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SWAP, CropSyst and MACRO comparison in two contrasting soils cropped with maize in Northern Italy

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ABSTRACT

The quantification of the water balance terms within soil-crop-climate systems is required to derive proper management for plant growth and irrigation. A large number of available models use the well known Richards' equation for the simulation of water redistribution at field scale. Despite their common basis of the representation of water flow in the unsaturated zone, apparently similar hydrological models give different answers if applied in the same pedological, climatic and agronomic scenarios.

The objective of the present study was evaluating and comparing the performance of three well known models (SWAP, MACRO and CropSyst) based on the solution of the Richards' equation: in a structured fine soil (Calciustepts located in Cerese, Mantova, Italy) and in a structured fine loamy over sandy soil (Hapludalf located in Caviaga, Lodi, Italy), both cropped with maize. The models were compared on the basis of their reliability to predict soil water content, measured by TDR, at 10 depths over 2 years.

We compared the three models on the basis of difference-based indexes (CRM and RMSE) and correlation statistics (r and EF): at three depths (0–0.15, −0.4 and −1.0 m), in terms of soil water content profile following a drainage process on bare soil and on soil water content over the whole soil profiles.

Although water retention and hydraulic conductivity curves were properly measured in laboratory on undisturbed soil samples, all three models required calibration and validation to obtain good quality simulations. The performances of the three models were quite similar: the average of all (models, sites and depths) root mean square error (RMSE) was 0.032 $cm^3\,cm^{-3}$ (±0.007).

Generally, SWAP had the best performance especially in simulating surface infiltration and drying processes, followed by CropSyst and then MACRO.

The better performance of SWAP respect the other two models seemed rely on the hydraulic properties parameterization (van Genuchten-Mualem vs. Campbell equation), and to the different techniques used for the numerical solutions of Richards' equation close to the bottom and upper boundaries. Moreover, despite its rather good performance, CropSyst, due to its internal numerical constraints in the parameterization of the retention and conductivity functions, needed a very strong calibration then loosing part of its "physical basis" towards an increasing of its empiricism.

1. Introduction

The accurate quantification of the water balance and water redistribution in soil is strictly required for a proper simulation of solute transport and for management of plant growth and irrigation.

Nowadays the solution of Richards' equation (Richards, 1931) is the standard approach in water balance modeling in order to deal with infiltration and water redistribution in soil. Several models solving Richards' equation are available (e.g., SWAP (Van Dam et al., 1997; Kroes et al., 1998), CropSyst (Stöckle et al., 2003; Stöckle and Nelson, 2005), Hydrus (Šimůnek et al., 2005), RZWQM (Ahuja et al., 2000) and MACRO (Larsbo and Jarvis, 2003)). Despite their common basis of the representation of water flow in the unsaturated zone, apparently similar hydrological models give different results when applied in the same pedological, climatic and agronomic scenarios (Šimůnek et al., 2003; Vanderborght et al., 2005).

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Evaluations of new models are frequently reported in the literature (i.e., Vanclooster et al., 1995; Kroes et al., 2000; Sheikh and van Loon, 2007; Abraha and Savage, 2008; Suleiman, 2008), whereas few studies are focused on models results comparison. This topic is very important when we have to choose the most suitable model for practical applications in terms of equilibrium between performance and complexity in input requirement (Confalonieri et al., 2009).

Scanlon et al. (2002) compared seven models simulating shallow soil water balance of non-vegetated systems. According to their results, most of the differences between measured and simulated soil water content (SWC) values are due to the water retention curve parameterization, to the time discretization of precipitation input, to the upper boundary condition during precipitation and to the lower boundary condition. Eitzinger et al. (2004) compared SWAP, WOFOST (Supit et al., 1994) and CERES (Ritchie, 1998) models performance in simulating soil water content and crop yields over winter wheat and spring barley cropping season. Parameterization of evapotranspiration and root growth shows to be the most relevant factor affecting models performance. Vanderborght et al. (2005) compared the numerical solution of Richards' and Convection–Dispersion equations for water flow and solute transport, implemented in five models (SWAP; MACRO; HYDRUS; WAVE (Vanclooster et al., 1996); MARTHE (Thiery, 1990)) against a set of analytical solutions. Spatial discretization of the pressure head profile close to the soil surface and methods of averaging the hydraulic conductivities show to be the main sources of differences in model results.

Most of these studies are conducted on soils ranging from sandy to loam while few are the scientific contributions on clayey soils.

Our study deals with field measurements and model simulations at two sites in the Po Valley, the largest irrigated area of Northern Italy with mainly loamy and clayey soils. In this area, cropping system models were evaluated by Confalonieri and Bechini (2004) on alfalfa, Acutis et al. (2000) on maize and rye grass, Donatelli et al. (1997) on barley, maize and soybean. Most of these works focused chiefly on yield and other crop features while they devote less attention to soil hydraulic parameterization and water flow. Since crop system modeling is strictly related to soil water balance, then an accurate analysis of soil hydraulic parameters and water flow processes is required to assess model performances.

The aim of the present study is to evaluate and compare the performance of three well known models (SWAP, MACRO and CropSyst based on the solution of the Richards' equation) in terms of simulated soil water contents, using detailed high frequency and high-resolution measured data. In detail, the comparison has been obtained through: (i) the overall evaluation along the profile of the response of the models in two soil types (a clay-loamy Inceptisol and a loamy over sand Alfisol); (ii) the evaluation at three soil depths (0–0.15, −0.4 and −1 m where some key water flow processes are relevant); (iii) the evaluation of models performance in terms of soil water content profile following a drainage process on bare soil.

Table 1
The materials and methods section division.

Materials and methods		
Data and measurements	Models description	Comparison procedures
Site description Field trials Soil hydraulic properties	Simulation models Soil water flow Water uptake Crop growth and its parameterization	Calibration procedures Evaluation model performance

2. Materials and methods

The section is divided in nine subsections accordingly to three main conceptual sections: "Data and Measurements", "Models description" and "Comparison procedures" as reported in Table 1.

2.1. Sites description

Experimental data were collected in two sites, Caviaga (45.31°N, 9.50°E, 72 m a.s.l.) in Lodi area and Cerese (45.12°N, 10.79°E, 20 m a.s.l.) in Mantova area, located in the Po Valley (Northern Italy), characterized by intensive crop-livestock system (corn, forage, cattle and pig rearing). The plain consists of a large subsidence basin subjected to complex lowering phenomena and to a gradual infilling by, largely Holocene, sediments derived from the erosion of nearby mountains and then subject to redistribution by alluvial processes.

The soil of Caviaga is a fine loamy over sandy, mixed, superactive, mesic, deep, moderately acid Ultic Hapludalf, widely unsaturated in the exchange complex. The soil of Cerese is a fine, mixed, superactive, mesic Vertic Calciustepts. It is a clay loam soil, characterized by a deep calcic horizon and high content of calcium carbonate with an exchange complex always saturated. A description of the main soils properties of each site is given in Table 2. In the Cerese site, despite the high clay content and the occurrence of slickensides (Bss horizon), no evident considerable cracking is detectable in the field; this feature could be related to the irrigation practice and the rather shallow actual groundwater.

The mean annual rainfall over 38 years (1971–2008) is about 752 mm in Cerese and 867 mm in Caviaga. The mean annual temperature in the same period is 13.5 °C in Cerese and 13.0 °C in Caviaga. Such values are related to Mantova and Lodi province observations, respectively (http://www.politicheagricole.it/ucea/Osservatorio/miekfyi01_index_zon.htm).

Table 2
Main soils properties.

Horiz.	Depth (m)	Sand (%) 2000–50 μm	Silt (%) 50–2 μm	Clay (%) <2 μm	OC g kg^{-1}	pH (H_2O) –	pH (KCl) –	$CaCO_3$ %	CEC mequiv. 100 g^{-1}
Cerese									
Ap	0–0.4	21.4	44	34.6	10.8	8.1	7	7	22.9
Bss	0.4–0.7	13.6	39.4	47	5.05	8.3	7.1	1	23.7
Bk	0.7–1.3	22.9	50.3	26.8	3.55	8.5	7.6	45	15.1
C	>1.3	88.2	7	4.8	1.75	8.7	8.1	40	1.2
Caviaga									
Ap1	0–0.2	49.5	32.6	17.9	8.15	5.9	5.1	0	15.4
Ap2	0.2–0.3	49.1	33.2	17.7	7.9	6	5	0	12.5
Bt1	0.3–0.6	46.8	31.4	21.8	4.4	6.2	4.7	0	12.2
Bt2	0.6–0.8	74.5	12.1	13.4	1.6	6.7	5.2	0	7.9
BC	>0.8	83.7	6.3	10	1.1	6.8	5.3	0	7.2