Agricultural Water Management 185 (2017) 137–144

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Estimating water balance, evapotranspiration and water use efficiency of spring safflower using the CROPGRO model

Sukhbir Singh[a,*], Kenneth J. Boote[b], Sangamesh V. Angadi[c,*], Kulbhushan K. Grover[c]

[a] Texas Tech University, Lubbock, TX, USA
[b] University of Florida, Gainesville, FL, USA
[c] New Mexico State University, Las Cruces, NM, USA

ARTICLE INFO

Article history:
Received 5 October 2016
Received in revised form 14 February 2017
Accepted 17 February 2017

Keywords:
Spring safflower
DSSAT
Simulation modeling
Evapotranspiration
Water use efficiency

ABSTRACT

Inclusion of drought tolerant, low input crops such as safflower (*Carthamus tinctorius* L.) is one of the strategies to extend the life of fast declining Ogallala Aquifer in the Southern High Plains (SHP). Crop modeling is a viable option to simulate safflower water footprints in different climatic scenarios to assess its feasibility in optimization of water use in the SHP. Such progress would join corollary efforts to improve irrigation management practices of safflower for increased water productivity. The primary objective of the study was to calibrate the CROPGRO model for improved ability to simulate water balance, evapotranspiration (ET) and water use efficiency (WUE) of spring safflower. The model was calibrated based on soil water extraction data from PI8311 cultivar in an experiment conducted during 2013 and 2014 at Clovis, NM. The observed data from other two cultivars, 99OL and Nutrisaff, were used to evaluate the model. The model was able to simulate total above ground biomass of safflower in a reasonable fashion. The optimal prediction of soil water content, water balance and seed yield of safflower led to excellent ET and WUE simulations with root mean square error of 34 mm and 0.6 kg ha^{-1} mm^{-1}, respectively. The satisfactory performance of the model for an independent data demonstrates that the CROPGRO model is capable of predicting water use of spring safflower in semi-arid regions of the SHP; however, site-specific calibrations based on weather, especially soil and rooting inputs may be needed in different regions.

Published by Elsevier B.V.

1. Introduction

Water deficit is a major limiting factor of crop productivity in the semi-arid Southern High Plains (SHP) of New Mexico and Texas. The frequent and intense droughts in the SHP are increasing pressure on the depleting Ogallala Aquifer, the primary source of irrigation in the region (Xue et al., 2014). The continued decline in the Ogallala Aquifer is adding to deteriorating climate constraints for crop production, and negatively impacting the agricultural sustainability in the SHP. With the growing emphasis on water conservation in conflict with the requirements of large quantities of water for most crops in irrigated agriculture, management of declining water resources increasingly focuses on the introduction of alternative, low-water-use crops such as safflower (*Carthamus tinctorius* L.) into the existing cropping systems.

Safflower is a drought-tolerant annual oil seed crop that originated in the desert environment (Hojati et al., 2011). Safflower is mainly grown for high quality edible oil and birdseed (Koutroubas et al., 2009). It is well adapted to arid and semi-arid regions of the world. Deep taproot system of safflower up to a depth of 2.2 m and xerophytic spines contribute to its ability to tolerate drought and heat (Dajue and Mündel, 1996). It fits well in the semi-arid climate of the SHP, and has considerable potential to provide solutions for optimal use of limited water, and to bring economic diversity and stability in the region. The drought tolerance of safflower is attributed, but not confined, to 1) physiological adaptations such as maintaining photosynthesis, stomatal conductance, water potential, and relative water content (Singh et al., 2016a), 2) minimizing water loss through reduction in canopy and leaf size, and leaf senescence (Singh et al., 2016c), and 3) maximizing water uptake via its long taproot to extract water from deep soil layers (Singh et al., 2016b). Despite being a drought tolerant crop, plantings of safflower in the SHP are still not common because of sparse data on its performance under low-input management. Decision makers often face questions such as: How much water is needed for successful safflower crop? What is its evapotranspiration (ET) requirement?

* Corresponding authors.
E-mail addresses: s.singh@ttu.edu, sssaini8@gmail.com (S. Singh), angadis@nmsu.edu (S.V. Angadi).

http://dx.doi.org/10.1016/j.agwat.2017.02.015
0378-3774/Published by Elsevier B.V.

How efficiently it can use the limited water? The previous studies conducted on safflower water use were field-based, and the results cannot be extrapolated from one site to another site easily.

A robust and process based crop simulation model reduces resource-intensive field experiments and allows analysis of a wide range of agronomic and climatic scenarios to extend the opportunities and limits of a new crop in a particular region. The models can be helpful in extrapolation of results from one site to other site, and turn into a practical decision tool accessed by extension workers, crop advisors, lenders, and farmers. With advancement in technology, the importance of crop models in agricultural research has increased, and many models have been tested and validated under different environments. The CROPGRO cropping system model in the Decision Support System for Agrotechnology Transfer (DSSAT) is a comprehensive model that can assess growth, yield, and water use of a crop based on cultivar genetic traits, weather, plant, soil and management inputs (Boote et al., 1998a,b; Boote et al., 2010; Hoogenboom et al., 1992; Jones et al., 2003). The CROPGRO model has been successfully used in many legumes such as soybean [*Glycine max* (L.) Merr.], peanut (*Arachis hypogaea* L.), dry bean (*Phaseolus vulgaris* L.) (Boote et al., 1998a,b), faba bean (*Vicia faba* L.) (Boote et al., 2002), velvet bean [*Mucuna pruriens* (L.) DC.] (Hartkamp et al., 2002a,b), and non-legume crops such as tomato (*Lycopersicon esculentum* Mill.) (Scholberg et al., 1997) and cotton (Pathak et al., 2007). Successful calibration of the model for safflower will have an application in evaluating safflower water use in different parts of the SHP to optimize the water use, and also in genetic improvement in relation to drought tolerance. These efforts could be helpful to open opportunities for removing genetic and management barriers to safflower becoming an attractive crop option in water-limiting environments. Therefore, we are proposing to simulate water balance, ET and water use efficiency (WUE) of spring safflower using the CROPGRO model in the SHP.

2. Materials and methods

2.1. Site and field experiment

The site description and experimental conditions are explained in detail by Singh et al. (2016d) and Singh et al. (2016c). In brief, a replicated field experiment was conducted during 2013 and 2014 at the Agricultural Science Center (ASC) of New Mexico State University (34° 35′ N, 103° 12′ W and altitude of 1348 m above sea level). The study site is characterized as semi-arid climate with hot summer (April–August). The average annual precipitation is 445 mm of which 63% is received during summer, and the mean annual maximum and minimum temperatures are 22 °C and 7 °C, respectively (Singh et al., 2014). The soil at the study site is Olton clay loam (fine, mixed, superlative, thermic aridic paleustoll).

Three spring safflower cultivars having different growth habits, PI8311, 99OL and Nutrisaff, were tested under four irrigation treatments: fully irrigated (FI), stress at vegetative stage (VS), stress at reproductive stage (RS), and dryland (DL) (Singh et al., 2016c). A center pivot system with spray pads was used to irrigate the plots. Since some irrigation for crop establishment is needed in dry years, therefore we applied 51 and 38 mm irrigation after planting to all treatments over 2-week period in 2013 and 2014, respectively. The actual irrigation treatments were started after crop establishment, and FI was the non-stressed treatment. In Vs treatment, irrigation was stopped after crop establishment to limit vegetative growth, and started again after flower initiation; while in RS treatment, irrigation was continued during the vegetative stage, and stopped after flower initiation to apply stress during reproductive growth. The DL treatment did not receive any irrigation after establishment, and survived on rainfall. The treatments were randomized and replicated four times in a split-plot design with irrigation as a whole plot and cultivar as a subplot.

2.2. Data collection

Volumetric soil water content was determined on selected dates during the growing season using a field-calibrated soil moisture neutron gauge (Model 503 DR, Campbell Pacific Nuclear Inc., CA, USA). Access tubes were installed in the center of each plot, and neutron probe readings were made from 0.1 m to 1.5 m depth at 0.2 m depth increments to assess the moisture (Singh et al., 2016b). Soil water content (mm) at each depth was calculated by multiplying depth increment (mm) with volumetric water content for that depth increment. Soil water depletion at each depth between two sampling dates was determined by subtracting the soil water content of later measurement from the earlier measurement. Seasonal crop ET was calculated as addition of rainfall, irrigation, and the difference between initial and final soil water content (Singh et al., 2016b; Xue et al., 2014). Since the experiment field was leveled and did not receive any high irrigation/rainfall amounts, the runoff and drainage were considered negligible. In addition, the neutron probe data collected from this study also supported negligible drainage down to the depth of 1.5 m. The WUE was calculated as the ratio of seed yield to ET. Safflower phenological observations such as emergence, beginning bloom, beginning head, beginning seed, and physiological maturity were recorded. The total above ground biomass accumulation was measured biweekly, and an area of 9.2 m^2 was harvested using a plot combine (Model Elite Plot 2001, Wintersteiger, Ried, Austria) for seed yield (Singh et al., 2016c,d).

2.3. Soil profile and daily weather data in the model

The soil file inputs in the CROPGRO model include percent sand, clay, stone, organic carbon, pH, cation exchange capacity, lower limit (SLLL; permanent wilting point), drained upper limit (SDUL; field capacity), saturation, bulk density, saturated hydraulic conductivity, and root growth factor (SRGF) (Jones et al., 2003). A soil fertility factor of (SLPF) 1.0 was used in this study because soils in this region are generally fertile with no major issues. The soil profile was divided into 8 layers to provide soil inputs for each layer that was used to collect the soil moisture data in the field experiment. The source of input soil data for the region was USDA-NRCS-NSSC-Soil Survey. The measured initial soil water content at each depth was specified in the model as an initial condition input. Based on soil and water input data, the model computes all the processes required to simulate soil water content, and calculates water balance using the following equation (Jiang et al., 2016; Jones et al., 2010):

$$\Delta S = RF + I - E - T - R - D$$

Where ΔS = Change in soil water content, RF = Rainfall, I = Irrigation, E = Evaporation, T = Transpiration, R = Surface runoff, and D = Drainage from soil profile.

The model considers day to day processes to simulate crop growth, and requires daily weather data. The daily solar radiation (MJ m^{-2} d^{-1}), minimum and maximum temperatures (°C), and rainfall (mm) data were collected from the weather station situated at the ASC, Clovis, NM. All these data were arranged in a standard format using Weather module of the model.

3.1. Model adaption approach

The CROPGRO model template was adapted to safflower (Singh et al., 2016d) through the approach used by Boote et al. (2002)