Climate, management, and soil health

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Soil health has been discussed among scientists in analytical terms at least as far back as the Dust Bowl era, and most assuredly by farmers in descriptive terms since the advent of agriculture. A uniting theme of modern definitions of soil health is its capacity to provide essential ecosystem services at present and into the future. Consequently, soil health is an important concept for quantifying soil regeneration or degradation due to historic and current land management practices, as well as a critical factor in building resiliency in an era facing an uncertain future climate. Soil organic matter (SOM) is often identified as one of the most crucial properties of soil and therefore is an important attribute of soil health.

IMPACT

Future climate scenarios indicate potential threats to soil health. Improved understanding of soil health monitoring appropriate for the inland PNW can help guide management decisions aimed at improving soil health, thereby bolstering the region's agricultural resiliency as the climate changes.

SOM is made up of a continuum of dead and decaying material ranging from fresh plant residue to soil humus, which can persist in the soil profile for thousands of years. While several models exist that attempt to capture the complexity of this continuum, a two-pool SOM model is the simplest, consisting of a labile or more transient pool and a recalcitrant or more stable pool. These two SOM pools are associated with distinct soil properties and processes: the labile pool provides energy to the soil food web, which in turn drives nutrient cycling, aggregation, and micronutrient chelation, and the recalcitrant pool contributes to cation-exchange capacity, water-holding capacity, and soil structure. In accordance with their nature, labile SOM is typically associated with rapid changes resulting from management or weather fluctuations, while recalcitrant SOM changes more slowly in response to these factors. Across the REACCH study area, we have collected both labile and recalcitrant SOM data and identified how mean annual temperature (MAT) and mean annual precipitation (MAP), as well as both tillage and cropping intensity, influence labile and recalcitrant SOM pools. An analysis of these data will not only help inform present and future efforts to monitor soil health in the REACCH study area, but will also help guide management decisions aimed at improving soil health and thus can bolster the region's agricultural resiliency under future changes in climate.

In water-limited regions such as the inland Pacific Northwest (PNW), rainfall drives biomass production and in turn organic inputs to the soil, while SOM decomposition is influenced by temperature, precipitation, and other soil factors. This interplay of temperature and precipitation in SOM dynamics is evident across four dryland sites in the REACCH study area (Table 1). Across these sites, soil organic carbon and total nitrogen, important proxy measures of SOM, increase with increasing MAP and decreasing MAT (Figure 1). These data indicate that an increase in the MAT/MAP ratio would result in degradation of SOM across the region. For the inland PNW, climate models predict a 3° to 4°F rise in MAT by 2050 and a 4° to 6.5°F rise in MAT by 2100 and, correspondingly, a 5% to 15% rise in MAP by the middle and latter part of the 21st century. These scenarios represent an increase in the MAT/MAP ratio and subsequently a potential decline in SOM from present-day levels (Figure 1). They do not, however, take into account the uncertainty surrounding microbial response to future climate scenarios that will ultimately play an important role in future SOM levels. Nonetheless, management decisions will remain an important consideration in combating this potential decline in SOM.

Two management decisions that influence SOM levels and soil health are cropping intensification and tillage. Reducing the frequency of fallow increases plant residue inputs to soil and subsequently has the potential to increase SOM and improve soil health. A reduction in tillage intensity or adoption of no-tillage can enhance aggregation, improve soil structure, and subse-

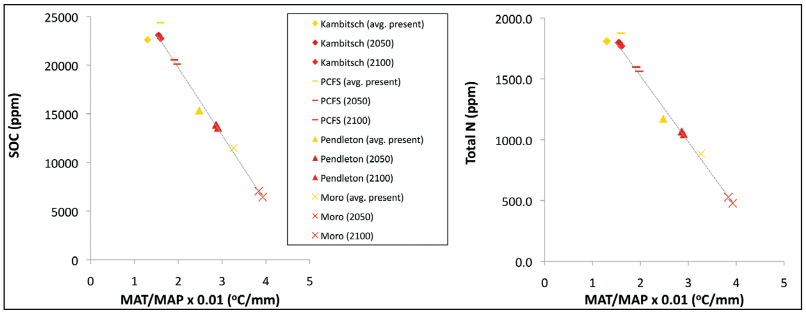

Figure 1. *Soil organic carbon (SOC) and total nitrogen (N) levels and their relationship to mean average temperature (MAT)/mean average precipitation (MAP) × 0.01 at present and under future climate scenarios for 2050 and 2100 across four dryland sites.*

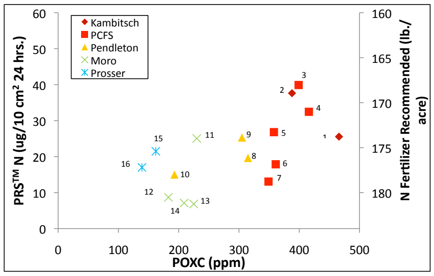

Figure 2. *Permanganate oxidizable carbon (POXC) with PRS nitrogen and corresponding recommended fertilizer application across five study sites and multiple treatments (numbers refer to treatment numbers in Table 1).*

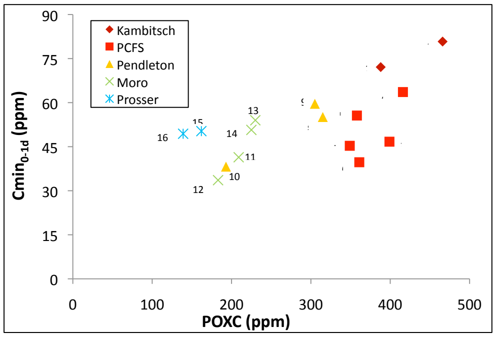

Figure 3. *Permanganate oxidizable carbon (POXC) with one-day carbon mineralization (C_{min}) across five study sites and multiple treatments (numbers refer to Table 1).*

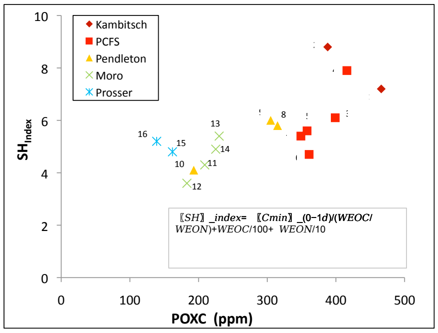

Figure 4. *Permanganate oxidizable carbon (POXC) with soil health index (SH_{index}) across five study sites and multiple treatments (numbers refer to treatment numbers in Table 1; WEOC and WEON refer to water-extractable carbon and nitrogen).*

quently protect SOM from microbial attack. Based on our analysis and review of multiple measures of SOM, we have selected four measures that are easily obtained and, when strategically coupled, are sensitive to climate and management practices, both important criteria for soil health monitoring. These measures are (1) permanganate oxidizable carbon (POXC); (2) one-day PRS™ nitrogen (plant root simulator; Western Ag Innovations, Saskatoon, Canada); (3) one-day carbon mineralization (C_{min}); and (4) a soil health index (SH_{index}) developed by the U.S. Department of Agriculture Agricultural Research Service (USDA-ARS) consisting of labile measures of SOM.

Across five study sites in the REACCH region (Table 1), POXC displayed sensitivity to both acid hydrolyzable carbon (r = 0.90) and nitrogen (r = 0.90), and acid non-hydrolyzable carbon (r = 0.84) and nitrogen (r = 0.80), providing evidence that it is a sensitive indicator of stabilized SOM. The other three measures of SOM capture a portion of the more labile SOM pool and, coupled with POXC, provide an inclusive method for monitoring both stable and labile SOM. POXC coupled with PRS™ nitrogen captures stabilized SOM along with plant-available nitrogen used to inform fertilizer applications (Figure 2). This method of soil health monitoring demonstrates the importance of nitrogen mineralization and emphasizes efficient use of fertilizer. POXC coupled with one-day C_{min} captures the microbial activity driving nutrient cycling along with stabilized SOM (Figure 3). Last, POXC coupled with SH_{index} captures the importance of the carbon-to-nitrogen (C/N) ratio in nutrient cycling (Figure 4). This method is also helpful in guiding cover crop choices to achieve a desired C/N ratio for improved efficiency of nutrient cycling. Ultimately, management goals should provide the basis for selecting methods of soil health monitoring.

Table 1. *Mean annual precipitation, temperature, and four measures of soil organic matter (SOM) across five study sites.*

Site	MAP[ŧ] (inches)	MAT[ŧ] (°F)	Treatment[†]	(parts per million)	(ug 10 cm^{-2} 24 hrs^{-1})	(parts per million)	SH_{Index}[§]
Kambitsch	26	47	1) WW/SB/SL – NT	466 a (8)	25.6 (55)	80.8 (16)	7.2 (19)
			2) WW/SB/SL – Till	388 b (6)	37.63 (44)	72.1 (23)	8.8 (27)
Palouse Conservation Field Station	21	47	3) WW/SL/SW – NT	399 (11)	39.9 (45)	46.7 (9)	6.1 (22)
			4) WW/SB/SW – NT	416 (9)	32.5 (50)	63.6 (53)	7.9 (37)
			5) Alf/SC/SL (organic) – NT	358 (11)	26.8 (30)	55.6 (50)	5.6 (33)
			6) Perennial tall wheat grass	361 (8)	17.9 (32)	39.7 (8)	4.7 (7)
			7) Native/CRP grass	349 (10)	13.1 (35)	45.3 (29)	5.4 (16)
Pendleton	16	51	8) WW/ NT Fallow – NT	315 a (10)	19.6 (35)	55.1 a (3)	5.8 a (4)
			9) WW/Pea – NT	305 a (11)	25.3 (26)	59.6 a (12)	6.0 a (7)
			10) WW/Fallow – Till	193 b (48)	15.0 (40)	38.2 b (7)	4.1 b (8)
Moro	11	49	11) WW/WP – NT	230 a (4)	25.0 a (12)	54.0 (24)	5.4 (15)
			12) WW/NT Fallow – NT	209 b (10)	11.3 b (13)	41.4 (34)	4.3 (17)
			13) WW/SB/NT Fallow – NT	225 ab (3)	6.9 b (51)	50.7 (42)	4.9 (28)
			14) WW/Fallow – Till	183 c (5)	8.7 b (45)	33.6 (16)	3.6 (13)
Prosser (irrigated)	8	52	15) WW/Sw. cn./Potato – NT	162 (10)	21.5 (35)	50.3 (14)	4.8 (32)
			16) WW/Sw. cn./Potato – Till	139 (28)	18.8 (9)	49.4 (18)	5.2 (13)

* Significant differences within sites at $p < 0.10$ and indicated by different letters; number in parentheses is coefficient of variation.

[ŧ] Based on closest weather station for the period 1955 to 2012.

[†] WW = winter wheat; SL = spring legume; SB = spring barley; SC = spring cereal; SW = spring wheat; WP = winter pea; Sw. cn. = sweet corn; Alf. = alfalfa; CRP = conservation reserve program; NT = no-till.

[§] POXC = permanganate oxidizable carbon; PRS $N_{0\text{-}1d}$ = N adsorbed to plant root simulator after 1 day; $Cmin_{0\text{-}1d}$ = cumulative 1-day carbon mineralization; SH_{index} = soil health index.