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Research Paper

Assessing potato transpiration, yield and water productivity under various water regimes and planting dates using the FAO dual K_c approach

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ABSTRACT

Two years of experimental field data on potato (var. Spunta) were used to calibrate and validate the SIMDualKc model. This model adopts the FAO dual K_c approach that provides the partition of crop evapotranspiration into crop transpiration and soil evaporation. Results of model calibration show a good agreement between soil water observations and predictions, with low errors of estimate – RMSE <3.7% of the mean observed soil water – and high modelling efficiency (>0.87). The calibrated basal crop coefficients for the initial stage, mid-season and end of season are 0.15, 1.10 and 0.35, respectively. After model calibration, the crop transpiration simulations were used to derive the yield response factor ($K_y = 1.09$). Coupling SIMDualKc with the Stewart's model provided for a good prediction of yields, with NRMSE lower than 8%. Irrigation scheduling scenarios were simulated with SIMDualKc model for various planting dates and limited stress conditions. Related results have shown that anticipating planting dates to the second half of February could lead to less irrigation requirements, higher yields and better water productivity relative to consumptive water use (WP_{ET}), crop transpiration (WP_T) and seasonal water use (WP_{WU}). These WP indicators were useful comparators. Contrarily, the WP relative to season irrigation depths (WP_{Irrig}) showed a great variation among scenarios and a tendency to be higher when deficit irrigation was applied, which contradicts the objectives of farmers in terms of obtaining high yields and economic returns. The model and methodologies used were adequate to support irrigation management advising for farmers.

1. Introduction

Potato (*Solanum tuberosum* L.) is one of the most important staple crops in the world, with 368 million t production (FAO, 1996). In the Mediterranean area, about 1 million ha are cultivated with potato (Cantore et al., 2014).

Potatoes have a relatively shallow rooting system (Yamaguchi and Tanaka 1990; Ahmadi et al., 2011; Quiroz et al., 2012), thus requiring frequent wetting by rain or irrigation, particularly in areas with high climatic evaporative demand and when cropped in soils with low water holding capacities (Ojala et al., 1990; Ahmadi et al., 2010). Potato is considered to be very sensitive to water stress during the tuber initiation and tuber bulking stages (Doorenbos and Kassam, 1979; Shock et al., 1998; Ierna and Mauromicale, 2006, 2012; Pavlista, 2015). In contrast, some studies report that water stress imposed during tuber initiation had limited effect on yield (Martin et al., 1990; Carli et al., 2014; Karam et al., 2014). However, numerous studies analyzing the impacts of deficit irrigation on potato yields mainly assess the impacts of decreased water applied regardless of crop growth stages, i.e. without properly considering the most sensitive water stress stages (e.g., Onder et al., 2005; Jensen et al., 2010; Carli et al., 2014). Other studies have focused on the interactive effects of water and fertilization, generally showing a marked impact on tuber yield of nitrogen associated with water availability (Ojala et al., 1990; Ferreira and Gonçalves, 2007).

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Nomenclature

List of acronyms and symbols

FI	Irrigation treatment aimed at full satisfaction of crop water requirements
NI	Rain-fed treatment
RI	Reduced irrigation treatment
Full	Full irrigation scenario
Mild	Mild water stress irrigation scenario
Mod	Moderate water stress irrigation scenario
AAE	Average absolute error (same units as observations)
a_D	Deep percolation equation parameter (dimensionless)
ARE	Average relative error (%)
ASW	Available soil water (mm)
b_0	Regression coefficient of the linear regression forced to the origin (dimensionless)
b_D	Deep percolation equation parameter (dimensionless)
BWUF	Beneficial water use fraction (dimensionless)
CGDD	Cumulative growing degree days (°C)
CR	Capillary rise from the shallow groundwater table (mm)
DP	Deep percolation (mm)
D_r	Root zone depletion (mm)
DU	Irrigation system distribution uniformity (%)
EF	Modelling efficiency (dimensionless)
E_s	Soil evaporation (mm)
ET_c	Standard (non-stressed) crop evapotranspiration (mm)
ET_{cact}	Actual crop evapotranspiration (mm)
ET_o	Reference evapotranspiration (mm)
f_c	Fraction of soil cover by vegetation (dimensionless)
h	Crop height (m)
I	Net irrigation depth that infiltrates the soil (mm)
IWU	Total irrigation water use (mm)
K_c	Average crop coefficient (dimensionless)
K_{cmax}	Maximum average crop coefficient (dimensionless)
K_{cmid}	Average crop coefficient for the mid-season stage (dimensionless)
K_{cb}	Basal crop coefficient (dimensionless)
K_{cbact}	Actual basal crop coefficient (dimensionless)
K_{cbend}	Basal crop coefficient for the end season (dimensionless)
K_{cbmid}	Basal crop coefficient for the mid-season (dimensionless)
K_e	Soil evaporation coefficient (dimensionless)
K_s	Water stress coefficient (dimensionless)
K_y	Yield response factor for the entire crop growth season (dimensionless)
LAI	Leaf area index ($cm^2\ cm^{-2}$)
MAD	Management allowed depletion (dimensionless)
MSE	Mean square error (same units as observations)
NID	Seasonal net irrigation depth (mm)
NRMSE	Normalized root mean square error (%)
P	Precipitation (mm)
p	Depletion fractions for no stress (dimensionless)
PBIAS	Percent bias (%)
P_e	Effective precipitation (mm)
R^2	Determination coefficient of the ordinary least-squares regression (dimensionless)
RAW	Readily available soil water (mm)
REW	Readily evaporable soil water (mm)
RH_{max}	Maximum air relative humidity (%)
RH_{min}	Minimum air relative humidity (%)
RMSE	Root mean square error (same units as observations)
RO	Runoff (mm)
R_s	Solar radiation ($MJ\ m^{-2}\ d^{-1}$)
SWC	Soil water content ($cm^3\ cm^{-3}$)
TAW	Total available soil water (mm)
T_c	Maximum crop transpiration (mm)
T_{cact}	Actual (or adjusted) transpiration (mm)
T_d	Transpiration deficit (mm)
TEW	Total evaporable water (mm)
T_{max}	Maximum air temperature (°C)
T_{min}	Minimum air temperature (°C)
u_2	Wind speed at 2 m height ($m\ s^{-1}$)
WP_{ET}	Consumptive use water productivity ($kg\ m^{-3}$)
WP_{Irrig}	Irrigation water productivity ($kg\ m^{-3}$)
WP_T	Transpiration water productivity ($kg\ m^{-3}$)
WP_{WU}	Water productivity of water used ($kg\ m^{-3}$)
Y_a	Actual yield ($t\ ha^{-1}$)
Y_m	Potential yield ($t\ ha^{-1}$)
Z_e	Thickness of the evaporation soil layer (m)
Z_r	Root depth (m)
ΔSW	Seasonal use of the soil water (mm)

Studies on impacts of irrigation on yields often refer to the appropriateness of adopting water saving irrigation strategies (e.g., Ierna and Mauromicale, 2012; Camargo et al., 2015), while others express doubts because high yield losses may occur (Jensen et al., 2010; Quiroz et al., 2012). Differently, some studies clearly suggest to reduce irrigation only after tuberization or during the late-season, when impacts on yields are less (Jensen et al., 2010; Carli et al., 2014; Karam et al., 2014; Pavlista, 2015). However, decisions on water saving require appropriate economic assessment of irrigation impacts on yields (Shock et al., 1998; Zairi et al., 2003; Woli et al., 2016). Several studies include water productivity assessments using various conceptual approaches that are, generally, insufficiently discussed. Some studies justify water saving in relation to the increase of water productivity (Ahmadi et al., 2010, 2014), but without economic considerations.

In the Mediterranean area, potato is often cropped during the winter-spring period, when most of precipitation occurs (Ierna and Mauromicale, 2012). On the one hand, early planting results in shorter day lengths and lower temperature, which may delay emergence, expand crop cycle and decrease tuber yield (Ierna and Mauromicale, 2006; Levy and Veilleux, 2007; Quiroz et al., 2012; Levy et al., 2013). On the other hand, late planting exposes the crop to higher risks of heat and water stress, namely during the most sensitive stages (Levy and Veilleux, 2007; Quiroz et al., 2012; Wang et al., 2015). Consequently, early planting may be considered as a climate change adaptation provided that an increase in temperature is predicted. If water and nutrients supply remains satisfactory, higher temperatures and higher CO_2 likely increase potato yields (Daccache et al., 2011; Haverkort and Struik, 2015). However, irrigation water requirements may increase by 30% (Daccache et al., 2011) and lead to a decrease of water productivity (Xiao et al., 2013; Haverkort and Struik, 2015).

Many potato growth and yield models exist. In their review, Raymundo et al. (2014) identified more than 30 models, but some of them are not specific for potato, e.g., the FAO AquaCrop model as used by Linker et al. (2016). Models have a very different structure, adopt diverse approaches and focus on different processes.