Agricultural Water Management 150 (2015) 119–128

Contents lists available at ScienceDirect

Agricultural Water Management

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

Modeling the impacts of irrigation treatments on potato growth and development

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ARTICLE INFO

Article history:
Received 4 April 2014
Accepted 30 November 2014
Available online 5 January 2015

Keywords:
Center pivot system
Degree days
Growth indices
Growth models
Water deficit

ABSTRACT

We analyze the effects of four irrigation treatments on the growth and development of potatoes (*Solanum tuberosum* L.) cv Agria, using a pivot irrigation system in the province of Albacete (Castilla-La Mancha, Spain), during 2011 and 2012. We find no significant differences between irrigation treatments regarding when the phenological phases are reached. The high day and night temperatures that occurred during the second season contributed to the lengthening of the agronomic cycle. We observed maximum values of leaf area index (LAI), total dry matter (TDM), crop growth rate (CGR), and relative growth rate (RGR) in the non-stress treatments (100% and 120% of crop water requirements). The highest values of total leaf area duration (LAD) were observed in the reference treatment (100% of crop water requirements) in both seasons, while the highest values of leaf area ratio (LAR) were observed when the crop reached full coverage of the soil. In the second season, the net assimilation rate (NAR) was more notably influenced by the water deficit treatments. A water application higher than 100% of crop water requirements did not influence crop growth and development. Therefore, deficit irrigation might be appropriate in areas where water is limited.

1. Introduction

Crop growth and development are important variables in analyzing the influence of climate and other factors on crop physiological processes. In addition, they are necessary variables for optimizing crop production (Botella et al., 1997). This methodology, which is useful for monitoring crop growth during the growing cycle, is based on the use of growth parameters, such as total dry matter or leaf area index.

The increase in accumulated biomass of a plant is the combined result of net photosynthetic activity and growth of vegetative and reproductive organs. Several researchers have studied the relationship between dry matter accumulation days after emergence or growing degree days for different crops (Losavio et al., 1985; Swank et al., 1987; Fabeiro et al., 2001). Mathematical functions that model crop behavior are used to predict and analyze agronomic and physiological processes (Heggenstaller et al., 2009). These models are useful Decision Support System tools (DSS) in irrigated and non-irrigated areas, where farmers incorporate efficient use of water and energy resources to minimize production costs (Tarjuelo et al., 2010).

In Spain, about 2.1 million tons of potatoes are produced annually on 73,900 ha, which represents an average productivity of about 30 t ha^{-1} (FAOSTAT, 2014), and as such is an important crop in this region. In addition, potatoes have a relatively high water consumption (about 6500 m^3 ha^{-1}). In the province of Albacete, groundwater supports about 92% of the irrigated area, and many of the aquifers are overexploited. Annual crops are grown extensively in the province, where sprinklers are used on about 85% of the irrigated area. Irrigation development in the province has been substantial, with about 80,000 ha developed in the last three decades, almost exclusively using groundwater (Montoro et al., 2011). Thus, it is necessary to improve water management by analyzing the influence of water deficit on the agronomic cycle and on crop growth and developmental stages.

Several authors have studied the response of potato to different irrigation treatments (Van Loon, 1981; Yuan et al., 2003; Onder et al., 2005). Ortega et al. (2004) reported that when planning for deficit irrigation of potato in the province of Albacete, it is necessary to consider the gross irrigation depths between 0.85 and 0.97 of ETm. Incorporating growth indices in the analysis is useful for identifying the factors that determine crop yields (Ferreira

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http://dx.doi.org/10.1016/j.agwat.2014.11.017
0378-3774/

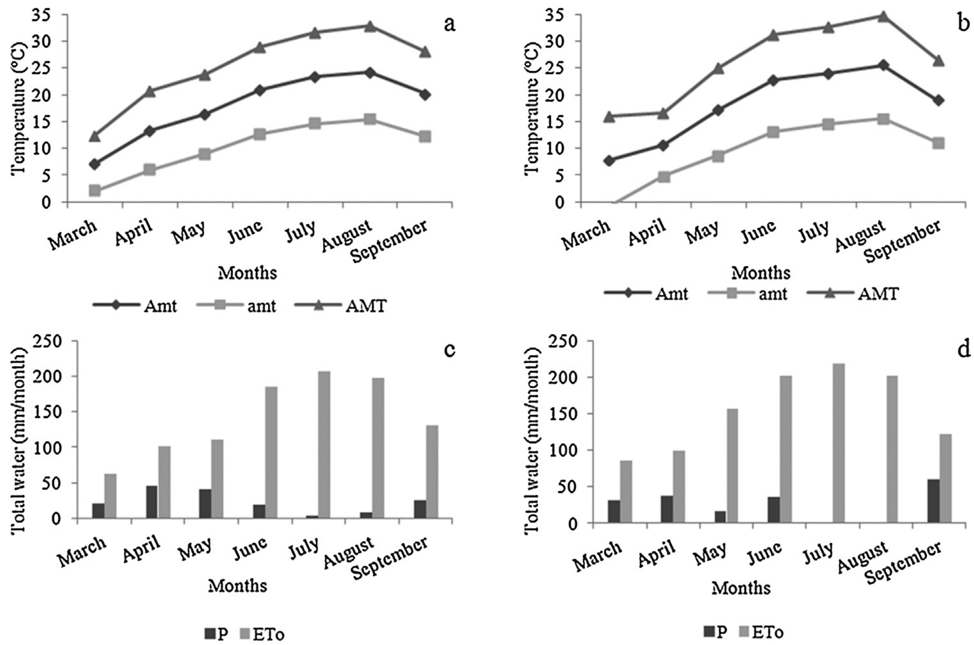

Fig. 1. Rainfall (P) and evapotranspiration (ET_o) monthly average in 2011 (a) and 2012 (b) irrigation season.

and Gonçalves, 2007). Growth analysis using functional or dynamic methods allows for description of growth as a continuous process, obtaining growth indices of the mathematical functions and representing the timing of the primary growth data (dry matter and leaf area) (Venus and Causton, 1979, Hunt, 1982, France and Thornley, 1984). Mathematical modeling is commonly used in agriculture as a methodology for studying physiological processes.

Mathematical crop growth models can be defined as non-linear, describing an asymptotic trajectory of the dependent variable (weight) as a function of time (independent variable) (López et al., 2000; Ruiz et al., 2012). Examples of crop growth models include those of Mitscherlich (1919), Von Bertalanffy (1957), Schnute (1981) and Meloun and Militky (1996). The Gompertz and Logistic models, which are based on a sigmoid function, are the most commonly used (Ratkowski, 1983, Barker et al., 2010). Although both models are similar, the Gompertz model describes a relative growth rate that decreases exponentially with time. In addition, the Gompertz model shows faster growth at the onset, but a slower approach to maximum weight (Barker et al., 2010). In order to model leaf area index (LAI), non-linear regression models are used, such as exponential, polynomial and expo-polynomial model (Tei et al., 1996; Botella et al., 1997; Rinaldi et al., 2010). Our goal in this paper is to analyze the impacts of irrigation treatments on potato crop growth and development in semiarid conditions, with a particular focus on pivot irrigation systems.

2. Materials and methods

2.1. Experimental design

We conducted a field experiment during the 2011 and 2012 irrigation seasons, on a commercial potato farm in Aguas Nuevas (Albacete, Spain). The soil is classified as Torriorthents (USDA, 2006), with medium depth (>600 mm), loam texture and a composition of 4% coarse sand, 28% fine sand, 44% silt, and 24% clay.

The study area is in a warm Mediterranean climate (Papadakis, 1960), characterized by high seasonal variation, with the lowest average temperature in January (monthly average 3.8 °C) and the hottest period between June and August (monthly average 21.5 to 24.4 °C). Average rainfall in the vegetation period is about 195 mm, ranging from 4.1 mm (July) to 40.3 mm (September) per month. The accumulated annual reference evapotranspiration in close to 1296 mm. During the irrigation seasons, the highest temperature was observed in August (above 30 °C). The maximum temperature reached higher values in 2012 (40.7 °C) than in 2011 (34.8 °C).

Fig. 1 shows the difference between the evaporative demand and water supply by precipitation for the 2011 and 2012 irrigation seasons. This difference was greatest in July and August, with reference evapotranspiration values as high as 200 mm (Fig. 1a and b). In 2011, the rainfall during crop establishment (April and May) reached values of 40 mm per month.

The experimental plot is a potato crop covering 4.9 ha of the total 18.4 ha. The central pivot irrigation system had five spans, four 50 m long and one 38 m long, with an overhang of 4 m. The sprinklers had pressure regulators with output pressure set to 140 kPa and a lateral pipe 168.3 mm in diameter. The designed flow rate was 86.4 $m^3 h^{-1}$ with a system capacity of 1.3 $l s^{-1} ha^{-1}$. Rotating Spray Plate Sprinklers (Rotator® manufactured bay Nelson Irrigation Co) were installed at 1.4 m height on all spans. At the beginning of the growing season the discharge from each nozzle was verified using a direct volumetric measurement method (Tarjuelo, 2005). Using data from an agrometeorological station located 150 m from the plot, we calculated reference evapotranspiration (ET) on a daily basis by means of the Penman–Monteith semi-empirical model (Allen et al., 1998)

The pivot irrigation system was equipped with electric valves controlled by one irrigation programer per span. The programer executes a time-based routine to open and close the valves as the pivot irrigates the selected experimental plots. During the irrigation of a quarter-circumference, valves open and close in the different spans to perform the differential irrigation treatments. The experiment was performed in 12 experimental plots, distributed at random between the third and fourth spans. Each plot was 6 m wide and 10 m long (60 m^2) (Fig. 2).

There were four irrigation treatments (with three replicates of each) with the proportions of satisfaction of the crop water requirements (CWR) set at 60%, 80%, 100% and 120%. Irrigation was scheduled using a simplified water balance method within the root zone, following the Food and Agriculture Organization