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Parametrization of Cropsyst model for the simulation of a potato crop in a Mediterranean environment

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ABSTRACT

Data from a two-year field experiment were used to calibrate (2011) and validate (2012) the parameters required by the CropSyst model for simulating the growth of a potato crop (Agria cultivar) in a semiarid area of Spain. The primary variables analysed during the parameterization model were leaf area index, canopy cover, total dry matter, total biomass at harvest, soil moisture balance, and evapotranspiration, being the potato crop subjected to four irrigation treatments (120%, 100%, 80%, and 60% of the crop water requirements "CWR") under a center pivot system. The results showed that the CropSyst model attained a suitable goodness of fit with regards to the simulated and observed values (Willmott's index close to 1 and errors around ± 10%). Although the model includes a reduction coefficient for taking into account the effect of both water and temperature stress on the reference harvest index, yields at harvest were not properly simulated by the model. According to the results, the calibrated and validated CropSyst model showed that the 100% and the 80% CWR treatments are the most interesting ones for the farmers in the study area (both reached a suitable rate between high yield and high efficiency in the use of water).

1. Introduction

Crop simulation models are currently widely applied in agriculture as tools in decision support systems (Bechini et al., 2006; Boote et al., 2010; Jones et al., 2017). Process-based crop models give estimates of yield and harvest time based on soil characteristics and weather dynamics under different management scenarios (Pereira et al., 2002; Confalonieri et al., 2009), leading to improved decision-making in fertilizer and water management (Benli et al., 2007). However, crop models need to be calibrated and validated through specific field experiments to be used in certain areas (Cabelguenne et al., 1990; Donatelli et al., 1997; Van Ittersum and Donatelli, 2003).

Many crop simulation models based on plant physiology have been developed during the last decades (Williams et al., 1989; Brisson et al., 2003; Jones et al., 2003; Keating et al., 2003; Stöckle et al., 2003; Van Ittersum et al., 2003). CropSyst (Stöckle et al., 2003) is a process-based simulation model that has been increasingly used in recent years with several crops and cropping systems (Stöckle et al., 1994; Pala et al., 1996; Donatelli et al., 1997; Stöckle and Debaeke, 1997; Pannkuk et al., 1998; Ferrer et al., 2000; Peralta and Stöckle, 2001; Confalonieri and Bechini, 2004; Confalonieri and Bocchi, 2005; Bechini et al., 2006; Benli et al., 2007; Marsal and Stöckle, 2012; Marsal et al., 2013). CropSyst is different from other models because it simplifies the description of some processes (Confalonieri and Bocchi, 2005), so it is easier to calibrate with a reduced set of crop parameters.

The cropping systems model CropSyst has been developed as a management-oriented tool which has been evolving to give responses to new demands on agro-ecosystem simulation capabilities such as combined cycling of carbon and nitrogen, carbon footprint of agricultural systems, improvements in the use of the water-use efficiency, as well as, assessment of climate change impact on agriculture (Stöckle et al., 2014). Although this model has been used with different purposes to simulate many crops, including potato (Peralta and Stöckle, 2001; Alva et al., 2010), there has been a lack of research focused on the experimental calibration and validation of this model specifically for potato. In addition, the technical adequacy of CropSyst for potato simulations under semiarid conditions has not yet been analysed.

The study area, located in Albacete, a province of Castilla-La Mancha (Spain), requires rational and responsible water management to ensure the sustainability of irrigated agriculture (Ortega et al., 2004). Authors as English et al. (1990) and Domínguez et al. (2012) propose deficit irrigation as a way to increase the water productivity and the profitability of crops. Nevertheless, the use of this methodology in potato may cause a drop in the quantity and quality of tubers (Shock et al., 1998; Fabeiro et al., 2001; Onder et al., 2005; Vos and Haverkort, 2007). As a result, the calibration of a model, such as CropSyst, may be

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useful for determining if deficit irrigation strategies will be able to reduce the use of irrigation water while maintaining the quality of the product and a profitable tuber yield.

The aim of this paper is the calibration and validation of the parameters required by the CropSyst model for simulating the growth of a potato crop in a semiarid Mediterranean environment.

2. Materials and methods

2.1. Experimental design

Experimental data were collected in "CIFP Aguas Nuevas" (Albacete, Spain; 38° 56′ N, 1° 53′ W; altitude: 695 m.a.s.l) during two irrigation seasons in 2011 and 2012 (Camargo et al., 2015). According to Papadakis (1966), the climate of this area is warm Mediterranean.

The agroclimatic station placed in the experimental farm registered the total rainfall during the crop cycle (160 mm and 130 mm, in 2011 and 2012, respectively), and the parameters required for calculating daily FAO-Penman-Monteith ETo (Allen et al., 1998). Temperatures were typical for this climate in 2011, but the maximum temperatures reached in the summer of 2012 were greater than normal (between 35 °C and 41 °C over 19 days). Moreover, 50% of the rainfall occurred between sowing and flowering stages.

The soil of the study area was classified as xeric torriorthent with a loam texture (composition: 4% coarse sand, 28% fine sand, 44% silt, and 24% clay) (USDA-NRCSS, 2006) while the average soil depth was 500 mm.

The experimental area, which was 4.9 ha of an 18.4-ha circular plot, was equipped with a center pivot irrigation system. The center pivot was 238 m in length with a system capacity of 1.3 $l\,s^{-1}\,ha^{-1}$, and it was equipped with "Rotating Spray Plate" type sprinklers (Rotator™ manufactured by Nelson Irrigation Co.). The sprinklers had pressure regulators (output pressure = 140 kPa); their spray pattern width was 9 m, and they were installed at 1.4 m above the soil and spaced 1.5 m apart.

The irrigation system supplied four percentages (120, 100, 80 and 60%) of the crop water requirements (CWR) determined by the methodology proposed by FAO (Allen et al., 1998), in three replicates (Fig. 1). Three replicates per treatment (10-m long and 6-m wide, 60 m^2; Fig. 1) were distributed at random in spans 3 and 4. Spans were equipped with electric valves controlled by the irrigation programmer, the frequency of irrigation was based on six center pivot paths applying the same dose in a given period of time (Table 1).

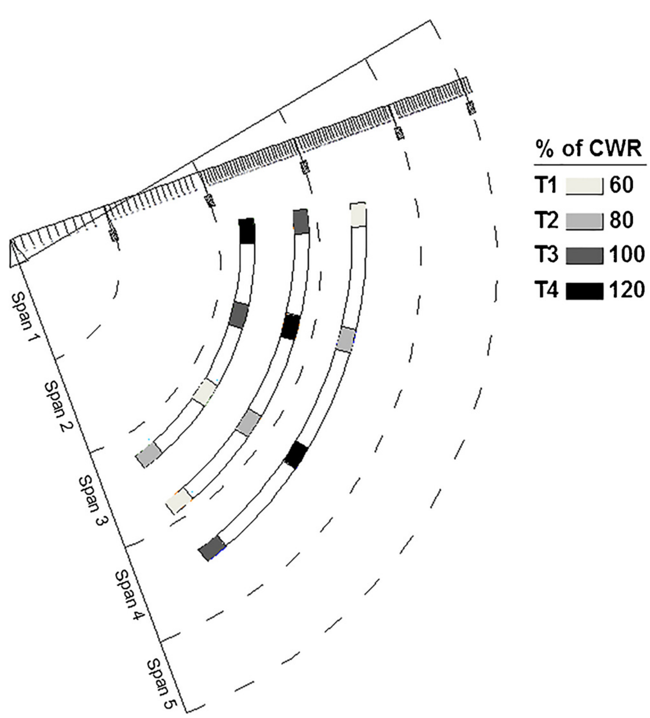

Fig. 1. Spatial treatments distribution in a section of the center pivot.

Table 1
The irrigation frequency (F) and the percentage of the crop water requirements (CWR) for each irrigation treatment.

Treatment	Frequency	% CWR
T1	6 of 6	120
T2	5 of 6	100
T3	4 of 6	80
T4	3 of 6	60

The crop used for the field experiments was the potato (*Solanum* sp.), which is the fifth most important crop grown in the world, and its primary use is as human food and for manufacturing (FAOSTAT, 2016). In Spain, the area of potato cultivation is approximately 71600 ha, of which approximately 2100 ha are located in the Castilla-La Mancha region. The province of Albacete represents 52% of the total area of this region (MAPAMA, 2017).

The potato tubers used at sowing in both seasons were Agria cultivar, whichwere directly sown in the second week of March and harvested at 152 (2011) and 173 (2012) days after planting. The population was 5.9 and 5.7 plants m^{-2} in 2011 and 2012, respectively.

2.2. Crop data sampling

Once per week and following the BBCH scale (Hack et al.,1993), the potato crop development was monitored in all replicates of each treatment. The thermal time required to achieve each phenological stage was computed using 2 °C as the base temperature (Tb) and 26 °C as the upper temperature (Tu) (Montoya et al., 2016; Steduto et al., 2012) (Table 2). The BBCH scale indicates that flowering and tuber formation stages occur simultaneously. Nevertheless, these two stages were not concurrent in 2012 because crop leaf senescence took place after the end of flowering (Camargo et al., 2015) (Table 2).

According with Alva et al. (2010), potato crop growth was monitored every 15 days by measuring dry matter weight, canopy cover (CC), leaf area index (LAI) and absorbed photosynthetically active radiation (PARab) for each replicate of the four treatments. Between crop establishment and harvest, the crop was sampled on 8 and 9 occasions in the 2011 and 2012 irrigation seasons, respectively. After being oven-dried at 60 °C for 48 h (until constant weight), the dry matter content of each potato vegetative structure was obtained for two plants selected on each sampling occasion. These plants were also used to measure the leaf area using a LI-COR-3100C (LI-COR Inc., Lincoln, Nebraska, USA) and to compute the LAI throughout the plant density. CC was obtained using LAIC software (Córcoles et al., 2013; Ballesteros et al., 2014) which inputs data were obtained by a digital camera (Pentax™; Golden, CO, USA) assembled in a quadracopter aircraft (md-400 microdrone; Microdrones Inc., Kreuztal/Germany). According to Varlet-Grancher et al. (1989a, 1989b), PARab was calculated by using a SunScan™ (Delta-T Devices Ltd., Cambridge, UK) device.

At harvest, the central 18 m^2 of each subplot were manually processed to determine crop yield, the dry matter content of the potato tubers (MSt), the total dry matter content (MST), and the harvest index (HI). MSt and MST were recorded through oven-dried of a representative crop sample of each subplot at 60 °C during 48 h (or until constant weight). HI was computed as MSt and MST ratio.

2.3. Irrigation management

Irrigation was scheduled using the simplified water balance in the root zone proposed by Allen et al. (1998). To determine the irrigation