Agricultural Water Management 101 (2011) 107–117

Contents lists available at SciVerse ScienceDirect

Agricultural Water Management

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

Evaluation of the VegSyst model with muskmelon to simulate crop growth, nitrogen uptake and evapotranspiration

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ARTICLE INFO

Article history:
Received 1 July 2011
Accepted 20 September 2011
Available online 14 October 2011

Keywords:
Crop growth
Model
Greenhouse
Nitrogen uptake
Evapotranspiration
Melon

ABSTRACT

Like many intensive vegetable production systems, the greenhouse-based system on the south-eastern (SE) Mediterranean coast of Spain is associated with considerable NO_3^- contamination of groundwater. Drip irrigation and sophisticated fertigation systems provide the technical capacity for precise nutrient and irrigation management of soil-grown crops which would reduce NO_3^- leaching loss. The VegSyst crop simulation model was developed to simulate daily crop biomass production, N uptake and crop evapotranspiration (ET_c). VegSyst is driven by thermal time and consequently is adaptable to different planting dates, different greenhouse cooling practices and differences in greenhouse design. It will be subsequently incorporated into a practical on-farm decision support system to enable growers to more effectively use the advanced technical capacity of this horticultural system for optimal N and irrigation management.

VegSyst was calibrated and validated for muskmelon grown in Mediterranean plastic greenhouse in SE Spain using data of four melon crops, two grown in 2005 and two in 2006 using two management strategies of water and N management in each year. VegSyst very accurately simulated crop biomass production and accurately simulated crop N uptake over time. Model performance in simulating dry matter production (DMP) over time was better using a double radiation use efficiency (RUE) approach (5.0 and 3.2 $g\,MJ^{-1}$ PAR for vegetative and reproductive growth phases) compared to a single RUE approach (4.3 $g\,MJ^{-1}$ PAR). The simulation of ET_c over time, was very accurate in the two 2006 muskmelon crops and somewhat less so in the two 2005 crops. The error in the simulated final values, expressed as a percentage of final measured values was −1 to 6% for DMP, 2–11% for crop N uptake, and −11 to 6% for ET_c. VegSyst provided effective simulation of DMP, N uptake and ET_c for crops with different planting dates. This model can be readily adapted to other crops.

1. Introduction

Intensive vegetable production systems commonly require large applications of irrigation and nutrients, particularly nitrogen (N) to achieve high yields (Pratt, 1984). The combination of irrigation and high N use, in intensive vegetable production, commonly results in substantial nitrate (NO_3^-) leaching loss and consequent NO_3^- contamination of groundwater (Pratt, 1984). This is the case with the greenhouse system located on the south-east (SE) Mediterranean coast of Spain, mostly in the province of Almería (Pulido-Bosch et al., 2000; Pulido-Bosch, 2005), which with 37,000 ha is one of the largest concentrations of greenhouses in the world (Castilla and Hernández, 2005).

This agricultural system, based on relatively simple plastic greenhouses, known as Mediterranean-type greenhouses, has been expanding rapidly throughout mild winter coastal areas in the Mediterranean Basin (Castilla, 2002; Castilla et al., 2004; Pardossi et al., 2004) and Central America (Castilla et al., 2004; Pardossi et al., 2004). This greenhouse system is principally used for vegetable production, and commonly crops are grown in soil (Castilla and Hernández, 2005; Pardossi et al., 2004). With the geographical expansion of this horticultural system, there is likely to be a similar expansion of associated environmental problems.

A survey, in commercial greenhouses in SE Spain, identified various N and irrigation management practices responsible for the large NO_3^- leaching loss in this system (Thompson et al., 2007). Many greenhouses have combined drip irrigation and sophisticated computer-controlled fertigation systems capable of precise N and

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doi:10.1016/j.agwat.2011.09.008

irrigation application (Thompson et al., 2007; Céspedes et al., 2009). Management tools are required to enable growers to more effectively use this advanced technical capacity for optimal irrigation and N management. An envisaged tool, for this purpose, is a practical decision support system (DSS), intended for on-farm use, that would provide daily plans of N and irrigation requirements.

To be effective for on-farm use, such a DSS requires a relatively simple simulation model to calculate N uptake and daily crop evapotranspiration (ET_c) using a small number of readily available data inputs. The various available models that simulate N and water dynamics in the crop-soil system such as EPIC (Williams et al., 1984), STICS (Brisson et al., 1998), CropSyst (Stöckle et al., 2003) and the DSSAT group of models (Jones et al., 1998) are large and complex models which commonly require numerous inputs, and generally have been developed for cereal crops.

Melon is the third most important crop, in terms of area, in the greenhouse-based vegetable production system of SE Spain (Consejería de Agricultura y Pesca, 2009). The area with melon has increased over recent years; in particular of the muskmelon types “Galia” and “Cantaloupe” that are mostly exported to northern Europe. The planting date of muskmelon, in this area, varies considerably, between mid-December and mid-May. Differences in planting date cause appreciable differences in growth pattern, and in water and N requirements. Additionally, differences between greenhouses in design and cooling techniques can also influence water and N requirements. Simulation models provide a means for developing crop N and irrigation management programs that consider these variations. Currently, there are no published simulation models of crop N uptake and ET_c for melon that have the simplicity required for on-farm use.

This work describes the VegSyst simulation model, developed to assist with N and irrigation management of greenhouse vegetable crops, and its calibration and validation with muskmelon. VegSyst is relatively simple crop simulation model driven by thermal time that calculates daily crop biomass production, N uptake and ET_c. The model assumes that crops have no water or nutrient limitations, which is realistic for intensively managed crops grown in greenhouses. Being driven by thermal time, VegSyst is adaptable to different planting dates, different greenhouse cooling practices and differences in greenhouse design. In subsequent work, the VegSyst model will be incorporated into a practical DSS intended for on-farm use.

2. Materials and methods

2.1. Model description

The VegSyst model simulates crop biomass production, crop N uptake and crop evapotranspiration in greenhouse-grown vegetable crops. In the present work it was calibrated and validated with muskmelon crops grown in soil in Mediterranean-type plastic greenhouses in SE Spain. The model inputs are daily climatic data of maximum and minimum daily temperature, maximum and minimum relative humidity, and the daily integral of solar radiation, in addition to latitude. The model assumes that crops have no water or nutrient limitations.

VegSyst simulates the fraction of intercepted photosynthetically active radiation (PAR) radiation ($f_{i\text{-}PAR}$) from thermal time. Thermal time is estimated from daily maximum and minimum air temperature using the single triangulation method (Zalom et al., 1983). The fraction of intercepted PAR ($f_{i\text{-}PAR}$) is calculated as a function of the relative thermal time (*RTT*) with respect to either the maximum intercepted PAR at full cover or at maturity, to avoid differences associated with the crop growing period (Eqs. (1a) and (1b)). Two periods are considered in the crop season: (i) period 1 from transplanting until maximum PAR interception and (ii) period 2 from maximum PAR interception until crop maturity (the end of the crop). In period 2, there is a reduction in PAR interception because of partial leaf senescence. For each period, *RTT* is calculated as:

$$RTT_1 = \frac{CTT_i}{CTT_f} \tag{1a}$$

$$RTT_2 = \frac{CTT_i - CTT_f}{CTT_{mat} - CTT_f} \tag{1b}$$

where RTT_1 and RTT_2 are relative thermal time for periods 1 and 2, respectively, and CTT_i, CCT_f and CTT_{mat} are the cumulative thermal time (CTT) at day *i*, at maximum PAR interception, and at crop maturity, respectively.

Two exponential relationships between $f_{i\text{-}PAR}$ and *RTT*, one for each period, were developed:

$$\text{Period}\quad 1: \quad f_{i\text{-}PAR} = f_0 + \left[\frac{f_f - f_0}{1 + B_1 \exp(-a_1 RTT_1)}\right] \tag{2a}$$

$$\text{Period}\quad 2: \quad f_{i\text{-}PAR} = f_f - \left[\frac{f_f - f_{mat}}{1 + B_2 \exp(-a_2 RTT_2)}\right] \tag{2b}$$

where f_f is the maximum fraction of intercepted PAR, and f_0 and f_{mat} are the fractions of PAR intercepted at transplanting and at maturity, respectively. The coefficients a_1, and a_2, are the equation fitting coefficients (called from here on the “shape coefficients”) for periods 1 and 2, respectively. B_1 and B_2 are coefficients derived from $RTT_{0.5}$ for periods 1 and 2, respectively. $RTT_{0.5}$ represents the relative thermal time at which $f_{i\text{-}PAR} = 0.5 \times (f_0 + f_f)$ (for period 1) or $f_{i\text{-}PAR} = 0.5 \times (f_f + f_{mat})$ (for period 2). In Eqs. (2a) and (2b), the B_1 and B_2 coefficients were calculated as:

$$B_1 = \frac{1}{\exp(-\alpha_1 RTT_{0.5})} \tag{3a}$$

$$B_2 = \frac{1}{\exp(-\alpha_2 RTT_{0.5})} \tag{3b}$$

in which $RTT_{0.5}$ in Eq. (3a) was for period 1, and $RTT_{0.5}$ in Eq. (3b) was for period 2.

Daily PAR interception (PAR_i) was calculated from daily values of $f_{i\text{-}PAR}$ and the daily sum of PAR inside the greenhouse that was obtained from the product of measurement of the daily sum of solar radiation inside the greenhouse (Rs), and a ratio PAR/Rs for plastic greenhouses of 0.43 (Kittas et al., 1999).

Dry matter production for a given day (DMP_i) was calculated as:

$$DMP_i = PAR_i \times \text{RUE} \tag{4}$$

where RUE is radiation use efficiency which was determined using the SOLVER procedure (Microsoft Excel 2003) as the value that minimized the differences between simulated and measured DMP against CTT. Two approaches were tested for muskmelon: (i) double RUE, where two values of RUE were obtained, one for the period of vegetative growth (for CTT < 585° D) and the other for reproductive growth (CTT ≥ 585° D), and (ii) the single RUE, where one value of RUE was obtained for the entire crop. In the double RUE approach, the second period started when the exponential growth phase of the fruits commenced and full canopy cover was obtained. Crop N uptake for a given day was determined as the product of the DMP_i and the simulated crop nitrogen content ($\%N_i$) for that day, calculated as:

$$\%N_i = a \times DMP_i^b \tag{5}$$

where *a* and *b* are calibration factors obtained from experimental data.

Crop evapotranspiration (ET_c) was simulated following the FAO approach (Doorenbos and Pruitt, 1977; Allen et al., 1998) as the