Full Length Research Paper

Performance of SMA-C model on crop evapotranspiration estimation

Bruno Patias Lena[1], Rogério Teixeira de Faria[2]*, Alexandre Barcellos Dalri[2], Luiz Fabiano Palaretti[2], and Miquéias Gomes dos Santos[2]

[1]Universidade de Sao Paulo, Piracicaba-SP, Brazil
[2]Universidade Estadual Paulista, Jaboticabal-SP, Brazil

Many simulation models found in the literature integrates data on climate and crop characteristics to provide great information on the season for different crops. The objectives of this study were: a) to measure soil water balance components of a wheat crop to determine its evapotranspiration (ETc) and crop coefficients (Kc) during the growing season; b) to use experimental data to evaluate the performance of SMA-C in estimating evapotranspiration for a wheat in Paraná State, Brazil; and c) to make adjustments to improve model estimates. Two weighing lysimeters cultivated with a wheat crop were used to measure soil water storage and ETc during the growing season of a wheat crop. Reference evapotranspiration (ET_o) was determined by FAO 56 method using data from a local weather station. Wheat crop coefficients were calculated by the ratio ET_c/ETo, were 0.7, 1.5 and 0.6, for initial, mid and late season, respectively. The comparison of SMA-C simulations with the observed data showed inaccuracies in estimation of soil water storage due to model underestimation for ETc. Estimates were improved by adjusting the model to consider K_c measured in the field.

Key words: Models, lysimeters, decision-making support.

INTRODUCTION

The economic viability of an agricultural business is associated with high quality and quantity of data collection during all seasons of a crop production. Utilizing information such as local climate variable and crop characteristics is very important to improve the decision-making by farmers.

Many simulation models found in the literature integrates data on climate and crop characteristics to provide great information during the season for different crops. Examples such as DSSAT (Jones et al., 2003), APSIM (Holzworth et al., 2014), AquaCrop (Steduto et al., 2009), CERES (Ritchie et al., 1998), STICS (Brisson et al., 2003), VegSyst (Giménez et al., 2013) and CropSyst (Stöckle et al., 2003) use mainly data on climate and crop characteristics to estimate crop development in different conditions, with the aim of improving decision-making by the user. In Brazil, MCID (Borges et al., 2008) provides data to help develop irrigation and drainage
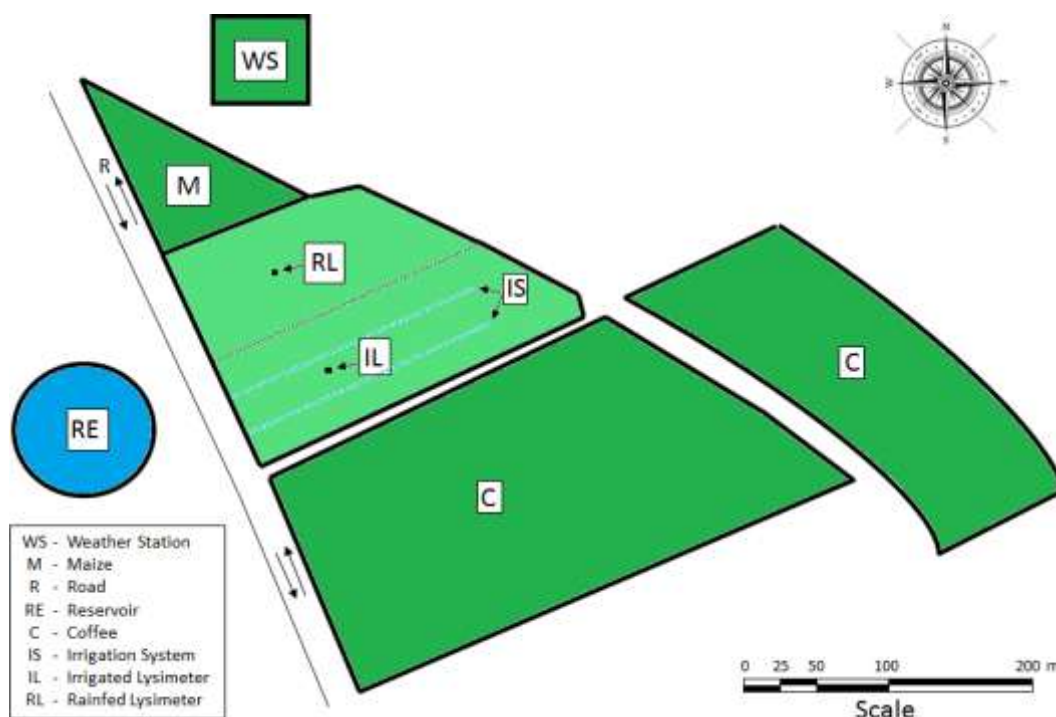
Figure 1. Field layout of the experimental area.

projects. The Agroclimatic Monitoring System (SMA-C) (Caramori and Faria, 2002) uses meteorological data from weather station across Paraná State, crop development and soil water characteristics to provide input information and evaluate the crop water demand.

Despite the fact that many models have the ability to provide good information on crop water demand during the season, it is important to verify their reliability. Thus, the test of models such as SMA-C is needed by comparing simulation with measured data. Since crop water balance is the main component in SMA-C, comparing crop evapotranspiration (ET_c) measured in the field with estimated ET_c is the right approach to test the model performance.

ET_c is a biophysical process to transfer liquid water to vapor through soil evaporation and plant leaf transpiration (Allen et al., 1998). It represents the crop consumptive use in a cultivated area. Besides ET_c, the reference evapotranspiration (ET_o) is a meteorological variable defined as the water demand of a reference surface (grass or alfalfa), which is used in many studies worldwide (Allen, 1998).

Although there are several methods to determine ETo, the standardized Penman-Monteith by FAO (Allen et al., 1998) is the most used so far. This method uses as input solar radiation, air temperature, wind speed and relative humidity.

In the past, it was difficult to measure ET_c in the field because of complex and expensive required equipment. Nowadays, with the advance of technology, it is possible to determine ET_c using different methodologies with low cost and easy maintenance equipment. The use of a high precision weighing lysimeter is one of the most suitable method to determine ET_c (Howell et al., 1985; Faria et al., 2006; Jia et al., 2006; Payero and Irmak, 2008; Mariano et al., 2015).

The objectives of this study were to: a) measure soil water balance components of a wheat crop to determine its evapotranspiration and crop coefficients during the growing season; b) use experimental data to evaluate the performance of SMA-C in estimating evapotranspiration for a wheat in Paraná State, Brazil; and c) make adjustments to improve model estimates.

MATERIALS AND METHODS

This study was conducted in an experimental area of Instituto Agronômico do Paraná (IAPAR), in Londrina, Paraná State, Brazil (23° 18′ S and 51° 9′ W, 585 m). The soil is classified as a Red Latosol and the climate is subtropical humid (Cfa), acording to Köppen-Geiger climate classification (Kottek el al., 2006), characterized by humid and hot summers and mild winter, with mean annual temperature of 21.5°C and annual precipitation of 1584 mm (IAPAR, 1994).

Wheat cultivar IPR-130 (IAPAR, 2016) was sown in two weighing lysimeters and also in a buffer area of about 0.5 ha, in May 2nd, 2009, with 0.17 m spacing between rows. The experimental area was divided into irrigated (T1) and rainfed (T2) treatments. Figure 1 shows the weather station, the buffer area and the two treatments, one with lysimeter installed in the irrigated area and the other in the rainfed area.
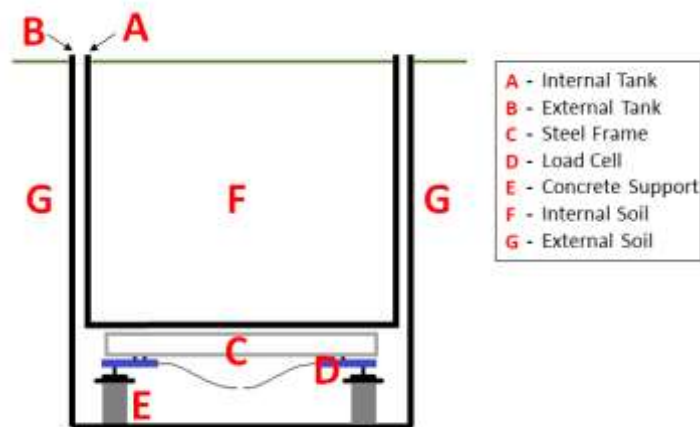
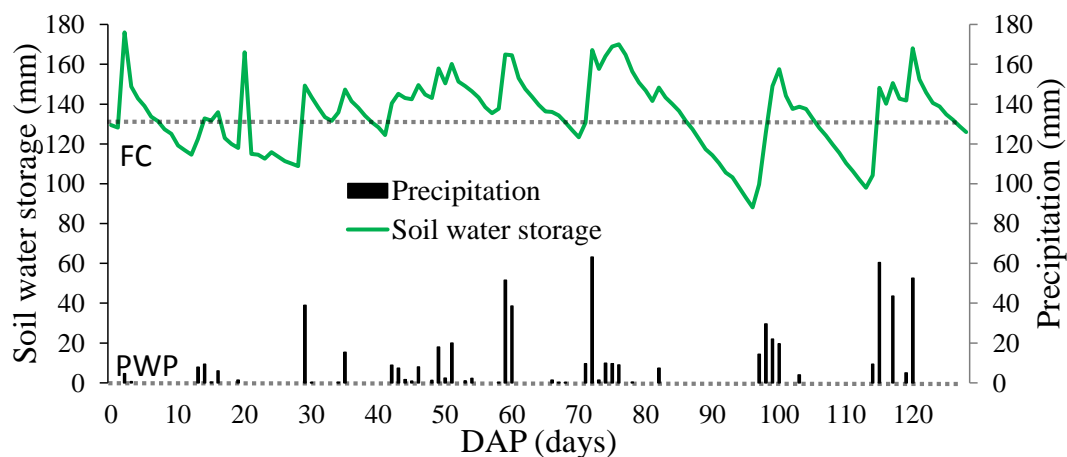**Figure 2.** Cross section view of a lysimeter and its components.

Figure 3. Soil water storage and precipitation during the growing season. FC is field capacity and PWP is permanent wilting point.

Figure 2 shows the cross section of the lysimeter system, with internal and external tanks, concrete pillars, steel frames and load cells. The lysimeter tank was made of fiber glass in a square format of 0.95 x 0.95 m and 1.3 m depth. An external fiber glass tank of 1 x 1 m surface and 1.5 m depth was installed to isolate the smaller lysimeter tank from the surrounding soil. Four load cells were placed between the concrete pillar and the steel frame.

Lysimeter mass was measured every 3 s by four load cells Model-I, ALFA Instruments (ALFA, 2016). The electric signals measured by each load cell were averaged every 10 min (200 readings) and then storage in a datalogger model CR10x (Campbel Scientific) was powered by a 12 V battery. The measured data by each load cell was sent to a union box through a coaxial cable and then to the datalogger. The data, in mV, were input in the calibration equation to calculate mass, in kg, using the procedure described by Faria et al. (2006) and Mariano et al. (2015). Soil water storage, in mm equivalent, was then calculated from lysimeter mass, in kg, by dividing by mass by lysimeter area (0.9 m²).

Irrigation management of treatment T1 was preconized to maintain soil water storage higher than 70% of the soil available water, by application of water to replace the soil at field capacity twice a week. Soil available water, as given by difference between field capacity and permanent wilting point for the experimental area, was determined by Faria and Caramori (1986) as 10% in a volumetric basis. Thus, the soil available water in 1.3 m depth in the lysimeter profile varied from zero, at permanent wilting point, to 130 mm, at field capacity. To represent graphically lysimeter mass variation in the range of soil available water (Figure 3), the lysimeter mass (converted to mm equivalent) at field capacity was assigned to 130 mm and the remaining measurements were calculated proportionally. The lysimeter was considered to be at field capacity at 4 days of drainage after occurrence of a precipitation sufficient to reach soil saturation (Faria and Caramori, 1986). Crop evapotranspiration and soil water storage in each lysimeter were determined according to the following equation:

$$ET_c = P + I - D - R \pm \Delta S \tag{1}$$

where ET_c is crop evapotranspiration, P is precipitation, I is
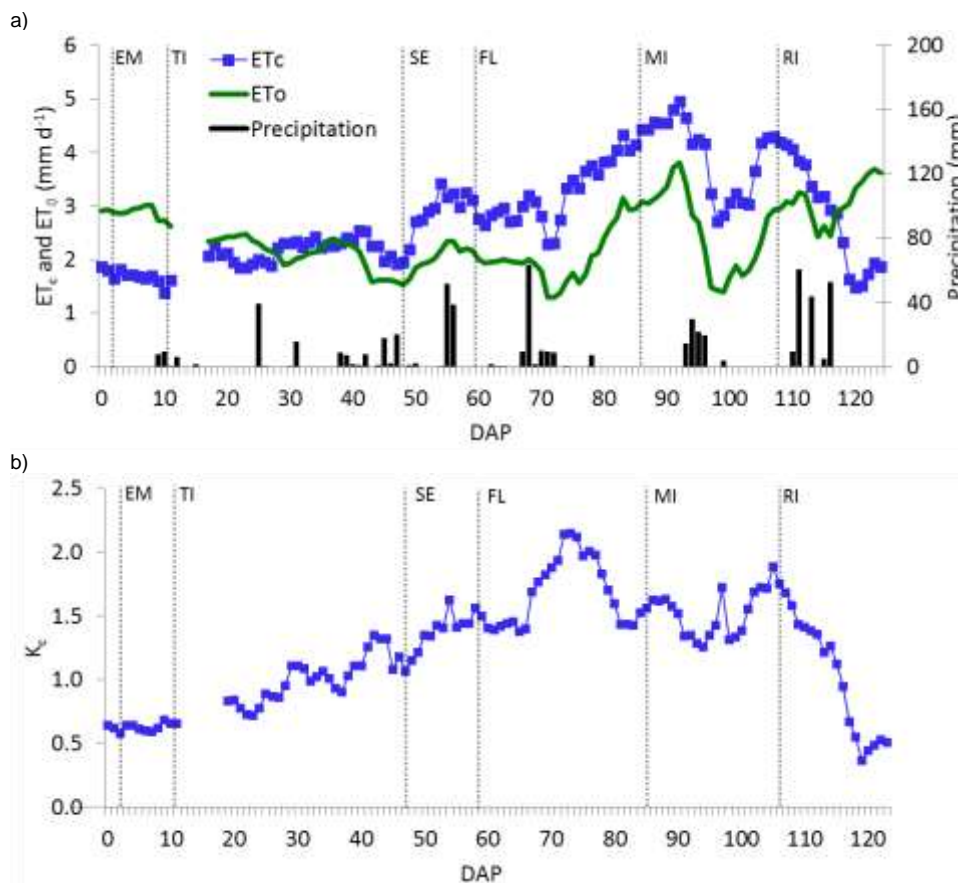
a)

b)

Figure 4. a) Crop evapotranspiration (ET_c) and reference evapotranspiration (ETo), and b) crop coefficient (K_c) during the growing season. EM: emergence, TI: tillering, SE: stem elongation, FL: flowering, MI: milk stage and RI: ripening.

irrigation, D is drainage, R is runoff (considered zero because the elevated edge of the lysimeter tank) and ΔS is variation soil water storage variation, all in mm d^{-1}.

Crop coefficient was determined by Equation 2 (Allen et al., 1998):

$$K_c = \frac{ET_c}{ET_0} \qquad (2)$$

Where K_c is crop coefficient (dimensionless), ET_c is crop evapotranspiration and ET_o is grass reference evapotranspiration, both in mm d^{-1}. Daily ET_o was computed by CLIMA software (Faria et al., 2002), using the standardized Penman-Monteith equation (Allen et al., 1998) with daily data from an automatic weather station installed in the IAPAR Experimental Station, at 150 m from the lysimeter (Figure 1).

SMA-C uses a soil moisture module described in detail by Faria and Madramootoo (1996). The inputs are plant characteristics such as rooting depth and leaf area index (LAI), soil water retention data and meteorological data to calculate soil water balance components of a specific crop. In this study, wheat LAI data was determined five times during the experimental period by a leaf area integrator (LI-COR, 1996), and soil water retention characteristics for the experimental area were taken from data collected by Faria and Madramootoo (1996). Wheat phenological stages were evaluated every week to characterize crop development. Daily simulated ET_c and water storage data were compared with measured data, using

linear regression and the t-test (p = 1%).

RESULTS AND DISCUSSION

This research reported on two treatments of water management, irrigated and rainfed. However, due to the high precipitation during the growing season (Figure 3), it was not necessary to irrigate and, thus, soil water storage was similar in both treatments. Instead of the two treatments, the measurements of the two lysimeters were averaged to perform the test of the model. The results show that precipitation was sufficient to supply crop requirements and soil water storage was close to the field capacity during the whole growing season (Figure 3).

Daily ET_c varied from 1 to 5 mm d^{-1} during the growing season. It was higher during milk stage and lower from emergence to the end of flowering and during ripening (Figure 4a). In addition, ET_c was low during some periods (45, 70 DAP and 100 DAP) due to decrease in ET_o, caused by low temperature, as a result of rainy periods. Average seasonal ETo was equal to 2.4 mm d^{-1}, which was about 10 and 20% less than seasonal ET_c. K_c
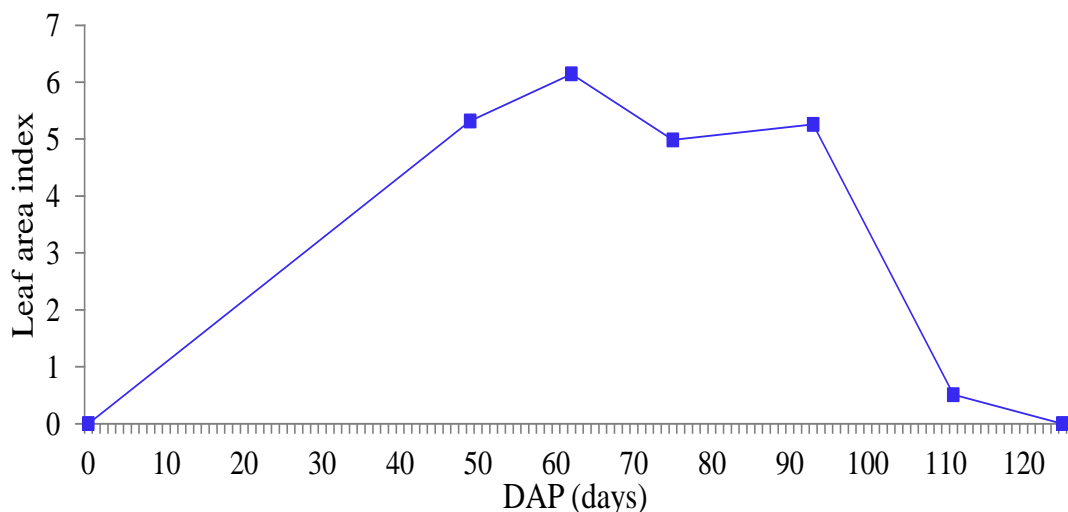
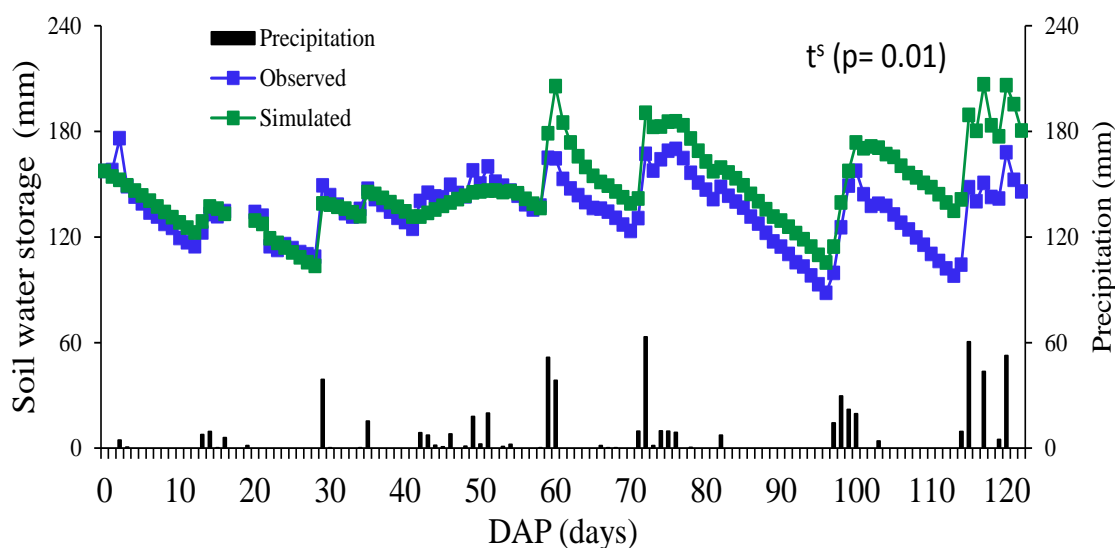**Figure 5.** Leaf area index during the growing season.

Figure 6. Precipitation and observed and simulated soil water storage during the growing season.

increased from emergence to reach higher values during the mid-crop stages, and then decreased during the later stages (Figure 4b). Variations in K_c were mostly related to LAI variation during the growing season (Figure 5). LAI was higher than 5 during flowering (60 DAP). At that time, transpiration was the main component of ET_c because of full soil cover by the canopy. After the reproductive period, the plant initiated the senesce, decreasing the LAI and also ETc.

The comparison between simulated and observed soil water storage showed that model followed the same trend with the observed data, decreasing when ET_c was high and increasing during precipitation events (Figure 6). Simulations agreed with the observed data from emergence to 55 DAP. After that, simulated soil water storage was always higher than observed data. The analysis by t-test showed significant difference (p = 1%) between the two data sets. Therefore, SMA-C over-estimates soil water retention, indicating that the model needs corrections in its calculation method.

Simulated ET_c overestimated observed data, as given by statistical difference at 1% probability by t-test using data for the whole growing season (Figure 7). While observed ET_c was 270 mm, the model simulated 220 mm during the growing season, was an underestimation of 18.5%. The difference between model estimates and field data was more evident for the period from 60 to 128 DAP. This finding confirms the need to correct the method
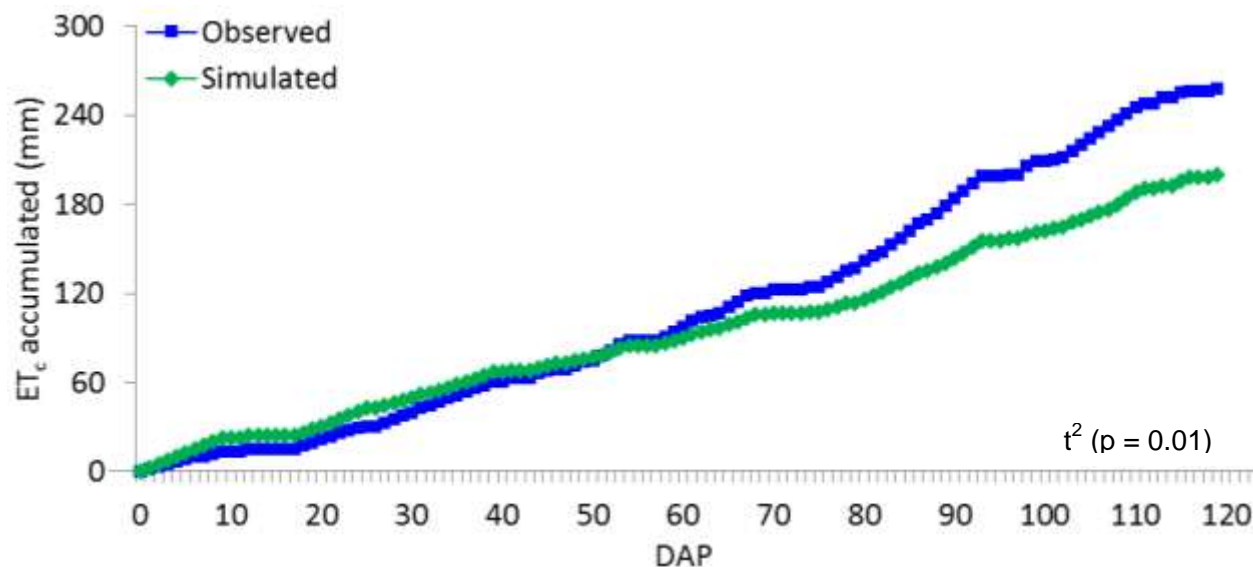
Figure 7. Observed and simulated accumulated crop evapotranspiration for the growing season.
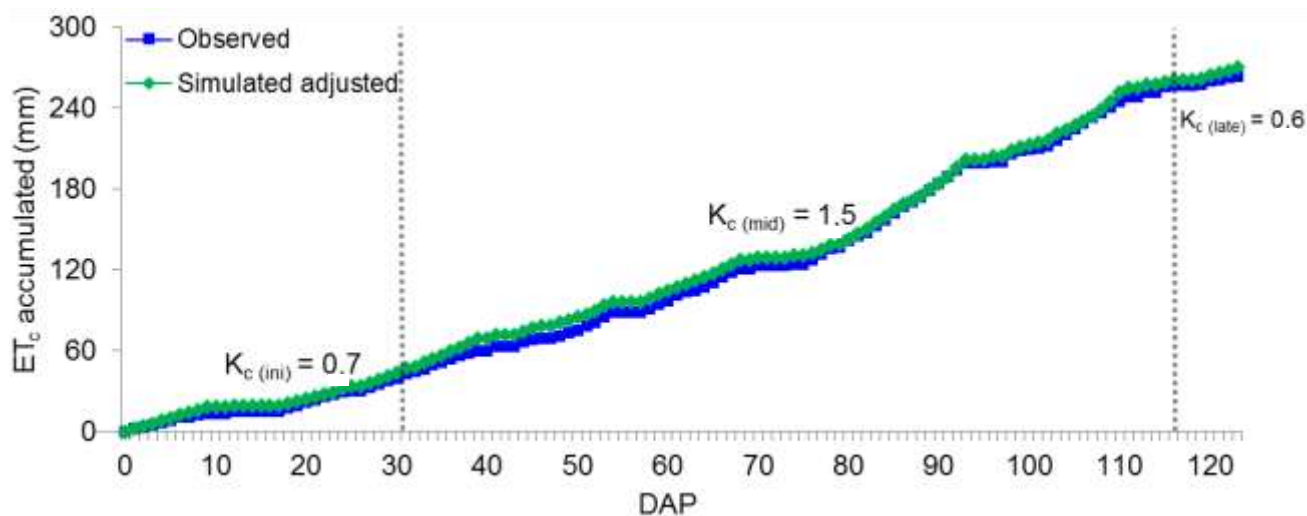

Figure 8. Accumulated crop evapotranspiration for the growing season, observed and simulated by adjusted SMA-C.

of calculating ET_c in SMA-C. In that model, K_c is equal to 1 by assuming ET_c equal to ET_o in conditions of no water stress. However, this was not correct because the values of K_c estimated using field data measured in this study varied according to crop development, as given in Figure 4b.

In order to improve SMA-C estimates, the model was modified to consider K_c measured in the field. That coefficient was used into the model to multiply ET_o and then to calculate ET_c, following the approach described by Allen et al. (1998). Therefore, the crop season was divided into three phases in which K_c was assumed to be

0.7, 1.5 and 0.6 for initial, mid and late seasons, respectively. The results in Figure 8 show that simulations are in close agreement with observed data.

In addition, to demonstrate the improvement in model estimates, a regression analysis was performed on daily and accumulated ET_c estimated by the original and adjusted model against observed data (Figure 9). The scatter of data around 1:1 curve decreased considerably for both, daily and accumulated ET_c data using the adjusted model. The linear regression for simulated vs. observed data gave a slope coefficient significantly different from 1 for the original SMA-C and not different
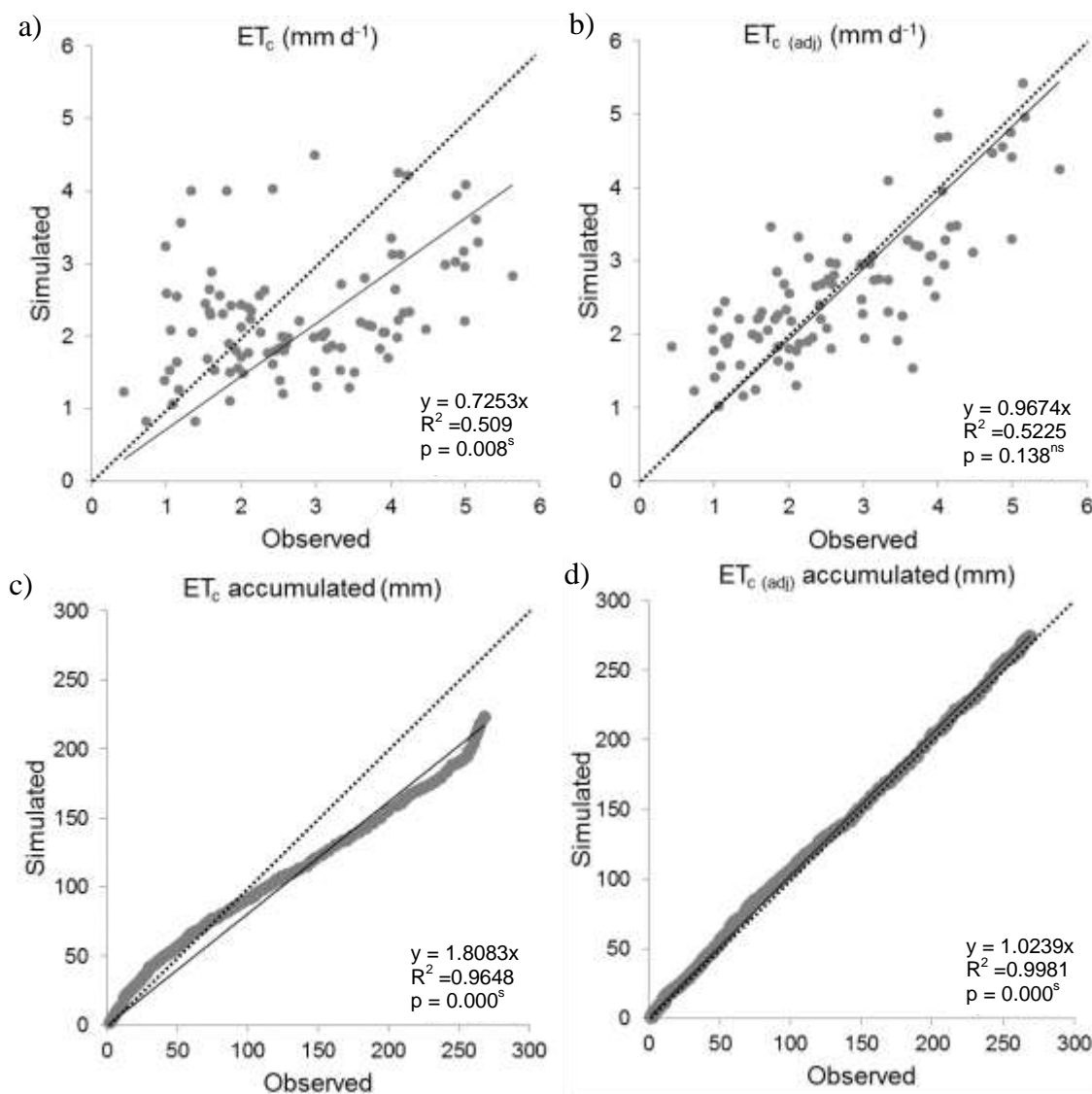
Figure 9. Regression of observed and simulated daily (a) and accumulated (b) crop evapotranspiration (ET$_c$) for the original and adjusted SMA-C.

from 1 for the adjusted model. Moreover, the comparison between simulated and observed ET$_c$ for the adjusted model did not differ statistically. The coefficient of determination increased from 0.753 for daily and 0.808 for accumulated ET$_c$ as calculated by the original model to 0.967 and 0.998, respectively, for adjusted SMA-C.

Conclusions

1. Soil water storage and ET$_c$ were measured by lisimetry and ET$_o$ were calculated from meteorological data during a wheat growing season.
2. Estimated K$_c$ by the ratio between ET$_c$ and ET$_o$ followed the course of LAI during the growing season. The test of SMA-C against experimental data showed low

performance of the model to simulate soil water storage, as a result of inaccuracies in the method of calculating ETc;
3. SMA-C estimates were improved by adjustment of the model to consider K$_c$ measured in the field. The coefficient varied during the growing season was used into the model to multiply ET$_o$ and then to calculate ET$_c$.

Conflict of interest

The authors have not declared any conflict of interest.

REFERENCES

ALFA (2016). ALFA Instrumentos. Lead Cell model I. Available at:

http://www.alfainstrumentos.com.br/I-Shear-Beam.html.

Allen RG, Pereira LS, Raes D, Smith M (1998). Crop evapotranspiration: guidelines for computing crop water requirements. Rome: FAO. Irrigation and Drainage Paper 56.

Borges JCF, Ferreira PA, Hedden-Dunkhorst B, Andrade CLT (2008). Modelo computacional para suporte à decisão em áreas irrigadas. Parte I: Desenvolvimento e análise de sensibilidade. Rev. Bras. Eng. Agríc. Ambient. 12(1):3-11.

Brisson N, Gary C, Justes E, Roche R, Mary B, Ripoche D, Zimmer D, Sierra J, Bertuzzi P, Burger P, Bussière F, Cabidoche TM, Cellier P, Debaeke P, Gaudillère JP, Hénault C, Maraux F, Seguin B, Sinoquet H (2003). An overview of the crop model STICS. Eur. J. Agron. 18:309-332.

Caramori PH, Faria RT (2002). SMA - Sistema de Monitoramento Agroclimático para o Estado do Paraná. IAPAR, Agrometeorologia, Monitoramento Agroclimático, Mapas Climáticos. Available at: http://www.iapar.br/modules/conteudo/conteudo.php?conteudo=983.

Faria RT, Caramori, PH (1986). Physical-Hydrical characterization in a Dystrophic dusky-latosol of Londrina, PR, Brazil. Pesqui. Agropecu. Bras. 21(12):1303‑1311.

Faria RT, Campeche FSM, Chibana EY (2006). Construção e calibração de lisímetros de alta precisão. Rev. Bras. Eng. Agríc. Ambient. 10(1):237-242.

Faria RT, Caramori PH, Chibana EY, Brito LRS, Nakamura AK, Ferreira AR (2002). CLIMA - programa computacional para organização e análise de dados meteorológicos. Bol. Técnico 56:1-23.

Faria RT, Madramootoo CA (1996). Simulation of soil moisture profiles for wheat in Brazil. Agric. Water Manage. 31(1-2)35-49.

Giménez C, Gallardo M, Martínez-Gaitán C, Stockle CO, Thompson RB, Granados MR (2013). Veg Syst, a simulation model of daily crop growth, nitrogen uptake and evapotranspiration for pepper crops for use in an on-farm decision support system. Irrig. Sci. 31(3):465-477.

Holzworth DP, Huth NI, Voil PG, Zurcher EJ, Herrmann NI, McLean G, Chenu K, Oosterom EJO, Snow V, Murphy C, Moore AD, Brown H, Whish JPM, Verrall S, Fainges J, Bell LW, Peake AS, Poulton PL, Hochman Z, Thorburn PJ, Gaydon DS, Dalgliesh NP, Rodriguez D, Cox H, Chapman S, Doherty A, Teixeira E, Sharp J, Cichota R, Vogeler I, Li FY, Wang E, Hammer GL, Robertson MJ, Dimes JP, Whitbread AM, Hunt J, Rees HV, McClelland T, Carberry PS, Hargreaves JNG, MacLeod N, McDonald C, Harsdorf J, Wedgwood S, Keating BA (2014). APSIM. Evolution towards a new generation of agricultural system simulation. Environ. Modell. Software. 62:327-350.

Howell TA, McCormick RL, Phene CJ (1985). Design and installation of large weighing lysimeters. Trans. ASAE 35:106-117.

IAPAR, Instituto Agronômico do Paraná (1994). Cartas Climáticas do Estado do Paraná. IAPAR, Londrina. 49 p (Documento 18)

IAPAR, Instituto Agronômico do Paraná Agrometeorologia (2016). Catálago de cultivar. Available at: http://www.iapar.br/arquivos/File/folhetos/trigo/ipr130.html.

Jia X, Dukes MD, Jacobs JM, Irmak S (2006). Weighing lysimeter for evapotranspiration research in a humid environment. Trans. ASABE 42(2):401-412.

Jones JW, Hoogenboom G, Porter CH, Boote KJ, Batchelor WD, Hunt LA, Wilkens PW, Singh U, Giksman AJ, Richie JT (2003). The DSSAT cropping system model. Eur. J. Agron. 18(3-4):235-265.

Kottek M, Grieser J, Beck C, Rudolf B, Rubel F (2006). World map of the Köppen-Geiger climate classification updated. Meteorol. Z. 15(3):259-263.

LI-COR (1996). LI 3100 area meter instruction manual. Lincoln, 1996. 34 p.

Mariano DC, Faria RT, Freitas PSL, Lena BP, Johann AL (2015). Construction and calibration of a bar weighing lysimeter. Acta. Sci. Agron. 37(3):271-278.

Payero JO, Irmak S (2008). Construction, installation, and performance of two repacked weighing lysimeter. Irrigation Sci. 26(2):191-202.

Steduto P, Hsiao TC, Raes D, Fereres E (2009). Aqua Crop – the FAO crop model to simulate yield response to water: I. Concepts and underlying principles. Agron. J. 101(3):426-437.

Stöckle CO, Donatelli M, Nelson R (2003). CropSyst, a cropping systems simulation model. Eur. J. Agron. 18(3-4):289-307.