietsch et al., 1992–1996a,b). The top five hybrids were used in an attempt to follow producers that use the best available hybrids. Nutrients, weeds, disease, and insects were considered not to be yield-limiting. The appropriate soil parameters for each site were used, and the weather data (measured daily maximum and minimum air temperatures, and rainfall) were taken from the nearest weather station. Distances between weather stations and yield plots are especially important for rain data. Having accurate rain data is critical for maize yield simulation, due to the crop's vulnerability to drought stress near the silking date. Daily solar radiation was the mean for the month for 20 yr at each site. Vapor pressure deficit was estimated from the maximum and minimum daily air temperatures using the technique of Diaz and Campbell (1988) as described by Stockle and Kiniry (1990).

Table 4. Sorghum measured and simulated mean grain yields and coefficients of variation (CV) for eight Texas locations for 1991 to 1995. Grain yields were from performance tests each year.

Town	Measured		ALMANAC	
	Mean	CV	Mean	CV
	Mg ha^{-1}	%	Mg ha^{-1}	%
Dumas	9.4	11	8.7	2
McKinney	5.9	10	5.8	17
Thrall	5.9	14	6.4	12
College Station	7.0	11	7.2	3
Wharton	6.1	12	6.2	12
Castroville	6.7	10	6.5	5
Corpus Christi	5.0	8	5.2	10
Weslaco	6.2	5	5.7	10

Population densities used were the means of the top five hybrids (in terms of yield) in each year at each location. CERES crop parameters were identical at all locations (except for G3, the potential kernel growth rate in mg seed^{-1} d^{-1}). Parameters and their values were: 220, for the degree days during the juvenile stage (P1); 0.52, for the photoperiod sensitivity coefficient (P2); 880, for the degree days from silking to physiological maturity (P5); and 730, for the potential number of seeds per plant (G2). Values for G3 were 7.5 for Weslaco and Corpus Christi, 8.25 for Wharton, 8.5 for Dumas and Castroville, 9.0 for Bardwell, 9.25 for College Station, 10.0 for Thrall, and 10.75 for McKinney. Such differences contribute to differences in grain size for hybrids in different areas of Texas.

One value for the degree days from planting to maturity (PHU) for ALMANAC was calculated for each crop at each location. This was calculated using the reported anthesis dates of maize and sorghum for each location for the five years. The PHU for maize was the mean sum of degree days calculated for each location for sowing to silking, and 630 degree days for silking to maturity (Kiniry and Keener, 1982). For sorghum, PHU was calculated assuming 30 d from anthesis to maturity (T.J. Gerik, personal communication, 1996). Degree days for sorghum were 2000 at Dumas, 1800 at Weslaco, and 1900 everywhere else. Degree days for maize were 1900 at Dumas and 1650 everywhere else. Based on these calculations, the degree days at flowering occurred at a mean of 0.52 of PHU for maize and 0.64 for sorghum. These values were used for DLAI; the fraction of the season when leaf area began to decline.

Soils at the sites differed in their capacity to store water (Table 2). Soils with the highest plant-available water (PAW) in the profile at field capacity were at Dumas, College Station, and the maize site at Wharton. McKinney, Corpus Christi,

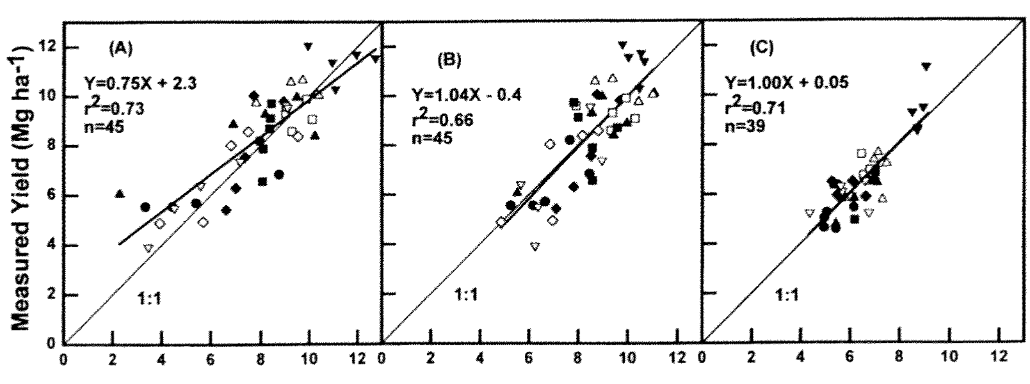

Fig. 1. Simulated vs. measured grain yields for nine sites in Texas using two models: (a) maize, CERES simulation; (b) maize and (c) sorghum, ALMANAC simulation. The dark lines represent the regression lines. Each point is for one year at a location.

Table 5. Bias (simulated minus measured grain yields) and root mean square error (RMSE) (Mg ha^{-1}) for 5 yr at nine Texas locations.

Town	CERES (maize)		ALMANAC Maize		ALMANAC Sorghum	
	Bias	RMSE	Bias	RMSE	Bias	RMSE
	Mg ha^{-1}					
Dumas	−0.06	1.14		1.39	−0.67	1.04
McKinney	−0.57	0.64	0.60	1.44	−0.57	0.88
Bardwell	−0.25	1.04	0.17	1.06	—	—
Thrall	−1.08	2.14	0.03	0.90	0.37	0.48
College Station	−0.72	1.14	−0.12	1.24	0.17	0.76
Wharton	−0.02	1.29	0.12	1.42	0.08	0.75
Castroville	0.20	0.63	0.08	0.98	−0.22	0.57
Corpus	−0.38	1.41	0.48	0.93	0.27	0.49
Weslaco	−0.28	1.26	0.56	1.25	−0.48	0.83
Mean	−0.35	1.26	0.08	1.23	−0.08	0.75

and Weslaco had the lowest PAW at field capacity. With ALMANAC, fertilizer applications were those given in the performance trial publications each year.

The two models were evaluated by addressing the following questions:

1. Can the models describe overall differences in grain yields of sorghum and maize? When measured grain yields are regressed on simulated grain yields, how close is the regression line to the 1:1 line and what is the r^2?
2. At each location, how does each model's coefficient of variation (CV) compare with the CV for measured grain yields?
3. How well do the models account for the variability in measured data at each site?

With regression analysis, we tested measured grain yield as a function of simulated grain yield, to see if the regression model was significant. We also checked to see if the regression lines' *y*-intercepts were significantly different from 0.0 and if the slopes were significantly different from 1.0. We used SAS GLM (SAS Inst., 1985) procedures for the regression analyses.

Bias values and root mean square error (RMSE) values were calculated as described by Retta et al. (1996).

RESULTS AND DISCUSSION

The models' mean simulated grain yields were within 10% of mean measured grain yield for all locations except one (Tables 3 and 4). CERES' mean simulated maize grain yield at Thrall was 13% low. The CVs of maize simulations were closer to CVs of measured grain yields for ALMANAC at five locations and were closer for CERES at three. The CVs for CERES were greater than the CVs for ALMANAC at the four sites with yields most limited by drought. These were McKinney, Bardwell, Thrall, and Corpus Christi. This could be the result of less stable simulated yields when yields components were simulated, such as in CERES, than when yields were simulated using a harvest index approach.

The models accounted for greater than 65% of the variability in grain yields for all 5-year data with all locations pooled (Fig. 1). Regression models for measured grain yield as a function of simulated grain yield were all significant ($\alpha = 0.05$). The slopes of these equations for ALMANAC simulations of maize and sorghum were not significantly different from 1.0 and the *y*-intercepts were not significantly different from 0.0. However, for CERES, the slope was significantly different from 1.0 and the intercept was significantly different from 0.0. Simulated yields of CERES tended to be too low when measured grain yields were $\leq$6 Mg ha^{-1}.

The models' bias values (simulated minus measured) and the root mean square error (RMSE) values were similar across locations (Table 5). For each location, bias values were <1.0 Mg ha^{-1}, except for CERES at Thrall and ALMANAC for maize at Dumas. Mean simulated yield was 1.08 Mg ha^{-1} too low at Thrall. At

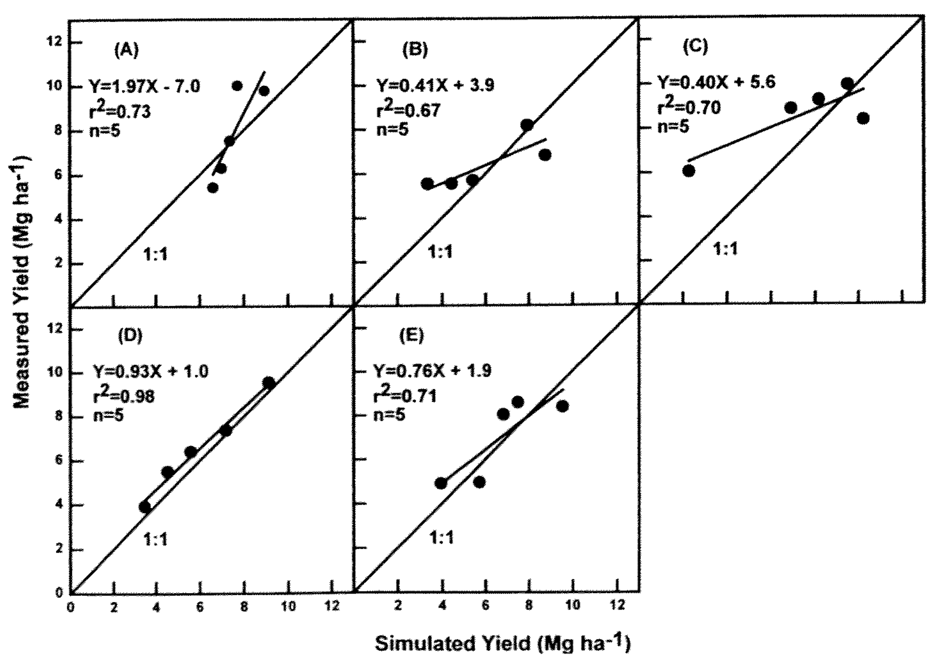

Fig. 2. Maize simulations with CERES at the five sites in Texas where there was a significant relationship between measured and simulated grain yields: (a) Weslaco, (b) Corpus Christi, (c) Thrall, (d) McKinney, and (e) Bardwell. The dark lines represent the regression lines.

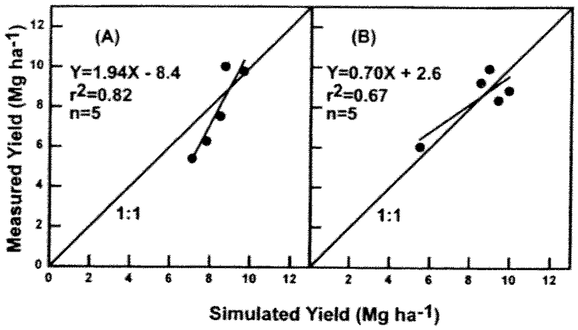

Fig. 3. Maize simulations with ALMANAC at the two sites in Texas where there was a significant relationship between measured and simulated grain yields: (a) Weslaco and (b) Thrall. The dark lines represent the regression lines.

Dumas, ALMANAC's mean simulated maize yield was 1.12 Mg ha^{-1} too low. Values for RMSE were always <2.0 Mg ha^{-1}, except for CERES at Thrall.

Fitting regressions for each location separately, models of comparisons between CERES-simulated grain yields and measured grain yields were significant (α = 0.10) at five locations (Fig. 2). Regressions between ALMANAC-simulated grain yields and measured grain yields were significant at two locations for maize and one for sorghum (Fig. 3 and 4). The other locations often had a narrow range for measured grain yield across years and little variability for which the models could account. This was often due to adequate irrigation or rain at a location. For example, CVs of measured maize yield were <7% at Dumas, College Station, and Castroville (Table 3). For measured sorghum grain yields, most sites had CV values ≤11% (Table 4).

In conclusion, CERES and ALMANAC performed adequately in simulating plot grain yields at these diverse sites in Texas. Both models reasonably simulated mean grain yields at each location. When models did not account for a significant amount of the year-to-year variability in measured grain yields at a site, it was usually due to the narrow range of measured grain yields. Thus, the ability of the models to simulate plot grain yields indicates that they will be useful in making management decisions at many locations in Texas. The RMSE values reported here provide some guidance as to what can be expected when these models are used as decision making tools.

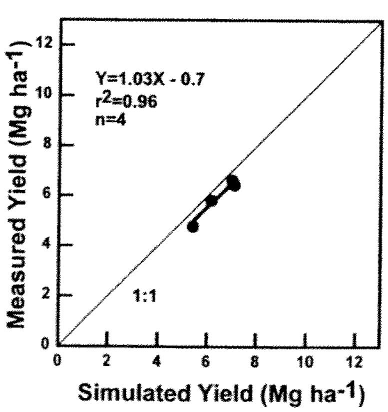

Fig. 4. Sorghum simulations with ALMANAC at Thrall, TX, the site where there was a significant relationship between measured and simulated grain yields. The dark line represents the regression line.

These models show promise as tools for decision making with maize and sorghum in Texas. The data sets developed here can be used as starting points to derive data sets for sites with similar soils, crop hybrids, and weather, providing users with examples of realistic values for soil and crop parameters.

AVAILABILITY

Models and data sets described herein are available to users at no charge. The files may be requested by e-mail (kiniry@brc.tamus.edu). Alternatively, mail a request along with three 1.44 MB diskettes to the corresponding author.

REFERENCES

Costa, J.O., L.G.R. Ferreira, and F. DeSouza. 1988. Produçáo do milho submetido a diferents níveis de estresse hídrico. Pesq. Agropec. Bras., Brasília 23:1255–1261.

Diaz, R.A., and Campbell, G.S. 1988. Assessment of vapor density deficit from available air temperature information. p. 16. *In* Agronomy abstracts. ASA, Madison, WI.

Griffin, J.L. 1980. Quantification of the effects of water stress on corn growth and yield. M.S. thesis. Univ. of Missouri, Columbia.

Jones, C.A., and Kiniry, J.R. (ed.). 1986. CERES-Maize: A simulation model of maize growth and development. Texas A&M Univ. Press, College Station.

Kiniry, J.R., and M.E. Keener. 1982. An enzyme kinetic equation to estimate maize development rates. Agron. J. 74:115–119.

Kiniry, J.R., and D.P. Knievel. 1995. Response of maize seed number to solar radiation intercepted soon after anthesis. Agron. J. 87: 228–234.

Kiniry, J.R., C.R. Tischler, W.D. Rosenthal, and T.J. Gerik. 1992a. Nonstructural carbohydrate utilization by sorghum and maize shaded during grain growth. Crop Sci. 32:131–137.

Kiniry, J.R., J.R. Williams, P.W. Gassman, and P. Debaeke. 1992b. A general, process-oriented model for two competing plant species. Trans. ASAE 35:801–810.

Kiniry, J.R., J.R. Williams, R.L. Vanderlip, J.D. Atwood, D.C. Reicosky, J.A. Mulliken, W.J. Cox, H.J. Mascagni, Jr., S.E. Hollinger, and W.J. Wiebold. 1997. Evaluation of two maize models for nine U.S. locations. Agron. J. 88:421–426.

Pietsch, D., A.J. Bockholt, R. Gaas, and F. Foyt III. 1992a. 1991 Corn performance tests in Texas. Tech. Rep. 92-1. Texas Agric. Exp. Stn., College Station.

Pietsch, D., A.J. Bockholt, R. Gaas, and F. Foyt III. 1993a. 1992 Corn performance tests in Texas. Tech. Rep. 93-1. Texas Agric. Exp. Stn., College Station.

Pietsch, D., A.J. Bockholt, L. Synatschk, and F. Foyt III. 1994a. 1993 Corn performance tests in Texas. Tech. Rep. 94-1. Texas Agric. Exp. Stn., College Station.

Pietsch, D., A.J. Bockholt, L. Synatschk, and F. Foyt III. 1995a. 1994 Corn performance tests in Texas. Tech. Rep. 95-1. Texas Agric. Exp. Stn., College Station.

Pietsch, D., A.J. Bockholt, L. Synatschk, and F. Foyt III. 1996a. 1995 Corn performance tests in Texas. Tech. Rep. 96-1. Texas Agric. Exp. Stn., College Station.

Pietsch, D., R. Gaas, D.T. Rosenow, F. Miller, and G.C. Peterson. 1992b. Grain sorghum performance tests in Texas—1991. Tech. Rep. 92-2. Texas Agric. Exp. Stn., College Station.

Pietsch, D., R. Gaas, D.T. Rosenow, F. Miller, and G.C. Peterson. 1993b. Grain sorghum performance tests in Texas—1992. Tech. Rep. 93-2. Texas Agric. Exp. Stn., College Station.

Pietsch, D., L. Synatschk, D.T. Rosenow, F. Miller, and G.C. Peterson. 1994b. Grain sorghum performance tests in Texas—1993. Tech. Rep. 94-2. Texas Agric. Exp. Stn., College Station.

Pietsch, D., L. Synatschk, D.T. Rosenow, F. Miller, and G.C. Peterson.

1995b. Grain sorghum performance tests in Texas—1994. Tech. Rep. 95-2. Texas Agric. Exp. Stn., College Station.
Pietsch, D., L. Synatschk, D.T. Rosenow, and G.C. Peterson. 1996b. Grain sorghum performance tests in Texas—1995. Tech. Rep. 96-2. Texas Agric. Exp. Stn., College Station.
Prihar, S.S., and B.A. Stewart. 1990. Using upper-bound slope through the origin to estimate genetic harvest index. Agron. J. 82:1160–1165.
Prihar, S.S., and B.A. Stewart. 1991. Sorghum harvest index in relation to plant size, environment, and cultivar. Agron. J. 83:603–608.
Retta, A., R.L. Vanderlip, R.A. Higgins, and L.J. Moshier. 1996. Application of SORKAM to simulate shattercane growth using forage sorghum. Agron. J. 88:596–601.
SAS Institute. 1985. SAS language guide for personal computers. SAS Inst., Cary, NC.
Sobriano, A., and H.D. Ginzo. 1975. Yield responses of two maize cultivars following short periods of water stress at tasseling. Agric. Meteorol. 15:273–284.
Stockle, C.O., and J.R. Kiniry. 1990. Variability in crop radiation use efficiency associated with vapor pressure deficit. Field Crops Res. 21:171–181.