Geoderma 361 (2020) 114079

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Exploring the effect of varying soil organic matter contents on current and future moisture supply capacities of six Italian soils

Antonello Bonfante[a,*], A. Basile[a], J. Bouma[b]

[a] Institute for Mediterranean Agricultural and Forest Systems – CNR-ISAFOM, Ercolano, Italy
[b] Em. Prof Soil Science, Wageningen University, the Netherlands

ARTICLE INFO

Keywords:
Available Water Capacity (AWC)
Moisture Supply Capacity (MSC)
Simulation modeling
Climate change
IPCC scenarios

ABSTRACT

The Available Soil Water Capacity (AWC) is standard data in most soil databases and expresses soil water contents in the rootzone between field capacity (FC; –33 kPa) and permanent wilting point (WP; −1500 kPa). Literature suggests that increasing the content of soil organic matter (SOM) of a given soil does not significantly increase AWC and this has important implications when estimating soil moisture supply to crops and evaluating the potential for climate mitigation. For most crops, the real FC values vary between −10 and −50 kPa in different soils and WP values between −800 and −1500 kPa. Thus standard values for AWC of FC and WP do not represent field conditions in many soils. When exploring AWC for six Italian soil series, ranging from clay to sandy, AWC values at increasing %SOM were lower in clay soils and higher in sand as compared with actual conditions, which could be explained by considering the shape of the corresponding moisture retention curves. Rather than focus on static AWC values to define moisture supply to plants, real or actual soil moisture supply capacities (MSC) can be obtained by dynamic modeling of the soil-water-atmosphere-plant system, including a “sink-term” indicating a continuous relation between water uptake and negative pressure head of soil water and evaporative demand. Also, only models allow exploration of the effects of future severe IPCC climate scenario RCP 8.5. Thus, studying MSC for the six Italian soil series showed that MSC values were: (i) on average 30% higher than the corresponding AWC; (ii) distinctly different for the six soils; (iii) affected by declines of 1–9% as a result of the effects of future climate scenarios.; (iv) not significantly affected by increases of %SOM when considering climate change, except for the sand. Generalizations as to the effect of future climate scenarios and %SOM on MSC can only be realistic when modeling is performed for soil series in different climate zones.

1. Introduction

Increasing the organic matter content of soil has been presented in the:”4per1000″ proposal as a significant climate mitigation measure with the suggestion that an annual average increase of 0.04% could be enough to offset emissions of greenhouse gasses (www.4per1000.org). Several papers have discussed the feasibility of this proposal (e.g. Arrouays et al., 2002; Baveye et al., 2018; Chenu et al., 2014; Gao et al., 2018; Kallenbach et al., 2019; Perego et al., 2019; Minasny et al., 2017; Smith, 2016, 2012; van Groenigen et al., 2017; White et al., 2018). Increasing the soil organic matter content could have additional benefits for farmers, such as increasing the soil moisture supply capacity (MSC) for plants during a growing season and the associated crop yield. Such a positive effect could, in fact, seduce farmers to support implementation of this climate mitigation measure. As climate-change scenarios indicate the future probability of increased dry spells in several agricultural areas in the world, the soil MSC becomes increasingly important.

Recent studies do, however, not focus on the MSC but on the AWC (Available Water Capacity). The static AWC value defines water held between pressures of –33 (or −10) kPa (Field Capacity, FC) and −1500 kPa (Wilting Point, WP) and is a standard soil characteristic in most soil databases, allowing objective comparisons between different soils.

Focusing on AWC values, Minasny and McBratney, (2018) concluded after reviewing 60 publications that: *“the effect of an increase of %C in soil on soil available water was negligible”*. Several recent studies used the soil available water capacity concept (AWC) to characterize soil moisture regimes. Yost and Hartemink (2019) reported that a 1% increase of soil carbon in a sandy Wisconsin soil increased AWC with a significant 0.05 m^3m^{-3}. Stoorvogel et al. (2019) discussed AWC at different spatial scales. Román Dobarco et al. (2019) discussed AWC variability in French soils. Before continuing, a critical analysis of the AWC concept is needed.

* Corresponding author.

https://doi.org/10.1016/j.geoderma.2019.114079
Received 31 July 2019; Received in revised form 8 October 2019; Accepted 7 November 2019

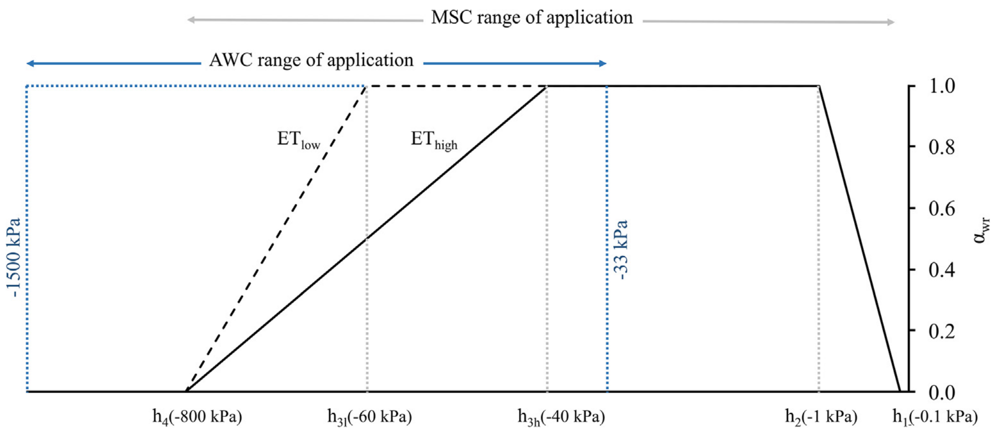

Fig. 1. Conceptual figure of sink term for the maize crop as used in this study showing the reduction coefficient (α_{wr}) of water uptake as a function of the negative soil water potential (h) and the potential evapotranspiration rate (low and high ET) (α_{wr} = 1, implies absence of crop water stress). The two traditional values for FC (-33 kPa) and WP (-1500 kPa) are added to illustrate the difference with the static AWC concept.

In contrast to what many non-soil scientists seem to believe, the AWC does not represent the amount of moisture that is "available" to crops during a growing season. This amount is determined by weather conditions during the growing season, rooting patterns of a given crop, water fluxes determined by basic hydraulic properties of the soil, such as moisture retention and hydraulic conductivity and water-table levels as will be discussed later when describing modeling techniques. Also, different crops have different "sink-terms" reflecting water uptake as a function of the negative soil water pressure and the evaporative demand. "Sink-terms", to be discussed later, are continuous expressions not considering arbitrary values for water content such as FC and WP (see Fig. 1).

So, rather than use the AWC to express the effect of increasing the soil organic matter content on moisture availability, use of widely available and operational simulation models for the soil–water-atmosphere-plant system can estimate real amounts of water that a plant transpires during a given growing season (MSC values) (e.g. Bouma, 2018; Holzworth et al., 2018; Jones et al., 2003; Kroes et al., 2017; Reynolds et al., 2018; White et al., 2013).

Two types of models can be distinguished. The CERES model (Jones et al, 2003) considers the rootzone as a "Tipping Bucket" that contains water between FC and WP, which are considered the minimum input for water dynamics simulation in crop models (Gijsman et al., 2002). When water is added to the soil by rain or irrigation it is not adsorbed by roots in the rootzone as long as the water content is higher than FC. Water disappears to the subsoil until FC is reached. Then water uptake starts and water is assumed to be freely available to plants until the water content at WP is reached. No water uptake beyond this point. The "Tipping Bucket"model thus uses the AWC concept in a dynamic context, including weather conditions and rooting depth but it does not allow upward unsaturated flow into the rootzone, nor does it allow for crop specific "sink-terms" (Bonfante et al., 2011).

The other models mentioned above use a dynamic and continuous characterization of water fluxes in the soil–water-plant-atmosphere system without arbitrarily fixed moisture values like FC and WP. Root uptake of water is defined by moisture retention and hydraulic conductivity data and a sink-term allowing a more realistic expression of the effect of soil water potentials on water uptake by roots (e.g. Bouma, 2018). Bouma and Droogers (1999) compared calculations of MSC values by a "Tipping Bucket" model with a continuous model and showed that the former produced lower values for the MSC. They concluded that use of the continuous model could better characterize dynamic soil moisture regimes in the field and the "Tipping Bucket" model will therefore not be further discussed in this study.

Models are not only important to characterize dynamic field soil moisture regimes but they represent the only way to explore the effects of future climate change in agriculture and then important also in the context of organic matter dynamics of soils. (e.g. Bonfante et al., 2019a,b).

The objectives of this paper are to: (i) explore the effects of an increase of % SOM on the moisture supply capacity (MSC) of six different Italian soils by applying the continuous SWAP model (Kroes et al., 2017): (ii) compare these results with AWC values for the same soils to demonstrate their different character, and (iii) explore effects of increased soil organic matter contents on MSC values obtained by applying current climate data and future IPCC climate scenarios. This paper explores effects of different %SOM and does not discuss management measures to increase %SOM that are widely discussed in literature (e.g. green manuring, crop rotations, minimum tillage, agroforestry etc.).

The study is based on Italian soil series, being used as "carriers of information" or as "class-pedotransferfunctions" (Bouma, 1989; Van Looy et al., 2017) as in classical soil survey interpretations that relate soil series to soil limitations for different forms of land use.

2. Materials and methods

2.1. Moisture availability

The availability of water to plants has been a common theme of soil research ever since the start of the last century. Romano and Santini (2002) present a comprehensive and illuminating overview of widely used concepts such as field capacity, permanent wilting point and water availability. As mentioned above, available water is a static characteristic and is derived from the difference between water at field capacity and permanent wilting point. Currently, the term available water has been enlarged to available water capacity (AWC).

Field capacity (FC) is defined as:*" the content of water remaining in a soil 2 or 3 days after having been wetted with water and after free drainage is negligible"* (SSSA, 1997). Values differ strongly among soils with a range of water contents corresponding with pressure heads between −10 and −50 kPa. A pressure head of –33 kPa represents somewhat of a compromise value (e.g. McIntyre and Loveday, 1974) and is now widely used to define FC. The permanent wilting point (WP) represents: "*the soil water content at which a plant wilts completely and is no longer able to recover its turgor and biological activity when placed in a humid environment"* (Romano and Santini, 2002). Richards and Weaver (1943) determined soil water matric potential values of permanent wilting of sunflower plants and found a value of about −1500 kPa. Other authors found different values for different crops, ranging from −100 to −1500 kPa as a function of evaporative demand, but the −1500 kPa value became the standard. Both FC and AW have by now become absolute, codified standards. Their origin and background appear to be unknown to current users. Clearly both FC and WP are highly variable among soils and so is, therefore, the meaning of the available water concept. As discussed above, simulation models of the soil–water-atmosphere-plant system can characterize the dynamic behavior of this system without arbitrary boundary values like FC and WP, allowing

Table 1
Physical characteristics and classifications of the six Italian soils being studied.

Soil			Hor.	Thick. (cm)	Clay	Silt	Sand	S.O.M.
ID	Series	Classification	%					
P1	Fiocche Sud*	Typic Calcixererts, fine, mixed, thermic	Ap	0–55	32.4	53.9	13.7	0.3
			Bgk1	55–90	42.8	54.1	3.1	0.3
		(Silty Clay Loam)	Bgk2	90+	48.9	44.6	6.5	0.3
P2	Torre dei Raghi**	Pachic Haploxerolls, fine loamy, mixed, thermic	Ap	0–45	35.4	43.0	21.6	2.3
			Bw1	45–65	27.6	37.9	34.5	1.9
		(Loam)	Bw2	65+	8.2	17.8	74.0	0.2
P3	Cifariello**	Typic Haploxerets, fine, mixed, thermic	Ap	0–45	32.8	57.1	10.1	2.6
			Bw1	45–65	35.6	56.7	7.7	2.2
		(Silty Clay Loam)	Bw2	65+	48.9	45.8	5.3	1.0
P4	Sordio+	Ultic Haplustalf, coarse loamy, mixed, mesic	Ap1	0–18	17.9	32.6	49.5	1.4
			Ap2	18–30	17.7	33.2	49.1	1.4
			Bt1	30–56	21.8	31.4	46.8	0.4
		(Sandy Loam)	Bt2	56–83	13.4	12.1	74.5	0.2
			BC	83+	10.0	6.3	83.7	0.1
P5	Masseria Manfredi++	Typic Ustivitrands, sandy, mixed, thermic	Ap1	0–10	10.5	38.5	51.0	2.6
			Ap2	10–40	5.9	43.6	50.5	2.6
		(Sandy Loam)	Bw	40–80	3.9	31.1	65.0	–
			BC	80–110	11.6	15.4	73.0	–
			C	110+	4.6	9.4	86.0	–
P6	Masseria Battaglia++	Vitrandic Haplustept, sandy, mixed	Ap1	0–20	4.1	18.6	77.3	1.7
			Ap2	20–53	6.1	18.4	75.5	1.6
		(Loamy Sand)	Bw1	53–61	1.4	12.4	86.2	0.9
			Bw2	61–106	2.2	8.7	89.1	0.9
			C	106+	1.0	24.6	74.4	0.2

* Soil series Destra Sele soil Map (1:50.000) (Regione Campania, 1996)
** Closed to soil series of "Destra Sele soil Map (1:50.000) RAG0 and CIF0, (Regione Campania, 1996)
+ Soil series The soil map of Lodi plain (1:37.500) (Arnoldus-Huyzendveld and Di Gennaro, 2000).
++ Closed to soil series of "The soil map of province of Naples" (1:75.000) (Di Gennaro et al., 1999)

estimates of the real volume of water that has been taken up by plants during the growing season (referred to as a MSC value). Even though AWC is useful to compare soils, only MSC is suitable to express water supply to crops under field conditions as affected by climatic conditions, including the evermore important climate change scenarios.

In this work, for each soil horizon, the FC and WP were calculated from the soil moisture retention curve measured in the lab. The AWC of each horizon was integrated along the depth of the rooting zone (0–80 cm) of each layer according to the following formula

$$AWC_{(0-80cm)}\,[mm] = \sum_{z=0}^{z=800mm} AWC_i \times z_i$$

where i is the layer, z_i is the depth in mm of each layer and AWC_i is the volumetric AWC of each horizon.

2.2. Soils

Physical characteristics, Taxonomy classifications and local soil series (Arnoldus-Huyzendveld and Di Gennaro, 2000; Di Gennaro et al., 1999; Regione Campania, 1996) of six Italian soils are presented in Table 1. Additional details of the soil series are presented in the quoted reports. Textures range from loamy-sand to silty-clay-loam and organic matter contents in Ap horizons are relatively low ranging from 0.34 to 2.60%. Based on field observations, rooting depth of maize was estimated to be 80 cm, implying that not the only Ap horizon but also subsoil horizons contribute to the water supply to maize. All selected soils are placed in an alluvial plain environment, five in the Campania region (P1, P2, P3, P5, and P6; southern Italy) and one in the Lombardy Region (P4; northern Italy). During the maize growing season (from April to September) the climate for soils of Campania region is characterized by an average monthly rainfall of 47 mm (± 26), and mean air temperature of 19.7 °C (± 4.3) (data from Servizio Metereologico Aeronautica Militare, period 1971–2000), while for the soil P4 in Lombardy region the climate is warm and temperate, with an average monthly rainfall of 73 mm (± 9), and mean air temperature of 19.4 °C (± 3.8) (data from Lodi province 1971–2000).

2.3. Soil hydraulic properties(SHP)

Water retention, θ(h), and hydraulic conductivity, k(θ), curves were measured in the laboratory. Undisturbed soil samples (volume ≈ 750 ml) were collected from all of the recognized horizons of the six soil profiles. Samples were slowly saturated from the bottom and the saturated hydraulic conductivity measured by a falling head permeameter (Reynolds and Elrick, 2002). Then, both couples of θ-h and k-θ data were obtained by means of the evaporation method (Arya, 2002) consisting in an automatically recorded of the pressure head at three different depths and the weight of the sample during a 1-dimensional transient upward flow. From these information, i) the water retention data θ-h were obtained applying an iterative method (Basile et al., 2012) and ii) the unsaturated hydraulic conductivity data were obtained by applying the instantaneous profile method, requiring the spatio-temporal distribution of θ and h, namely θ(z,t) and h(z,t), being z and t the depth and time, respectively (Basile et al., 2006). Additional points of the dry branch of the water retention curve were determined using a dewpoint potentiometer (WP4-T, Decagon Devices, Washington, USA).

The parameters of the van Genuchten-Mualem model for water retention and hydraulic conductivity functions were obtained by fitting the experimental θ-h and k-θ data points (Van Genuchten, 1980).

One of the goals of this paper concerns the effects of increasing SOM on MSC in future climates and because MSC is largely driven by hydraulic properties, a procedure to consider the increase of SOM on soil hydraulic properties was developed. Regardless on several local factors (e.g. climate, geomorphology, land use and soil management) producing SOM formation, its variation can cause a variation in soil hydraulic properties, that was considered in this paper.. Specifically, soil hydraulic properties of Ap horizon were modified according to the increase of SOM following the algorithms proposed in the development of

Table 2
Climate information during the maize cropping season (average ± standard deviation).

Climate scenario and time windows	Temperature			Rainfall	Et_0
	Min	Max	Mean	mm	
	°C				
RC (1971–2005)	−0.3 (±3.2)	41.1 (±3.5)	19.1 (±3.1)	227 (±108)	246 (±14)
RCP 8.5 (2010–2040)	0.0 (±3.1)	42.6 (±3.3)	20.5 (±2.9)	235 (±112)	251 (±11)
RCP 8.5 (2040–2070)	1.5 (±3.3)	45.5 (±3.5)	22.1 (±3.1)	185 (±118)	273 (±14)
RCP 8.5 (2070–2100)	3.2 (±3.1)	47.2 (±3.5)	24.5 (±3.0)	142 (±121)	291 (±13)

the PTF HYPRES (Wösten et al., 1999). On the basis of 5521 soil samples they found relationships between the SOM and the parameters of the van Genuchten-Mualem equations. We applied these relationships to the measured SHPs of the Ap horizon of six soils under study in order to create different simulation scenarios of %SOM (2% and 4%). In such a way we have maintained the (measured) original SHPs modifying them through a PTF in order to take into account the effect of SOM percent increase. Finally, it is important to stress that despite the content of SOM in soil depends on several local factors (climate, geomorphology, land use and soil management), its variation can produce a variation in soil hydraulic properties, that was considered in this paper as an empirical relationship.

2.4. Simulations of the soil–water-atmosphere-plant system

The SWAP simulation model was used to estimate MSC values during the maize cultivation under estimated climate change and % SOM scenarios of Ap horizons. SWAP is an integrated physically-based simulation model of water, solute and heat transport in the saturated–unsaturated zone in relation to crop growth. It was not used to simulate SOM dynamics but to explore the effects of different SOM contents on crop growth. In this study only the water flow module was used; it assumes unidimensional vertical flow processes and calculates the soil water flow applying the Richards equation. Soil water retention θ(h) and hydraulic conductivity k(θ) relationships as proposed by van Genuchten (1980) were applied. The unit gradient was set as the condition at the bottom boundary. The upper boundary conditions of SWAP in agricultural crops are generally described by the potential evapotranspiration ETp, irrigation and daily precipitation. Potential evapotranspiration was then partitioned into potential evaporation and potential transpiration according to the LAI (Leaf Area Index) evolution, following the approach of Ritchie (1972). An important feature of the SWAP model is the sink-term (Fig. 1) defining a reduction factor for water uptake by plant roots (α_{wr}) as a function of the negative soil pressure head (h) and the potential transpiration rate. The sink term for maize shows that maximum water uptake ($\alpha_{wr} = 1$) is only possible between −1 kPa (h_1) and −40 kPa (h_{3h}) at high transpiration rates and to −60 kPa (h_{3l}) at low rates. A gradual reduction to $\alpha = 0$ occurs until $h_4 = -800$ kPa. The AWC values for field capacity (FC = –33 kPa) and wilting point (WP = -1500 kPa) are also indicated, showing completely different patterns with no water adsorption in wet soil until –33 kPa and beyond −1500 kPa. The sink term predicts therefore more water uptake in wet soil and lower uptake in dry soil. The maize was simulated from May (emergence) to the end of August (harvest) with a peak of LAI of 5.8 $m^2\ m^{-2}$.

The model was validated for Italian conditions in earlier studies on different crops and pedoclimatic conditions (Bonfante et al, 2019a,b, 2017, 2011, 2010; Crescimanno and Garofalo, 2005). A long list of references of applications can be found at http://www.swap.alterra.nl/.

2.5. Climate scenarios

The simulation runs were performed for all six selected Italian soils using a future climate scenario of a site of southern Italy (Destra Sele plain) where half of the analysed soils occur. The future climate scenarios were obtained by using the high resolution regional climate model (RCM) COSMO-CLM (Rockel et al., 2008), with a configuration employing a spatial resolution of 0.0715°(about 8 km), which was optimized over the Italian area. The validations performed showed that model data agree closely with different regional high-resolution observational datasets, in terms of both average temperature and precipitation in Bucchignani et al. (2015) and in terms of extreme events in Zollo et al. (2015)

The severe Representative Concentration Pathway (RCP) 8.5 scenario was applied, based on the IPCC (Intergovernmental Panel on Climate Change) modelling approach to generate greenhouse gas (GHG) concentrations (Meinshausen et al., 2011).

Initial and boundary conditions for running RCM simulations with COSMO-CLM were provided by the general circulation model CMCC-CM (Scoccimarro et al., 2011), whose atmospheric component (ECHAM5) has a horizontal resolution of about 85 km. The simulations covered the period from 1971 to 2100; the CMIP5 historical experiment (based on historical greenhouse gas concentrations) was used for the period 1976–2005 (Reference Climate scenario - RC), while for the period 2006–2100, a simulation was performed using the IPCC scenario mentioned. The analysis of results was made on RC (1971–2005) and RCP 8.5 divided into three different time periods (2010–2040, 2040–2070 and 2070–2100) (Table 2).

The choice of severe RCP 8.5 scenarios was related to three principal reasons: 1) the CO_2 emission trends are in line with RCP 8.5 pathway (Fuss et al., 2014; Peters et al., 2013); 2) In our region until the 2040 the RCP 4.5 and 8.5 are very similar; 3) we are interested to compare soils behavior under a severe climate change condition, able to cover a large climate variability. Daily reference evapotranspiration (ET_0) was evaluated according to the Hargreaves and Samani, (1985) equation (HS). The reliability of this equation in the study area was tested by Fagnano et al., (2001) comparing the HS equation with the Penman–Monteith (PM) equation (Allen et al., 1998).

Under the RCP 8.5 scenario the temperature in Destra Sele is expected to increase approximately two degrees Celsius respectively every 30 years to 2100 starting from the RC. The differences in temperature between RC and the period 2070–2100 showed an average increase of minimum and maximum temperatures of about 6.2 °C (for both min and max over the year). The projected increase of temperatures produces an increase of the expected ET_0. In particular, during the maize growing season, an average increase of ET_0 of about 18% is expected until 2100.

3. Results and discussion

3.1. AWC as a function of %SOM

Table 3 shows AWC values for the six soils, which are constant during the analyzed time period. Values for current SOM conditions range from 85.3 mm in the Inceptisol to 120.0 mm in the Andosol with relatively low values for soils P1, P2 and P3 with > 30% clay and higher values for soils P5 and P6 with lower clay content. Soil P4 has an intermediate position. Differences can be explained by the shapes of the measured moisture retention curves, shown as examples in Fig. 2 for the Ap in P1 and P6. The curves show a stronger drop for P6 than for P1 in the FC to WP range, yielding a larger value for AWC.

Table 3 also illustrates the effects of higher organic matter contents on AWC values, again for the reference climate period. When comparing 2%SOM with the 4% SOM level a decline of the AWC occurs of −6% (P1), −2% (P2) and (P3). In contrast P6 shows an increase of +12%, while P4 and P5 are lower at +3 and +2% respectively. For

Table 3
Available Water Capacity (AWC) for six Italian soils (Table 1) calculated over the rooting depth of maize (0–80 cm). The soil organic matter percent (SOM) is indicated for each Ap horizon, the current SOM value is reported in brackets near each soil profile.

SOM	AWC 0–80 cm (mm)					
	P1 (0.3%)	P2 (2.3%)	P3 (2.6%)	P4 (1.4%)	P5 (2.8%)	P6 (1.7%)
Current	97.1	99.6	85.3	89.0	120.0	107.1
2%	94.3	100.0	86.0	89.6	118.4	108.8
4%	91.2	97.8	83.6	91.3	122.2	120.1

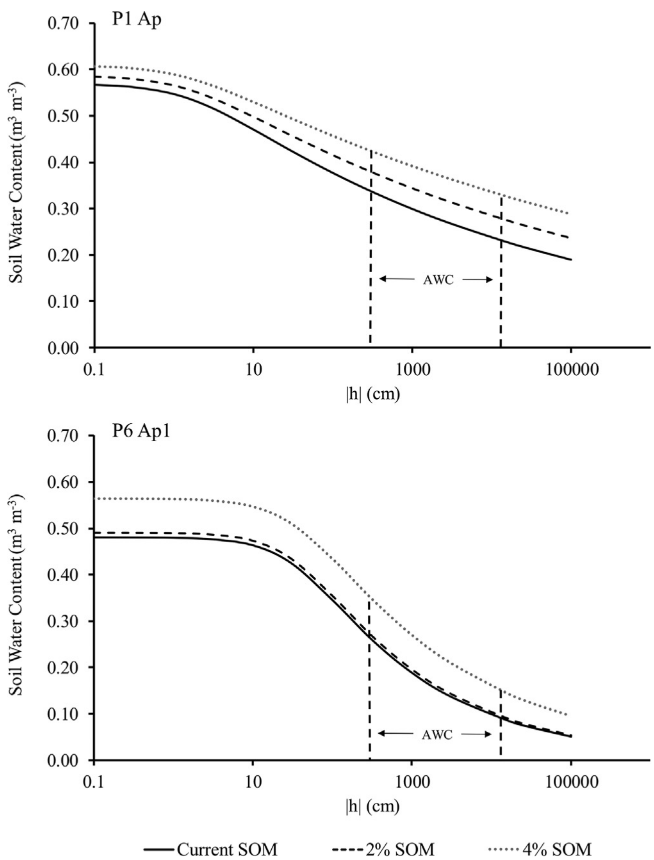

Fig. 2. Moisture retention curves for the Ap horizon of soils P1 and P6 at different percent of soil organic matter (SOM). The current SOM curves have been measured in the laboratory, the others have been defined through a scaling procedure based on HYPRES PTF rules.

soils P1 and P6 differences are significant, in contrast to other soils. Differences can be explained by considering – again – the water retention curves and the hydraulic conductivity curves (Figs. 2 and 3) for the contrasting soils 1 and 6. When water retention curves for the current %SOM and the higher %SOM are parallel or when the higher %SOM curve moves slightly downwards, as in P6 (and, less so, in P4/P5), the value for AWC will increase or stay the same. When, however, the curves for increased %SOM become more horizontal, as in P1 (and P2/P3), AWC values decline even though the soil will contain more water at a given negative pressure head, which will affect the MSC value as shown in the next section.

3.2. The basic difference between AWC and MSC

Fig. 4 shows calculated MSC values for the six soils in the four climate periods considering current %SOM. These values can be compared for each soil with corresponding AWC values that are at least 30% lower than the MSC values, as they don't reflect weather conditions in the growing season. AWC values for each of the soils are constant in all periods because moisture retention curves are assumed not to change until 2100. Thus, only the MSC values reflect the effect of the climate on moisture supply to maize plants and are therefore more realistic than AWC values when assessing the moisture supply capacity of soils.

3.3. MSC in the reference climate

Table 4 shows MSC values (mm) for the six soils for four climate periods and three levels of %SOM. Values for the reference climate with current %SOM range from 132 mm (soil P2) to 175 mm (soil P6). Soils P2 and P3 are significantly different from soil P6. The lower MSC values for soils with > 30% clay, as compared with the other soils, can be explained by higher K-unsat values in the deepest horizon of the clay soil which lead to higher water fluxes and drainage outside the soil (Fig. 5). The steep slope of the k(h) function of the bottom horizon of the current P6 acts as relatively impeding layer, producing less drainage, high water content and consequently higher MSC. But the effects of the sink-term (Fig. 1) are most prominent as it leads to lower moisture availability in the later parts of the growing season when moisture contents are relatively low.

3.4. MSC in future climates with unchanged %SOM

Considering the current %SOM of the six soils, slight decreases of MSC are observed for the four climate scenarios. Soil P1 reduces by 7% (143 mm-134 mm); soil P2 by 6% (132 mm-124 mm), soil P3 by 9% (134 mm-122 mm), soil P4 by 9% (144 mm-131 mm), soil P5 by 5% (157 mm-150 mm) and soil P6 by 1% (175–173 mm). None of these differences are significant indicating that for the applied Italian conditions reduced precipitation and increased evapotranspiration in future climates have a relatively small effect on MSC. The next section addresses the important question whether an increase of %SOM could reduce or perhaps even reverse this relatively small reaction to climate change.

3.5. Effects of increasing SOM on MSC in future climates

Again, the six soils react differently to increases of %SOM. Considering an increase of SOM to 4%, soil P1 shows a reduction of MSC at RCP 8.5(2070–2100) of 8% as compared with the reference climate and current %SOM (143 mm-131 mm); Soil P2 reduces 7% (132 mm-122 mm), Soil P3 reduces 10% (134 mm-121 mm); Soil P4 reduces 8% (134 mm-121 mm); Soil P5 reduces 3% (157 mm-152 mm) and Soil P6 increases 5% (175 mm-184 mm).

The increase of %SOM does not significantly change the effect of climate change on MSC. Soils P1, P2, P3 and P4 show a limited decrease of MSC of 6–9% as a result of climate change at current %SOM and this value is not significantly different when estimating the effect of an increase to 4%SOM (8–10%). Soil P5 shows a lower decrease of 3% while P6 shows a positive effect of 5%. Though not significant, indications are that increasing %SOM in sandy soils can have a positive effect on MSC to the extent that negative effects of climate change can be mitigated. This calls for additional research covering more soil types in different climate zones.

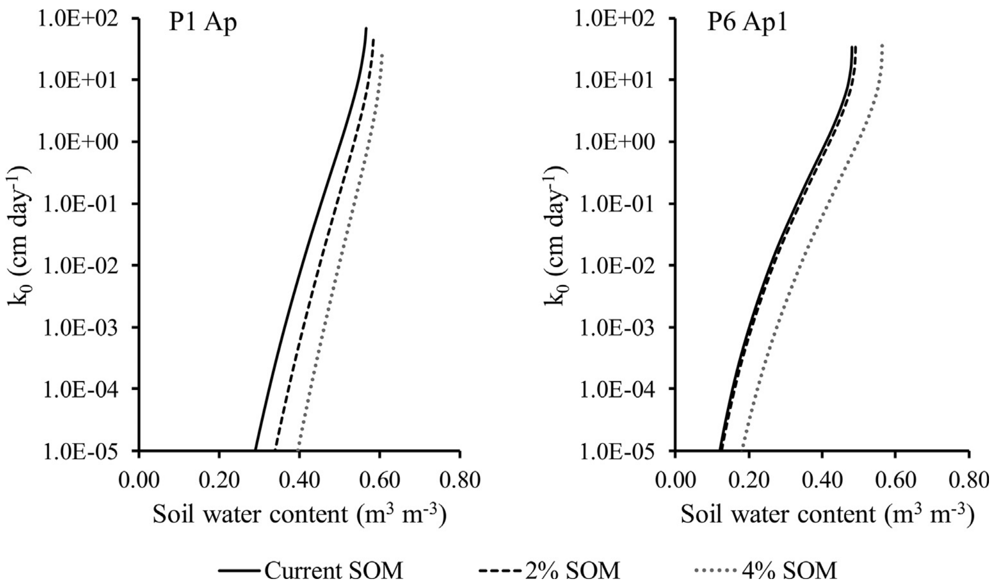

Fig. 3. Hydraulic conductivities of the Ap horizons of soils P1 and P6 at different percent of soil organic matter (SOM). The Ap2 of P6 is almost similar to the curve for the Ap1 and is not shown. The current SOM curves were measured in the laboratory, the curves for increased %SOM were defined through a scaling procedure based on HYPRES PTF rules.

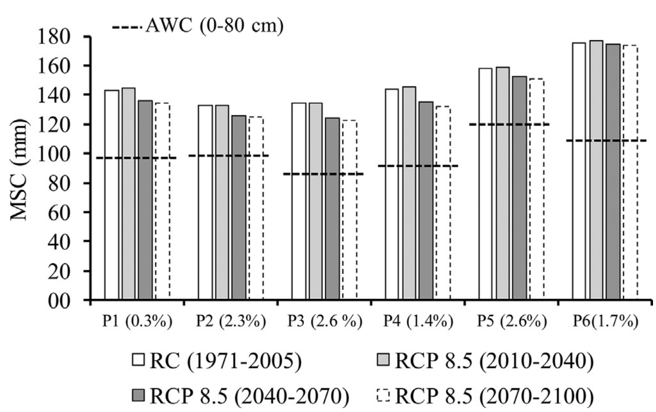

Fig. 4. Calculated soil moisture supply capacities (MSC) values for the six soils in four climate periods considering current % of soil organic matter (SOM). The available soil water capacity (AWC) values for the six soils are also shown and illustrate the basic difference between AWC and MSC.

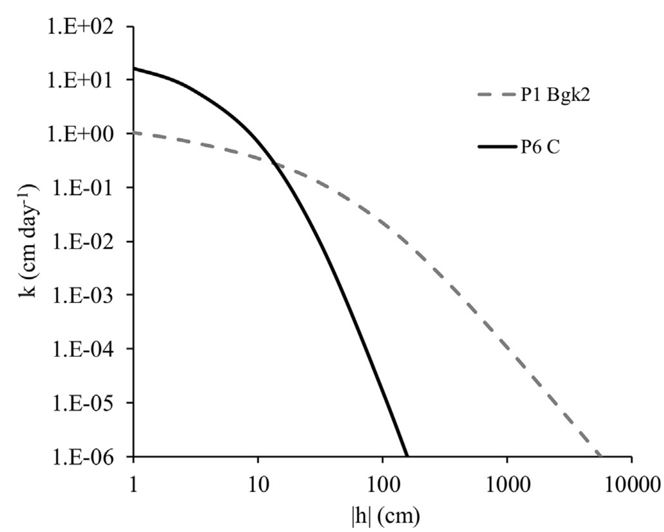

Fig. 5. K(h) Hydraulic conductivities of the bottom horizons of the current soils P1 and P6.

4. Discussion

The capacity of soils to provide water (and nutrients dissolved in water) to plant roots is one of the most important soil functions, directly affecting the possibility of different forms of land use. As the world is

Table 4
Calculated MSC data, including standard deviations, for six Italian soils, three assumed increases of current %SOM and two climate scenarios reference climate (RC, 1971–2005) and RCP 8.5 (three time windows 2010–2040; 2040–2070; 2070–2100).

Climate period	SOM	MSC (mm)					
		P1	P2	P3	P4	P5	P6
	Current	143 (± 12.7)	132 (± 14.9)	134 (± 16.2)	144 (± 14.9)	157 (± 12.5)	175 (± 8.1)
RC (1971–2005)	2%	139 (± 12.8)	132 (± 14.9)	134 (± 16.3)	144 (± 14.9)	156 (± 12.8)	177 (± 7.5)
	4%	138 (± 12.5)	130 (± 15.0)	133 (± 15.5)	145 (± 14.8)	158 (± 12.2)	181 (± 6.8)
	Current	144 (± 13.2)	132 (± 14.0)	134 (± 16.3)	145 (± 14.5)	159 (± 11.3)	176 (± 6.6)
RCP 8.5 (2010–2040)	2%	141 (± 13.1)	133 (± 14.0)	134 (± 16.3)	145 (± 14.5)	157 (± 11.6)	179 (± 5.9)
	4%	139 (± 12.5)	130 (± 14.1)	133 (± 15.8)	147 (± 14.2)	160 (± 10.9)	183 (± 4.6)
	Current	135 (± 15.5)	125 (± 15.3)	124 (± 17.0)	135 (± 17.7)	152 (± 14.9)	174 (± 10.5)
RCP 8.5 (2040–2070)	2%	133 (± 15.4)	125 (± 15.3)	124 (± 17.1)	135 (± 17.7)	151 (± 15.1)	177 (± 9.7)
	4%	132 (± 15.0)	123 (± 15.3)	123 (± 16.7)	136 (± 17.6)	153 (± 14.7)	183 (± 8.0)
	Current	134 (± 19.5)	124 (± 20.7)	122 (± 22.8)	131 (± 22.3)	150 (± 19.0)	173 (± 14.3)
RCP 8.5 (2070–2100)	2%	132 (± 19.7)	124 (± 20.7)	122 (± 23.0)	131 (± 22.3)	149 (± 19.2)	177 (± 13.4)
	4%	131 (± 19.6)	122 (± 20.7)	121 (± 22.0)	133 (± 22.2)	152 (± 18.7)	184 (± 11.7)
Current value of SOM		*0.3%*	*2.3%*	*2.6%*	*1.4%*	*1.7%*	*2.6%*

facing major challenges to secure a sustainable future, the UN Sustainable Development Goals (SDGs) (http://www..un.org/sustainabledevelopment/sustainable-development-goals) (e.g. Keesstra et al., 2016) become ever more important. For example, SDG2 focuses on *ending hunger, achieve food security and improved nutrition and promote sustainable agriculture.* Adequate water supply to crops is crucial to crop growth and, ultimately, food security ending hunger. To define the capacity of soils to deliver water to plant roots, the soil science discipline has produced much research including definition of the AWC, the Available Water Capacity: the volume of water held between arbitrarily defined values for field capacity (FC) and permanent wilting point (WP) as analyzed in this paper. Many soil databases contain AWC data. Many non-soil scientists interpret the AWC as defining the amount of water that soils can provide to plants during a growing season. As shown and discussed above, this is incorrect and this study, as have many others, has demonstrated, that dynamic modeling of the soil-- water-atmosphere-plant system can produce estimates of the real amounts of moisture (MSC) that plants adsorb during a growing season.

This procedure has also been applied using the SWAP model to address another SDG, no 13: *Take urgent action to combat climate change and its impacts.* The French proposal:"*4per1000*" (4per1000.org) suggested that increasing the organic matter content of soils would be an effective procedure to enhance climate mitigation (see introduction). This paper does not address this issue but a related question as to whether raising the soil organic matter content would also have a side benefit of raising the moisture supply capacity of soils.

Calculations covering four successive IPCC climate scenarios up to the year 2100 for six Italian soils showed that lower rainfall and higher potential evapotranspiration of the applied climate scenarios had a dominant effect on MSC, causing reductions of 6–9%. Hypothetically increasing the %SOM had little effect on MSC except in a sandy soil where an increase of %SOM could negate the negative climate-change effects.

These calculations have an exploratory character and more studies are needed for different soils in different climate zones. But so far it seems that for Southern-Italy increasing the MSC by raising the %SOM does not present significant increase in MSC. Particular attention for sandy soils may be advisable in future as these soils seem to have the highest potential to negate the climate effects on SMC by increasing %SOM. But results presented refer to climate conditions applied and results elsewhere may produce different results.

The current study had some limitations: When exploring effects of increasing MSC by raising %SOM, pedotransferfunctions (PTFs) of HYPRES were used. An alternative would be to initiate fieldwork to find certain soil types (soil series) with different %SOM in surface soil due to past management, as was done by Pulleman et al. (2000) and Sonneveld et al. (2002).

In any case sampling by soil type is advisable. Each of the six Italian soil types showed a different and characteristic dynamic behavior, where clayey subsoil horizons and the particular sink-term, defining moisture extraction by roots of maize, appeared to have a higher impact on MSC than a small increase of %SOM in the surface Ap horizon. But, again, this was different in the sandy soil. Focusing on soil types (using soil series as class-pedotransferfunctions) and using soil–water-atmosphere-plant simulation models. allow innovative and quantitative soil survey interpretations in addition to the empirical and qualitative interpretations of classic soil surveys (e.g. soils having "moderate limitations" for a given form of land use).

5. Conclusions

1. AWC is suitable to rank different soils but does not represent the capacity of soils to supply water to plants during a growing season. Soil-water-atmosphere-plant simulation models, producing MSCvalues, do.
2. Increasing %SOM of five Italian surface soils did not siginificantly increase MSC both for current and future IPCC climate scenarios. A sandy soil appears to be an exception inviting further studies. But climate conditions outside Italy are likely to produce different results.
3. When modeling MSC, soil profile properties, including those of subsoils, have a major impact. As different soil types showed a characterisitically different behavior in this study, future research should be focused on well defined soil types, often soil series, as "carriers of information" or "class-pedotransferfunctions".
4. Concerns articulated by the UN Sustainable Development Goals should not be restricted to current conditions but be investigated as well by exploring effects of future IPCC climate scenarios, as presented in this paper.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

Acknowledgments

We acknowledge Mrs. N. Orefice and Dr. R. De Mascellis for soil hydraulic property measurements and Dr. Eugenia Monaco and Dr. Guido Rianna for the supporting in the analysis of climate scenarios. Climate data from the "Regional Models and Geo-Hydrogeological Impacts Division" of the Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC), Capua (CE) – Italy, were applied in this study, with support by Dr. Paola Mercogliano and dr. Edoardo Bucchignani.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.geoderma.2019.114079.

References

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., W, a B.,, 1998. Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56. Irrig. Drain. 1–15. https://doi.org/10.1016/j.eja.2010.12.001.

Arrouays, D., Balesdent, J., Germon, J.C., Jayet, P.A., Soussana, J.F., Stengel, P., 2002. Increasing carbon stocks in French agricultural soils. Synth. an Assess. Rep. by French Inst. Agric. Res. Req. French Minist. Ecol. Sustain. Dev. Sci. Assess. Unit Expert. INRA, Paris, Fr.

Arya, L.M., 2002. Wind and hot-air methods, in: Physical Methods. Soil Science Society of America, Inc., pp. 916–926.

Arnoldus-Huyzendveld, A., Di Gennaro, A., 2000. I suoli del Lodigiano. ERSAL- Regione Lombardia Quaderno SSR 30.

Basile, A., Buttafuoco, G., Mele, G., Tedeschi, A., 2012. Complementary techniques to assess physical properties of a fine soil irrigated with saline water. Environ. earth Sci. 66, 1797–1807. https://doi.org/10.1007/s12665-011-1404-2.

Basile, A., Coppola, A., De Mascellis, R., Randazzo, L., 2006. Scaling approach to deduce field unsaturated hydraulic properties and behavior from laboratory measurements on small cores. Vadose Zo. J. 5, 1005–1016. https://doi.org/10.2136/vzj2005.0128.

Baveye, P.C., Berthelin, J., Tessier, D., Lemaire, G., 2018. The "4 per 1000" initiative: a credibility issue for the soil science community? Geoderma 309, 118–123. https://doi.org/10.1016/j.geoderma.2017.05.005.

Bonfante, A., Alfieri, S.M., Albrizio, R., Basile, A., De Mascellis, R., Gambuti, A., Giorio, P., Langella, G., Manna, P., Monaco, E., et al., 2017. Evaluation of the effects of future climate change on grape quality through a physically based model application: a case study for the Aglianico grapevine in Campania region. Italy. Agric. Syst. 152, 100–109.

Bonfante, A., Basile, A., Acutis, M., De Mascellis, R., Manna, P., Perego, A., Terribile, F., 2010. SWAP, CropSyst and MACRO comparison in two contrasting soils cropped with maize in Northern Italy. Agric. Water Manag. 97, 1051–1062. https://doi.org/10.1016/j.agwat.2010.02.010.

Bonfante, A., Basile, A., Manna, P., Terribile, F., 2011. Use of Physically Based Models to Evaluate USDA Soil Moisture Classes. Soil Sci. Soc. Am. J. 75, 181. https://doi.org/10.2136/sssaj2009.0403.

Bonfante, A., Monaco, E., Manna, P., De Mascellis, R., Basile, A., Buonanno, M., Cantilena, G., Esposito, A., Tedeschi, A., De Michele, C., Belfiore, O., Catapano, I., Ludeno, G., Salinas, K., Brook, A., 2019a. LCIS DSS—An irrigation supporting system for water use efficiency improvement in precision agriculture: a maize case study. Agric. Syst. 176, 102646. https://doi.org/10.1016/J.AGSY.2019.102646.

Bonfante, Antonello, Terribile, F., Bouma, J., 2019b. Refining physical aspects of soil quality and soil health when exploring the effects of soil degradation and climate change on biomass production: an Italian case study. SOIL 5, 1–14. https://doi.org/10.5194/soil-5-1-2019.

Bouma, J., 2018. Comment on: B. Minasny & A.B. Mc Bratney. 2018. Limited effect of organic matter on soil available water capacity. 154 154. Eur. J. Soil Sci. 69. https://doi.org/10.1111/ejss.12509.

Bouma, J., 1989. Using Soil Survey Data for Quantitative Land Evaluation. Springer, New York, NY, pp. 177–213. https://doi.org/10.1007/978-1-4612-3532-3_4.

Bouma, J., Droogers, P., 1999. Comparing different methods for estimating the soil moisture supply capacity of a soil series subjected to different types of management. Geoderma 92, 185–197. https://doi.org/10.1016/S0016-7061(99)00027-0.

Bucchignani, E., Montesarchio, M., Zollo, A.L., Mercogliano, P., 2015. High-resolution climate simulations with COSMO-CLM over Italy: performance evaluation and climate projections for the 21st century. Int. J. Climatol. 36, 735–756.

Chenu, C., Klumpp, K., Bispo, A., Angers, D., Colnenne, C., Metay, A., 2014. Stocker du carbone dans les sols agricoles : évaluation de leviers d'action pour la France. Innovations Agronomiques.

Crescimanno, G., Garofalo, P., 2005. Application and evaluation of the SWAP model for simulating water and solute transport in a cracking clay soil. Soil Sci. Soc. Am. J. 69, 1943–1954.

Di Gennaro, A., Terribile, F., De Mascellis, R., Maisto, G., Rivieccio, R., Vingiani, S., Aronne, G., Buonanno, M., Basile, A., Leone, A., 1999. I suoli della provincia di Napoli. Selca, Firenze.

Fagnano, M., Acutis, M., Postiglione, L., 2001. Valutazione di un metodo semplificato per il calcolo dell'ET0 in Campania. Model. di Agric. sostenibile per la pianura meridionale Gest. delle risorse idriche nelle pianure irrigue. Gutenberg, Salerno, ISBN 88–900475.

Fuss, S., Canadell, J.G., Peters, G.P., Tavoni, M., Andrew, R.M., Ciais, P., Jackson, R.B., Jones, C.D., Kraxner, F., Nakicenovic, N., Le Quéré, C., Raupach, M.R., Sharifi, A., Smith, P., Yamagata, Y., 2014. COMMENTARY: Betting on negative emissions. Nat. Clim. Chang. https://doi.org/10.1038/nclimate2392.

Gao, X., Li, H., Zhao, X., Ma, W., Wu, P., 2018. Identifying a suitable revegetation technique for soil restoration on water-limited and degraded land: Considering both deep soil moisture deficit and soil organic carbon sequestration. Geoderma 319, 61–69. https://doi.org/10.1016/j.geoderma.2018.01.003.

Gijsman, A., Jagtap, S., Jones, J., 2002. Wading through a swamp of complete confusion: how to choose a method for estimating soil water retention parameters for crop models. Eur. J. Agron. 18, 77–106. https://doi.org/10.1016/S1161-0301(02)00098-9.

Hargreaves, G.H., Samani, Z.A., 1985. Reference crop evapotranspiration from temperature. Appl. Eng. Agric. 1, 96–99.

Holzworth, D., Huth, N.I., Fainges, J., Brown, H., Zurcher, E., Cichota, R., Verrall, S., Herrmann, N.I., Zheng, B., Snow, V., 2018. APSIM Next Generation: Overcoming challenges in modernising a farming systems model. Environ. Model. Softw. 103, 43–51. https://doi.org/10.1016/j.envsoft.2018.02.002.

Jones, J., Hoogenboom, G., Porter, C., Boote, K., Batchelor, W., Hunt, L., Wilkens, P., Singh, U., Gijsman, A., Ritchie, J., 2003. The DSSAT cropping system model. Eur. J. Agron. 18, 235–265. https://doi.org/10.1016/S1161-0301(02)00107-7.

Kallenbach, C.M., Conant, R.T., Calderón, F., Wallenstein, M.D., 2019. A novel soil amendment for enhancing soil moisture retention and soil carbon in drought-prone soils. Geoderma 337, 256–265. https://doi.org/10.1016/j.geoderma.2018.09.027.

Keesstra, S.D., Bouma, J., Wallinga, J., Tittonell, P., Smith, P., Cerdà, A., Montanarella, L., Quinton, J.N., Pachepsky, Y., van der Putten, W.H., Bardgett, R.D., Moolenaar, S., Mol, G., Jansen, B., Fresco, L.O., 2016. The significance of soils and soil science towards realization of the United Nations Sustainable Development Goals. Soil 2, 111–128. https://doi.org/10.5194/soil-2-111-2016.

Kroes, J.G., Van Dam, J.C., Bartholomeus, R.P., Groenendijk, P., Heinen, M., Hendriks, R.F.A., Mulder, H.M., Supit, I., Van Walsum, P.E.V., 2017. Theory description and user manual SWAP version 4. Wageningen.

McIntyre, D.S., Loveday, J., 1974. Methods for analysis of irrigated soils. Tech, Commun.

Meinshausen, M., Smith, S.J., Calvin, K., Daniel, J.S., Kainuma, M.L.T., Lamarque, J.F., Matsumoto, K., Montzka, S.A., Raper, S.C.B., Riahi, K., et al., 2011. The RCP greenhouse gas concentrations and their extensions from 1765 to 2300. Clim. Change 109, 213.

Minasny, B., Malone, B.P., McBratney, A.B., Angers, D.A., Arrouays, D., Chambers, A., Chaplot, V., Chen, Z.-S., Cheng, K., Das, B.S., Field, D.J., Gimona, A., Hedley, C.B., Hong, S.Y., Mandal, B., Marchant, B.P., Martin, M., McConkey, B.G., Mulder, V.L., O'Rourke, S., Richer-de-Forges, A.C., Odeh, I., Padarian, J., Paustian, K., Pan, G., Poggio, L., Savin, I., Stolbovoy, V., Stockmann, U., Sulaeman, Y., Tsui, C.-C., Vågen, T.-G., van Wesemael, B., Winowiecki, L., 2017. Soil carbon 4 per mille. Geoderma 292, 59–86. https://doi.org/10.1016/j.geoderma.2017.01.002.

Minasny, B., McBratney, A.B., 2018. Limited effect of organic matter on soil available water capacity. Eur. J. Soil Sci. 69, 39–47. https://doi.org/10.1111/ejss.12475.

Peters, G.P., Andrew, R.M., Boden, T., Canadell, J.G., Ciais, P., Le Quéré, C., Marland, G., Raupach, M.R., Wilson, C., 2013. The challenge to keep global warming below 2C. Nat. Clim. Chang. https://doi.org/10.1038/nclimate1783.

Perego, A., Rocca, A., Cattivelli, V., Tabaglio, V., Fiorini, A., Barbieri, S., Schillaci, C., Chiodini, M.E., Brenna, S., Acutis, M., 2019. Agro-environmental aspects of conservation agriculture compared to conventional systems: A 3-year experience on 20 farms in the Po valley (Northern Italy). Agric. Syst. 168, 73–87. https://doi.org/10.1016/j.agsy.2018.10.008.

Pulleman, M.M., Bouma, J., Van Essen, E.A., Meijles, E.W., 2000. Soil organic matter content as a function of different land use history. Soil Sci. Soc. Am. J. 64, 689–693.

Regione Campania, 1996. I Suoli della Piana in Destra Sele. Progetto carta dei Suoli della Regione Campania in scala 1: 50.000 e lotto CP1 e Piana destra. Sele (Salerno).

Reynolds, M., Kropff, M., Crossa, J., Koo, J., Kruseman, G., Molero Milan, A., Rutkoski, J., Schulthess, U., Sonder, K., Balwinder-Singh, Tonnang, H., Vadez, V., Reynolds, M., Kropff, M., Crossa, J., Koo, J., Kruseman, G., Molero Milan, A., Rutkoski, J., Schulthess, U., Sonder, K., Balwinder-Singh, Tonnang, H., Vadez, V., 2018. Role of Modelling in International Crop Research: Overview and Some Case Studies. Agronomy 8, 291. https://doi.org/10.3390/agronomy8120291.

Reynolds, W.D., Elrick, D.E., 2002. Falling head soil core (tank) method. Methods soil Anal. Part 4, 809–812.

Richards, L.A., Weaver, L.R., 1943. Fifteen-atmosphere percentage as related to the permanent wilting percentage. Soil Sci. 56, 331–340.

Ritchie, J.T., 1972. Model for predicting evaporation from a row crop with incomplete cover. Water Resour. Res. 8, 1204–1213.

Rockel, B., Will, A., Hense, A., 2008. The regional climate model COSMO-CLM (CCLM). Meteorol. Zeitschrift 17, 347–348.

Román Dobarco, M., Bourennane, H., Arrouays, D., Saby, N.P.A., Cousin, I., Martin, M.P., 2019. Uncertainty assessment of GlobalSoilMap soil available water capacity products: A French case study. Geoderma 344, 14–30. https://doi.org/10.1016/J.GEODERMA.2019.02.036.

Romano, N., Santini, A., 2002. Methods of soil analysis physical methods. In: Dane, J.H., Topp, G.C. (Ed.), Methods of Soil Analysis, Part 4. Physical Methods. Soil Sci.Soc.of America Book Series 5, Madison, Wisc. USA.

Scoccimarro, E., Gualdi, S., Bellucci, A., Sanna, A., Fogli, P.G., Manzini, E., Vichi, M., Oddo, P., Navarra, A., 2011. Effects of Tropical Cyclones on Ocean Heat Transport in a High-Resolution Coupled General Circulation Model. J. Clim. 24, 4368–4384. https://doi.org/10.1175/2011jcli4104.1.

Smith, P., 2016. Soil carbon sequestration and biochar as negative emission technologies. Glob. Chang. Biol. 22, 1315–1324. https://doi.org/10.1111/gcb.13178.

Smith, P., 2012. Soils and climate change. Curr. Opin. Environ. Sustain. 4, 539–544.

Sonneveld, M.P.W., Bouma, J., Veldkamp, A., 2002. Refining soil survey information for a Dutch soil series using land use history. Soil Use Manag. 18, 157–163.

SSSA, 1997. Glossary of soil science terms.

Stoorvogel, J.J., Mulder, V.L., Hendriks, C.M.J., 2019. The effect of disaggregating soil data for estimating soil hydrological parameters at different scales. Geoderma 347, 185–193. https://doi.org/10.1016/j.geoderma.2019.04.002.

Van Genuchten, M.T., 1980. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. Soil Sci. Soc. Am. J. 44, 892–898.

van Groenigen, J.W., van Kessel, C., Hungate, B.A., Oenema, O., Powlson, D.S., van Groenigen, K.J., 2017. Sequestering Soil Organic Carbon: A Nitrogen Dilemma. Environ. Sci. Technol. 51, 4738–4739. https://doi.org/10.1021/acs.est.7b01427.

Van Looy, K., Bouma, J., Herbst, M., Koestel, J., Minasny, B., Mishra, U., Montzka, C., Nemes, A., Pachepsky, Y., Padarian, J., others, 2017. Pedotransfer functions in Earth system science: challenges and perspectives. Rev. Geophys.

White, J.W., Hunt, L.A., Boote, K.J., Jones, J.W., Koo, J., Kim, S., Porter, C.H., Wilkens, P.W., Hoogenboom, G., 2013. Integrated description of agricultural field experiments and production: The ICASA Version 2.0 data standards. Comput. Electron. Agric. 96, 1–12. https://doi.org/10.1016/j.compag.2013.04.003.

White, R.E., Davidson, B., Lam, S.K., Chen, D., 2018. A critique of the paper 'Soil carbon 4 per mille' by Minasny et al. (2017). Geoderma 309, 115–117. https://doi.org/10.1016/j.geoderma.2017.05.025.

Wösten, J.H., Lilly, A., Nemes, A., Le Bas, C., 1999. Development and use of a database of hydraulic properties of European soils. Geoderma 90, 169–185. https://doi.org/10.1016/S0016-7061(98)00132-3.

Yost, J.L., Hartemink, A.E., 2019. Effects of carbon on moisture storage in soils of the Wisconsin Central Sands, USA. Eur. J. Soil Sci. 70, 565–577. https://doi.org/10.1111/ejss.12776.

Zollo, A.L., Turco, M., Mercogliano, P., 2015. Assessment of hybrid downscaling techniques for precipitation over the Po river basin, in: Engineering Geology for Society and Territory-Volume 1 Springer, 193–197.