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COMPARISON OF SOIL WATER RELATIONSHIPS OF COTTON SIMULATION MODELS IN THE TEXAS HIGH PLAINS

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Abstract

Crop models potentially allow producers to test alternative management practices for their fields more quickly than with field experiments. Model-based experimentation would be beneficial to allow producers to evaluate new practices such as site-specific management. Use of cotton simulation models has been limited in the High Plains region of Texas. In this study, three cotton simulation models, GOSSYM, COTONS, and Cotton2k were tested for their ability to predict evapotranspiration and soil water movement for a typical high plains growing environment. Differences exist in the models in the equations used for evapotranspiration prediction and in how weather information is used in the equations. Cotton2k performed better for predicting evapotranspiration and soil water content in the soil profile than the other two models.

Introduction

Agricultural water usage from the Ogallala Aquifer is a pressing need for the state of Texas as water levels in the aquifer continue to decline. Agriculture uses 95% of the water from the aquifer in this area (Martin et al., 2005). From observations of past farming practices affecting present crop growth patterns to large ranges of yields from yield monitors large amounts of variability have been observed in farm fields. Evidence of variability in plant water needs across fields comes from variation in soil properties that affect water holding capacity and studies showing variations in crop temperature across fields which indicates crop water stress. Despite the evidence of this variability farm fields have had inputs such as water and fertilizer applied uniformly for many years resulting in areas of over and under application of each input. The ability to manage this within field variability has only arisen with the convergence of global positioning systems, geographic information systems, and control technologies in recent years. Site-specific agriculture involves adjusting inputs at specific locations in fields rather than applying inputs uniformly across fields. Site-specific farming could potentially reduce application inefficiencies for farm inputs and improve farm profitability. Implementing irrigation site-specifically could allow Southern High Plains farmers to more efficiently use their irrigation water and/or improve farm profit.

Implementing site-specific agriculture increases the number of management decision that producers will have to make. Each management zone in a field could potentially receive different quantities and timings of inputs. In the case of irrigation, which requires management decisions throughout the growing season, the task of decision making could become quite daunting. One possible method of determining the effects of each strategy used in a field would be to conduct in-field tests from year to year. This method of decision making is slow and affected by yearly weather patterns, however. Use of crop models for producer decision making could be faster than field experiments and allow producers to deal with the larger number of decisions that will need to be made in a site-specific production environment. Models represent some degree of empiricism since model relations are developed from data sets that represent specific locations, management conditions, and plant genotypes. Only after being tested in other settings and scenarios can models be deemed suitable for these new settings and scenarios.

The overall goal for this project is to develop a set of tools so that individual producers could examine the potential for the use of site-specific irrigation on their farms. The objective for this part of the project was to select the best cotton simulation model from GOSSYM, COTONS, and Cotton2k for the examination of site-specific irrigation in the Texas High Plains. To meet this objective, the models will need to accurately predict the movement of water in the soil, through evapotranspiration, and the use of water by plants for producing lint yield.

Background

Crop growth models have been developed in many settings and for many applications. While the goal is a universally applicable model that will allow producers to make decisions for their sites, current models need to be tested when applied to new situations. Model evaluation has often been based on visual evaluation of agronomic information such as plant height, leaf area index, and fruiting development.

For modeling cotton growth, the most widely used model in the United States is GOSSYM (Baker et al., 1983). More recent model development has occurred in the COTONS (Jallas et al., 1999) and the Cotton2k models (Marani, 2004). Both of these models were derived from GOSSYM, but each has different modifications. All three models are dynamic, process-oriented simulation models of crop development and yield. GOSSYM and COTONS primarily use a daily time step for calculations, while Cotton2k computes and uses weather information on an hourly basis. Weather inputs used in the models are maximum and minimum temperature, rainfall, global radiation, and wind speed. Other inputs in the models include management practices such as irrigation, fertilizer, and chemical applications, and a soil profile description. New concepts in COTONS include simulation of plant populations and competition among plants rather than single plant simulations. Cotton2k is based on the CALGOS model which has been developed and tested in California growing conditions (Marani et al., 1992a, Marani et al., 1992b, Marani et al., 1992c).

Water Balance Methods

Movement of water through the soil – plant – air system will be important for analyzing variable rate irrigation. The effect of having less than a full soil moisture profile on plant growth will also be important. The amount of soil moisture in a soil profile can be modeled by the soil water balance. A general equation for describing the overall soil profile water balance (Martin et al., 1991) is:

$$D_e = D_b + R_e + I_n + U_f - ET - P_d$$

where

- D_e = depth of soil water at the end of the period
- D_b = depth of soil water at the beginning of the period
- R_e = rainfall during the period
- I_n = net irrigation during the period
- U_f = amount of upward flow of water from lower depths
- ET = combined evaporation from the soil and transpiration from plants
- P_d = deep percolation or drainage

GOSSYM, COTONS, and Cotton2k model the soil profile by dividing it into multiple cells both horizontally and vertically. In GOSSYM and COTONS the plants grow on the edges of the soil cells, while in Cotton2k the plants grow in the middle of it. Initial water movement following a rainfall or irrigation event is by gravity flow from layer to layer. In the following days, movement is based on differences in soil water pressure potentials between cells.

The relation between water content and soil pressure potential in GOSSYM and COTONS is modeled by the Marani soil-moisture-release equation. This equation is defined as:

$$\theta_i = \theta_{AD} + (\theta_{FC} - \theta_{AD})(h_{FC} / h_i)^{TEMP}$$

where

$$TEMP = \frac{Ln(-15 / h_{FC})}{Ln((\theta_r - \theta_{AD}) / (\theta_{FC} - \theta_{AD}))}$$

- θ_r = residual (15 bar) water content (cm^3 soil cm^{-3} H_20)
- θ_{FC} = water content at field capacity (cm^3 soil cm^{-3} H_20)
- θ_{AD} = air-dry water content (cm^3 soil cm^{-3} H_20)
- θ_i = current water content (cm^3 soil cm^{-3} H_20)
- h_i = current soil water potential (bar)
- h_{FC} = soil water potential at field capacity (bar)
- Ln = natural log

In Cotton2k, the soil moisture release curve is modeled with the Van Genuchten equation:

$$\frac{\theta - \theta_r}{\theta_s - \theta_r} = \frac{1}{\left[1 + (\alpha h)^n\right]^m}$$

where

- θ_r = residual water content (cm^3 soil cm^{-3} H_20)

θ_s = saturated water content (cm^3 soil cm^{-3} H_20)
α, m , and n are empirical constants that can be varied with specific soil properties

When irrigating in a semi-arid climate, it is assumed that evapotranspiration is much larger than other components in the equation therefore components such as upward flow and deep percolation are often considered negligible. Thus from a management stand point, the comparison between the water inputs of irrigation and rainfall and the water leaving the system in the form of evapotranspiration is important. The amount of evapotranspiration is also important because it is highly correlated with the overall yield.

The GOSSYM and COTONS models use equations from Ritchie (1972) for prediction of potential evapotranspiration. The Ritchie model partitions total evapotranspiration into two parts – a below canopy portion and an above canopy portion. The above canopy evaporation is calculated with,

$$E_o = \left[\frac{\Delta}{\gamma}R_{no} + 0.262*(1+0.0061*u)(e_o - e_a)\right](\frac{\Delta}{\gamma}+1)^{-1}$$

where
E_o = potential evaporation – canopy
Δ = slope of the saturation vapor pressure curve at mean air temperature
γ = constant of the wet and dry bulb psychrometric equation
R_{no} = net solar radiation above the canopy, mm/day
u = wind speed at height of 2 m
e_o = saturation vapor pressure at mean air temperature, millibars
e_a = mean vapor pressure of the atmosphere calculated from wet bulb and dewpoint temperatures as measured during a day, millibars

In these two models, the mean vapor pressure is calculated at the minimum daily temperature rather than the wet bulb or dewpoint temperatures. This difference can reduce the potential evapotranspiration rate predicted by the model as compared to the original Ritchie equation.

For constant rate soil evaporation, GOSSYM and COTONS use the following equation:

$$E_{so} = \left[\frac{\Delta}{\Delta+\gamma}\right]((1-INT)-(1-INT)*\lambda_s)*RS$$

where
Δ = slope of the saturation vapor pressure curve at mean air temperature
γ = constant of the wet and dry bulb psychrometric equation
INT = Fraction of light intercepted by plant leaves
λ_s = soil albedo; the fraction of incident radiation reflected by the soil
RS = solar radiation

The above equation for constant rate soil evaporation differs from the original equation used by Ritchie (1972):

$$E_{so} = \left[\frac{\Delta}{\Delta+\gamma}\right]R_{no}\exp -0.398L_{ai}$$

where
Δ = slope of the saturation vapor pressure curve at mean air temperature
γ = constant of the wet and dry bulb psychrometric equation
R_{no} = net solar radiation above the canopy, mm/day
L_{ai} = leaf area index

For the falling rate portion of soil evaporation GOSSYM and COTONS, used the following equation from Ritchie (1972):

$$\sum E_{s2} = \alpha*(t^{1/2} - (t-1)^{1/2})$$

where
α = the slope of the curve plotting cumulative soil evaporation against the square root of time
t = time, days

Cotton2k uses a version of the Penman equation for plant evapotranspiration that is modified for hourly calculations:

$$E_o = \left(\frac{\Delta}{\Delta+\gamma}\right) * \left(\frac{R}{694.5*(1-0.000946*T)}\right) + \left[1-\left(\frac{\Delta}{\Delta+\lambda}\right)\right] * \left(e_s - e\right) * \mathrm{FU2}$$

where

- E_o = potential evaporation – canopy
- Δ = slope of the saturation vapor pressure curve at hourly air temperature
- γ = constant of the wet and dry bulb psychometric equation
- e_s = saturation vapor pressure at the hourly average air temperature
- e = vapor pressure in kilopascals
- FU2 = wind speed function
- FU2 = 0.125+0.0439(U2) for net radiation <0
- FU2 = 0.030+0.0576(U2) for net radiation >0
- U2 = wind speed at height of 2 m

Soil evaporation in Cotton2k is calculated with the following relationship:

ES = ES1HOUR[IHR] * RRACOL[K] + ES2HOUR[IHR]

where

- ES = potential evaporation from soil surface of a column, mm per hour.
- ES1HOUR[24] = part of hourly Penman evapotranspiration affected by net radiation, in mm per hour.
- ES2HOUR[24] = part of hourly Penman evapotranspiration affected by wind and vapor pressure deficit, in mm per hour
- RRACOL[K] = relative radiation reaching a given column

Since all three models use a form of a combination evapotranspiration equation, the results of the calculations should be similar. The total potential evapotranspiration is removed from the soil cells with roots capable of moisture uptake. As soil water in each cell is reduced, the soil water potential in the cell is adjusted based on the new soil moisture.

The soil water balance method changes from GOSSYM to Cotton2k, give Cotton2k potential advantages in prediction for the High Plains environment. The temperature inputs to the evapotranspiration equations in GOSSYM and COTONS use the daily minimum temperature rather than dewpoint temperature, which will cause under-prediction of evapotranspiration. Cotton2k accounts for dewpoint temperature by predicting it from other inputs on an hourly basis. The change in plant location from the center to the edge of the soil column in Cotton2k is better for the High Plains because it

Model Validation

The GOSSYM model was originally developed in a humid Mississippi climate. Overall model performance was confirmed by qualitatively comparing time series of plant height, number of squares, and number of bolls with measured data. Tests of the agronomic components of the model have been made for the semi-arid Arizona climate (Fye et al., 1984). For the model to work in this region, coefficients in the model for a number of equations were adjusted. The model was then run for Mississippi conditions and one by one the adjustments removed. After these adjustments the following differences still existed in the model equations between the two sites: the effect of water stress on canopy photosynthesis, potential root growth rate, growth rate of plant height, and growth rate of the leaves. Other tests of this model for semi-arid regions including the Texas High Plains have been made with differing results. Wanjura (1989) used the model for nitrogen level study in this region. Relationships adjusted in this calibration were: “temperature-node equations that determine the time interval for initiating main stem nodes, squares, and bolls”, minimum leaf water potential, average night time temperature, and lint yield composition. Staggenborg et al. (1996) found that the model under-predicted evaporation in this region and recommended that it be modified to utilize weather information on humidity.

Tests of CALGOS, an earlier version of Cotton2k, were made with field data from the San Joaquin Valley of California (Marani et al., 1992a, 1992b, 1992c). Qualitative assessment was made of the following model components: distribution of water in the root zone, midday leaf water potential, LAI, and green boll weight. These tests indicate improvement in model performance over the previous equations, but potential need for work on water stress effects on boll shedding.

Evaluation of the model components modified from GOSSYM to COTONS was made by Jallas (1998). The modified light interception component was compared to the original GOSSYM light interception equation on a relative basis for data sets in Mississippi. Qualitative evaluation of the results showed that light interception calculated with the two equations was similar. Evaluation of other model changes were made by examining the variability in yield, number of nodes, and number of bolls with each modified component (emergence, node appearance, and abscission) turned on separately and seeing if it seemed reasonable.

Methodology

Site Description and Field Experiments

Data available for model evaluation were from a site at the Texas Agricultural Experiment Station at Halfway, Texas. The experiment at Helms farm at the Halfway site was conducted on a 4.86 ha section of a field in a corn-cotton rotation. The soil survey map unit for this site was a Pullman sandy clay loam. Soil textures for individual points for the field were obtained by Robert Lascano (2004, personal communication) and provided for use in this study.

The Helms data set was from a field-scale variable rate irrigation study with the goal to "level lint yields by reducing irrigation in areas of high SWHC (soil water holding capacity) and adding water to areas of low SWHC (soil water holding capacity)" (Bordovsky and Lascano, 2003). Fields were irrigated with a LEPA center pivot system with its center point at 34° 9'6"N 101°56'52"W. The experiment area covered three pivot spans, each with three manifolds capable of being controlled separately. In the 2001 growing season, manifolds were used with variable rate and uniform rate water application strategies. For this season, three management zones for the variable rate applications were determined from soil texture and slope (Bordovsky and Lascano, 2003). Water application rates of 75%, 100%, and 125% of the uniform rate (UR) were applied to the management zones. The water application rate for the UR areas was 80% of potential evapotranspiration (PET). Figure 1 shows the areas where each water rate was applied. This map shows that strips of variable rate and uniform rate irrigations were alternated across the center pivot manifolds at the site. Further description of the experiments at the site in 2001 can be found in Bordovsky and Lascano (2003). Management information for the site is summarized in table 1. Weather data for the simulations were obtained from a weather station at the Halfway Experiment Station (South Plains Evapotranspiration Network, 2004). During the 2001 growing season, the maximum daily temperature was 1.1° C above normal and the rainfall was 13.1 cm below normal. This weather station was located 3.22 km from the research field therefore there is the potential for discrepancies between the quantity of rain in the weather data and the quantity that actually fell at the site. Both plant and soil data were obtained as a part of this experiment by Robert Lascano (personal communication, 2004). Measured data on soil water content by depth was obtained from bi-weekly sampling with neutron probes. Plant parameters collected as a part of this experiment included plant height, leaf area index, and square and boll mapping.

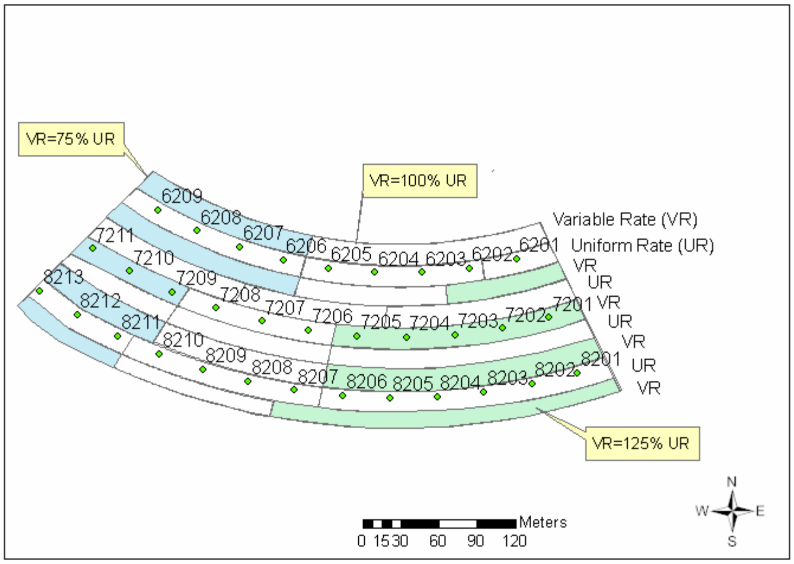

Figure 1. Soil sampling points and control management zones in 2001 for field 5D at Helms Farm site

Table 1. Experiment management parameters for Helms Farm study.

	2001
Plant date	May 15
Harvest date	Oct. 18
Row spacing	76.2 cm
Plants per meter	10.8
Irrigation date range	May 26 – Aug. 30
Fertilizer quantity	143.4 kg N /ha

Input File Creation

Each crop simulation model tested consisted of an executable program that read in text files for input then executed to simulate output on crop growth and yield parameters. Inputs are organized into files for soils, management, weather, and initial conditions. Soil inputs for all three were organized by soil layers. The soil hydrology inputs for the three models are shown in table 2. Inputs that were the same for all three models were percent sand, percent clay, saturated water content and residual water content. The differences in required soil inputs were due to different soil moisture retention curve equations used by the three models.

Table 2. Model soil input variables.

GOSSYM and COTONS	Cotton2k
Percent sand	Percent sand
Percent clay	Percent clay
Bulk density	Bulk density
Hydraulic conductance	Hydraulic conductivity at saturation
	Hydraulic conductivity at field capacity
Diffusivity at -15,000 cm potential	
Saturated volumetric water content	Saturated volumetric water content
Volumetric water content at field capacity	
Volumetric water content at -15,000 cm potential	
Residual volumetric water content	
Volumetric water content at air dry	Volumetric water content at air dry
	Alpha coefficient for the Van Genuchten equation

	Beta coefficient for the Van Genuchten equation

Management parameters for all three models include timing and quantity of fertilization, and timing and quantity of irrigation events. The GOSSYM and COTONS inputs differed from Cotton2k inputs because GOSSYM fertilizer quantities were entered as total quantity of fertilizer applied, while Cotton2k used entries for the quantity of each specific form of nitrogen applied.

Weather inputs for the three models included daily solar radiation, daily maximum and minimum temperature, daily precipitation, and daily wind run. In Cotton2k, the daily weather inputs are converted to hourly values for its hourly calculations. A fifth text file, the profile file, contains the names of each of the other input files required for simulation was used by each model. Simulation start and stop dates were entered in the profile file.

Points were selected for analysis at the Helms farm site so that all three irrigation treatments were analyzed and to account for as much of the field soil variability as possible. Points 7202 and 8202 were from the east side of the field and points 7210 and 8210 from the west portion of the field.

Soils files were created based on soil texture information that was sampled to 80 cm depths in 20 cm increments (Robert Lascano 2004, personal communication). From 80 to 201 cm, the soil texture used was from the Pullman sandy clay loam based on the soil survey map unit (USDA-SCS, 1974). A summary of the soil textures from top 20 cm for the points used for evaluating the three models appears in table 3. The sampled soil textures were used with tabular lookups and calculations based on the soil water retention relationships in the model to create the remaining soil inputs. The source of each soil input for the GOSSYM and COTONS models is shown in table 4 and for Cotton2k in table 5. Soil inputs varied for the three models due to different equations and soil water potentials used to describe the soil moisture release curve. Values for van Genuchten equation parameters for the Cotton2k soil inputs were obtained for each sampling point based on tables from van Genuchten et al. (1991). The remaining Cotton2k inputs of saturated water content, hydraulic conductivity, and bulk density were obtained from the Soil Water Characteristic program that was based on Saxton et al. (1986). Soil moisture retention curve parameters for GOSSYM and COTONS were calculated from the van Genuchten equation at the soil water potentials used in GOSSYM and COTONS for field capacity and wilting point. The soil water potential used for wilting point was -15,000 cm. and for field capacity it was – 300 cm.

Table 3. Helms farm experiment soil textures.

LOCATION	Depth (cm)	% Sand	% Clay	Texture
7202	20	51	34	Sandy Clay Loam
7210	20	37	41	Clay
8202	20	55	31	Sandy Clay Loam
8210	20	27	47	Clay

Table 4. GOSSYM model soil input sources for Helms farm simulations.

Input	Source
Percent sand	Soil sampling
Percent clay	Soil sampling
Bulk density	Soil Water Characteristic program, Saxton et al. (1986)
Diffusivity at -15,000 cm potential	Calculated from Gardner-Mayhugh equations using soil water retention curve points generated with Saxton calculator
Volumetric water content at -15,000 cm potential	Calculated from Van Genuchten equation at -15000 cm
Hydraulic conductance	Calculated from Gardner-Mayhugh equations using soil water retention curve points generated with Saxton calculator
Saturated volumetric water content	From table 3 in van Genuchten et al. (1991) by soil texture
Volumetric water content at field capacity	Calculated from Van Genuchten equation

Residual volumetric water content	From table 3 in van Genuchten et al. (1991) by soil texture
Volumetric water content at air dry	Calculated from Van Genuchten equation

Table 5. Cotton2k model soil input sources for Helms farm simulations.

Input	Source
Percent sand	Soil sampling
Percent clay	Soil sampling
Bulk density	Saxton calculator
Volumetric water content at air dry	Calculated from Van Genuchten equation
Saturated volumetric water content	From table 3 in van Genuchten et al. (1991) by soil texture
Alpha coefficient for the Van Genuchten equation	From table 3 in van Genuchten et al. (1991) by soil texture
Beta coefficient for the Van Genuchten equation	From table 3 in van Genuchten et al. (1991) by soil texture
Hydraulic conductivity at saturation	From table 3 in van Genuchten et al. (1991) by soil texture
Hydraulic conductivity at field capacity	Soil Water Characteristic program, Saxton et al. (1986)

Initial model soil moisture conditions were manually selected based on average water content profiles from the Helms Farm site. The initial soil water content is entered as a percent of field capacity for all three models. Soil water content data for the first sampling date from ten points in both 2001 and 2003 were averaged together (figure 2). Percent field capacity in the initial condition files was selected to match average water contents from a combination of the two years soil water content profiles. Other initial soil inputs for residual nitrate, ammonia and organic matter were kept as in the sample initial file that came with GOSSYM.

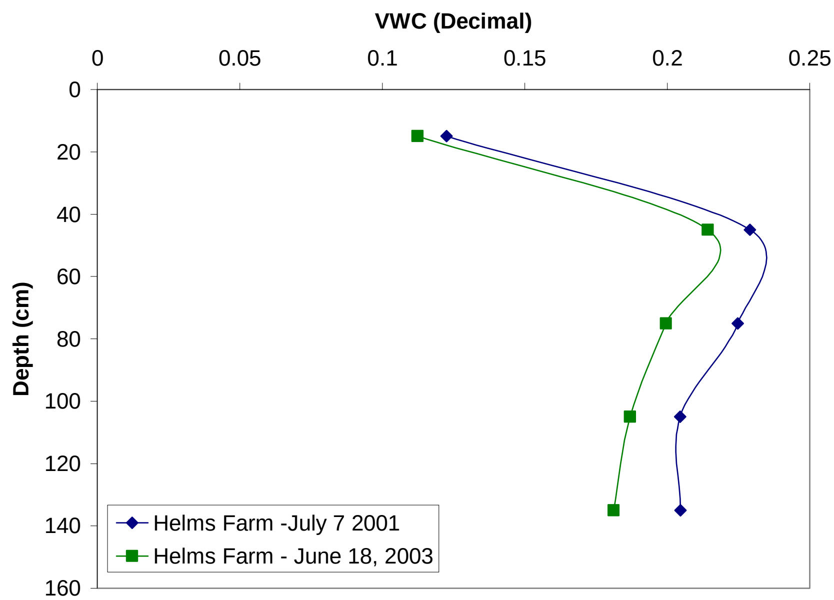

Figure 2. Volumetric water content for Helms Farm site on July 7, 2001 and June 18, 2003 – averaged across ten sampling points.

<u>Evaluation Tests</u>

The models were compared for their ability to track water movement and use in the soil -plant –atmosphere continuum on a point by point basis. Model predictions were compared against measured values of cumulative evapotranspiration (ET), soil water content by depth in the soil profile, and yield by applied water quantity. Model predictions were made for individual sampling points within the field. Seasonal cumulative ET allowed for assessment of the model's tracking of long term plant water use. Data from the Helms farm site was used with this assessment. ET from the field experiments was not measured directly but was determined from a soil water balance using the neutron probe data. In the determination of the soil water balance, it was assumed that no soil water drained through the bottom of the soil profile. The soil water balance tracking was begun on the first day of soil moisture measurement. Initial soil moisture values were from averages of soil moisture from the three models on this date. Soil water content by depth provides more detail about the location of water in the soil as compared to the total quantity of water leaving through evapotranspiration. Model predictions of soil water content at the measured depths were determined from soil water profile map model output.

Model evaluations were made both qualitatively and quantitatively with graphs and summary statistics. Root Mean Square Error (RMSE) was used for the quantitative evaluation of the soil water parameters examined. RMSE is defined as:

$$\mathrm{RMSE} = \left[\frac{1}{n} \sum_{i=1} (y_i - \hat{y}_i)^2 \right]^{1/2}$$

where

y_i = measured values,
$\hat{y}_i$ = predicted values
n = the number of values compared.

Results and Analysis

Points 7202, 7210, 8202, and 8210 were used for testing the three cotton models. Point 7202 was under the 75% UR management, point 7210 under 125% of UR management, and the remaining two points were under 100 % of UR management. Figures 3 through 6 show measured and predicted cumulative evapotranspiration for four points from the 2001 growing season. RMSE between measured and predicted cumulative ET for these four points are in table 6. Trends in the ordering of the model predictions are consistent on all four graphs. GOSSYM predicted the lowest cumulative ET, COTONS the middle cumulative ET, and Cotton2k the highest cumulative ET. Comparisons of the predicted ET curves to measured values vary between the four points. For points 7202, 8202, and 8210, the Cotton2k predicted curves matched the measured ET curves best. For point 7210, the predicted curve from COTONS matched the measured data best based on the graphical and RMSE criteria. For point 7210 the measured ET was 63 mm less than for any other point, however. This observation suggests that the soils are allowing drainage or different initial soil water conditions are needed for this point.

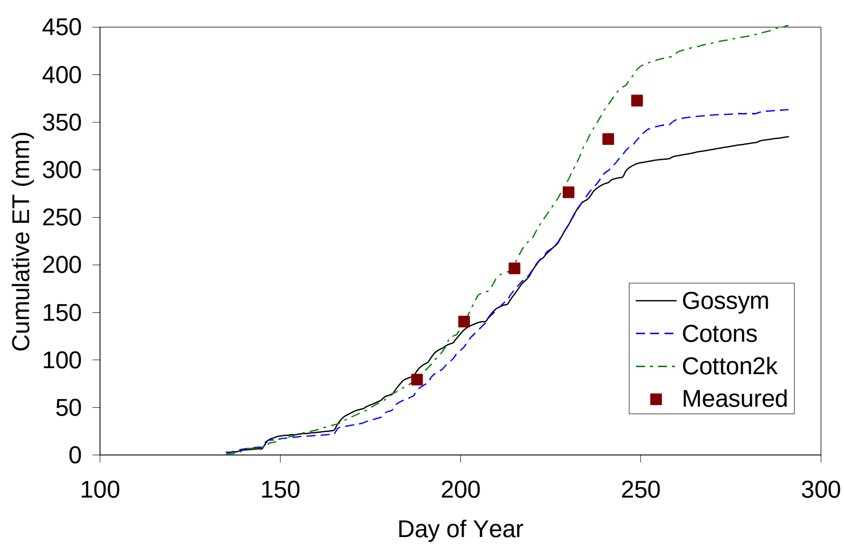

Figure 3. Measured and predicted cumulative ET in 2001 growing season at point 7202.

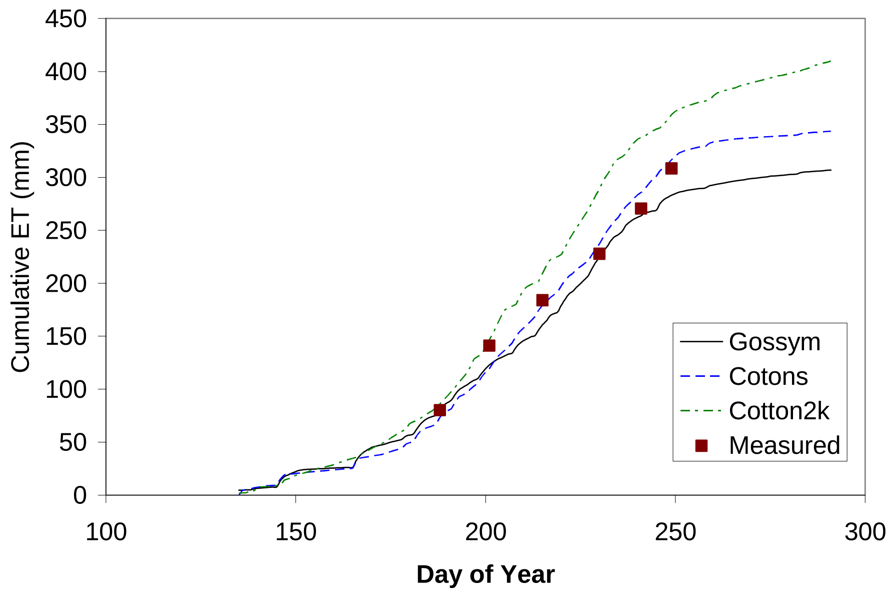

Figure 4. Measured and predicted cumulative ET in 2001 growing season at point 7210.

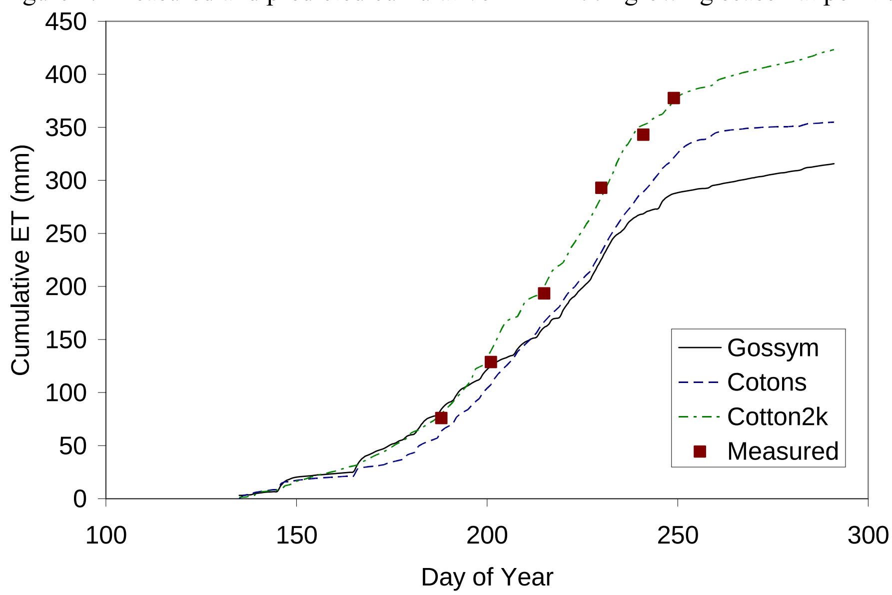

Figure 5. Measured and predicted cumulative ET in 2001 growing season at point 8202.

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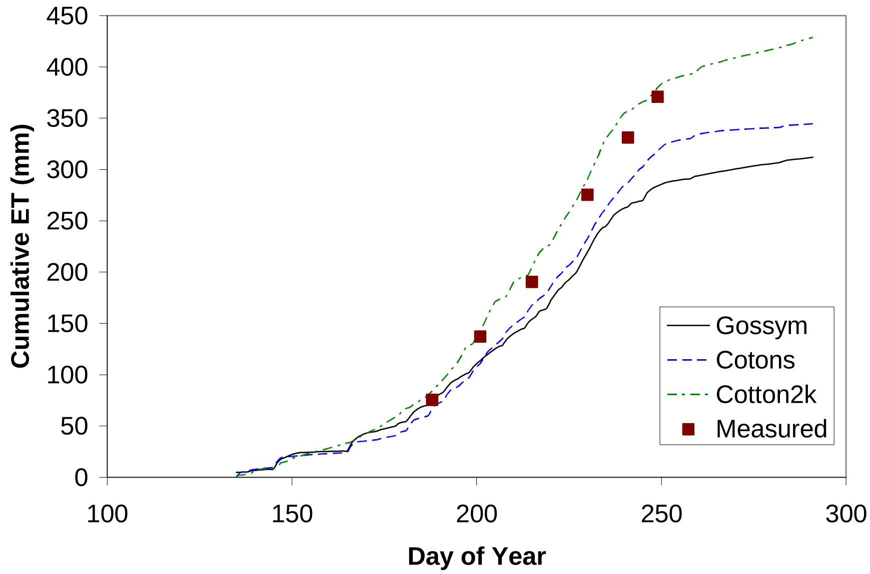


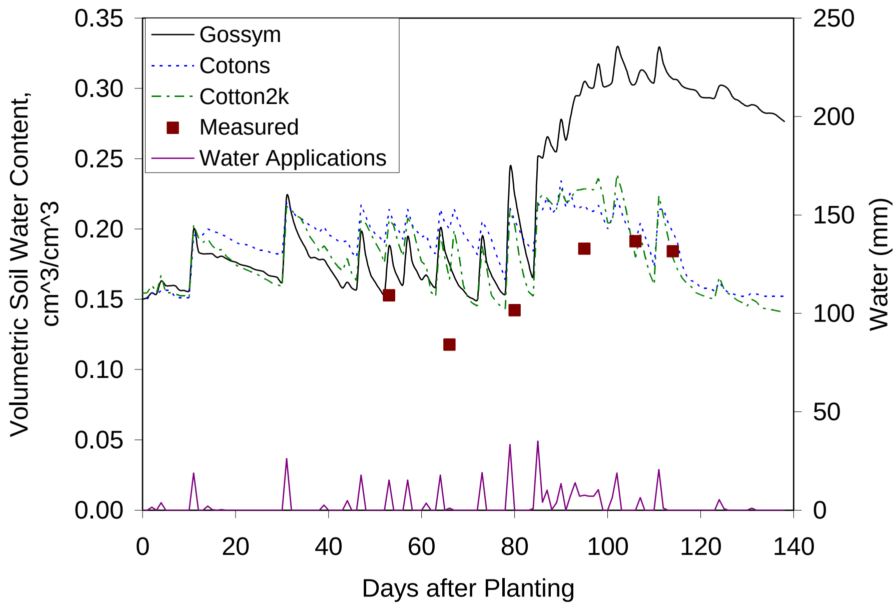
Figure 6. Measured and predicted cumulative ET in 2001 growing season at point 8210.

Table 6. RMSE between measured and predicted cumulative ET in 2001 season.

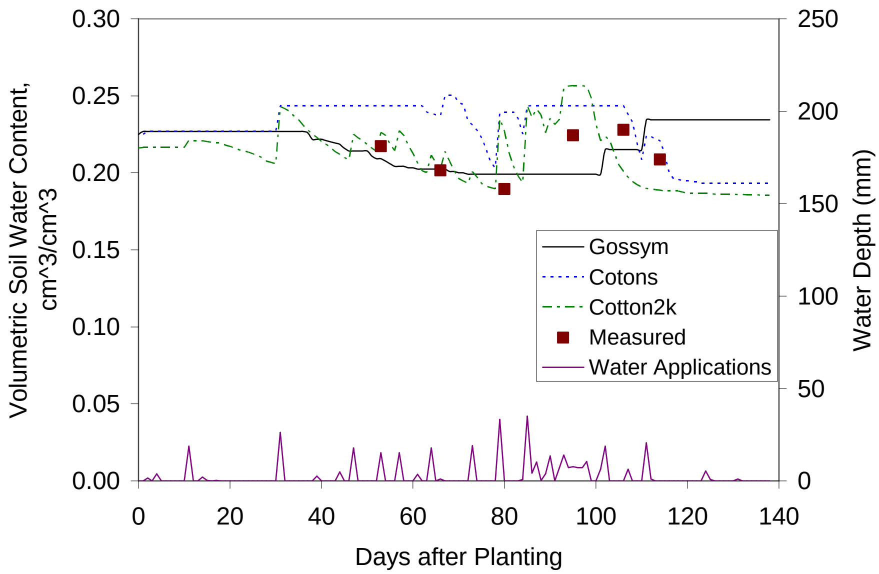
Point	GOSSYM	COTONS	Cotton2k
7202	41.05	32.22	22.86
7210	17.74	13.36	47.96
8202	62.03	46.67	8.03
8210	89.13	73.05	38.61

The evapotranspiration equations used between GOSSYM and COTONS are identical. The modified light interception component in COTONS would cause the differences in ET between GOSSYM and COTONS by increasing the COTONS prediction of light interception. Cotton2k on the other hand used similar equations as GOSSYM for the prediction of light interception, but predicted higher cumulative ET than GOSSYM. Cotton2k utilized an hourly form of the Penman equation rather than the Ritchie form, which is likely the cause if it's higher cumulative ET predictions.

Soil water contents by layer for points 7202 and 7210 are shown in figures 7 through 8. RMSE between measured and predicted values of soil water content appear in table 7. Differences in initial water contents between the three models occurred due to differences in breakpoints between categories in the soil water outputs for the three models. Model predictions were within +/-0.025 cm^3/cm^3 of water for the majority of the soil depths and measurement days.

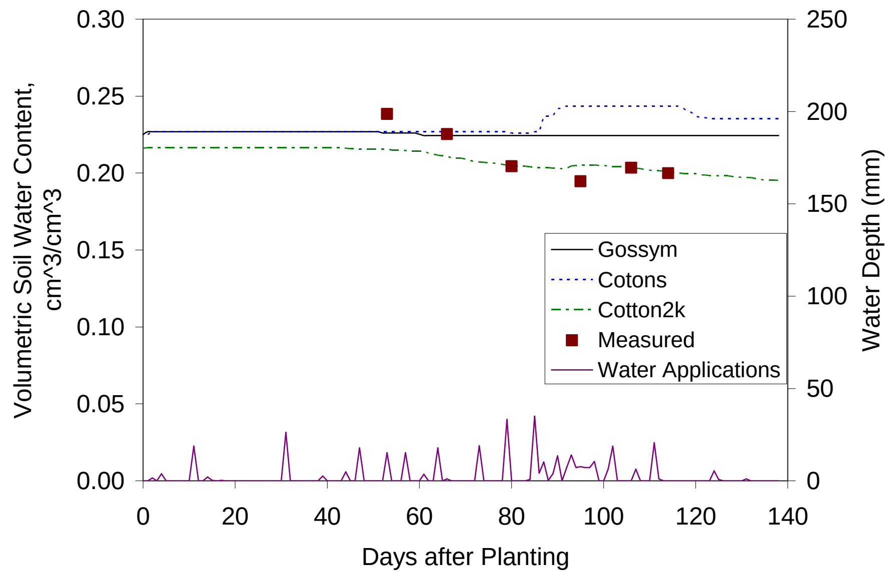


(a) 0-30 cm

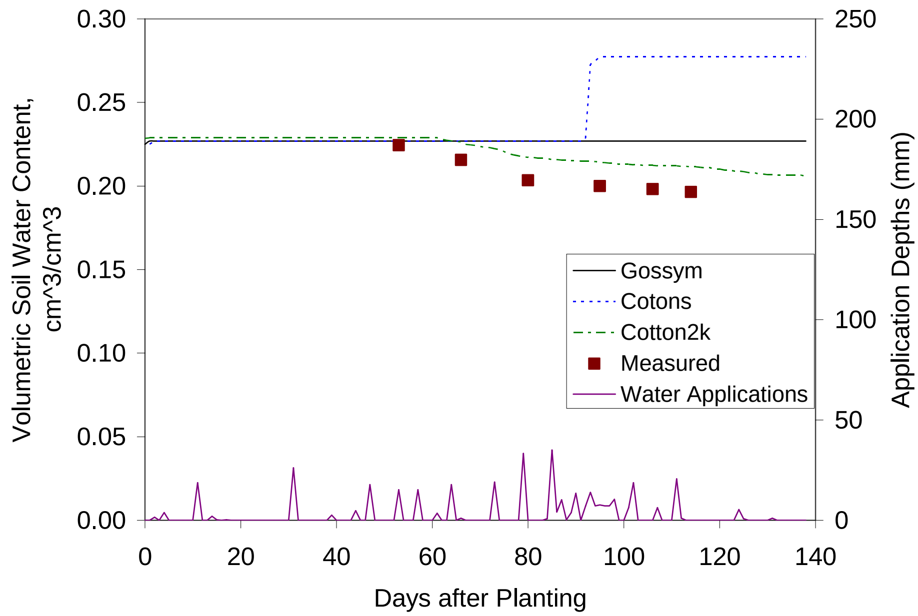


(b) 30-60 cm

Figure 7. Measured and predicted volumetric water content by depth for point 7202 in 2001 season. Layers shown are (a) 0-30 cm and (b) 30-60 cm.



(a) 60-90 cm



(b) 90-120 cm

Figure 8. Measured and predicted volumetric water content by depth for point 7202 in 2001 season. Layers shown are (a) 60-90 cm and (b) 90-120 cm.

Table 7. RMSE between measured and predicted volumetric soil water content by layer in 2001 season.

Point	GOSSYM	COTONS	Cotton2k
7202	0.0473	0.0452	0.0257
7210	0.0587	0.0622	0.0589
8202	0.0589	0.0650	0.0314
8210	0.0704	0.0654	0.0393

GOSSYM and COTONS did not follow measured data trends for several layers. For the 0-30 cm depth at point 7202, GOSSYM spiked up above the other models after day 80. COTONS also showed a spike above the predictions of the other two models for the 90-120 cm depth for this same sampling point. Cotton2k followed decreasing trends in soil water content for this point for depths below 60 cm. Cotton2k had better RMSE's between measured and predicted values for three of the four points examined.

GOSSYM predicted cumulative ET an average of 19.4% less than measured cumulative ET for the points examined. The lower ET predictions of GOSSYM and COTONS are likely from the used of daily minimum temperature in the Ritchie ET equation rather than dewpoint temperature. COTONS ET predictions were closer to measured values than GOSSYM predictions showing that the modified light interception component in it did improve model predictions. The improvements in ET predictions with the COTONS light interception equations were not as great as the improvements in Cotton2k with the use of dewpoint temperatures in the evapotranspiration equations and the use of the hourly evapotranspiration equation. The large difference in yield predictions at different water application levels between COTONS and GOSSYM and Cotton2k indicates that the modifications to water stress effects in Cotton2k makes it better for yield predictions in a semi-arid environment.

Conclusions

GOSSYM, COTONS, and Cotton2k were tested for their ability to track water as it moved through the soil and predict yield. Tests were conducted with data sets at multiple water levels from the High Plains region. From these tests, Cotton2k is the most suitable choice for simulating the effects of site-specific irrigation on cotton for the Texas High Plains. These results illustrate the need for evapotranspiration prediction in semi-arid regions to use dewpoint temperature rather than some other temperature, such as daily minimum temperature.

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