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Comparing AquaCrop and CropSyst models in simulating barley growth and yield under different water and nitrogen regimes. Does calibration year influence the performance of crop growth models?

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ABSTRACT

This work investigated the performance of AquaCrop and CropSyst in simulating barley growth under three water treatments (full irrigation, 50% irrigation and rainfed) and two nitrogen levels (high and low) with a particular attention to the influence of calibration year on the modelling results. Three years (2006–2008) of data from the experimental work carried out in Southern Italy were used. The models were calibrated for each of three years and then validated for two other years. The overall results pointed out that both models could be calibrated with data of one of any the three years and validated with all other data. Nevertheless, errors of estimate slightly changed in respect to the year of calibration and were sensitive, from one year to another, to weather conditions and different water and nitrogen regimes. The results indicated AquaCrop superior than CropSyst when the calibration was done on the basis of 2006 and 2008 data, whereas the models performed in a similar way when the calibration was done for 2007. In the case of final biomass, the relative RMSE was lower for AquaCrop (from 0.09 to 0.15) than for CropSyst (from 0.15 to 0.17). Similarly, in the case of final yield, the relative RMSE of AquaCrop was lower (from 0.11 to 0.17) than that of CropSyst (from 0.16 to 0.23). AquaCrop overestimated final biomass by 0.18 and 0.27 t ha^{-1} for 2006 and 2008 calibration year, respectively, and underestimated biomass by 1.02 t ha^{-1} when calibration was done on 2007 data. CropSyst underestimated biomass independently on the calibration year, from 0.83 to 1.26 t ha^{-1}.

1. Introduction

The simulation of crop development and growth is based on a complex interaction between weather parameters, soil properties, plant genetic characteristics and management practices that influence crop response to various water and nutrient inputs (Sinclair and Seligman, 2000; Janssen and van Ittersum, 2007). Nowadays, there is an increasing number of models and modelling approaches being adapted for specific purposes and scales of application, and using different input variables and crop growth engines (Hammer et al., 2002; Li et al., 2009; Todorovic et al., 2009). The capability of models to simulate adequately crop growth and development under different management practices is one of challenges to modern agricultural production. The use of crop growth models in agriculture favours pro-active management of water resources and supports the elaboration and comparison of the management scenarios that aim at the reduction of non-beneficial water uses and the increase of crop water productivity and economic farm revenue. In fact, many modelling efforts have clearly led to the improvement of scientific understanding of the crop response under different environmental conditions and management strategies (van Ittersum et al., 2003; Singh et al., 2008; Evett and Tolk, 2009). A particular attention has been given to the improvement of model's capability for simulation of cereals growth and yield due to their strategic importance for food security at global and regional scale. Such examples are the CERES family of crop growth models, developed within the decision support system for agro-technology transfer—DSSAT (Tsuji et al., 1994; Jones et al., 2003), CropSyst (Stöckle et al., 1994, 2003), WOFOST (Boogaard et al., 1998), APSIM (McCown et al., 1996; Keating et al., 2003), EPICphase (Cabelguenne et al., 1999), STICS (Brisson et al., 2003) and AquaCrop (Steduto et al., 2009; Raes et al., 2009).

Crop production and yield stability of cereals are strongly questioned by availability of water and nitrogen and their mutual

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interaction over the growing season (Cooper et al., 1987; Campbell et al., 1993; Albrizio et al., 2010). This is especially true for arid and semi-arid regions, such as the Mediterranean environments, characterized by variable distribution of precipitation and climatic conditions along a year and among the years, permanent water shortage, poor soil quality and limited availability of arable land (Oweis et al., 1998; Passioura, 2002; Abeledo et al., 2008). In these environments, the inter-annual variability produces a high uncertainty in which crop management decisions, such as nitrogen fertilization and water input, have to be taken. Consequently, crops such as durum wheat and barley are largely cultivated because of their ability to use precipitation input during the winter season and to keep a satisfactory level of agricultural production even under moderate water stress especially if it occurs after the flowering (Oweis et al., 2000; Acevedo et al., 2002). In particular, this has been proved for barley, indicating this crop to be more tolerant than wheat to drought conditions in the areas with annual precipitation below 400 mm (Jamieson et al., 1995) and seasonal precipitation between 250 and 350 mm (Wahbi and Sinclair, 2005). However, few works were addressed to investigate barley response under different water and nitrogen regimes (Albrizio et al., 2010 and references within). Moreover, only few studies were addressed to model growth and yield of barley. Goyne et al. (1996) simulated barley yields in southern Queensland, Australia. Ferrer-Alegre and Stöckle (1999) applied CropSyst in assessing the barley response to salinity at several locations in Spain and California. At several locations in Italy, Donatelli et al. (1997) used CropSyst for the simulation of durum wheat and barley growth, while Tubiello et al. (2000) employed CropSyst for assessing the impact of climate change on wheat and barley growth and development. Wahbi and Sinclair (2005) developed a specific modelling structure for comparisons between simulation results for barley and wheat grown at several locations in Syria. Araya et al. (2010a) tested AquaCrop model, for simulating biomass and yield of barley grown under different water inputs in Ethiopia. Abrha et al. (2012) applied AquaCrop to analyze barley yield response to water under different sowing strategies and at different locations; Rötter et al. (2012) compared nine crop models by simulated spring barley yield in different climatic zones of Northern and Central Europe. Finally, Dechmi and Skhiri (2013) evaluated best management practices for barley using SWAT model. However, no crop growth model has been applied so far for simulation of barley growth and yield under different nitrogen regimes.

This work aims at comparing CropSyst with AquaCrop, by modelling growth and yield of barley under different water and nitrogen regimes in a Mediterranean environment. The models used in this study differ in the crop growth engine, the number of input parameters, the way of simulation of canopy growth, the partitioning between evaporation and transpiration, and accumulation of harvestable yield. Therefore, it is expected that these peculiarities could affect the simulation results. Secondary objective is to examine the conservative behaviour of the main crop growth parameters of both models when calibration was performed for different years, i.e. under specific weather conditions. In fact, it is expected that the variability of weather factors and management practices from a year to another could influence the calibration parameters and affect the performances of crop growth models.

2. Materials and methods

2.1. Experimental work

2.1.1. Site description

The data used in this study were obtained from the field experiments conducted at the Mediterranean Agronomic Institute of Bari (Southern Italy, latitude 41°03′N, longitude 16°52′E, and elevation 72 m a.s.l). The fields were located about 8 km far from Adriatic Sea in an area characterized by typical Mediterranean climate. 35-year average annual rainfall of 528 mm is mostly concentrated in autumn and winter seasons. Daily weather data were collected regularly at the agro-meteorological station of Bari Institute placed about 200 m far from the experimental fields. The soil of the experimental fields, around 0.7–0.8 m deep over bedrock, was a sandy clay–loam and defined as Lithic–Ruptic–Inceptic–Haploxeralfs (USDA, 2006). Permanent wilting point and field capacity, measured in the laboratory by pressure plate apparatus (Dane and Hopmans, 2002) were at 0.16 and 0.31 $cm^3\ cm^{-3}$, respectively; the saturated hydraulic conductivity, measured by falling head permeameter (Reynolds and Elrick, 2002), was 20 cm day^{-1}; the soil water holding capacity was about 120 mm. All the measurements were an average of the whole soil profile (0–80 cm).

2.1.2. The experiments

Barley (*Hordeum vulgare* L.), cv Ponente sown in rows 0.18 m apart with a final density of about 250 plants m^{-2}, was cultivated for three consecutive growing seasons 2005–2006, 2006–2007, and 2007–2008, labelled in the text as 2006, 2007 and 2008, respectively. The barley cultivar required the vernalization period.

The experiment, including three irrigation treatments (full recovering of crop evapotranspiration, 50% of full irrigation supply and rainfed) and two nitrogen (N) levels (with N and without N application) with three replicates, was part of a more complex experiment (for details see Albrizio et al., 2010). A total of 18 plots were established corresponding to the following treatments: (a) full irrigation with N (I100 + N), (b) full irrigation without N (I100), (c) deficit, 50% irrigation with N (I50 + N), (d) deficit, 50% irrigation without N (I50), (e) rainfed with N (R + N) and (f) rainfed without N supply (R). The analysis of variance has been preliminary performed in order to assess that the treatments were statistically different.

Nitrogen, in the form of ammonium sulphate (21%), was applied manually two times during the growing cycle: before tillering and at the beginning of stem elongation phase. Total amount of N applied in 2006 was 60 kg ha^{-1}, while it was 120 kg ha^{-1} in 2007 and in 2008 (for further information see Albrizio et al., 2010).

The irrigation was managed using an Excel model for real-time irrigation management at field scale (Todorovic, 2006). Reference evapotranspiration (ET_o) was calculated on a daily basis by using weather data acquired at the nearby meteorological station and applying the FAO Penman–Monteith equation (Allen et al., 1998). The crop evapotranspiration was calculated through the single crop coefficient approach. The K_c values were fixed following Allen et al. (1998). The gravimetric method was used several times during each of three growing seasons to measure the soil water content in the root zone and to make eventual adjustments of soil water balance and irrigation supply with respect to the estimated values (Todorovic, 2006).

Drip irrigation method was applied by using one emitter line for two crop rows and drippers with 1.5 L h^{-1} flow rate, 0.2 m apart. Flow-meters, one for each irrigation treatment, was placed on the main lines of the experimental field to measure the amount of water supplied. Irrigation was stopped at dough maturity stage. Due to plenty precipitation input in all of three years under study, total net irrigation supply was low: it was similar in 2006 and 2008 (143 and 146 mm, respectively supplied to I100), whereas in 2007 the amount supplied to I100 was 106 mm; half amount was supplied to I50.

2.1.3. Measurements

A synthesis of main weather variables and reference evapotranspiration corresponding to the phenological phases of barley for three years of experimental work are given in Table 1. Both