IX. IRRIGAÇÃO

TEST OF A SOIL WATER ASSESSMENT MODEL FOR A SORGHUM CROP UNDER DIFFERENT IRRIGATION TREATMENTS (1)

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ABSTRACT

A model to monitor the soil water status using automated weather station data, crop phenology, and soil information was adjusted and tested for a sorghum crop using field experiments with eight different water treatments in a randomized split factorial block irrigation design during the 1990 and 1991 growing seasons at Mead, Nebraska-USA. Estimates of the total soil water content from the soil water balance model matched well with neutron-probe readings in the sorghum crop. Model performance by soil layer indicates slight underestimates of soil water content in the upper layers of soil, slight overestimates of soil water content in the lower soil layers, and close agreement between simulated and observed soil water contents in the middle soil layers. Elimination of these small offseting errors from the model would result in an improved performance within layers. One possible means of eliminating the error is to adjust the root soil water extraction slightly away from the upper levels and toward the lowest levels. Based on the fact that model estimates of total soil water were in good agreement with observations, it is concluded that it is reasonable to estimate soil water conditions on a routine basis using near-real time automated weather station data.

Index terms: soil water balance, *Sorghum bicolor* L., evaporation, transpiration, soil moisture.

RESUMO

TESTE DE UM MODELO DE MONITORAMENTO DE ÁGUA NO SOLO PARA UMA CULTURA DE SORGO SUBMETIDA A DIFERENTES TRATAMENTOS DE IRRIGAÇÃO

Um modelo de balanço hídrico diário utilizando informações de estação meteorológica automática, fenologia e informações edáficas foi ajustado e testado para uma cultura de sorgo usando experimentos de campo com diferentes tratamentos

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de irrigação durante o verão de 1990 e 1991, em Mead, Estado de Nebraska-EUA. Estimativas do total de água no solo a partir do balanço hídrico compararam-se bem com as leituras de sonda de nêutrons tomadas nos diferentes tratamentos. O desempenho do modelo, por camadas de solo, indicou pequena subestimativa da umidade nas camadas superiores, pequena superestimativa nas inferiores e boa estimativa nas intermediárias. A eliminação desses erros resultaria em melhor desempenho do modelo nas diferentes camadas. Boas estimativas do total de água no solo podem ser obtidas através deste balanço hídrico edafoclimático modificado com base em informações fenológicas, edáficas e de dados obtidos de estações meteorológicas automáticas.

Termos de indexação: balanço hídrico, sorgo, *Sorghum bicolor* L., evaporação, transpiração, umidade do solo.

1. INTRODUCTION

In the past decade, regional climate centers have been established in the USA to enhance national efforts in climate services and applied climate research. By design, these centers are located in regions that differ topographically, climatically, and economically (Hubbard, 1989). The High Plains Climate Center with headquarters at the University of Nebraska-Lincoln entered into monitoring agreements with 6 regional states (Colorado, Iowa, Kansas, North Dakota, South Dakota, and Wyoming). To date, the High Plains Climate Center has more than 110 automated weather stations in the Automated Weather Data Network (AWDN). The objective of these stations is to obtain surface weather data in near real-time.

In the 1980's, a study was initiated at the University of Nebraska-Lincoln to monitor soil water in the High Plains region. This region-wide study linking weather to soil water status was undertaken by the High Plains Climate Center. The soil water balance developed by Hanks (1974) was modified by Hubbard & Hanks (1983), and further modified by Sagar (1988), and Robinson & Hubbard (1990). Performance of the model described by Robinson & Hubbard (1990) was reported for 20 separate examples involving 5 crops, 9 locations, and 2 years of data. For most part the variance explained by the model was in excess of 70 percent.

The root zone water content may vary considerably in response to variations in precipitation and irrigation, evaporation, transpiration, runoff, and drainage below root zone. In turn, the spatial variability of ET from a crop-covered field is caused by field variability in microclimatic conditions, soil physical properties, and pertinent crop properties (Hansen & Jensen, 1986). Soil physical properties that may vary include porosity, permeability and hydraulic conductivity, whereas pertinent crop propertiHx that influence water use patterns include leaf area index, phenological devel- opmental rate and the ability of the roots to extract soil water. Variations in topography, vegetative cover and soil properties can result in large within-field variations of soil water content (Hawley et al. 1983). According to Robinson & Hubbard (1990), vertical variations in soil properties can result from the formation of a claypan beneath the soil surface, crusting of the soil surface, and soil compression resulting in altered infiltration and drainage patterns. Models can be used to explain the majority of the variance in a set of observations only if the above mentioned sources of variations are dealt with by the models.

In view of the preceeding, an agrometeorological study of sorghum was conducted with the objective of adjusting and testing a model that monitors the soil water status using automated weather station data, crop phenology, and soil information for a sorghum crop using field experiments with different water treatments.

2. MATERIAL AND METHODS

Field experiments were conducted during the summers of 1990 and 1991 at the University of Nebraska's Agricultural Meteorology Laboratory (41°09'N, 96°30'W, 354m above m.s.l.) located 50 km northeast of Lincoln, Nebraska, USA. The site is in a rural region, located in relatively flat terrain (0-2% slope). The soil in the study area is a Typic Argiudoll (Sharpsburg silty, clay loam), deep, well drained soil (Garay, 1981). Field preparation included fall plowing, and disking in the spring.

Grain sorghum (*Sorghum bicolor* L. Moench cv. DK-57) was planted May 22, 1990 and May 15, 1991 in a 5 ha field (aproximately 250 x 200m) under conditions of natural rainfall with a row spacing of 0.75 m in north-south oriented rows and a population density of 250,000 plants ha^{-1}. Two areas inside the main field were subdivided for use in irrigation treatments. In 1990, an area (18 x 48 m) in the northeastern part of the field was subdivided in 24 plots of 6 x 6 m. In 1991, an area (36 x 96 m) was subdivided in 24 plots of 12 x 12 m in the north central portion of the field. Agronomic practices and pest management were conducted at near optimum levels to provide a well-developed crop canopy depending only on the soil water regime.

Growth stages were determined using two well known classifications. For identifying characteristics and approximate time intervals between growth stages of sorghum the Vanderlip (1972) classification was used. In this procedure, the crop was checked regularly and rated according to the ten stages of development, zero to nine. The water balance model employs growing degree days (GDD) to estimate this classification, and in turn GDD determines the value of the crop coefficient.

The other classification (Eastin, 1972) was used to schedule irrigation application based on the three stages of sorghum development: **GS1**, *vegetative*, planting to panicle initiation (PI); **GS2**, *inflorescence development*, PI to anthesis (bloom); **GS3**, *grain fill*, bloom to physiological maturity (kernel dark layer). The specific dates were those on which 50% of the sorghum was judged to be in that growth stage.

The experiment consisted of a randomized split factorial block irrigation design with 8 independent water treatments. The design consisted of 3 blocks and 3 developmental stages (GS1, GS2, and GS3). Experimental units were restricted to the interior of plots (3 x 3 m), with four rows (3 m each) inside each plot. The treatments included of all possible combinations of irrigation during the developmental stages and were labeled:

Treatment A: Noirrigation in any stage;

Treatment B: Irrigation only during GS2 stage;

Treatment C: Irrigation only during GS3 stage;

Treatment D: Irrigation only during GS1 stage;

Treatment E: Irrigation during the GS1 and GS2 stages;

Treatment F: Irrigation during the GS1 and GS3 stages;

Treatment G: Irrigation during the GS2 and GS3 stages;

Treatment H: Irrigation during all three stages.

All measurements and observations, such as phenological stage, soil water and irrigation amount were taken close to the center of each experimental unit.

In order to achieve independent water treatments, individual sprinkler controls were installed using 4 above ground impact sprinklers, one at each corner of the square plots. Each sprinkler covered a 1/4 circle. Overlap of sprinkler coverage allowed for a uniform water application for each plot treatment. Tests of water coverage were conducted before each growing season. Irrigation was usually conducted early in the morning or in the evening to avoid high winds. Irrigation applications were made when 50% of available water in the 0-90 cm layer was depleted, as measured at the center of the irrigated plots.

The soil water content measurements were taken using the neutron attenuation technique. A neutron access tube was installed in the center of each experimental unit, between rows. Soil water content measurements were taken weekly starting at 15 cm, down to the depth of 150 cm in increments of 30 cm. The neutron probe was calibrated in 1990 and 1991 during installation of access tubes at the beginning of each growing season.

An automated weather station was installed over grass at the north edge of the sorghum field under nonirrigated condition. This station measured solar radiation, air temperature, relative humidity, wind speed, and precipitation. Data were recorded on a Campbell CR10 datalogger with one minute samples and all measurements output on 60 minute intervals. These hourly data were summarized into daily values and they served as input to the combination equation to estimate potential evapotranspiration.

The soil water balance model (Hanks 1974; Hubbard & Hanks 1983) was modified so that the modeled root zones at any one time were represented by four layers of equal thickness. The model estimates root soil water extraction as follows: 40% of the transpired water from the top root layer, 30% from the second layer, 20% from the third layer, and the remaining 10% from the bottom layer. Root growth was estimated as a linear function of the time elapsed between the crop planting date and the maturity date, according to Robinson & Hubbard (1990). These root zones are overlaid onto the fixed-depth soil layers as appropriate to represent the total root depth.

The model uses the soil water balance equation to calculate the soil water storage (S) in the root zone from its value 24 hours before (S_o). Precipitation (P) and irrigation (I) are measured inputs to the model, while ET, runoff (R_o) and drainage below the root zone (D_r) are estimated by the model. The water balance equation with a daily time step is:

$$S = S_o + P + I - R_o - D_r - ET \qquad (1)$$

P and I were measured using rain gauges, while measurements of S were taken on selected days using the neutron probe. ET is the loss of water by evaporation (soil and crop surface) and transpiration via plant extraction from the root zone. Potential evapotranspiration (ET_p) was calculated using the Penman combination equation with the wind function determined by Kincaid & Heerman (1974).

The meteorological inputs for the equation were derived from hourly values of air temperature and humidity, global solar radiation, and wind speed obtained from the automated weather station over grass. Net radiation was estimated using the coefficients and equations of Kincaid & Heermann (1974) which employ global radiation, expected clear day global radiation, saturated vapor pressure at the mean dew point, and the maximum air temperature. The soil heat flux term was set to zero in this estimation of ET_p because it is not commonly measured in networks and its estimation in a previous study did not increase the accuracy of the ET_p estimate (Norman & Nielsen, 1983).

Actual evapotranspiration is calculated in this model as:

$$ET_a = T_a + E \qquad (2)$$

where E is the estimated surface evaporation and T_a is the estimated actual transpiration.

The evaporation term (E) is calculated as a function of the number of days (d) since the last wetting by either precipitation or irrigation:

$$E = Ep \,.\, \left(\frac{d_o}{d}\right)^{0.5} \qquad (3)$$

where the potential evaporation (E_p) for the day is taken as ET_p, unless ET_p exceeds 50% of the incoming solar radiation (Rs), in which case $E_p = 0.5\ Rs$ (Hanks, 1974). The variable d_o is taken as 1.0 and d is the number of days since the last wetting. The result is that evaporation decreases exponentially from the day of the last wetting. A shallow surface layer (0-5 cm) was incorporated in the soil water model to limit soil water involved in evaporation to that near the soil surface.

The actual transpiration is treated in the model as a function of the potential transpiration (T_p) from a crop with adequate soil water:

$$T_a = T_p \cdot F_s \qquad (4)$$

where T_p is the potential transpiration, $T_p = Kc\ (ETp-E)$; f_s is a soil water reduction factor that depends on the current soil water status (Campbell & Diaz, 1988), K_c is the basal crop coefficient adapted from the literature (Jensen, 1968; Hinkle et al., 1984; Robinson, 1989). These crop coefficients were specified according to the accumulation of GDDs and ranged from 0.0 at emergence to 1.1 at the beginning of the boot stage. In this study, growth stages were identified through direct observation using the Vanderlip (1972) classification, and were estimated by accumulating GDDs (base= 10°C and upper limit= 30°C).

The soil water reduction factor (f_s) allows the model to simulate transpiration when the crop is not well watered. In general, approximately 50% of the volumetric water content between field capacity and permanent wilting point can be extracted from the root zone before measurable growth reduction is observed in sorghum (Sweeten & Jordan, 1987). In the model, f_s depends on the current soil water status:

$$f_s = 1 \quad \text{if} \quad \frac{S}{AWp} \geq F \qquad (5)$$

$$f_s = \frac{S}{(F)(AWp)} \quad \text{if} \quad \frac{S}{AWp} < F \qquad (6)$$

The factor (f_s) is equal to one at high soil water storage (S) relative to the potential available water in the soil (AWp). The value F represents a critical ratio of available water to potential available water. When the ratio of S/AWp falls below F, calculated transpiration is reduced by ($1-f_s$). Values of F vary, depending on soil texture, but transpiration is not generally affected by soil moisture levels near field capacity. For the soil texture encountered in this study, a value of F=0.5 was used as suggested in Dyer & Baier (1979). Drainage due to gravity was calculated from an equation derived by Campbell (1985) for water movement between layers as a function of the actual soil water content and field capacity. Drainage below the root zone (D_r) was taken as the water moving out of the bottom layer. Runoff (R_o) was assumed to occur when daily values of P+I exceeded a fixed limit (R_{lim}). Previous use of the model at the Mead study site suggest a value of 38.1 mm (1.5 in) for R_{lim}.

Additional inputs into the soil water balance model include planting date, emergence date, the maximum crop height, the number of GDDs accumulated between time of emergence and time of maximum root depth (assumed to occur toward the middle to late stages of anthesis), the crop reflection coefficient or albedo (assumed to be 0.20 throughout the growing season), and the initial soil moisture content of each soil layer at the beginning of the growth stage. The majority of these inputs were supplied from field data. Information regarding field capacity, permanent wilting point, saturation, and fraction of silt, sand, and clay, were taken from pertinent literature (Garay, 1981).

The model estimated the soil water content of each specified soil layer on a daily basis, and were compared with to the measured soil water content. Model performance was examined for each layer and also for the entire root zone.

3. RESULTS AND DISCUSSION

Precipitation and irrigation amounts received during the three growth stages in 1990 and 1991 are shown in Table 1, for the eight different treatments. In 1990, a heavy rainfall occurred during early GS2, almost 150 mm fell during one day. Light amounts of rain were received during the last growth stage resulting in some water stress. In 1991, heavier amounts of rainfall occurred during the first growth stage, followed by light amounts during GS2 and GS3. Some water stress occurred during GS3.

The daily pattern of water use illustrates the dynamic nature of water use by the sorghum crop under varying levels of soil water content. Under well-irrigated conditions, such as treatment H, the calculated mean daily rate of ET during GS1 was 3.9 and 3.7 mm for 1990 and 1991, respectively; close to the values obtained for treatment A in both years, 3.6 mm. Presumably, the relatively high initial values of soil water content were responsible for the lack of distinction between treatments A and H early in the season. During GS2, treatment A had an average ET rate of 4.1 and 4.4 mm/day. Due to irrigation, treatment H showed higher average daily ET, 5.7 mm for both years. Mean daily values of ET were also different for GS3, 1.5 and 1.3 mm (treatment A) compared to 3.1 and 2.8 mm (treatment H) in 1990 and 1991, respectively.

The relationship between simulated and measured soil water in the root zone for the dryest (A) and wettest (H) treatments in 1990 and 1991 can be seen in Figure 1. The simulated values generally reproduce the trends seen in the observations. Upward trends indicate the response to precipitation and irrigation, and downward trends are an indication of actual ET during the different growth stages. The soil water content was slightly overestimated during the first part of GS1 (about 8%), with the agreement between predicted and observed values improving as the season progressed. A minor underestimation can be seen in the latter part of GS3, especially in the dry treatments (about 9%).

Historically the coefficient of determination (r^2) has been widely used as an index of agreement; however, the relationship between r^2 and performance of a model is not always instructive and it should not be used alone as an indication of model performance (Willmott et al., 1985). Thus, Willmott's (1981) d-index of agreement for assessing model performance was used here. The d-index is a more sensitive indicator of systematic model error than r^2, and reflects systematic model bias when coupled with the r^2 statistic (Willmott et al., 1985). Values fo the d-index range from 0, for complete disagreement, to 1 for perfect agreement between observed and predicted values.

Table 1. Total water received, in mm, (precipitation and irrigation) during the three growth stages, according to the differents treatments in 1990 and 1991

Treat.	Growth stages						Total	
	GS1		GS2		GS3			
	1990	1991	1990	1991	1990	1991	1990	1991
A	127	243	175	71	22	35	324	349
B	125	243	245	145	22	35	392	423
C	126	243	177	71	123	138	426	452
D	145	262	176	71	22	35	343	368
E	145	258	251	149	22	35	418	442
F	146	259	178	71	118	145	442	475
G	126	243	244	142	109	142	479	527
H	148	262	241	152	112	143	501	557

Other measures of model performance are the systematic (E_s) and unsystematic (E_u) components of the root mean square error (RMSE) and the mean absolute error (MAE), a measure of the average magnitude of the differences between the predicted and actual values which is considered to be less sensitive to extreme values than is RMSE (Fox, 1981). Statistics on model performance by treatment reveal a close agreement between predicted and observed values (Table 2). Predicted and observed values had small absolute and relative dispersion, as evidenced by respective values of their variance. The overestimation and underestimation of soil water content was not a serious systematic problem (E_s < mm all cases). In 1990, the systematic component of error (E_s) was small relative to the random component of error (E_u) and the coefficient of determination (r^2) was a little smaller than the d-index of agreement (Willmott, 1981).

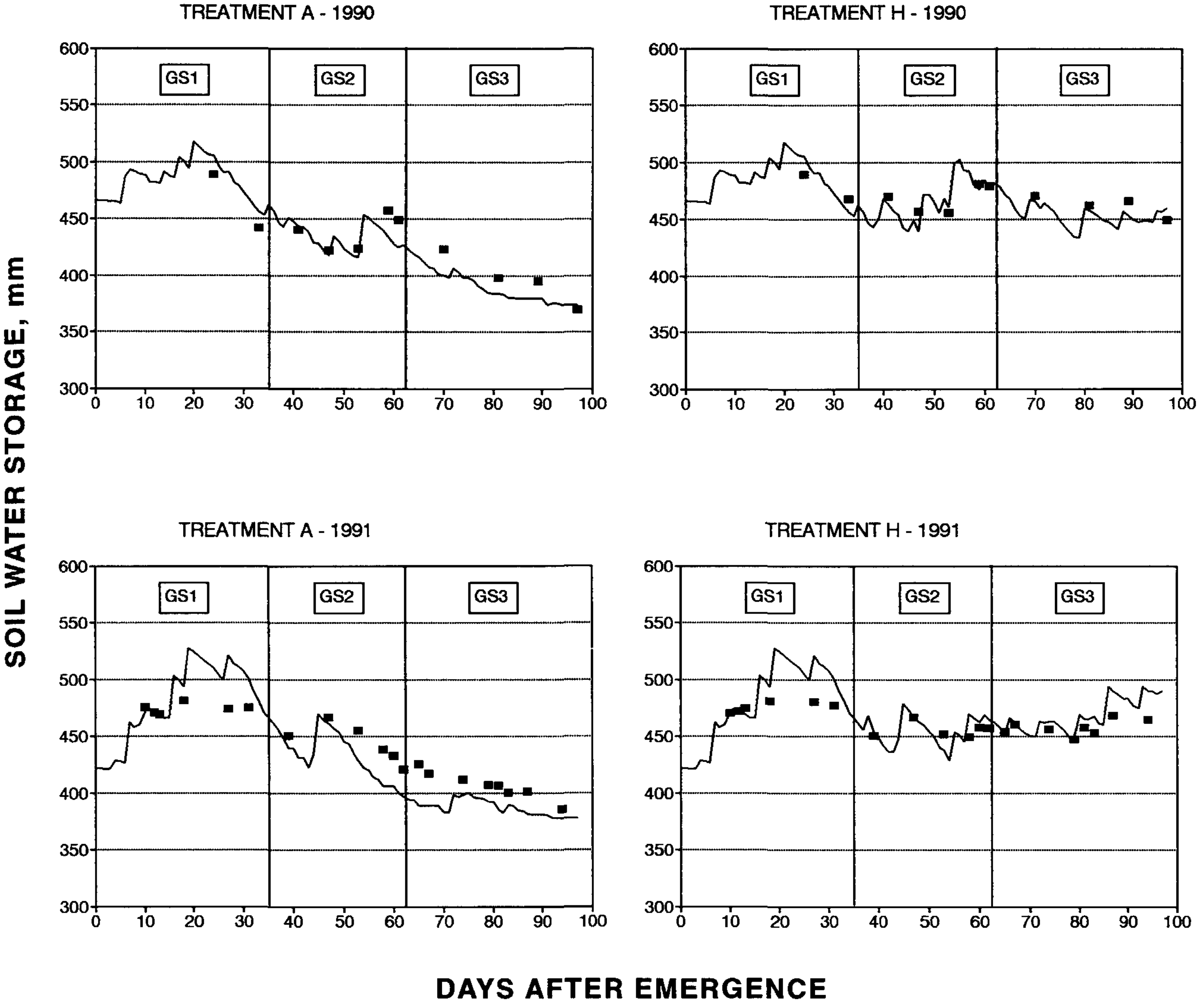

Figure 1. Simulated and observed total soil water in the root zone (150 cm) for a sorghum crop (treatments A and H) at Mead, NE, for the 1990 and growing season.

All treatments showed d-index values larger than 0.78, and the mean absolute error (MAE) was small (MAE < 19 mm) for all treatments. Analysis of treatment H during 1990 and 1991 resulted in small r^2 values (0.68 and 0.64) because neither the predicted nor the measured water content of the soil changed appreciably. This is consistent with the small variance for observed values (σ_o^2 =11.3 and 10.7 mm^2, respectively), and for predicted values (σ_p^2 = 16.5 and 18.7 mm^2, respectively). Although the r^2 values were relatively small, the d-index values (0.86 and 0.78) indicate good agreement between observed and predicted soil water content. There is a slight tendency for the model to overestimate the soil water at high values, especially in 1991. In spite of this problem, r^2 values were larger than 0.83 for both years.

Model performance statistics for each of the five 30 cm soil layers under the dryest (A) and wettest (H) treatments are shown in Table 3. The soil water content was slightly underestimated in the upper layers of soil and overestimated in the lower soil layers. The closest agreement between simulated and observed values occurred for the middle soil layers. The soil water content from the surface to a depth of 30 cm exhibited the most fluctuation of the 5 layers, especially for treatment A. Except for this layer, there was no significant recharge of soil water during the season. The 30-60 and 60-90 cm layers showed only a modest recharge near the end of GS2. The average difference between predicted and observed values is greater for the 0-30 and 120-150 cm layers than for the 3 other layers, as evidenced by the relatively large MAE of the modeled soil water values.

Table 2. Statistics on soil water balance model performance, by treatments, during 1990 and 1991

Year Treat.	d	r^2	MAE	σ_p^2	σ_o^2	E_s	E_u	RMSE
			mm	mm^2		mm		
1990								
A	0.95	0.86	13.7	36.7	31.4	7.1	13.9	15.6
B	0.96	0.92	9.2	32.7	25.2	7.6	9.2	11.9
C	0.80	0.46	14.8	23.6	19.1	7.5	17.4	18.9
D	0.94	0.85	14.5	37.7	29.9	6.0	14.6	15.8
E	0.94	0.88	12.1	32.1	25.5	8.9	11.4	14.4
F	0.78	0.58	15.2	22.6	13.2	7.8	14.6	16.5
G	0.94	0.81	6.4	18.4	16.1	1.8	8.0	8.2
H	0.86	0.68	8.4	16.5	11.3	3.5	9.3	9.9
1991								
A	0.90	0.87	18.9	43.9	27.7	16.3	15.8	22.8
B	0.92	0.86	10.7	33.5	23.9	9.7	12.6	15.9
C	0.92	0.88	11.5	36.6	24.4	11.0	12.8	16.9
D	0.96	0.93	12.7	46.2	35.8	9.7	12.0	15.4
E	0.89	0.89	11.6	28.8	18.8	12.9	9.4	16.0
F	0.92	0.84	12.4	33.7	22.8	8.2	13.4	15.7
G	0.86	0.84	12.3	23.7	16.0	12.0	9.6	15.3
H	0.78	0.64	9.5	18.7	10.7	8.0	11.2	13.8

d: Willmott index of agreement. r^2: Coefficient of. determination. MAE: Mean absolute error. σ_p^2 and σ_o^2: Variance for the predicted and observed data. Es and E_u: Systematic and Unsystematic error. RMSE: Root mean square error.

The underestimation in the 0-30 cm layer and overestimation in 120-150 cm layer represent relatively large systematic errors (Es > 6 mm). This is an area of the model that has potential for improvement as this error has not yet been minimized. Although the extraction percentages (40, 30, 20, 10) for the root layers were not adjusted in this study, different values might have led to closer agreement.

Sources of error contributing to the differences in estimated and observed soil water content are not difficult to identify since the model contains parameters whose values are calculated from empirical relationships. Although soil water estimates were in good agreement with observations, these results should be tempered against the limitations. There are some areas of the model that can be improved:

Table 3. Statistics on soil water balance model performance, by layer. Data is for five 30 cm layers for the treatments A and H during 1990 and 1991

Layer	d	r^2	MAE	σ_p^2	σ_o^2	Es	Eu	RMSE
cm			mm	mm^2		mm		
A-1990								
0-30	0.82	0.91	8.6	11.0	9.3	8.7	3.2	9.3
30-60	0.78	0.80	8.4	7.1	9.6	8.2	3.2	8.8
60-90	0.85	0.90	7.2	10.1	8.3	6.8	3.1	7.5
90-120	0.95	0.96	3.1	7.9	7.3	3.1	1.6	3.5
120-150	0.53	0.73	5.5	2.1	2.6	5.6	1.1	5.7
H-1990								
0-30	0.70	0.38	7.1	11.0	5.9	1.7	8.6	8.8
30-60	0.78	0.62	5.9	9.6	4.9	2.9	5.9	6.6
60-90	0.73	0.92	7.8	7.4	6.0	7.9	2.1	8.2
90-120	0.75	0.74	4.5	7.0	3.1	3.6	3.6	5.1
120-150	0.66	0.79	3.3	2.1	2.4	3.4	1.0	3.5
A-1991								
0-30	0.88	0.89	7.9	12.4	12.2	8.0	4.1	9.0
30-60	0.95	0.95	6.3	15.9	12.4	5.7	3.4	6.7
60-90	0.90	0.88	7.0	14.2	9.0	5.7	4.8	7.5
90-120	0.87	0.87	4.8	9.2	6.4	4.7	3.4	5.8
120-150	0.52	0.94	7.9	6.0	2.9	8.4	1.4	8.6
H-1991								
0-30	0.66	0.26	5.7	6.7	6.1	6.1	5.8	8.4
30-60	0.78	0.73	5.6	10.2	4.8	4.3	5.3	6.8
60-90	0.81	0.78	6.3	11.5	5.4	4.9	5.4	7.3
90-120	0.83	0.83	4.7	8.3	5.5	4.8	3.5	5.9
120-150	0.52	0.85	8.5	6.0	3.5	8.7	2.3	9.0

d: Willmott index of agreement. r^2: Coefficient of determination. MAE: Mean absolute error. σ_p^2 and σ_o^2: Variance for the predicted and observed data. E_s and E_u: Systematic and Unsystematic error. RMSE: Root mean square error

a) Tests have only been conducted in relatively flat terrain. Root growth and water extraction is considered in a very simplified form. For this model a homogenous soil was assumed in which the basic soil properties change only with water content. According to Hanks (1991), most soils go through very significant changes in soil properties with time upon wetting and drying, especially at the soil surface. This is a particular problem with infiltration and soil evaporation estimates. The evaporation estimate is independent of crop cover, and a more accurate estimate of evaporation could be developed and applied. Also, improvements in the soil water balance could result if more complex runoff and drainage models can be used.

b) An error in the empirically derived crop coefficients, a function of phenological growth stage, may lead to errors in estimating evapotranspiration. Another source of error may be the transpiration reduction factor for soil (fs) that is dependent on the value of F (0.5 used here). The value of F depends on the soil type and if F is chosen too low, it may lead to an overestimation of transpiration, and vice-versa (Robinson and Hubbard, 1990).

4. CONCLUSIONS

The simulated and observed soil water content data in the root zone showed small systematic and unsystematic errors. There is a slight tendency for the model to overestimate the soil water at high values. This could possibly be due to inaccuracy in the drainage term.

Reliable estimates of soil water content for sorghum crop can be found using this modified soil water balance model on a routine basis using crop phenology and soil information, and automated weather station data.

The results for a specific sorghum variety support the overall conclusion that the "soil water balance model" can be used as an effective tool in soil water monitoring. The simulated plant-soil-atmospheric results combined with known cropping patterns and soil data can provide valuable information and techniques for future research in the areas of soil water management, yield forecasting, and planning and management of agricultural resources.

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