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The role of soil series in quantitative land evaluation when expressing effects of climate change and crop breeding on future land use

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ABSTRACT

Climate change and the development of new plant hybrids raise questions about future agricultural land use potentials that cannot be answered by expert knowledge based on past experience. This case study for maize cultivation in the Destra Sele region in southern Italy applied therefore the SWAP (Soil–Water–Atmosphere–Plant) simulation model to explore the effects of limited water availability under future climate conditions on growth of eleven maize hybrids. Five selected soil series were analyzed. Compared with optimal water availability by irrigation, results were significantly different for 80% and 60% water availability with respect to different hybrids and soil series. The soil series are distinguished by stable criteria, allowing, in principle, their use as "class pedotransfer functions" not only in space but also in time, reflecting effects of climate change by 2050. Presenting alternative land use options by simulations rather than empirical conclusions about limitations or suitabilities is attractive for land evaluation, allowing a pro-active and interactive approach by soil scientists vis-a-vis farmers, hydraulic engineers, crop breeders and policy makers.

1. Introduction

While soil mapping has been revolutionized by introducing geostatistics and various remote and proximal sensing techniques, all embedded in Information and Communication Technology (ICT), the basic assumptions underlying soil survey interpretation and land evaluation have not evolved much since the publication of the landmark FAO Framework in 1976 (FAO, 1976) and the introduction of soil survey interpretations (as discussed in Soil Survey Staff, 1993). FAO procedures have been automated (e.g. Rossiter, 1990) and additional emphasis on involvement of stakeholders and societal aspects have been proposed (FAO, 2007). But the basic procedure of soil scientists using expert knowledge to define relationships between soil characteristics on the one hand and land use requirements on the other, resulting in relative suitabilities or limitations for a given land use, has remained (e.g. Bouma et al., 2012). This matching procedure is also used in defining soil productivity indexes (PI) (e.g. Huddleston, 1984). More recently, Dobos et al. (2008) defined a PI for several crops relating soil characteristics (Available Water Capacity, Bulk density, K-sat), LEP (soil shrink-swell), rock fragments, rooting depth and % sand, silt and clay to crop yields, expressed on a scale of 1–100. The Geospatial Information Office in Minnesota similarly defined a PI for soil mapping units at the soil series level, presenting maps for the state (Minnesota GIC, 2011). Schaetzl et al. (2012) produced a PI using the family level of Soil Taxonomy. None of these studies considered climate data directly.

These empirical procedures have certainly proved their value (see, aside from the PI papers, examples in FAO, 2007) but that soils have "moderate limitations" for growing a given crop or have a given PI value, can only be a very first step towards answering modern land use questions. Future population growth, combined with increased demand for high quality food, climate change and water shortages are important challenges for modern society. Improved soil and water management are therefore key ingredients for innovative future agricultural management, that cannot be based on experience alone because new conditions will arise as the climate changes. At the same time, plant breeding has been revolutionized by genetic modification that can make crops more suitable for facing changing environmental conditions. Quantitative process studies and simulation modeling are therefore essential to address these future challenges and models need to be fed with relevant soil data. Such future studies have an exploratory character as they, obviously, cannot be validated by observations. In one third of the world (semi) detailed soil survey information is available (Arrouays et al., 2014) and this study focuses on using this type of information, as derived for five Italian soil series. When no soil surveys are available, alternative procedures are being explored in the GSM (Global Soil Mapping) program (e.g. Arrouays et al., 2014).

In land evaluation soil types, most often soil series, are used as "carriers of information". They act as class-pedotransfer functions, where the soil series represents a class (Bouma, 1989). Measurements or simulations for a given site, where a particular soil series is found,

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are considered to be representative for other sites without measurements where the same soil series occurs. This represents upscaling in space and is common practice in soil survey and land evaluation. But does this also apply in terms of time? Will the soil series of today at certain locations still be there in, say, 2050 when effects of climate change are expected to be undeniable? This is important because only then can simulations for a given soil series, considering climate change, still be assigned to certain land areas where the soil series is found. Upscaling of land evaluation in time has so far not been addressed as the climate at any given location has implicitly been assumed to be stable. Climate change challenges this assumption. Extrapolation in time will only be possible if the distinguishing characteristics for soil series are stable and this aspect will therefore be further explored in this paper. Also, use of soil series when upscaling data in time will be compared with procedures of the GSM program, where direct use of soil data is preferred over deriving soil data through soil classification.

In summary, the objectives of this study are: (i) to define a quantitative procedure that can assess possibilities to grow a given crop at a given site occupied by a particular soil series, considering effects of climate change and introduction of new crop cultivars; (ii) to explore whether soil series are sufficiently stable to allow upscaling in time of simulation results, considering periods of at least 30 years, and (iii) to discuss implications for soil science research.

2. Materials and methods

2.1. Inherent diagnostic features of five Italian soil series

The equivalent of soil series in the Italian soil classification is the Soil Typological Unit (STU) (Costantini, 2007) but for communication purposes, the term soil series will be used in this paper.

The study area “Destra Sele”, is a flat area of 22,000 ha (18,500 ha being used for agriculture) located in the south of Campania Region, Southern Italy (Fig. 1). Main agricultural production consists of irrigated crops (maize, vegetables and fruits), greenhouse vegetables and water buffalo breeding. It is characterized by four different physiographic regions (hills/footslopes, alluvial fans, fluvial terraces and dunes) with heterogeneous parent materials in which twenty different soil series were distinguished (Inceptisol, Alfisol, Mollisol, Entisol and Vertisol soil orders), according to Soil Taxonomy (Soil Survey Staff, 1999). Five soil series were selected in the area to test use of soil series as a class pedotransfer function when predicting conditions in thirty year's time (Table 1). Decision trees were developed to test whether the selection process of the soil series was based on stable criteria, allowing extrapolation of results from measured to unmeasured locations when considering effects of climate change. While extrapolation in space of soil series data has been a common procedure in soil survey (e.g. Soil Survey Staff, 1993; Hudson, 1992; Bouma et al., 2012), extrapolation in time has not received as much attention. A basic principle of many taxonomic soil classification systems is a focus on stable soil characteristics when selecting diagnostic criteria for soil types. Also, emphasis on morphological features allows, in principle, a soil classification without requiring elaborate laboratory analyses. (e.g. Soil Survey Staff, 1993). A given soil classification should not change following plowing or other management measures as long as this does, of course, not result in removal of soil or in invasive anthropic activity. This way, soil classification results in an assessment of the (semi)-permanent physical constitution of a given soil in terms of its horizons and textures.

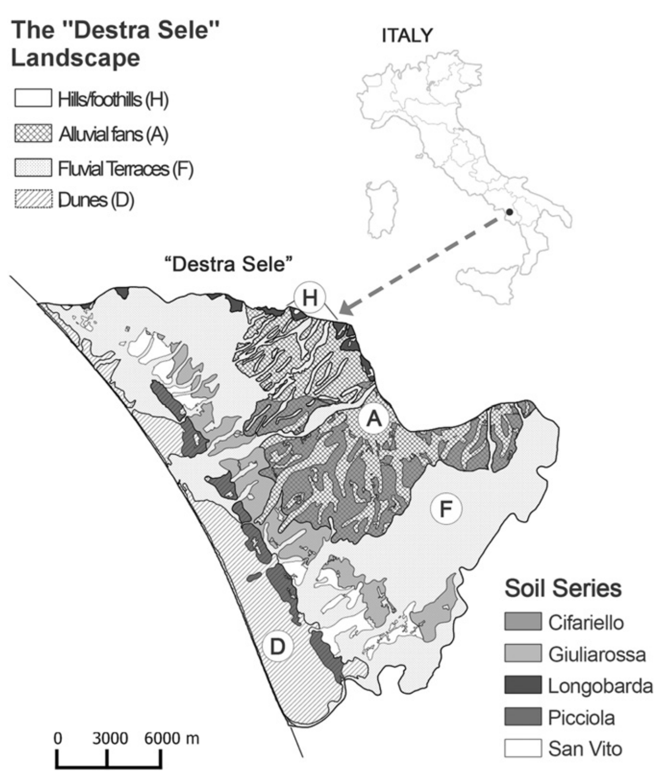

Fig. 1. The four landscape units of the “Destra Sele” plain and the five soil series selected.

2.2. Effects of climate change

One important aspect of future climate change in Mediterranean areas is the maximum daily air temperature that should not exceed 32 °C to avoid permanent damage to the maize crop that is considered here. This aspect was studied elsewhere and data showed that this type of risk was sufficiently low to be ignored in this particular area (Bonfante et al., in press; Monaco et al., 2014). Tmax was 24.8 °C and 26.3 °C for the reference and future climates, respectively. Attention is focused here on the difference between two climates, one predicted to be representative for climate change in the periods 2021–2050 based on IPCC projections (A1B emission scenario IPCC-SRES) and the other acting as a reference for 1961–1990. The reference climate for the test fields was calculated applying the kriging-with-external-drift method (Wackernagel, 2003) to the meteorological data included in the National Agro-meteorological database (Ministero dell'Agricoltura e Foreste, 1990). In the kriging procedure, three auxiliary variables were applied: distance, orientation, and difference of elevation between points. Daily values for the future climate were produced in two phases. First, seasonal mean and standard deviations of meteorological variables were generated by a statistical downscaling model, SDM (Tomozeiu et al., 2007), starting from coupled atmosphere–ocean global climate models (AOGCMs) under emission scenario A1BIPCC-SRES (ENSEMBLE) (Van der Linden and Mitchell, 2009). Second, the results were used by a weather generator to produce 50 realizations of the daily values of the same variables for a year taken as being representative of the period between 2021 and 2050. Further details about the procedure were presented by Villani et al. (2011) and Tomozeiu et al. (2013).

Daily reference evapotranspiration (ET_0) was evaluated according to the HS equation of Hargreaves and Samani (1985). The reliability of this equation for this study area was tested by Fagnano et al. (2001) who compared the HS equation with the Penman–Monteith (PM) equation (Allen et al., 1998). They showed that on average the HS equation produced values of seasonal (May–September) ET_0 values that were only 4% lower than the PM equation which was considered acceptable. Cumulative ET_0 was 619 mm and 646 mm, for the reference and future climate, respectively. Rainfall was 159 mm versus 145 mm.

2.3. Simulation modeling

The Soil–Water–Atmosphere–Plant (SWAP) model (Kroes et al., 2008) was applied to solve the soil water balance and to calculate the