Assessment of soil water balance at a distributed scale in Southern Italy

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Abstract
The purpose of this study is to analyse the components of soil water balance in an important district included in the Basilicata and Puglia regions (Southern Italy) mainly cropped with horticultural crops. The study was performed by using the spatially distributed and physically based model SIMODIS in order to individuate the best irrigation management maximizing the water use efficiency and minimizing water losses by deep percolation and soil evaporation. SIMODIS was applied taking in account the soil spatial variability and localization of cadastral units for two crops, durum wheat and water melon. Water melon cultivation was simulated adopting different water supply managements and several indicators were calculated and mapped in a GIS environment. The analysis allowed to identify the areas particularly sensitive to water losses by deep percolation because of their hydraulic functions characterized by low water retention and large values of saturated hydraulic conductivity. The irrigation scheduled on a soil basis allowed management of the irrigation in a more efficient way.

Key Words
Irrigation, distributed modelling, soil hydraulic properties, crop.

Introduction
In Mediterranean regions of Southern Italy, the efficient use of water resources in agriculture is extremely important in order to improve the economical and environmental sustainability of the agricultural activity in an environment characterized by high evaporative demand of atmosphere, water scarcity and increasing negative consequences of climate change. Different simulation models can be used for describing the soil water fluxes at spatial and temporal scales and characterizing the physical and biological processes of the soil-plant-atmosphere agrosystem. The spatially distributed and physically based model SIMODIS (SImulation and Management of On-Demand Irrigation Systems) (D'Urso 2001) is a Decision Support System (DSS) based on the integration of different tools such as agrohydrological hydraulic simulation model and GIS techniques where, for each calculation unit with homogeneous climate, crop and soil conditions, in which the total area can be divided, the SWAP model is applied in a distributed approach. The main objective of this study, carried out at a distributed scale, was to analyse the components of soil water balance through the model SIMODIS, to identify the irrigation strategies with the highest efficiency and to localize the main vulnerabilities in an important district included in the regions of Basilicata and Puglia and situated in the Ionical coastal area of Southern Italy, as regarding the cultivation of water melon (*Citrullus lanatus* Thunb).

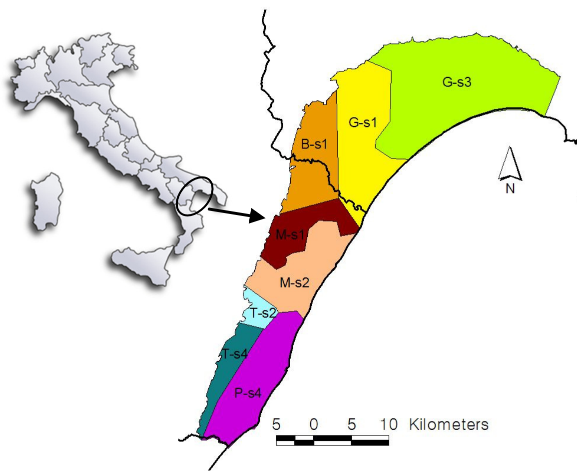

Figure 1. Map units in the Jonical coastal area.

Methods

The agricultural district of Jonical coast is located in the Puglia and Basilicata regions and has an extension of approximately 620 Km^2 (Figure 1). The area extends along the coast of Jonical Sea and toward the inside of the territory to an altitude of 60 meters including the basins of four rivers: Sinni, Agri, Cavone and Basento. With an extension of 4303 ha and 21672 ha for permanently and no- irrigated lands, respectively, the area is mainly cropped with horticultural crops, orchards and vineyards, distributed in relation to the position in the landscape: fruit and vegetable crops prevail in the alluvial deposits, cereals and olive trees predominate in the marine terraces. The data set utilized for producing the land cover maps consists of a multispectral remote sensing image used to discriminate the water melon cover class, taken by SPOT5 satellite, with the spatial resolution of 10 m and four bands in visible and near/medium infrared spectrum. To investigate the multivariate spatial structure of soil data a linear model of coregionalization (Castrignanò *et al.* 2000) was fitted to all direct and cross-variograms. All the variables were interpolated on a 500 by 500 m-grid using the geostatistical technique of cokriging. In order to divide the study area into homogeneous soil clusters or classes an algorithm based on nonparametric density estimate, was used (Scott 1992). An approximate p-value for each cluster is computed by comparing the estimated maximum density in the cluster with the estimated maximum density on the cluster boundary. The clustering approach was implemented by using the MODECLUS procedure of the SAS/STAT software package (SAS 2008; release 9.2).

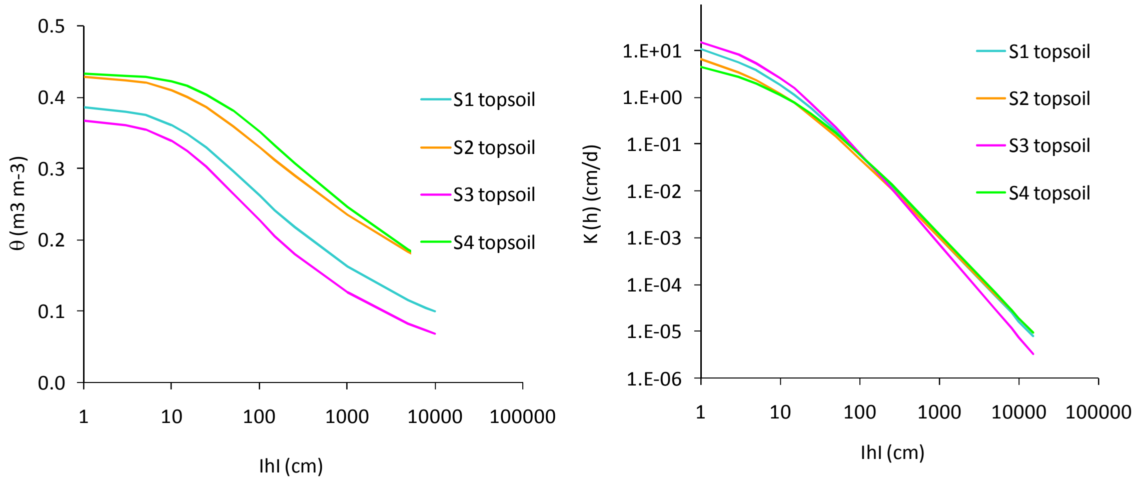

Figure 2. The estimated soil hydraulic functions.

The SIMODIS model was constituted as a Decision Support System with the main goal to simulate the irrigation requirement of a irrigation district integrating different aspects. The information about the soil concerns the depth and discretization of each horizon soil profile and the parameters of the functions of retention and hydraulic conductivity expressed in the parametric of Mualem- van Genuchten form (van Genuchten, 1980). In this work, the soil hydraulic parameters were determined through the PTF HYPRES (HYdraulic PRoperties of European Soils) (Wösten *et al.* 1998). This PTF comes from information collected in the database HYPRES containing information of 5521 soil horizons involving 20 institutions from 12 European countries. On the basis of linear regression , HYPRES estimates the hydraulic parameters of Mualem- van Genuchten equations – θs and θr, the saturated and residual soil water content, Ks, the saturated hydraulic conductivity and α, n, and l, usually considered as fitting parameters – starting from the values of sand, silt and clay, as well as organic matter and bulk density.

For water melon, five irrigation managements were simulated: (i) without irrigation (M1); (ii) allowed fraction of soil water deficit of 100% (M2), 50% (M3) and 25% (M4) with the lower limit of soil pressure head (h) equal to the value below which the crop water uptake is reduced; (iii) irrigation strategy based on monitoring of plant water status with the irrigation scheduled when the ratio "actual transpiration/potential transpiration" is equal or lower than a critical fraction defined by user (0.98 in our case) (M5). For all the M_ irrigated strategies the irrigation depth was calculated on the basis of soil water content corresponding to the field capacity. For each simulation run the following soil water balance indicators were considered at a seasonal scale: actual transpiration (Ta, mm), actual evaporation (Ea, mm), deep percolation (Perc, mm), seasonal irrigation depth (Irr, mm), watering depth (Vmed, mm) and seasonal number of irrigations (ni, -).

Results

According to the results of geostatistical analysis, the study area was subdivided into 4 distinct classes realising the best visual accordance with the prior description of the spatial variation of the soil attributes. (Figure 1). The clusters S1 and S3 (Table 1), in the Northern and Central parts of the district, respectively, are characterized by the highest percentages of sand (more than 50%) with the first one having a significant component of clay, above all in the subsoil (more than 22%). The Ks of such soils are particularly high with values for the topsoil that overcame 50 cm/d. Due to significant sandy component, the θs are not particularly high (less than 0.39) contrary to the n parameters (more than 1.2). Such findings indicate high

Table 1. Hydrological parameters according to Mualem-van Genuchten (1980).

Soil	USDA classification	θs	Ks	α	l	n
		cm^3/cm^3	cm/d	1/cm	-	-
S1	Sandy clay loam	0.388	51.1	0.058	-2.95	1.21
S2	Clay loam	0.431	46.8	0.049	-3.76	1.15
S3	Sandy loam	0.370	52.8	0.058	-2.04	1.26
S4	Silty clay loam	0.434	21.8	0.027	-3.18	1.17

rate of drainage and water profile distribution after infiltration events. In the Central and Southern part of the district the finest component of texture increases in the topsoil (32 and 28% for S2 and S4, respectively) and even more in subsoil (38 and 31%), indicating higher soil water retention and high values of θs (more than 0.43) and low values of α and n parameters (less than 0.05/cm and 1.17, respectively) . The Ks, lower than 47 and 22 cm/d for S2 and S4, respectively, indicates a low infiltration rate and a sensitivity to runoff water losses (Figure 2). According the technique of Thiessen polygons, we interpolated five climatic areas (related to 2007 data) that combined with the 4 soils gave a total of seven map units (Figure 1: the unit P-s4 was not considered because no watermelon cultivation took place in 2007).

The results of SIMODIS application in the irrigated district of Southern Italy are synthetised in Figure 3 and 4. Significant variations were found as a function of irrigation management in the various map units in terms of watering depth (Vmed, the depth of water applied in a single irrigation event), actual evapotranspiration (Eta) and deep percolation (Perc). The Eta increased from about 200 mm without irrigation (M1) to over 320 mm, with irrigation, with peak values under M3 and M4. A linear increment of Eta was evident coming from M2 to M4 while M5 was characterized by values of Eta comparable to those of M2. Regarding the differences related to different pedoclimatic characteristics, the lowest average values of Eta were obtained for B-S1, regardless of the irrigation strategies adopted. The Figure 3 shows also interesting values of Vmed. In this case more evident differences can be attributed to the irrigation strategies with linearly decreasing values from M2 to M4 (from 100 to 20-30 mm) and M5 that had the second highest values (80 mm in average) with the exception of S3. The corresponding values of Vmed for S3 and S4 tended to be lower than the other soils. Obviously, low values of Vmean mean more frequent irrigation: with a Vmed of about 20-30 mm about 10-11 irrigations were simulated. Moreover, increasing the single irrigation depth, the risks of losses by deep percolation increase as reported in Figure 4 that shows the lowest water losses were obtained with M3 and M4. The graph highlights the high sensitivity, in order of magnitude, of M5 and M2 irrigation strategies that, for every map unit, showed the highest values of percolation depth: such a trend is particularly evident in G-S3 unit under M5.

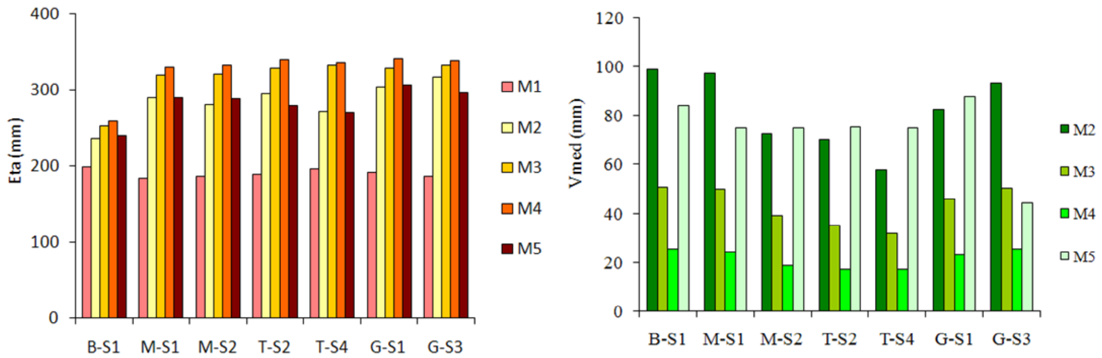

Figure 3. Actual evapotranspiration (Eta) and irrigation depth (Vmed) for watermelon simulation.

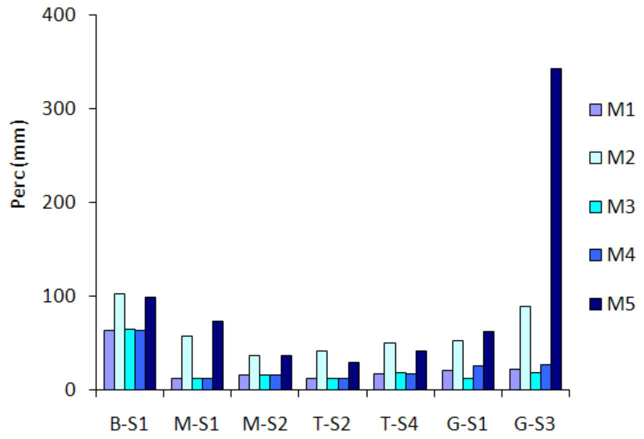

Figure 4. Deep water percolation for watermelon simulation.

Conclusion

The use of model SIMODIS allowed to estimate the principal components of soil water balance a distributed scale in an area situated in the Jonical coast of Southern Italy and cultivated mainly durum wheat and water melon. The study allowed to identify the most sensitive zones to water losses by deep percolation. For the irrigation strategies based on the concept of "allowable depletion of soil readily available water", the efficiency was higher when a depletable fraction of 0.25 was applied and the results, obtained in term of watering depth (20 mm) and number of irrigation for season (about 10), were very similar to those actually adopted by the farmers of the region. With irrigation carried out when the soil water reservoir is completely depleted (M2) the losses by deep percolation tended to increase and consequently the irrigation efficiency decreased.

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Changes in soil pH as a result of lime addition as affected by rates, time and incorporation method

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Abstract
Sandplain soils on the south coast of Western Australia are naturally acidic. Cropping systems can further reduce soil pH by as much as 0.3 pH units in seven years. A series of experiments were established to determine the effects of lime addition on soil pH within the root zone. Lime applied at rates ranging from 0.5 to 8.6 t/ha resulted in significant increases in topsoil pH. Only the highest rates of lime (> 1.5 t/ha) resulted in pH increases beyond 15 cm depth seven years after application. Only systems that incorporated lime at depth and or mixed soils to depth through slotting/trenching resulted in significant crop yields and soil pH increases within the root zone (0 - 60 cm) immediately after being applied. The resultant crop yields where subsoils pH was modified were as much as 80% higher than the control.

Key Words
Acidification, limesand, application methods, amelioration.

Introduction
The sandplain soils on the south coast of Western Australia cover some 2 M ha and are widely used for agricultural production. The soils are naturally acidic. This combined with grain removal, acidic fertilizers and nitrate leaching has resulted in a reduction in soil pH within the root zone in farmed soils when compared to native soils. The rate of acidification is exacerbated by poor chemical buffering associated with low organic carbon (<1.5%) and clay (<3 %) contents. Consequently soil pH is declining from relatively low base with most cropped sandplain soils having a pH <5 within the root zone. Limesand (crushed native limestone) is almost solely used to ameliorate acidity on the south coast of WA. However limesand, being comparatively insoluble, takes time to increase soil pH at depth within the soil profile. In order to understand how to manage soil acidification a series of experiments were conducted on the Esperance sandplain between 1999 and 2009. The aim of this research was to measure soil pH changes over time in soils treated with limesand applied at different rates and application methods.

Methods
Three experiments were established between 1999 and 2006 (Table 1). Each of the experiments was statistically designed as a randomised block with three replicates. The three experimental sites were located within 50 km of Esperance, WA on grey deep sandy duplex soils which are classified under the Australian system as hypocalcic mesonatric Sodosols (Isbell 1996). These soils form part of the Esperance sandplain and consist of a fine sand A horizon overlying a sodic B horizon light to medium clay. The sands are often > 60 deep, have low organic carbon (<1.5 %) and cation exchange (<4 me/100g) within the Ap horizon with values decreasing with depth. Soil pH_{Ca} commonly ranges from 4.3 to 5.5 with exchangeable aluminium less than 10 ppm. Two sources of liming material were used in the experiments, limesand and G Lime. The limesand was quarried at Dalyup (40 km to the west of Esperance) and had a neutralising value of 69% with 97% of particles less than 0.5 mm. The G lime, a by-product of cement manufacture, has a neutralising value of >85 % and 90% of particles less than 1 mm. For sites 1 and 2 the limesand and G lime were applied using commercial spreaders.

For site 3, limesand was either top dressed at rates of 1.6, 4.3 and 8.7 t/ha or incorporated to 60 cm depth within a slot. The slots were dug with a trenching machine with each slot 0.15 m wide and 0.6 m deep. Three slots per plot were dug along the length of the plot spaced at 0.5 m intervals. Limesand was added manually to the trenched spoil, mixed and manually incorporated back into each slot. Soil pH was measured in 0.1M $CaCl_2$ solution using the method of Rayment and Higginson (1992). Crop yields were measured at sites 1 and 2 using commercial harvesters and at site 3 using a ‘Kingaroy’ plot header with a 1.65 m wide front.