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WATER, SOIL, CROPS, AND PEOPLE IN A CHANGING CLIMATE: THE AGRONOMIC LEGACY OF DR. B.A. STEWART

Soil organic matter and water retention

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Abstract

The current and projected anthropogenic global warming and the attendant increase in the severity and extent of soil degradation may exacerbate the intensity and duration of drought occurrence in agroecosystems. Restoration of the soil organic matter (SOM) content of degraded/depleted soils can increase soil water retention (SWR) more at field capacity (FC) than that at the permanent wilting point (PWP), and thus increase the plant available water capacity (PAWC). The magnitude of increase in PAWC may depend on soil texture and the initial SOM content. Thus, restoration of the SOM content of degraded/depleted soils can make them as well as agroecosystems climate-resilient. Management practices which enhance soil health by restoring SOM content include conservation agriculture, cover cropping, residue mulching, and complex farming systems involving integration of crops with trees and livestock. Such technologies must be fine-tuned under site-specific conditions. Additional research is needed to establish the cause-effect relationship between increase in SOM content and PAWC and the ameliorative effect on drought-resilience for diverse crops and cropping systems.

1 | INTRODUCTION

Global warming has already reached 1 °C above the pre-industrial levels (Lindsey & Dahlman, 2020; Sánchez-Lugo, Berrisford, Morice, & Nicolas, 2018), which in turn has aggravated the severity of drought caused by soil moisture deficit (Berg & Sheffield, 2018). Additionally, the positive net ecosystem exchange (NEE), caused by soil-water deficit, can make soil a net source of CO_2 (Green et al., 2019), especially following some repeated summer droughts (Sowerby, Emmett, Tietema, & Beier, 2008). Further, anthropogenic perturbations may even destabilize the vast amount of soil organic carbon (SOC) stocks in the subsoil (Rumpel & Kögel-Knabner, 2011), making soil even a bigger source of gaseous emissions. Additionally, human activities (i.e., deforestation, excessive plowing, continuous monocropping, removal or in-field burning of crop residues, draining wetlands, excessive grazing), and the attendant climate change, may lead to global soil moisture drying (Gu et al., 2019). A review of global soil water trends indicate that the climate is getting drier in dry and wetter in wet regions through the accelerating anthropogenic climate change, or ACC (Feng & Zhang, 2015). Soil water retention (SWR) in the root zone is critical to alleviating the ever-growing risks of pedologic and agronomic drought.

The ACC is also aggravating the loss of soil organic matter (SOM) in agricultural soils (Wiesmeier et al., 2016). Yet SOM is a critical determinant of SWR in the root zone. Thus, there is a growing need to understand the

Abbreviations: ACC, anthropogenic climate change; FC, field capacity; L, liter; NEE, net ecosystem exchange; PAW, plant available water; PAWC, plant available water capacity; pF curve, moisture characteristic curve; PWP, permanent wilting point; RMPs, recommended management practices; SOC, soil organic carbon; SOM, soil organic matter; SWR, soil water retention relationship between SOM content and SWR. In other words, can an increase in the SOM content of degraded and depleted soils alleviate risks of drought under climate change, and save scarce water resources from excessive withdrawal for supplemental irrigation?

The importance of SWR to agronomic productivity can never be over-emphasized, especially in arid and semi-arid regions (B. A. Stewart & Lal, 2018), and the current and projected climate change may reduce SWR capacity (Feddema & Freire, 2001). In addition, SOM content is a key parameter affecting soil quality, aggregation, and hydrological properties (Carter, 2002; Franzluebbers, 2002). It has been stated that each 1% increase in SOM can store a large amount of water (Bryant, 2015) (Table 1). Thus, the objectives of this review article are to discuss the impact of SOM content on SWR, specifically on the plant available water capacity (PAWC), and also identify some recommended management practices (RMPs) which may enhance SOM content, increase PAWC, and reduce the risks of pedologic and agronomic drought.

2 | MATERIALS AND METHODS

This review article is based on collation and synthesis of published articles on SOM content and SWR. Published articles were obtained from the Web of Science. These articles were grouped under several categories as follows: 1) SOM content and SWR, 2) soil quality effects of SOM content, 3) the SOM quality and SWR, 4) SOM and soil water retention characteristics, 5) experimental methodology to test the relationship between SOM content and SWR, 6) saving in irrigation and drought avoidance by increasing SOM content, and 7) impact of RMPs on SOM content in relation to SWR. Discussion below is based on the research articles collated and synthesized under these broad categories.

TABLE 1 Examples of presumed impacts of increase in organic matter content by 1% on soil water retention

Reference	Impact of increasing SOM content by 1% on water retention in soil
Sullivan (2002)	Each cubic foot (0.0283 m^3) of soil can hold an additional 1.5 quarts (1.42 L) of PAW
Scott, Wood, and Miley (1986)	Soil can hold an extra 16,500 gallons (61,875 L0 of PAW in an acre foot (0.4 ha to 30 cm depth)
Gould (2015)	Increasing SOM from 1 to 2% would increase the volume of water to 3 quarts (2.84 L) per cubic foot (0.0283 m^3) of soil
Glenn (2014)	Compost can hold 20 times its weight in water

Core Ideas

- Restoring soil organic matter can increase plant available water capacity in the root zone.
- High soil organic matter in the root zone increases resilience to short dry spells.
- System-based conservation agriculture can increase soil organic matter and drought tolerance.
- Irrigation amount and frequency can be reduced in soils with high organic matter.

2.1 | Soil organic matter content and water retention

The impact of SOM content on PAWC, difference in moisture content at field capacity (FC) and the permanent wilting point (PWP), depends on a range of factors, including inherent soil properties, terrain characteristics, land use, climate, and management (Figure 1). It also depends on how the change in SOM content affects change in SWR at FC and the PWP, and the soil water retention characteristics, or p^F curves. Important among inherent factors affecting SWR are: texture (sand, silt, and clay content); type and the amount of clay and nature of the clay minerals, including those of the sesquioxides; aggregation and stability of aggregates along with pore size distribution (i.e., proportion of retention pores); internal drainage of the soil solum (well-drained vs. poorly drained soil profile); and of course, the SOM content and composition of its fractions (Figure 1). The impact of SOM on SWR also depends on the methodology used, and therefore it is important that the experiment is specifically designed to eliminate the effect of all other factors except that of the SOM content. Three among a wide range of external factors with a strong impact on SWR are the following: terrain and, especially, the slope aspect (Geroy et al., 2011; LeClair-Bernal, 2019); climate and, in particular, the amount and distribution of precipitation and the evaporative demand of the atmosphere that affects the water balance; and, finally, management (i.e., soil, crop, livestock, vegetation, drainage/irrigation). Land use and soil management can impact SWR by altering SOM content, aggregation, porosity, and pore-size distribution, surface runoff versus infiltration, and evaporation and deep drainage (Figure 1). Increase in SOM content can suppress evaporation and

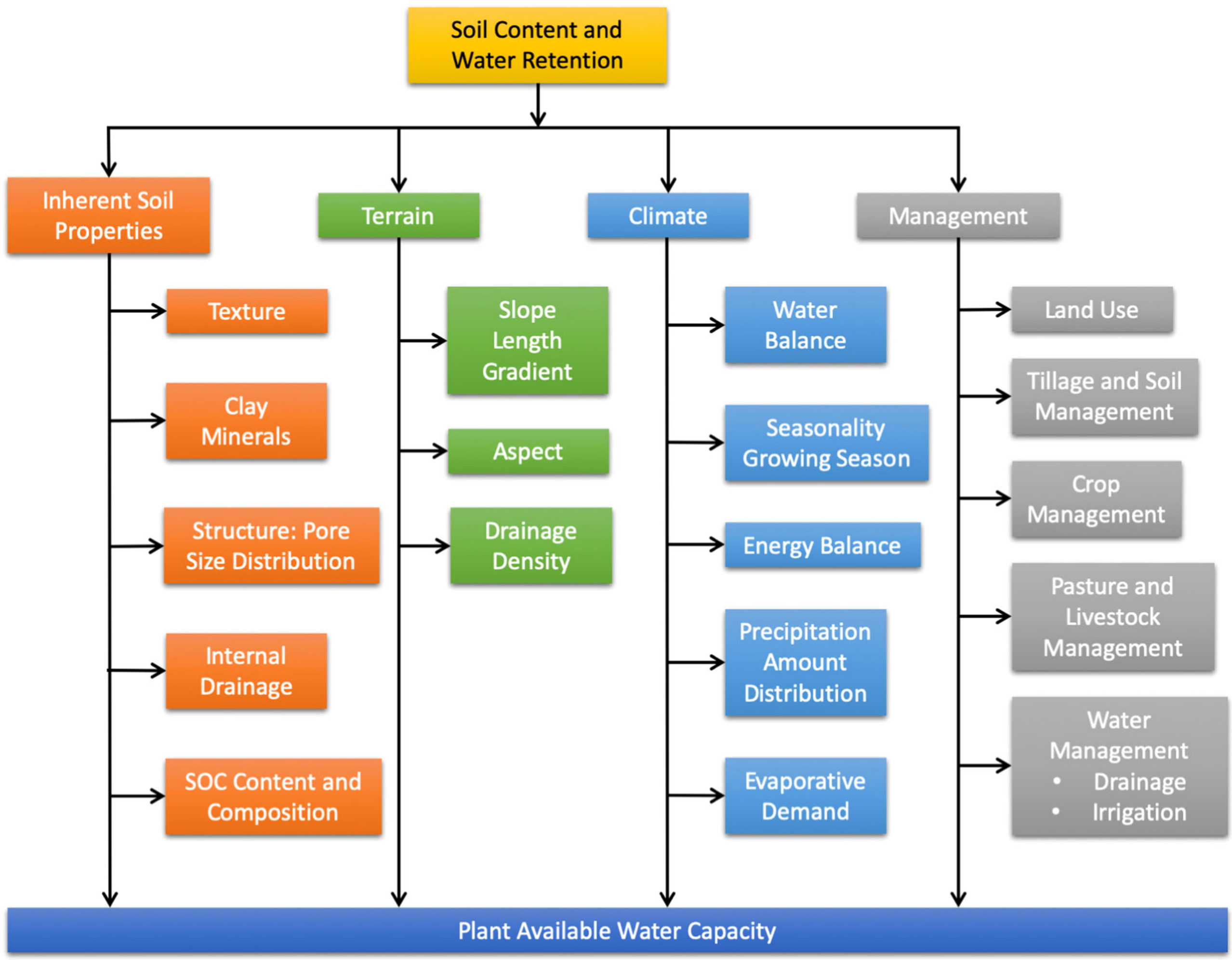

FIGURE 1 Factors affecting the impact of soil organic matter content on soil water retention and plant available water capacity

infiltration of water (Ding, Huang, Wang, Zhang, & Zhang, 2014). Complex and strongly interacting factors make it a daunting methodological challenge to establish the direct cause-effect relationship between SOM content and SWR or PAWC.

Methods of determination of SWR impact its assessment both directly and indirectly. For example, there can be substantial differences in data from in-situ field measurements versus disturbed sampling for assessment of soil water content (Iiyama, 2016). Conversion of gravimetric soil moisture into volumetric moisture content depends on an accurate and credible measurement of soil bulk density or, more precisely, the specific gravity of the soil. Soil bulk density is a highly variable and dynamic parameter that changes over time and space (Alletto & Coquet, 2009; Cassel & Nelson, 1985; Logsdon, 2012). Yet, credible data on SWR and PAWC are critical to sustainable agriculture and achievement of global food and nutritional security. An important challenge in the choice of an appropriate experimental design is to ensure that the effects of texture, bulk density, and other variables are duly accounted for.

2.2 | Soil quality effects of organic matter content

That SOM content is among some key indicators of soil quality, and this has been recognized for centuries (Allison, 1973; Darwin, 1840; Howard, 1943, 1945; Hyams, 1952; Jenny, 1941; Rodale, 1945). Most indicators of soil health, defined as "the capacity of the soil to function as a vital living ecosystem that supports plants, animals, and humans (USDA-NRCS, 2019)," are based on the quantity and quality of SOM content (Gardi, Tomaselli, Parisi, Petraglia, & Santini, 2002; Haney, Haney, Smith, Harmel, & White, 2018; Hurisso et al., 2018; Lehman et al., 2015; Moebius-Clune et al., 2016; Morrow, Huggins, Carpenter-Boggs, & Reganold, 2016; Ndiaye, Sandeno, McGrath, & Dick, 2000; Schindelbeck et al., 2016, 2017; van Es & Karlen, 2019; Zobeck, Halvorson, Wienhold, Acosta-Martinez, & Karlen, 2008, 2015). However, agronomic N fertilization is critical to maintain or increase SOC of the U.S Midwest cropland (Poffenbarger et al., 2017), such as through the use of fertilizer and manure (Weyers, Johnson, Archer, Gesch, &

Forcella, 2018). A critical review of this and other literature indicates that SOM content is the most often measured parameter to assess the impact of land use and RMPs on agronomic productivity and soil functionality (Reeves, 1997), which depend on PAWC and the amount of water stored in the root zone. Thus, sustainable management systems are those that enhance and sustain SOM content (Carter, 2002) as well as the quality of its fractional components, while also increasing the PAWC. Loveland, Webb, and Bellamy (2001) stated that the active fraction of SOM is a more pertinent determinant of changes in soil properties than total SOM content, and that a single value of SOM content cannot be established as a threshold for its critical levels. Thus, it is important to establish the direct cause-effect relationship between SOM content and SWR in general and PAWC in particular by carefully eliminating the confounding impact of other variables. The capacity of SOM to moderate PAWC, through its effects on soil structure (Bronick & Lal, 2005a; Carter & Stewart, 1995; Emerson, 1954; Greenland, 1975; Tisdall & Oades, 1982; R. J. B. Williams, 1970), is important to sustaining the agronomic productivity under the current and projected climate change (B. A. Stewart & Lal, 2018).

2.3 | Soil organic matter quality and water retention

The decomposed SOM content, or the humus, has a relatively higher water retention capacity because of its low bulk density (Périé & Ouimet, 2008), high porosity, low crusting (de Rouw & Rajot, 2004), high aggregation and water infiltration (Franzluebbers, 2002; Mills & Fey, 2003), high surface area, high absorption capacity, and favorable properties of some hydrophilic compounds such as polysaccharides gum (Bronick & Lal, 2005b). Polysacchride-C can reportedly be an even more important agent in the aggregation process than microbial-C and fungal hyphae (Abdollahi, Schjønning, Elmholt, & Munkholm, 2014). Some hydrophobic organic substances, including stearic acid, can also enhance aggregate stability (Piccolo & Mbagwu, 1999). Soil texture is an important determinant of the hydrophobicity or hydrophilicity of SOM compounds. For example, the SOM content in sandy soils may contain more alkyl compounds (and fewer carbohydrates and proteins) compared with those in clayey soils, which impart hydrophobicity (Capriel, Beck, Borchert, Gronholz, & Zachmann, 1995). Thus, hydrogel and other organic substances containing hydrophilic compounds are used as amendments to increase SWR (Miller & Naeth, 2019). In contrast, however, understanding of the hydrophobicity of some compounds is also useful to manage the water repellency. For example, the aliphatic C-H to C_{org} ratio can be used as an index of hydrophobicity, and it can be influenced by management. Capriel (1997) proposed that the hydrophobicity index is a useful indicator to evaluate the quality of SOM content, which may, however, be not a satisfactory indicator of soil water repellency for all soils (Leelamaanie & Karube, 2009). In the Sudano-Sahelian region of Mali and Burkina Faso, Dutartre, Bartoli, Andreux, Portal, and Ange (1993) observed that soils with most stable structure were characterized by large contents of humin, uronic acids osamines and polyphenols. Among these substances, uronic acids produced the strongest aggregative effects.

Research on the effect of texture on SWR dates back to the 1930s (Baver, 1940). Soil texture affects SWR by moderating aggregation, pore-size distribution and relative proportion of retention versus transmission pores. Rawls, Pachepsky, Ritchie, Sobecki, and Bloodworth (2003) used the U.S. National Soil Characterization database and concluded that increase in SOM content increased SWR in sandy soils but decreased it in fine-textured soils. The highest increase in SWR by increase in SOM content was in sandy and silty soils. However, the effects of texture (particle size) on SWR in response to SOM content can be altered by land use, such as forest versus cultivated lands (Rajkai et al., 2015).

2.4 | Soil organic matter content and water retention characteristics

SWR characteristic curves (p^F curves) depict the relationship between soil water potential (the energy status of water in soil) and the volumetric water amount (Childs, Collis-George, & Taylor, 1950; Schaap & Bouten, 1996; Schofield, 1935; van Genuchten, 1980; R. Zhang & van Genuchten, 1994). The p^F curves, an important diagnostic tool for assessing management-induced changes in soil structure and especially the pore-size distribution, are strongly affected by the SOM content (Wösten & Groenendijk, 2019), texture (Bauer & Black, 1992; De Jong, 1983), and bulk density (Vereecken, Maes, Feyen, & Darius, 1989). Thus, the p^F curve and soil moisture constants (e.g., FC and PWP) are estimated from key soil properties (Gupta & Larson, 1979; Saxton & Rawls, 2006; Vereecken et al., 1989). For light and medium-textured soils, SOM content is an important determinant of SWR (Yang et al., 2015). Because of its impact on soil processes and productivity, management of SOM content is also receiving attention of some policymakers. For example, the Dutch Minister of Agriculture stated that “a soil containing much organic matter is better equipped to absorb water and is more resistant against drought” (Schouten, 2018), and that SOM content is also significant to the Climate Accord

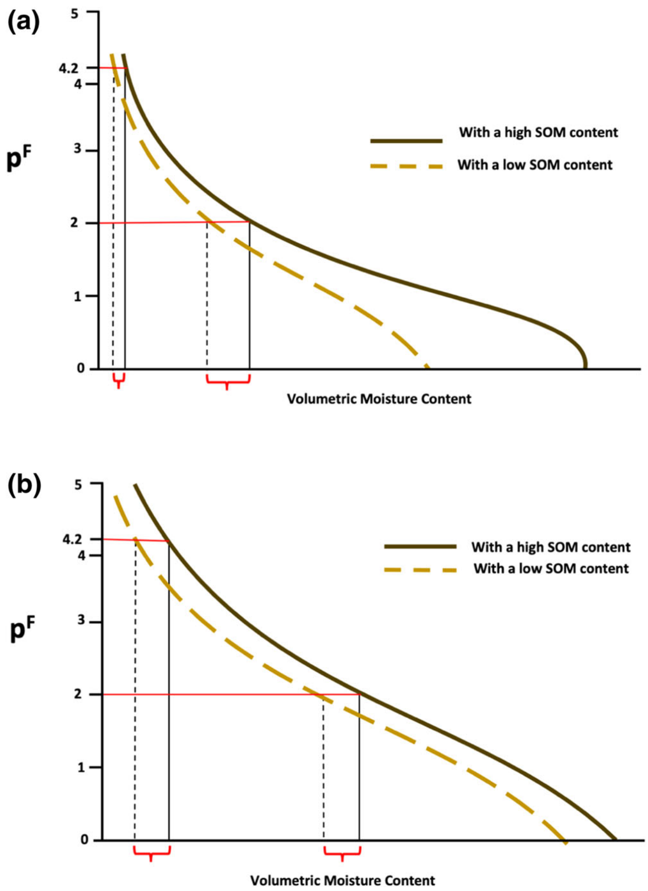

FIGURE 2 A schematic of p^F curve in soils, (A) where soil organic matter induced increase in soil moisture retention is more at field capacity than at permanent wilting point. In these soils, an increase in soil organic matter content increase plant available water capacity. In soil (B), soil organic matter induced increase of moisture retention is similar at field capacity and permanent wilting point. Thus, there is no net gain of plant available water capacity

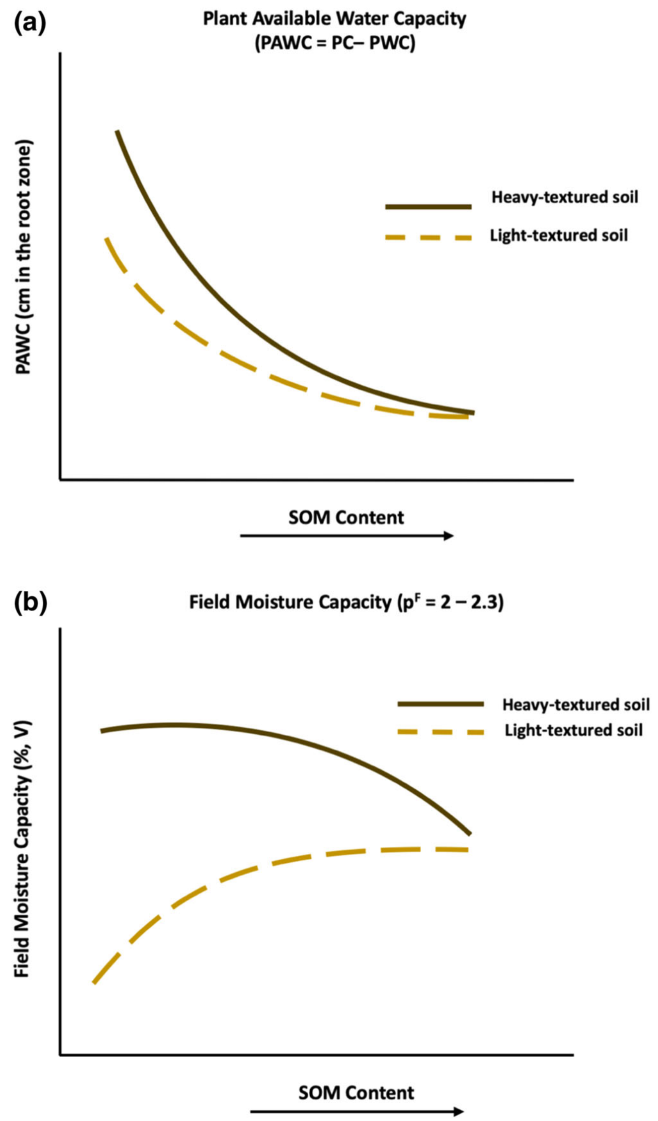

FIGURE 3 A schematic of the response of (A) plant available water capacity to increase in soil organic matter content of a light- and heavy-textured soil, (B) of field moisture capacity of a light- and heavy-textured soil

(Chambers, Lal, & Paustian, 2016; INRA, 2015; Kilmaatberrad, 2018). For some sandy soils in the Netherlands with an SOM content of 0.5-1.0%, a 1% increase in SOM content in the 0–20 cm depth would increase PAWC by 3–4 mm. For soils with an SOM content of 1–3%, the PAWC increase would be 2–3 mm. And for soils with SOM content of >3%, the PAWC increase would be 1 mm (Wösten & Groenendijk, 2019). Such an incremental increase would be possible in those soils where an enrichment of SOM content has a more favorable effect on SWR at FC than that at the PWP (Figure 2a). However, there are some soils in which the effects of SOM content are similar both at FC and at PWP (Figure 2b). In such cases, increase in SOM may have no effect on PAWC. A schematic of the response of SWR to increase in SOM content, in accord with that of Figure 2A, are shown in Figure 3A for PAWC and Figure 3B for FC.

Soil-specific mechanisms of response to an increase in SOM content on p^F curves (differential or similar incremental increases in moisture content at FC and PWP; Figure 2a vs. Figure 2b) are not well understood. Important determinants of response include texture, SOM content and specific fraction (i.e., hydrophilic or hydrophobic, polysaccharides, and uronic acids), land use history, in-field biomass burning, type of soil amendment, etc. Some examples of the literature for positive, slight or none, and negative responses of PAWC to increase in SOM content are depicted in Tables 2, 3 and 4, respectively. Some peat soils, with a high SOM content, may also have a negative response to increase in SOM content (Rocha Campos et al., 2011).

Literature on the effect of SOM content on PAWC between 1930 and 1990 was critically reviewed by Hudson (1994). Hudson pointed out the importance of the

TABLE 2 Some examples of positive response of plant available water capacity to increase in soil organic matter content

Country/region	Soil	Land use management	Increase in PAWC per unit increase in SOM content	Reference
Australia: NSW	General database	Miscellaneous	Increase 2–3 mm/10 cm	Murphy (2015)
UK	Long-term field experiment	Cropland	A significant positive impact	Salter et al. (1961); Salter and Haworth, 1961); Salter and Williams (1963)
UK: West Midlands	General database	Cropland	A significant positive impact	Hollis, Jones, and Palmer (1977)
USA	Sandy	Miscellaneous	+ 1–4 mm/1%increase in 10 cm layer	Wösten and Groenendijk (2019)
USA	National Database	Miscellaneous	Positive for sandy soil with low SOM content	Rawls et al. (2003)
USA	USDA-NRCS soil database	Miscellaneous	Increase water holding capacity by 1.3–2.3%	Bhadha, Capasso, Khatiwada, Swanson, and Laborde (2017)
USA	USDA-NRC's database	Miscellaneous	Increases PAWC by 2–7.5%	Olness and Archer, (2005)
USA	NCSS database	Miscellaneous	Increase PAWC by 1.5–1.7%	Libohova et al. (2018)
USA	Sand and decomposed compost	Lab study	Significant positive impact	Bouyoucos (1939)
USA	General database	Cropland	Positive effect on sandy soils with <15% clay	Jamison (1953)
USA: Florida	SSIR Database	Cropland	A significant positive impact for sand, silt and clayey soils	Hudson (1994)
USA: Michigan	Droughty soils	Cropland	Increase water retention	Gould (2015)
USA: Missouri	General database	Cropland	Significant positive impact for soils with <2% SOM content	Jamison and Kroth (1958)
USA: North Dakota	Sandy	Cropland	Positive	Bauer and Black (1992)
USA: Sierra Nevada, CA	Sand and gravel overlain by SOM-rich soil	Meadow	Significantly positive	Ankenbauer and Loheide II (2017)

TABLE 3 Some examples of no or slight plant available water capacity to increase in soil organic matter content

Country/region	Soil	Land use management	Increase in PAWC per unit increase in SOM content	Reference
Australia	National database	Cropland	Little effect	Minasny and McBratney (2018)
Canada		Mine land	No gain in PAWC because SOM increased both PC and PWP	Gardner, Broersma, Naeth, Chanasyk, and Jobson (2010)
USA	Medium and fine-textured	Cropland	No change in PAWC	Bauer and Black (1992)
USA	Sand and peat mixture	Lab study	No effect	Feustal and Byers, (1936)
USA: Pennsylvania	Silt loam soils	Cropland	Little effect for soils with <2% SOM content	Petersen, Cunningham, and Matelski (1968)
USA	Review of literature	Miscellaneous	No effect	Kelley (1954)
USA	General data	Cropland	Minor effect even in sandy soils	Jamison (1956)
USA	General database	Miscellaneous	A lot of uncertainty	Huntington (2016)

TABLE 4 Some examples of negative effects of increase soil organic matter content on plant available water capacity

Country/region	Soil	Impact	Reference
Brazil	Peatlands	Increase in humic acid content decreased water retention, but that of humin increased water retention	Rocha Campos et al. (2011)
USA	Soils of different textures	In clayey soils of a heavy texture increase in SOM content may decrease PAWC	Rawls et al. (2003)

TABLE 5 Increase in water storage in soil and saving of irrigation by increasing the soil organic matter content

Reference	Increase in water storage
Libohova et al. (2018)	1% increase in SOM content increased PAWC by 1.5 times its weight. This is equivalent to 10,800 L of water to 15 com depth per acre (0.4 ha)
Maynard and Hill (1994, 2000)	Compost (7.5 cm thick layer) mixed 15 cm depth increased PAWC 2.5 times that of a sandy soil, providing a 7 to 14-day supply of water
Ankenbauer and Loheide II (2017)	Increased water retention by SOM contributes as much as 8.8 cm to transpiration, or 35 additional water-stress free days, during the dry summer
Wösten and Groenendijk (2019)	In poor sandy soils, an increase of SOM content by 1% increased PAWC 1–4 mm in 20 cm depth depending on the SOM content
Sullivan (2002)	Each 1% increase in SOM content can increase water storage by 16,000 gallons per acre foot (60,560 L in 30 cm depth of 0.4 ha)

methodology used. Referencing the U.S. National Soil Characterization Database and the information from pilot studies on soil quality, Rawls et al. (2003) reported that increase in SOM content is more in sandy and loam soils but decreases in clay soils. For soils of NSW, Australia, Murphy (2015) summarized the available information with regard to increase in PAWC for 10 cm layer with increase in SOM content by 1% as follows: 3 mm for sandy soils, 2.5 mm for loam soils, 2 mm for clayey soils, and relative increase at FC (10 kPa suction) was more than that at PWP (1500 kPa suction).

In Burkina Faso, (Leu, Traore, Wang, & Kan, 2010) recommended increase in SOM content for saving irrigation water in the Sahelian environment of Africa. In addition to saving water, increasing SOM content (through input of compost and mulch) of the surface layer also enhances the rate of soil formation from top downward than only from bottom up (Shaxson, 2009). Olness and Archer (2005) concluded that 1% increase in SOC content increases PAWC by 2 → 5% (see also Table 1).

2.5 | Experimental methodology to determine the relation between soil organic matter content and water retention

On the basis of the review of research conducted since the 1930s, Hudson (1994) concluded that many studies failed to demonstrate any effect of SOM content on PAWC because these studies were neither specifically nor properly designed to assess the effect. Using a regression analysis involving a wide range of variables (sand, silt, clay, SOM, and stone/gravel content), any effect of SOM content on PAWC is masked by the dominant effect of textural properties. Results of the SOM effect on PAWC would only be valid for a study involving soil samples that vary widely in SOM content but are otherwise uniform in texture, clay minerology, stone content, etc. Based on this hypothesis and a careful selection of soil, Hudson (1994) concluded that SOM content had a significant impact on PAWC for soils of all textures: sand, silt, and clay. Experimental data by Hudson (1994) clearly showed that an increase in SOM content increased moisture content at FC more than that at PWP (Figure 2a) and that significantly enhanced PAWC regardless of the texture class. The data by Hudson showed that as SOM content increase from 1–3%, the PAWC doubled. The effect was less for SOM content of 4% (60% increase), and above. The increase in PAWC by increase in SOM content is attributed to its low bulk density of 0.25–0.3 Mg m^{-3} (Adams, 1973; Hudson, 1994; V. I. Stewart, Adams, & Abdulla, 1970). Bulk density of the mineral fraction is ~5 times that of the SOM. Thus, SOM content must be appropriately reported on volume rather than on weight basis.

2.6 | Saving in irrigation and drought avoidance by increasing soil organic matter content

Drought, along with high air and soil temperatures, is a serious risk in global agriculture (Iizumi & Wagai, 2019).

TABLE 6 Effect of soil organic matter application and soil management practices on an increase in water retention

Country/region	Impact of increase in SOM on water retention	Reference
Brazil	Reducing the need for irrigation be increasing soil water storage through increase in SOM content	Klein and Klein (2015)
Brazil	SOM content improved aggregation under pasture	Suzuki, Reichert, and Reinert (2013)
Brazil	High SOM under no-till increased water storage	Figueiredo, Ramos, and Tostes (2008)
Burkina Faso	SOM increases field capacity and permanent wilting point	Leu et al. (2010)
Canada: Manitoba	High correlation among SOC, soil water conditions, content, and bulk density	Manns, Parkin, and Martin (2016)
China	Total organic carbon was correlated with water holding capacity	Li, Li, Zed, Zhan, and Singh (2007)
China	SOM content suppresses evaporation losses	Ding et al. (2014)
China	SOM has a positive effect on soil water content	S. X. Zhang, Zhang, Jiang, and Yu (2013)
China: Alpine	SOM content plays a dominant role in SWR	Yang et al. (2015)
Hungary	A slight effect of SOM on moisture storage C	Rajkai et al. (2015)
Italy	Input of compost and manure increased water capacity	Elia, Conversa, Trotta, and Rinaldi (2007)
Spain	SOM content increased water retention and aggregation	Acín-Carrera et al. (2013)
Spain	Humic acids with aliphatic domain displayed favorable hydrological properties of semi-arid soils	Álvarez, Carral, Hernández, and Almendros (2013)
Turkey	Organic matter incorporation can enhance soil resilience against extreme weather	Mujdeci, Simsek, and Uygur (2019)
USA	Crop residue management and conservation tillage for semi-arid regions	Unger, Stewart, Parr, and Singh (1991)
USA	Maintaining and improving hydrological functions of soil	Hatfield, Cruse, and Tomer (2013)

The current and projected climate change, as well as the increase in risks of soil degradation, may aggravate the drought stress during crop growth because of reduction in PAWC (pedological drought) of soil, and depletion of soil water in the root zone at the critical stage of crop growth (i.e., flowering stage) in conjunction with high air and soil temperatures associated with a heat wave (agronomic drought). The information presented herein indicates the beneficial effects of restoring SOM content in either alleviating drought or reducing its severity and duration by enhancing PAWC of the root zone (Table 5). The SOM-induced improvement in soil health can lead to drought-resilient soil (Sullivan, 2002), suppress evaporation (Ding et al., 2014), and reduce the need for any additional irrigation (Klein & Klein, 2015). Iizumi and Wagai (2019) reported that even a small increase in topsoil-SOM content could enhance drought tolerance of the food production systems over 70% of the global harvested areas, especially in drylands of the world. Iizumi and Wagai estimated that global addition of SOC by 4.87 Gt C (Gt = gigaton = billion metric ton = Pg) could enhance farmer's economic output during the drought years by 16%, while also reducing the global mean decadal temperature warming by 0.011 °C. Ankenbauer and Loheide II (2017) observed that an increase in SOM content contributed 8.8 cm to transpiration and/or 35 additional water-stress free days. Using the U.S. National Soil Characterization Database, Libohova et al. (2018) reported that an increase in SOM content by 1% would increase PAWC by 1.5–1.7% for the 0–8% SOM range, equating to about 10,800 L of water in 0.4 ha land in the 15 cm layer. On the basis of some regional scale analysis of risks and volatility in the U.S. rainfed maize, Williams et al. (2016) recommended investment in SOM storage. They reported that soil water holding capacity, which strongly affected maize yield in four states (Minnesota, Pennsylvania, Illinois, and Michigan), can be enhanced by restoring SOM content.

2.7 | Technologies to restore and sustain soil organic matter content

There is "no one size fits all" RMP to enhance and sustain the SOM content in diverse soils and global ecoregions. Site-specific technologies (as shown in Table 6), and those which can create a positive soil carbon budget, depend on biophysical and socio-economic and cultural factors. In general, however, the basic concept is to control erosion, moderate mineralization and decomposition, and minimize leaching losses. These objectives are achievable by creating a continuous soil cover, even during the off-season by establishing a cover crop. Some practices which achieve these conditions of mimicking nature and enhancing soil health include conservation agriculture (based on no-till, residue retention, cover cropping, and integrated nutrient management), complex farming systems, and integration of crops with trees and livestock (USDA-NRCS, 2018). Examples of such technologies for increasing SOM content, outlined in Table 6, must be adapted under site-specific conditions. Fine tuning is critical to the adaptation of such technologies under site-specific conditions. An example of one such site-specific condition that would need to be considered is the use of cover crops in semi-arid areas. This is because the potential increase in SOM content will generally not improve PAWC sufficiently to offset the cover crop water use (Unger and Vigil, 1998).

3 | CONCLUSIONS

The synthesis of literature supports the following conclusions:

- Increase in SOM content increases PAWC for all soils (sand, silt, and clayey texture).
- The magnitude of increase depends on site-specific inherent and external factors.
- Increase in PAWC by increase in SOM content is attributed to relatively greater increase in FC than that in PWP.
- No or a slight response of PAWC to an increase in SOM content is reported for those studies that were not specifically designed to evaluate the effect of SOM content.
- Because SOM has a low bulk density (0.25–0.3 Mgm^{-3} compared with 1.5–1.6 Mg m^{-3} for the mineral fraction), SOM content may be better expressed on volume rather than on the weight basis.
- Restoration of SOM content of degraded and depleted soils may save water resources by creating drought-resilient soils.
- Increasing SOM content may also enhance tolerance to short-duration drought during the growing season.
- Additional research is needed to understand the effects of SOM content on SWR at FC and PWP, under site-specific situations.
- Further research must also be encouraged to better understand the mechanisms and soil process that lead to increased PAWC in association with increased SOM content.

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