The carbon sequestration potential of Oregon soils

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Synopsis: We want to take carbon out of the atmosphere and put it in the soil. How much carbon can Oregon soils hold? And which soils in Oregon are best suited for this?

Introduction: Organic matter - the amorphous residue of decaying vegetation - is of disproportionate importance for the functionality of the soil as a life-giving system. While most of the mass of a soil comes from minerals and from water (when moist), organic matter concentrations are rarely much higher than 5 % in the upper solum. But the functional importance of this supposedly minor phase is known to anyone who has ever added compost to their garden.

Beyond being composed of gases, water, minerals and organic compounds, soils are living systems inhabited by complex interconnected networks of microbes, invertebrates and even mammals. These are, in fact, the actors whose zeal in decomposing the organic matter into nutrient elements and mineral salts determine the productivity and fertility of a soil. Because "corruption is the mother of vegetation", meaning that organic matter must suffer decay or decomposition before it serves its proper purpose in the soil, the organic phase in a healthy soil can never be static. Rather, organic matter has to continuously 'flow' through the soil (**Figure 1**).

Figure 1: Flow of organic matter through the soil. Conversion of plant debris with clearly recognizable macroscopic plant structure (soil surface, near fingertips) into an amorphous, black residue (40-cm depth) and eventually to CO_2 (invisible gas, coming off at all stages of decomposition). Image taken by the author, showing 5–10 cm depth increments from the surface of a Haplorthod at the Oregon Coast.

Natural, unmanaged soils have organic matter contents that reflect the productivity of the native ecosystems, where dead plants fall to the ground and are incorporated in the local organic matter flow cycle. Managed lands, however, suffer disruptive treatment such as tillage and the removal of produce and crop residues. Accordingly, managed soils tend to have organic matter levels far below those of their native state.

Right now, we have much more carbon in the atmosphere than is desirable. This is bad on many fronts, making weather more violent, increasing droughts as well as flood events, forcing growers to switch to less rewarding crops, etc. While the obvious remedy is to reduce further carbon emissions (such as not idling the engine while waiting for somebody in your parked vehicle), the urgency of the matter is such that we need to consider all available means to remove carbon from the atmosphere.

Putting some of the surplus atmospheric carbon back into soils is a suggestive consideration, but it is not a trivial undertaking. We need to be sure that the soils where sequestration practices are implemented are in fact able to <u>protect</u> the added organic carbon against decomposition for time scales in the order of 30 - 50 years - they can't already be stuffed full with carbon. Unfortunately, soils do vary in their capacity to protect organic matter against decomposition. This is because soils are natural bodies with unique properties that evolve over time. The State of Oregon is blessed with a particularly rich soilscape, reflected in the fact that 10 of the 12 soil orders of USDA soil taxonomy can be found across the State. An important factor here is the matter of previous land use: lands with a history of horticultural use tend to be much higher in organic matter (and hence, less able to receive and protect surplus organic carbon) compared with lands used for summer fallow rotations such as the wheat fields in the eastern Oregon. **Figure 2** illustrates the extent to which natural, unmanaged Oregon soils can vary in organic matter content, emphasizing the point that not every soil may have the ability to protect much additional carbon.

Figure 2a: Initial soil development in a coastal sand dune. Organic matter enrichment is limited to the top 10 cm (Total organic matter = 3 kg m^2)

Figure 2b: Thick (60cm) organic topsoil in a coastal rainforest soil (Total organic matter = 15 kg m^{-2})

Methods: Accordingly, we identified the need to determine the carbon sequestration potential of Oregon soils. Because the state is huge, we conducted an initial survey of data needs and availability, leading us to focus our efforts on Sherman, Gilliam, Morrow and Umatilla counties (**Figure 3**).

Figure 3: Agricultural landscape in Umatilla County

In these counties, we have great gaps in data availability, but we also have a vibrant Ag industry with the technical means to increase soil carbon levels and hence a realistic chance to actually implement any soil carbon sequestration measures. To collect soil samples, we dig a wedge-shaped pit by hand with shovels (**Figure 4**).

Figure 4: A soil pit from Umatilla county just prior to the sampling process. Area on left side of the tape measure has been moistened with a spray bottle to enhance colors. Note how it is especially the topsoil (one ft = about 30 cm) that is enriched in organic matter

The widest and deepest face of the pit needs to be around four feet deep to allow us to maneuver at our one-meter sampling depth. We divide the pit face into three to five horizons – horizontal layers where we expect similar soil properties – based on color, consistence (degree of hardness), root density, and structure. From each horizon we collect a bulk sample to analyze texture and carbon concentration and several volumetric rings to calculate the bulk density (= mass of soil per volume of soil). Bulk density allows us to calculate the mass or 'stock' of carbon that a horizontal slice of a given thickness contains. At this point it is appropriate to remember that fundamentally, soils have a limited capacity to protect organic matter from decomposition known as the carbon saturation limit. The carbon saturation limit depends on several variables, but most of the ability of a soil to protect carbon is explained by the percentage of silt and clay. By estimating the saturation limit of a given soil, it is therefore possible to predict an eventual saturation deficit and calculate the amount of carbon that could be added before saturation. Once all laboratory analyses are complete, we can calculate the carbon saturation level and compare the value obtained with the amount of carbon that is already in the soil, and this is how we know whether the soil is undersaturated with carbon (meaning it can hold more) or whether the soil is already saturated (meaning it has more carbon than it can protect against decomposition). A good example for the latter would be a raised garden bed. That organic matter is meant to decompose rapidly, in order to quickly release all its nutrients for the benefit of the plants growing in the bed. Adding more organic matter in such a situation would not lead to an effective removal of carbon from the atmosphere.

Results: At this point, we have sampled about half of the 110 locations we are planning to visit across the four counties and have complete laboratory data for a total of 30 soils, most of them from Umatilla county. Our samples represent 5 different soil orders (there are 12 soil orders in USDA soil taxonomy), 23 Mollisols, 4 Aridisols and one each of the order Andisols, Entisols and Inceptisols. Figure 5 plots just the two soil orders for which we have replicate data, and shows that the order Mollisols (Grassland soils already having high organic matter levels) may be able to accommodate more carbon than the order Aridisols (Soils of arid lands). Most significantly however, we identify two soils where the carbon saturation limit has been exceeded. One of these soils is an organic farm that relies exclusively on organic matter additions as a nutrient source for its plants, while the other is a grazed pasture - both situations somewhat untypical for land management in the Columbia basin. The good news is that there is indeed room in PNW soils for carbon to be added in a way that its retention over the critical 30-50 year time period can be asserted.

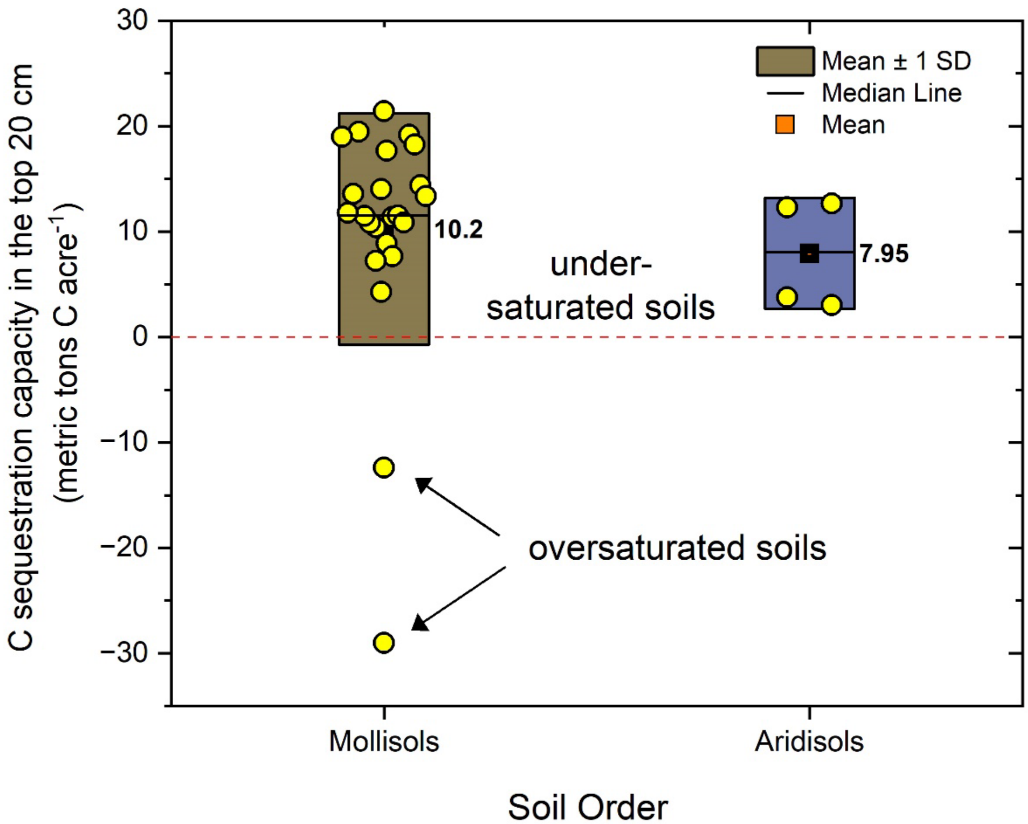

Figure 5: Carbon saturation capacity (inverse of the carbon saturation deficit) for Mollisols (n = 23) and Aridisols (n=4) from eastern Oregon. Out of 30 soils, two were found to be oversaturated.

However, going by soil order is not a very precise guide for land management planning. Orders such as the Mollisols are a population of numerous Soil Series (a series can be thought of as an individual soil on the landscape) that are mapped in detail in the contiguous United States at a scale of 1:12,000 to 1:24, by NRCS and the National Cooperative Soil Survey. Our 30 fully analysed locations represent 16 soil series, and we have replicate data for four of these, allowing us to estimate average soil properties and the associated level of confidence. **Figure 6** gives the carbon sequestration potential for these four soil series, revealing that hidden among the Mollisol order with its average sequestration capacity in the top 20 cm of about 10 metric tons per acre (**Figure 5**) there are soil series that can do much better, such as the Ritzville and Walla Walla soil series.

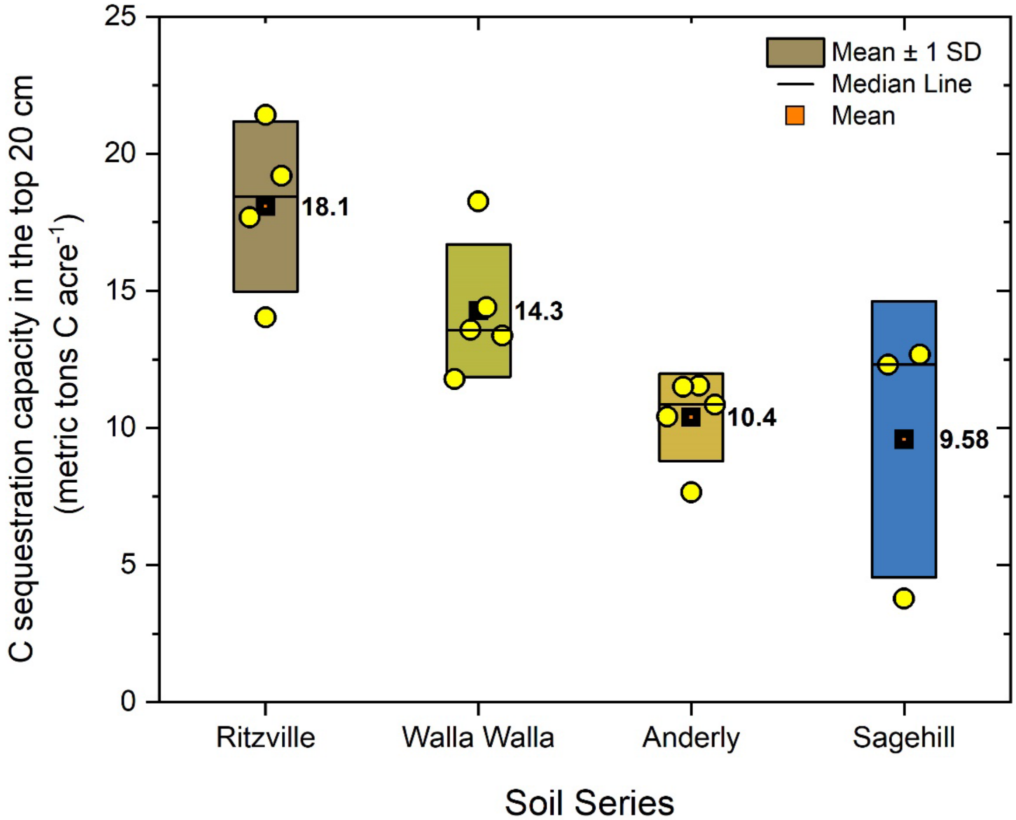

Figure 6: Carbon saturation capacity (inverse of the carbon saturation deficit) for the Ritzville (n = 4); Walla Walla (n = 5); Anderly (n=5) and Sagehill (n=4) soil series. Ritzville, Walla Walla and Anderly belong to the Mollisol order, the Sagehill soils (n=3) are Aridisols

It is intriguing to attempt an early estimation of the relevance of these numbers for statewide soil carbon sequestration. The four soil series represented in Figure 6 make up a very large part of the agriculturally used land in the greater Columbia basin (**Figure 7**). Knowing their carbon sequestration capacity, we are in a position to calculate the amount of carbon dioxide that could potentially (assuming all technological and organisational obstacles are resolved) be accommodated in the first 20 cm of these soils. Doing so yields the staggering number of 39 (range 31 - 47) Million tons of carbon or 143 (range 114 - 172) Million CO_2 equivalents. Here the reader needs to remember that we would be filling a deficit in the soil, which means we would be adding to the functional capacity of the soil, and very likely make it more fertile than it is right now if we were able to achieve such a feat. To get a better grip on the dimensions of these numbers, we can compare them to the CO2 emissions of the State of Oregon, available here: https://www.oregon.gov/energy/energy-oregon/pages/greenhouse-gas-snapshot.aspx

From this website, we learn that the entire State of Oregon has emitted 61 Million CO_2 equivalents (CO_2e) in the year 2021. Accordingly, the colored area in Figure 7, in its top 20 cm/8 inches, would be able to accommodate roughly two years of carbon emissions of the entire State of Oregon - if we can figure out how to do this technically and organisationally. While this may not sound spectacular, it is worth noting that the emissions from agriculture alone in Oregon were 7 million CO_2e in 2021. This suggests that the Ag industry actually might have a place other than the atmosphere where it could put its carbon emissions, if technical and organizational difficulties can be overcome.

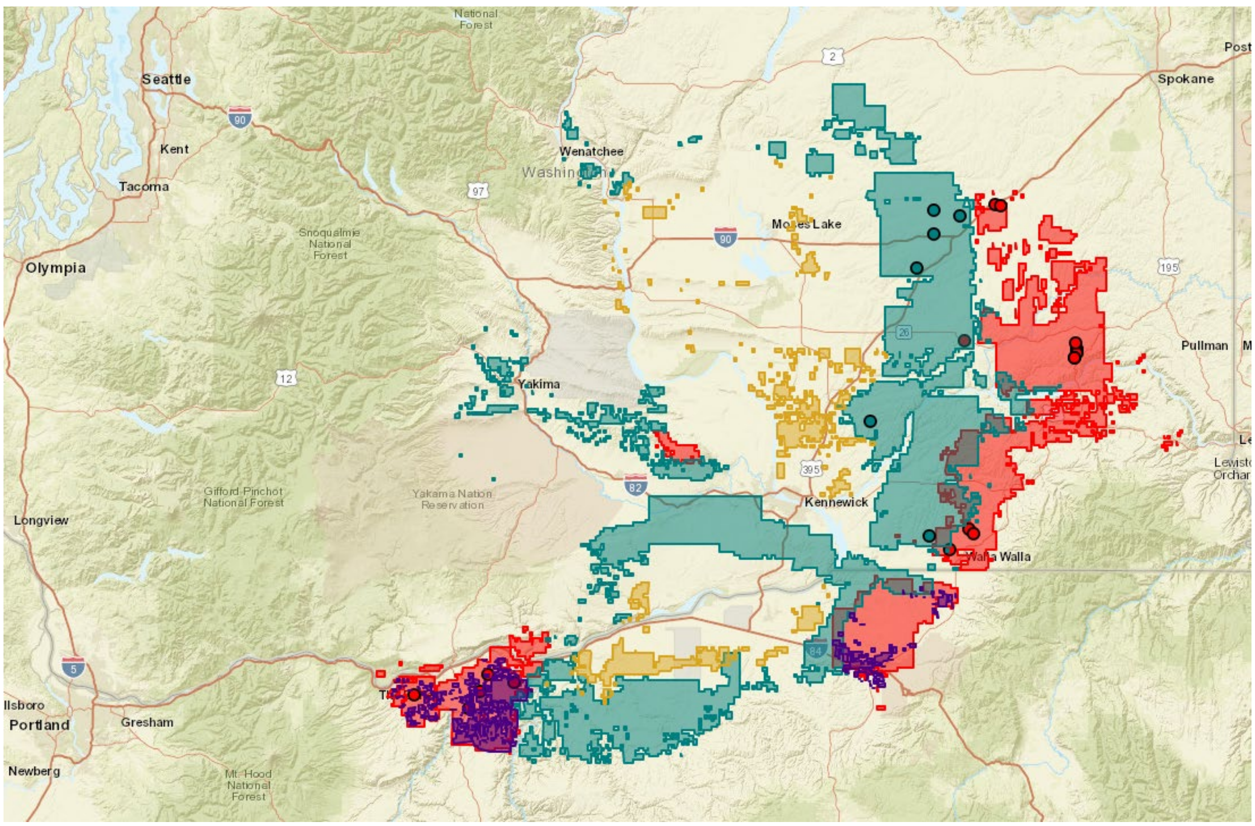

Figure 7: Spatial extension of the four soil series **Ritzville** (green, 1,417,443 acres); **Walla Walla** (red, 807,151); **Sagehill** (yellow, 139,918 acres) and **Anderly** (blue, 45,718 acres) in the Columbia basin.

Conclusion: As we complete sampling and analytical activities over the coming year, we expect to be able to reduce uncertainties on these numbers and eventually present the citizens and legislators of Oregon with a robust recommendation regarding the places in the state where soil carbon sequestration might be a climate mitigation strategy worthy of consideration.