African Journal of Agricultural Research Vol. 5(8), pp. 606-613, 18 April, 2010
Available online at http://www.academicjournals.org/AJAR
ISSN 1991-637X © 2010 Academic Journals

Full Length Research Paper

Evaluation of CERES-maize simulation model results with measured data using water pillow irrigation under semi-arid climatic conditions

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Accepted 15 March, 2010

The computer-based CERES-maize model for simulating maize growth and development was used to simulate maize yield in a semi-arid region of Harran Plain of Southeastern Turkey in 2005 and 2006. Irrigation water was applied with the water pillow (WP) method at three rates: full ($WP_{1.0}$); and two deficit irrigation treatments, $WP_{0.75}$ and $WP_{0.50}$, which were 75 and 50% of $WP_{1.0}$, respectively. Measured yields values ranged from 5600 to 9450 kg ha^{-1} and 5040 to 8565 kg ha^{-1} in 2005 and 2006, respectively, whereas measured biomass values for the same years varied from 11020 to 17965 kg ha^{-1} and 10985 to 17025 kg ha^{-1}. Statistical analysis of the measured yield and biomass values indicated that there was a significant difference between irrigation treatments for both years ($P < 0.05$). Simulated results for 2005 and 2006 varied from 5072 to 8991 kg ha^{-1} and from 4924 to 8168 kg ha^{-1}, while biomass values for the same years ranged from 10098 and 16906 kg ha^{-1} and from 10105 to 15985 kg ha^{-1}. For all treatments, yield and biomass were adequately simulated by the model: differences between simulated and measured values were less than 6%. Comparison of the model data with the measured values showed that there was a satisfactory agreement between the measured and simulated values and the model performed well for both, yield and biomass. Overall, it could be suggested that full irrigation is required for optimum yield and biomass and CERES-maize model satisfactorily simulated maize yields and biomass in semi-arid conditions.

Key words: CERES-maize model, water pillow, maize, water deficit.

INTRODUCTION

An agricultural water resource development project has potential impact on the economic, social and natural environments of the project region. The Southeastern Anatolia Project (GAP) is one of Turkey's biggest capital investment projects in the upper reaches of the Euphrates and Tigris rivers, which is an area known as the Fertile Crescent. This project will enable irrigation of 1.82 million hectares of agricultural lands. Cotton (*Gossypium spp.*) is the dominant crop (~ 90% coverage) in the Harran Plain, which is located in the middle of the project area with about 140 000 hectares area. Maize (*Zea mays*) is under consideration as an alternative crop, since it grows rapidly, has a high yield potential, and is a valuable food item in the form of cereals and snack foods (Otegui et al., 1995), and also subsidized by the government.

Of all the natural resources needed for economic and agricultural development, water is usually the most important, particularly in arid and semi-arid regions. The impact of irrigated agriculture on water resources is important and irrigation-related efficiency is vital. Researchers have been studying the design and development of effective irrigation methods and evaluating simulation models (Nouna et al., 2000; Dogan et al., 2006; Mercau et al., 2007). The water pillow (WP) is a novel irrigation method that combines drip irrigation and mulch techniques, and offers some solutions to current irrigation problems, which include low levels of irrigation efficiency, crop diseases, soil erosion and weed control

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Abbreviation: WP, Water pillow.

Figure 1. Maize irrigation with the water pillow (WP) method.

(Gerçek, 2006). Many studies have shown that both drip irrigation and mulch techniques increase yields (Srivastava et al., 1994; Tiwari et al., 1998; Tiwari et al., 2003). The WP irrigation method could be used to irrigate crops grown in rows, such as maize, cotton, soybean and pepper. The main elements of the WP method are portable, elastic and everlasting black plastic pipes, and laterals (Figure 1). The bottom of the plastic pipe is pierced with usually 1 mm holes and laid onto the soil surface with both ends closed. The diameter of the pipe should almost cover the row spacing; in this way, the water content in the root zone in the intervals between irrigation and the maximum mulching effect throughout the growing season can be sustained.

The design and inter-spacing of the holes depends on the soil infiltration capacity, and needs to be determined for each soil type. Lateral fed pipes are used to convey irrigation water to the plastic pipe. Before installing the pipes, land should be leveled to achieve more uniform water distribution in the soil. Then, the pipe is laid on the soil surface and both the ends are closed by tying with a rope. The pipes remain on the soil surface from sowing until harvest. Therefore, plastic pipes have performed a duty of mulch effect at the same time. For irrigation, one end of the pipe is opened and needed water is stored through the lateral pipe, and then pipe is closed again. In the WP method, there are two successively irrigation phases, filling and trickling. Filling is done only once and the phase can be quite short, depending on the rate of discharge. For example; a pipe 45 cm in diameter and 50 m in length is filled within 13.2 min with a 10 Ls^{-1} discharge. Otherwise, the trickling phase is quite lengthy and takes up 24 h. Unlike pressurized irrigation systems such as drip and sprinkler, the WP method requires no pumping. Once the plastic pipe is filled, irrigation water in the plastic pipe seeps out onto the soil surface under the action of gravity (Figure 1). Many studies proved that plastic mulch prevents evaporation from soil surface and conserves soil moisture so that soil water in root zone is used efficiently by crops (Srivastava et al., 1994; Herrera et al., 2002; Ramakrishna et al., 2006). The WP method saves energy and water therefore is claimed to be suitable for sustainable agriculture and is a more economical irrigation method than furrow which is a main way of irrigation in the region. Early studies have confirmed that the WP method can reduce water use, and increase yield (Y) and water use efficiency (WUE), in various crops, such as soybean (*edamame; Glycine max*; Gerçek et al., 2009a) and pepper (*Capsicum sp*.; Gerçek et al., 2009b). It was reported also that the WP method suppressed weed growth in soybean crops (Bükün et al., 2005) and decreased plant mortality for an eggplant crop (*aubergine; Solanum melongena*; Ürkmez, 2008).

Crop simulation models have been used for many different applications in various countries. The CERES-Maize model is part of the Decision Support System for Agrotechnology Transfer (DSSAT; Jones et al., 2003), which uses daily weather variables, crop parameters, soil parameters, and crop and soil management practices. The daily weather variables include solar radiation, maximum and minimum air temperature, and rainfall. The model simulates the vegetative and reproductive development of maize.

The CERES-maize model has proved satisfactory for use with various crops under a wide range of climatic conditions and soil types (Gencoglan, 1996; Garrison et al., 1999; Paz et al., 1999; Alagarswamy et al., 2000; Fraisse et al., 2001; Mavromatis et al., 2001; Thorp et al.,

Table 1. Chemical and physical characteristics of the soil in the study site.

Soil depth (cm)	Particle size distribution			Texture class	SHC (cm h^{-1})	pH	$CaCO_3$ (%)	EC (dS m^{-1})	*OM* (%)	Water content (g g^{-1})		*BD* (g cm^{-3})
	Sand (%)	Silt (%)	Clay (%)							*FC*	*PWP*	
0–30	18	23	59	Clay	1.7	7.2	11.40	1.0	1.39	31.5	23.5	1.38
30–60	19	21	60	Clay	1.7	7.2	18.15	0.9	0.87	32.5	22.5	1.40
60–90	21	21	58	Clay	1.7	7.3	20.57	0.9	0.70	32.6	22.7	1.41

SHC, saturated hydraulic conductivity; EC, electrical conductivity of soil-saturated extract; FC, field capacity; BD, bulk density; OM, organic material; PWP, permanent wilting point.

Table 2. Chemical properties of irrigation water.

Source	EC (dS m^{-1})	pH	Cations (me l^{-1})			Anions (me l^{-1})			Class
			Na^+	K^+	Ca^{2+} + Mg^{2+}	HCO_3^{2-}	Cl^-	SO_4^{2-}	
Deep well	0.31	7.0	0.25	0.02	1.98	0.90	0.60	0.75	C_2S_1

2005; Dogan et al., 2006; Guerra et al., 2007). The model has been used successfully to simulate the effects of irrigation (Panda et al., 2004; Anapalli et al., 2005). Nouna et al. (2000) reported that the CERES-maize model simulation of fully irrigated plots agreed well with measured growth and yield stages. Under mild soil water shortage conditions, however, there were differences between observation and prediction, which increased with increased level of water stress. The objectives of this study were both to determine the effect of deficit irrigation on yield, biomass and water use efficiency of maize and to evaluate the CERES-maize model predicted results with WP irrigated maize measured data grown under semi-arid climatic conditions of Harran Plain.

MATERIALS AND METHODS

The study was done at the Research Farm of the Agriculture Faculty, University of Harran, Sanliurfa, Turkey (37° 08′ N, 38° 46′ E, and 464 m) during the months of July to October in 2005 and 2006. The soil at the experimental site was a clay loam textured, deep and well drained with average values of 63% clay, 27% silt, and 9% sand, pH value of 7.9 between 0 and 90 cmdepth. Values of the average field capacity, permanent wilting point, bulk density and pH of the soil are given in Table 1. The study area is a semi-arid region characterized by cool winters, and hot dry summers with temperatures reaching 43°C. Average relative humidity is about 50% and annual rainfall is 390 mm. Meteorological parameters were taken from a weather station located adjacent to the experimental site. Table 3 gives some monthly climate parameters during the 2005 and 2006 growing seasons, showing that 2005 was hotter and drier than 2006, especially in the early crop growing season. There was a drought during the crop growth period in both years and no rainfall was recorded. Seasonal average temperature, relative humidity, wind speed, and solar radiation values were 28.0 °C, 44.1 %, 1.8 m s^{-1} and 478.5 cal cm^{-2} in 2005 and 27.8 °C, 48.4 %, 1.5 m s^{-1} and 442.4 cal cm^{-2}, respectively, in 2006. The irrigation water was obtained from a deep well classified as C_2S_1 according to USSL classification system (USSL, 1954), with pH 7.0 and an electrical conductivity of soil-saturated extract (EC) value of 0.31 dS m^{-1} (Table 2). The experimental field preparations before planting included ploughing, tilling and seeding. Before planting, land leveling was undertaken for a uniform distribution of the irrigation water. A four-row planting machine sowed seeds 5 cm deep and 25 cm apart in rows of 70 cm wide. Corn (*Z. mays var. indentata* TC513 maize cultivar) was planted on the 5th of July 2005 and on the 3rd of July 2006. In both years, all plots were irrigated three times immediately after sowing with a sprinkler irrigation system to promote uniform emergence. The amount of this pre-treatment irrigation water was 90 mm in 2005 and 95 mm in 2006. The WP irrigation began on the 29th of July 2005 and on the 31st of July 2006. Fertilizer application was done on the basis of soil analysis and all treatment plots received the same amount of fertilizer. A granular compound fertilizer of (20 - 20 - 0) was applied at a rate of 120 kg of N and 100 kg of P_2O_5 per hectare on the day of sowing. The rest of the nitrogen (100 kg ha^{-1} N in urea form) was applied on the day of starting the WP treatment.

The experiment used a completely randomized design with three replicates. Each treatment plot was 10 m long and 2.8 m wide (4 rows/treatment) with a total area of 28 m^2 (Figure 2) There was a 2.1 m buffer space between each plot in order to minimize water movement among treatments. Delibaş (1994) established the effective rooting depth under comparable conditions as 90cm, thus the soil water content at depths of 0 - 30 cm, 30 - 60 cm and 60 - 90 cm was determined by a gravimetric sampling method on the day before the irrigation to determine the amount of irrigation water to be applied. Soil samples were taken from the spot between the crops in a row. To do this, the pipe was moved gently to one side and replaced carefully after sampling. Irrigations were scheduled using 10-day interval based on the results of earlier studies conducted in this area (Gercek et al. 2009a; Dogan et al. 2007). The $WP_{1.0}$ irrigation treatment was designated as full, in which the root zone soil-water content was increased to field capacity with each irrigation event. The $WP_{0.75}$ and $WP_{0.5}$ irrigation treatments, which were designated as deficit, were 75 and 50% of the full treatment, respectively. The plastic pipe used in this experiment was 0.3 mm thick, 38 cm in diameter with 1 mm holes in the bottom at 75 cm spacing (Figure 1). Before irrigation, the soil surface was cleared of sharp materials and leveled to achieve a well uniform water distribution in the soil throughout the row. Then the plastic pipe was laid on the soil and the ends were closed. For the irrigation process, water was delivered to each plastic pipe through

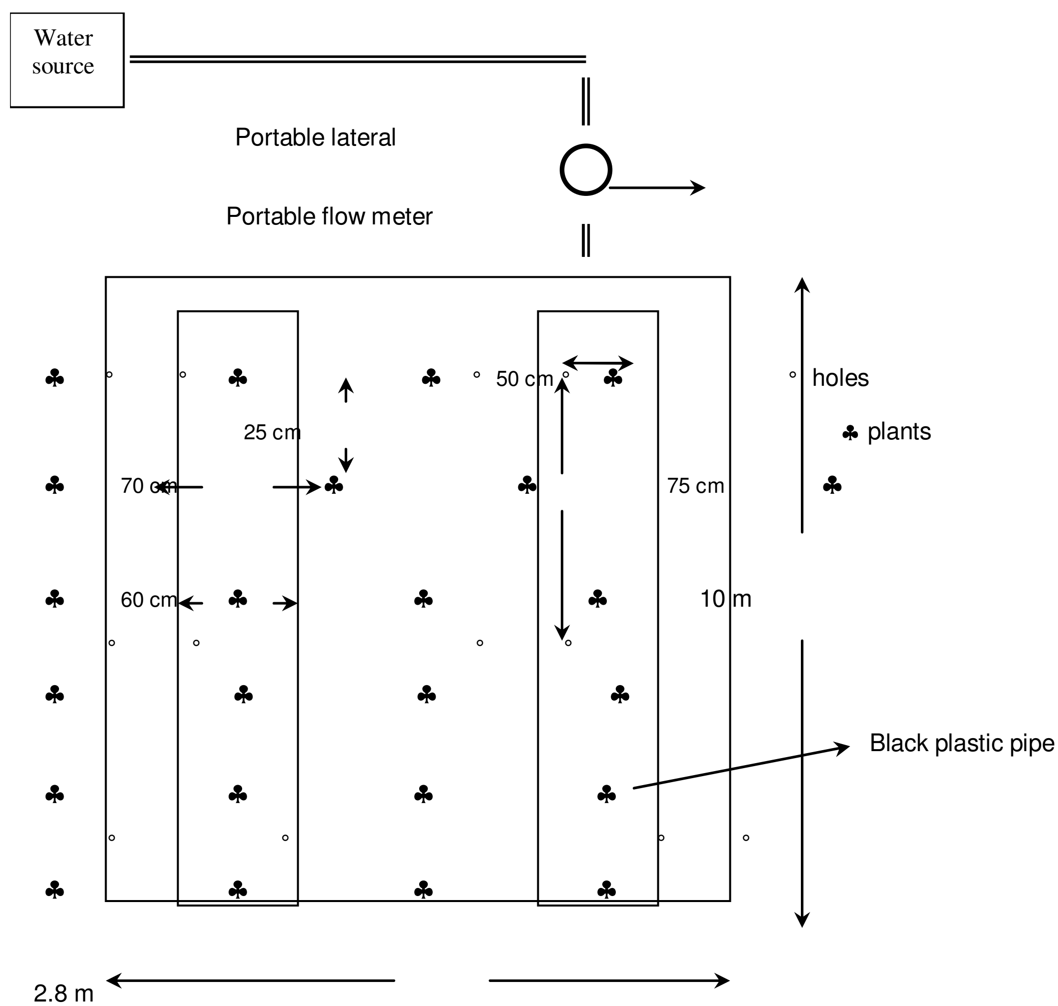

Figure 2. The WP experimental sub-plot (not to scale).

the lateral feed pipes Irrigation water amounts to each plot were measured by a portable flow meter (Teksan Inc, Flow meter) for recording purposes (Figure 2). Water drained out of the plastic pipe through the holes in the bottom at an average rates of 2.13 l h^{-1} (max. rate of 3.6 l h^{-1}). Irrigation was continued until 18 - 26 days before harvest. For yield and biomass analysis, 20 plants were harvested by hand from the middle two rows of the four rows for each treatment. Evapotranspiration (ET) under various watering regimes was calculated using the soil water balance equation (Doorenbos and Kassam, 1992) for the growing season:

$$ET = I + P - D - R_{off} \pm \Delta SW \quad (1)$$

Where I is the irrigation application (mm), P is precipitation (mm), D is soil water drainage (mm), R_{off} is the surface runoff (mm), and ΔSW, is the change in seasonal soil water content (mm). Since there was no runoff during irrigation, it was assumed to be negligible in the calculation of ET. On the basis of a number of soil water content measurements, drainage below 90 cm was considered zero since irrigation was based on soil water depletion replenishment. No significant rainfall was recorded during the study. Thus, the above equation (1) was simplified as:

$$ET = I \pm \Delta S \quad (2)$$

Water use efficiency (WUE in kg mm^{-1} ha^{-1}), defined as the ratio of grain yield per hectare to seasonal water consumption (Howell et al., 1990) was calculated as:

$$WUE = Y / ET \quad (3)$$

Where Y is maize yield (kg ha^{-1}) from irrigated plants.

The CERES-maize growth simulation model used in this study is part of the Decision Support System for Agrotechnology Transfer (DSSAT v 3.5) (Jones et al., 2003). It operates on a daily time-step with inputs including weather variables, crop parameters, soil parameters, and crop and soil management practice. Inputs for the model include management practice (genetics, population, row spacing, planting and harvest dates, fertilizer and irrigation application amounts and dates), environmental factors (soil type, drainage upper limit and lower limit, saturated hydraulic conductivity) and weather (daily minimum and maximum temperature, solar radiation, and precipitation).

The measured data were analyzed statistically by ANOVA and by regression analysis with the SPSS computer program. Both measured and simulated values were tested using a coloration model, also with SPSS.

Table 3. Climatic data of the experimental area during the growing season.

Climatic parameters				
2005	**July**	**August**	**September**	**November**
Temperature				
Maximum (°C)	40.3	40.4	33.6	25.5
Minimum (°C)	25.6	24.6	19.8	13.2
Average (°C)	33.0	33.4	27.2	18.6
Relative humidity (%)	32.8	44.7	46.0	52.9
Precipitation (mm)	0.0	0.0	0.0	0.0
Wind speed (m s^{-1})	2.8	1.7	1.5	1.3
Solar radiation (Cal cm^{-2})	602.7	529.4	438.5	343.4
2006				
Temperature				
Maximum (°C)	38.5	39.2	32.3	25.9
Minimum (°C)	24.9	26.0	22.4	12.8
Average (°C)	32.2	32.1	26.3	20.6
Relative humidity (%)	45.5	44.6	42.3	61.5
Precipitation (mm)	0.0	0.0	0.0	0.0
Wind speed (m s^{-1})	2.0	1.5	1.8	0.9
Solar radiation (Cal cm^{-2})	560.5	462.2	455.4	291.7

Table 4. Measured and simulated maize ET, biomass, yield and WUE values.

	Treatment								
	$WP_{1.0}$			$WP_{0.75}$			$WP_{0.50}$		
Variable	**Measured**	**Simulated**	**Dif. (%)**	**Measured**	**Simulated**	**Dif. (%)**	**Measured**	**Simulated**	**Dif. (%)**
2005									
ET (mm)	660	639	3.2	520	508	2.3	430	414	3.7
Yield (kg ha^{-1})	9450a	8991	4.9	8320b	8179	1.7	5600c	5072	9.4
Biomass (kg ha^{-1})	17 965a	16 906	5.9	16 125b	15 519	3.8	11 021c	10 098	8.4
WUE (kg mm^{-1} ha^{-1})	14.3	14.0	2.1	16.0	16.1	-0.6	13.0	12.3	5.4
2006									
ET (mm)	640	621	3.0	532	505	5.1	436	417	4.4
Yield (kg ha^{-1})	8565a	8168	4.6	7522b	7233	3.8	5040c	4924	2.3
Biomass (kg ha^{-1})	17 025a	15 985	6.1	15 140b	14 952	2.0	10 985c	10 105	8.0
WUE (kg mm^{-1} ha^{-1})	13.4	13.2	1.5	14.1	14.3	-1.4	11.6	11.8	-1.7

Dif. (%): difference. Values followed with the same letter are not significantly different at $P < 0.05$.

RESULTS AND DISCUSSION

The amount of irrigation water ranged from 315 mm ($WP_{0.50}$) to 630 mm ($WP_{1.0}$) in 2005 and from 315 mm ($WP_{0.50}$) to 625 mm ($WP_{1.0}$) in 2006. The total ET, yield, biomass and WUE values of maize given different irrigation treatments in 2005 and 2006 are given in Table 4. The measured ET values for all treatments were 660 - 430 mm in 2005 and 640 - 436 mm in 2006. Similarly, CERES-Maize simulated ET values for all treatments were 639 - 414 mm in 2005 and 621- 417 mm in 2006. In general, both measured (ET_m) and simulated (ET_s) ET values were higher in 2005 than those in 2006 (Table 4), and the difference was attributed to higher climatic parameters in 2005. Regression analysis of the data indicated a highly significant relationship between ET_m and ET_s for all irrigation treatments (Figure 3) and the regression equation was:

$$ET_m = ET_s + 13.6 \text{ with } R^2 = 0.99 \ (p < 0.01).$$

In both years, the relationship between the measured yield (Y_m) and ET_m for all irrigation treatments was polynomial andthe regression equation was:

$$Y_m = -0.09\ ET_m^2 + 125.1\ ET_m - 30188 \text{ with } R^2 = 0.96$$ (Figure 4).

Similar results were reported by Nouna et al. (2000), in which CERES-maize underestimated the ET values. The $WP_{1.0}$ irrigation treatment, as expected, resulted in a significantly higher ($P < 0.05$) yield than the $WP_{0.75}$ and

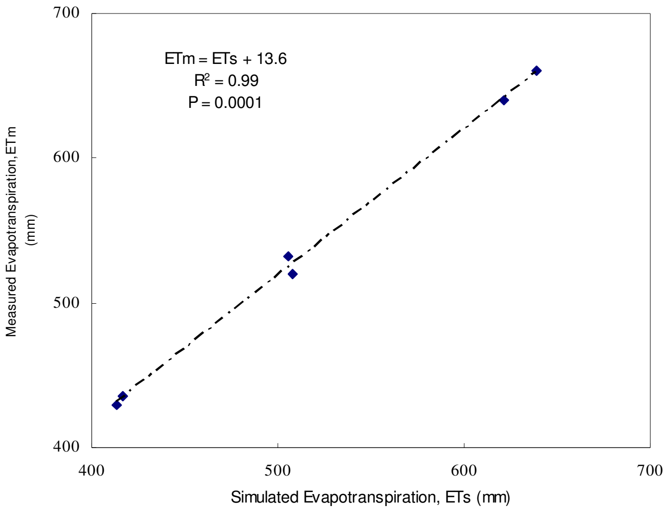

Figure 3. The relationship between the measured and simulated ET for 2005 and 2006.

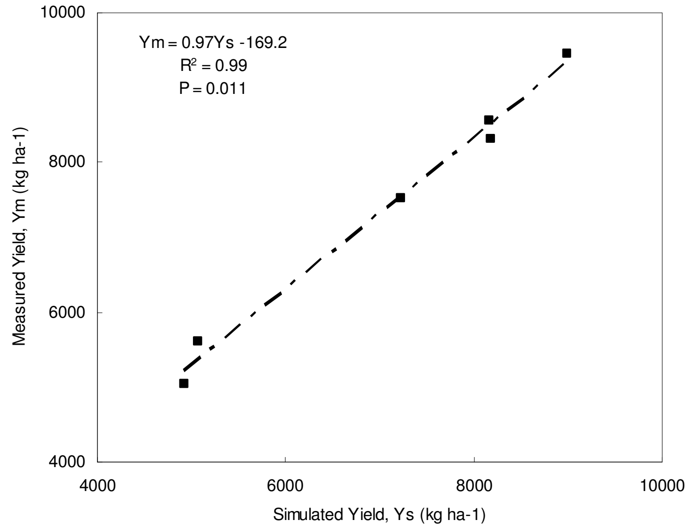

Figure 5. Comparison between the measured (Y_m) and simulated (Y_s) yields in 2005 and 2006.

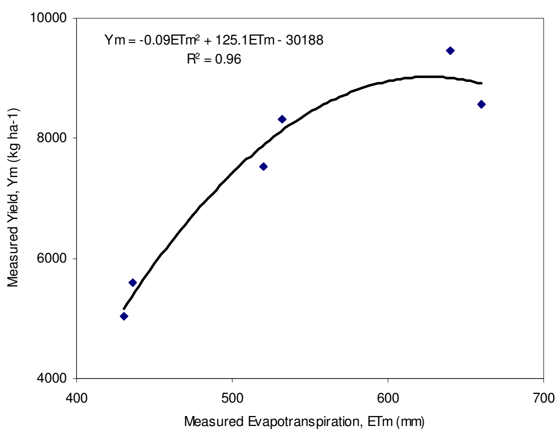

Figure 4. The relationship between the measured yield (Y_m) and ET_m for all forms of irrigation in 2005 and 2006.

$WP_{0.50}$ irrigation treatments in both years. In 2005, the measured yields were 9450 kg ha^{-1} ($WP_{1.0}$), 8320 kg ha^{-1} ($WP_{0.75}$) and 5600 kg ha^{-1} ($WP_{0.50}$) and the measured yields were in the same order in 2006 (Table 4); 8565 kg ha^{-1} ($WP_{1.0}$), 7522 kg ha^{-1} ($WP_{0.75}$) and 5040 kg ha^{-1} ($WP_{0.50}$). Setting the $WP_{1.0}$ yield in each year as 100%,the $WP_{0.75}$ yield (88%) and the $WP_{0.50}$ yield (59%) in both years were significant ($P <0.05$) reduction of crop yield. These results were similar to those in the literature (Castrignano et al. 1998; Karam et al., 2005; Saseendran et al., 2005; Dogan et al., 2007; Mercau et al., 2007). CERES-maize simulations of yield in 2005 ranged from 5072 kg ha^{-1} ($WP_{0.50}$) to 8991 kg ha^{-1} ($WP_{1.0}$). The $WP_{1.0}$ simulated yield was 9% higher than that of $WP_{0.75}$, and 43% higher than that of $WP_{0.50}$. Similarly, simulated yields ranged from 4924 kg ha^{-1} ($WP_{0.50}$) to 8168 kg ha^{-1} ($WP_{1.0}$), and the $WP_{1.0}$ simulated yield was 11% higher than that of $WP_{0.75}$, and 40% higher than that of $WP_{0.50}$ in 2006. In general, there were only slight differences between the simulated and measured yields. Our results agreed with those reported by Nouna et al. (2000), who found that with well-watered treatments, values for measured biomass and yield were simulated by the model with a difference of <10%. Regression analysis indicated that there were significant relationships ($P = 0.01$) between the measured (Y_m) and simulated (Y_s) yields ((Table 4 and Figure 5). These results were in agreement with those reported by Gerçek et al. (2009a and 2009b). Measured biomass values varied from 11 021 kg ha^{-1} ($WP_{0.50}$) to 17 965 kg ha^{-1} ($WP_{1.0}$) in 2005 and from 10 985 kg ha^{-1} ($WP_{0.50}$) to 17 025 kg ha^{-1} ($WP_{1.0}$) in 2006 (Table 4). The variation of biomass values was similar in both years and there was a significant difference between treatments ($P <0.05$). Deficit irrigation reduced biomass values in both years. In 2005, the measured biomass for $WP_{1.0}$ was 11% higher than that of $WP_{0.75}$, and 38% higher than that of $WP_{0.50}$. In 2006, the yield for $WP_{1.0}$ was 12% higher than that of $WP_{0.75}$, and 35% higher than that of $WP_{0.50}$. In 2005 and 2006, simulated biomass values were lower than those measured for all treatments. These results were in agreement with those in the literature (Nouna et al., 2000; Mercau et al., 2007; Karam et al., 2005; Cedrón et al., 2005; Saseendran et al., 2005; Dogan et al., 2007). The relationship between measured biomass and seasonal ET values for all irrigation treatments is presented in Figure 6. A polynomial relationship was found between the measured biomass (B_m) and seasonal (ET_m) for all irrigation treatments: $B_m = - 0.14\ ET_m^2 + 187\ ET_m - 42720$

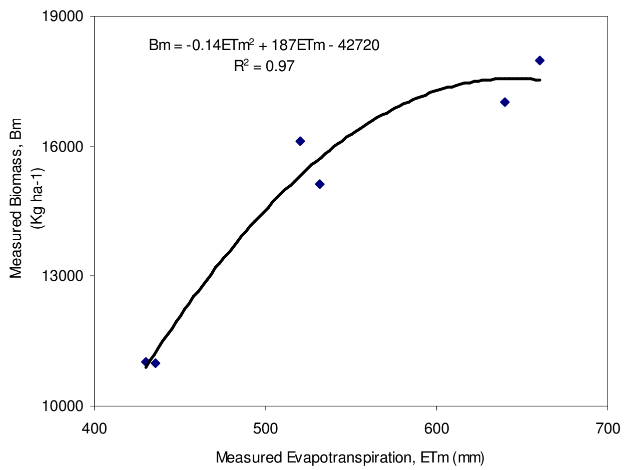

Figure 6. Relationship between the measured biomass (B_m) and evapotranspiration (ET_m) for all forms of irrigation in 2005 and 2006.

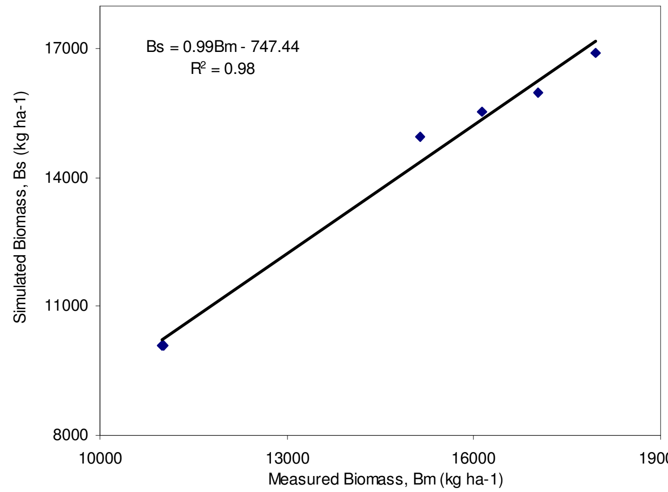

Figure 7. Comparison between the measured (B_m) and simulated biomass (B_s) for 2005 and 2006.

with R^2 = 0.97. In general, measured B_m was consistently higher than the simulated values. Differences between the measured B_m and the simulated values ranged from 1.0% ($WP_{0.50}$) to 5.23% ($WP_{1.0}$) in 2005, and from 6.11% ($WP_{1.0}$) to 2.0% ($WP_{0.75}$) in 2006 (Table 3). A linear relationship was determined between B_m and simulated biomass (B_s) for all irrigation treatments using all biomass data from both of the study years and the equation is:
$B_s = 0.99\ B_m - 747.44$ with R^2 = 0.98 (Figure 7).

The WUE for all treatments varied from 13.0 kg mm^{-1} ha^{-1}to 16.0 kg mm^{-1} ha^{-1} in 2005 and from 11.6 kg mm^{-1} ha^{-1}to 14.1 kg mm^{-1} ha^{-1} in 2006. The highest WUE was found for treatment $WP_{0.75}$ (16.0 kg mm^{-1} ha^{-1} and 14.1 kg mm^{-1} ha^{-1}), while the lowest was found for treatment $WP_{0.50}$ (13.0 kg mm^{-1} ha^{-1} and 11.6 kg mm^{-1} ha^{-1}) in 2005 and in 2006, respectively. The 25% reduction in water use under $WP_{0.75}$ resulted in only a 12–13% reduction of total yield as compared to $WP_{1.0}$, while the 50% reduction in water use under $WP_{0.50}$ resulted in a 41 - 42% reduction in yield compared to $WP_{1.0}$. These results indicate that the water was used most effectively in the $WP_{1.0}$ and $WP_{0.75}$ treatments, in agreement with the results of work reported by Ramakrishna et al. (2006) and by Gerçek et al. (2009b). The simulated WUE values were 12.3 - 14.0 kg mm^{-1} ha^{-1} in 2005 and 11.8 – 13.2 kgthe lowest simulated WUE values were found for the $WP_{0.75}$ (16.1 and 14.3 kg mm^{-1} ha^{-1}) and $WP_{0.50}$ (12.3 and 11.8 kg mm^{-1} ha^{-1}) treatments in both years, respectively.

Conclusion

The experimental results indicated that both yields and biomass values were variable (mainly due to irrigation treatments) and there was a significant ($P < 0.05$) difference between the treatments in both years of the study. Current study results clearly showed that there mm^{-1} ha^{-1} in 2006, in good agreement with the measured values. Similar to the measured values, the highest and was a strong relationship between irrigation amounts and yield and biomass values resulting in a strong quadratic correlation between evapotranspiration and both of the yield and biomass values. There was a good agreement between the measured and simulated results using CERES maize model. The measured yields were 5600 - 9450 kg ha^{-1} in 2005 and 5040 to 8565 kg ha^{-1} in 2006, while the simulated results for the same years were 5072 - 8991 kg ha^{-1} and 4924 - 8168 kg ha^{-1}, respectively. (Quantify the deviation between measured and simulated result, which is average simulated results / average measured results). Both measured and simulated yields showed that a decrease in the amount of irrigation water resulted in a significant ($P < 0.05$) reduction in yield for both years. In conclusion, the CERES-maize model satisfactorily simulated maize yields and could be used for other areas with similar climatic conditions. The analysis of the CERES-maize model results showed that the WP irrigation method can be considered satisfactory and could mimic maize plant biomass and yield under semi-arid conditions.

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