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Soil Management for Increased Soil Organic Matter

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Soil organic matter (SOM) affects many soil properties and processes. For given climate, soil, and management conditions, SOM moves towards a steady state level. Sustained increases of SOM above the steady state level may not be feasible. Substantial SOM increases can be expected when SOM is below steady state but little increase above the steady state can be expected without a change in climate, soil, or management. Management practices such as erosion control, tillage, crop residue management, rotations, cover crops, and manure application are discussed for increasing SOM and for shifting the steady state upward.

Soil Organic Matter

Soil organic matter affects many soil chemical, physical, and biological properties and their interactions. It affects soil nutrient and water availability, soil aggregation, resistance to erosion, porosity, water infiltration, and the amount and diversity of soil microorganisms and their activity. For example, the available soil water-holding capacity could double as SOM is increased by 1 percent of soil weight. The SOM level varies with climate, soil, land use, management, and erosion rates (*Figure 1*).

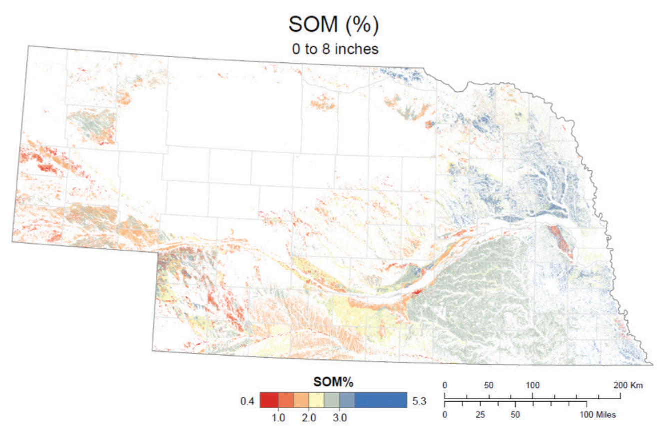

Figure 1. Soil organic matter (%) for non-eroded loamy soil croplands of Nebraska (developed from NRCS SSURGO data).

Soil is the largest terrestrial pool of carbon (C) with three times as much as in the atmosphere and four times as much as in plants. Soil organic matter averages 58 percent C. Wide scale changes in SOM affect atmospheric carbon dioxide (CO_2). Great Plains farmland has been a net source rather than a sink for atmospheric CO_2 since conversion from grassland.

Carbon, oxygen, and hydrogen account for about 92 percent of SOM dry weight with much of the balance being organically bound nutrients, primarily nitrogen (N). SOM forms a continuum of compounds that vary in their bioavailability, from more stable humus forms (fulvic and humic acids, and humin) through partially degraded plant materials (particulate organic matter) to simple molecules readily decomposable by soil microorganisms. The turnover of different organic materials in the soil from microbial decomposition ranges from days to millennia (*Table 1*).

In addition to biochemical properties, SOM stability is affected by interactions with metals such as iron and through binding to silt and clay particles with more SOM expected to bind with fine-textured compared with sandy-textured soils. Soil micro-aggregates (< 0.25 mm diameter), whether freestanding or parts of larger aggregates, protect SOM and contribute to SOM stability and slow turnover. There is little nutrient release from the protected, stable components, which are important to soil physical properties and microbial habitat. The less stable, unprotected organic materials and SOM components with relatively high turnover rates are important sources of nutrients and energy for soil microbes.

Table 1. Soil organic materials and turnover half-life in the soil.

Organic material	Turnover half-life in soil
Microbial biomass, root exudates	Days to weeks
Plant and animal materials, low C:N ratio	Weeks to months
Plant and animal materials, high C:N ratio	Months to years
Roots of grasses, including small grains	More months to years
Particulate SOM	Years to decades
Humus-fulvic and humic acids	Decades to centuries
Humus-humin	Centuries to millennia

Distribution of SOM by soil depth is important for various reasons. The SOM in the upper inches of soil is especially important agronomically with implications for soil aggregation, porosity, microbial biomass and activity, and nutrient availability. Surface SOM is the most vulnerable in that it is easily lost to erosion, but it is also more easily increased by reducing tillage, retaining more crop residue, and applying organic inputs compared with increasing deep SOM. However, deeper SOM is also important for available water-holding capacity, nutrient availability, and C storage. Deep SOM is likely to have a higher proportion of resistant and recalcitrant SOM fractions relative to labile fractions compared with surface soil.

Soil microbial biomass increases with SOM level, and the amount of new organic material supplied to the soil such as by aboveground and belowground plant residues, root exudates, and microbial turnover affects microbial activity. Most agricultural soils harbor a large quantity and great diversity of soil microbial biomass estimated at 10 billion microbes per teaspoon of soil and over 1,000 species per acre. Soil microbial activity varies throughout the year, especially with soil temperature, but also with the supply of energy and nutrient sources (primarily decomposable organic materials and applied nutrients), water, and oxygen. As expected with such dynamic biological diversity, microbes compete for these available essential resources. Increased microbial activity will increase the rates of CO_2 emission, turnover of supplied organic materials, and active SOM, and possibly the rate of stable SOM formation, although this formation may not result in a net increase in stable SOM.

The Soil Organic Matter Steady State Concept

For a given set of soil, soil depth, environment, and management conditions, SOM concentration has a steady state. Natural grassland and forest ecosystems, compared with annual cropland, contain more total biomass in root systems and have less soil disturbance and generally lower rates of soil erosion. These factors result in SOM levels that are high compared with annual cropland. In soils of long-term natural ecosystems, where C inputs are in long-term equilibrium with C loss to oxidation and erosion, SOM is considered to be at or near a “pre-cultivation steady-state” (PCSS). A natural ecosystem with high biomass production and/or fine-textured soil is expected to have a higher PCSS than an ecosystem with low biomass and/or coarse-textured soil. Ironically, regular burning of prairie grasslands may lead to higher PCSS from the accumulation of very stable C in charred organic material.

Many years after conversion of a natural ecosystem to annual crop production, an annual crop steady state (ACSS) is likely to be attained, which may have 30 to 50 percent less SOM than PCSS. Extreme erosion or conversion of a wetland will result in a much lower ACSS. With non-eroded lands, the decline to steady state, while rapid during the first years following conversion, will start to level out after 30 to 40 years and may continue slowly for more than 100 years before the steady state is reached. The ACSS is reached when SOM gains are in equilibrium with losses and is more associated with changes in easily decomposed compared with stable SOM.

As with PCSS, ACSS varies with climate, soil properties, and land management (*Figure 2*). Modifications in agronomic management can cause a shift in ACSS but generally the sustained upward or downward shift will be small. If management is changed to include regular manure

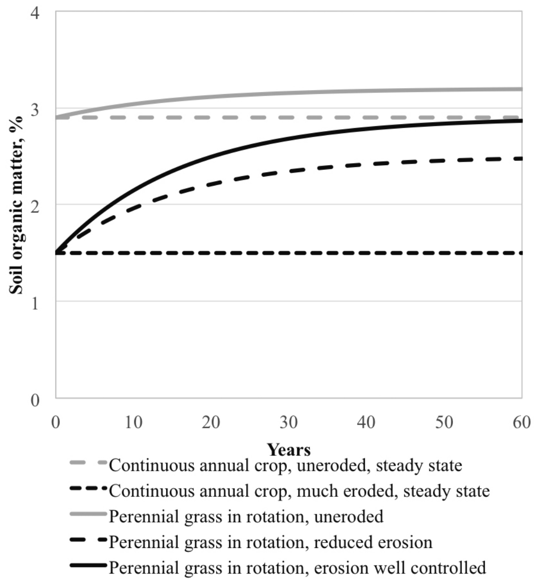

Figure 2. A hypothetical illustration of soil organic matter content and steady state for a silty clay loam soil of eastern Nebraska as affected by erosion and cropping system.

application, a higher ACSS may be achieved, but if the regular applications cease, ACSS may return to the previous level. In cases of little soil disturbance and little erosion but where SOM continues to slowly decline despite higher levels of biomass returned to the soil, it is likely that SOM is above ACSS and attempts to increase and sustain SOM are likely to be futile with current land use. Alternatively, if much of the surface soil was lost to erosion, it is likely that SOM is well below ACSS, and there is great potential to increase SOM with some management practices if erosion is greatly reduced.

If SOM input can be increased and/or SOM oxidation decreased, ACSS can shift upward. Switching from rainfed to irrigated production with retention of crop residues can increase SOM inputs from aboveground and, more importantly, root biomass, and all else being equal, shift ACSS upward. Switching from tillage to no-till can reduce SOM oxidation and shift surface soil ACSS, especially if erosion is reduced. These switches are not likely, however, to result in increased SOM if the SOM level is above ACSS for the new management system. If SOM is below ACSS, significant gains in SOM may occur.

The SOM steady state concept is relatively new, and PCSS and ACSS have not been determined for different climate, soil, land use, and management situations. The NRCS estimate of typical SOM by soil unit, if not much eroded and predominately used for annual crop production, should be near ACSS (*Figure 1*). The average SOM for annual crop fields of similar soil type and management with very low rates of erosion can give reasonable estimates of near or above ACSS. Therefore, ACSS for the surface 8 inches of Nebraska loamy soils may be near 3 percent in eastern Nebraska but slightly higher in the northeast, and less than 2 percent, with some exceptions, in the west. Alternatively, the average SOM for never-tilled natural rangeland is likely to be near the PCSS. The PCSS may range from 6 to 2.5 percent SOM going from eastern to western Nebraska for loam soils.

Increasing Soil Organic Matter of Cropland Based on the Steady State Concept

Various factors, especially land and crop management (*Table 2*), will determine SOM levels and ACSS. Management practices that minimize SOM loss from erosion and breakdown of soil macro-aggregates are essential in efforts to increase SOM. Improvement of SOM to ACSS levels may require an increase in crop species diversity and/or increased biomass production, especially in the root system.

Reducing Soil Organic Matter Loss

Control of excessive soil erosion by water or wind through use of one or more conservation practices is essential to reducing SOM loss. Four to five percent of soil loss by weight may be SOM. The SOM is usually highest in the upper and most exposed soil surface layer. Farmers are often not aware of the severe soil loss from sheet erosion of the surface soil layer, since sheet erosion is less obvious than rill and gully erosion. A large proportion of sheet erosion loss occurs from highly erodible land that is tilled up or down slopes or that lacks cover from crop canopies or crop residues.

Tillage affects SOM levels, commonly with increased losses associated with increased erosion but also with breakdown of soil macro-aggregates and exposure of SOM to microbial activity. In cases of reduced erosion, the effect of tillage on total SOM compared with no-till has been inconsistent but SOM gains are common if SOM is below ACSS. An exception may be in fields with high crop residue amounts; irrigated continuous corn has been observed to gain more SOM with inversion tillage than with no-till.

Crop residue retention is important to SOM and ACSS levels, especially on eroding lands (see the NebGuide *Harvesting Crop Residues* (G1846)). Crop residue retention for soil cover is important to control both wind and water erosion. For soils well below ACSS, full crop residue retention can increase SOM. If the soil is near or above

ACSS, some crop residue can be removed without directly affecting SOM.

Table 2. Management practices for increasing soil organic matter content.

Reducing SOM loss
Reduce erosion
Reduce tillage (for reduced erosion and SOM decomposition)
Retain more crop residue if SOM is below ACSS
Increasing SOM
Increase soil organic matter by:
Adding small grains to the rotation
Adding grazed or hayed perennial grass to the rotation
Increasing rotation intensity with cover crops and double-crop forages
Increasing crop production
Incorporating some crop residue for irrigated continuous corn
Retaining crop residue in field
Applying manure periodically

Increasing SOM and ACSS

Diversification of crop rotations may affect SOM dynamics and ACSS. Crop rotations of three or more years are generally expected to have higher SOM levels than shorter rotations.

Root systems are especially important for increasing SOM and ACSS. Biomass produced belowground, compared with aboveground, at least with herbaceous species, tends to have a slower turnover in the soil and contributes more to increased SOM and ACSS. Evidence for the value of wheat root systems for increasing SOM is especially strong. Root growth contributes to the increase of SOM by producing organic exudates, stimulating microbial activity and turnover, and by adding carbon in root tissues. Root exudates may account for 5 to 10 percent of the total net C fixed by the plant, varying with plant age, species, and cropping system. Root biomass tends to be greater for wheat, followed by corn, and then soybean.

Adding perennials, especially perennial grasses, to a crop rotation may be a feasible means to increase SOM and ACSS, especially if soil erosion control is a benefit (*Figure 2*). For each 2 ton/acre/year average reduction in soil loss to erosion, SOM loss would be reduced by about 1 t/ac during the 10-year cycle. Perennial crops tend to have longer root life with more root biomass and rhizo-deposition compared with annual crops. In the short term, perennial root growth may stimulate active SOM decomposition because of microbial response to easily degraded root exudates, mucilage, and sloughed cells. Introducing hayed or grazed perennial grass into the annual crop rotation (such as in a 10-year cycle with four years of continuous perennial grass or grass-legume mix) is expected to result in a large gain in SOM and ACSS.

In addition to increasing SOM, the practice provides valuable surface cover and increased soil aggregation, thereby reducing soil erosion. In Minnesota, land converted from annual crop production to perennial grass had a linear increase in SOM of 800 lb/ac/yr in the top 8 inches. Greater gains in SOM are expected if SOM is below the ACSS, and especially if soil erosion is reduced.

Extensive, perennial root systems should also contribute SOM deeper in the soil profile. Some of the gain in SOM from the perennial phases is likely to be lost during the annual crop phase with loss likely to increase with increased tillage. However, a net gain in SOM, especially stable SOM, and a gradual increase in ACSS is expected with each rotation cycle, especially where soil erosion is substantially reduced. Grazing of perennials is likely to increase SOM more than haying or not harvesting the perennials.

When SOM is less than ACSS, cover crops and double cropping with annual forage crops have potential to increase SOM and to slightly boost ACSS upward. This is true only if adequate root growth is achieved through early establishment of the cover or forage crop in late summer or early fall. The early harvest of small grains, compared with warm-season crops, allows for planting a late summer cover crop to obtain good root growth. A cover crop can follow wheat harvest immediately and be successful if there is adequate soil N and soil water. If soil water is depleted, there may be an opportunity to match the planting date with rainfall events to establish cover crops early enough for good root growth.

The SOM gain would be enhanced when the cover crop contributes to reduced erosion and likely would be greater with grass, compared with broadleaf species. If a single well-selected cover crop species matches the environment, it will outperform a mix of species. However, a mix of species with diverse adaptation may provide greater insurance than a single species against the risk of failed establishment if the weather around the date of planting favors one of the species in the mix.

Occasional incorporation of crop residues in high residue situations as with continuous irrigated corn has been observed in Nebraska to increase SOM. Crop residue retention is addressed above and in NebGuide *Harvesting Crop*

Residues (G1846). A guideline for low erodibility lands with SOM near or above ACSS is that an average of at least 2 t/ac of crop residue should be retained on the land to complement belowground growth and allow for maintenance of SOM and soil aggregation. For medium and high erodibility situations where SOM is likely below ACSS, more, and maybe all, crop residues need to be retained for erosion control and maintenance or increase of SOM stocks.

Crop productivity and SOM are related: as one increases, the other is likely to increase. Increasing crop productivity is likely to increase root growth and root exudation, with a concomitant increase in soil microbial biomass and turnover, and therefore, an increase in SOM and maybe an upward ACSS shift.

Several management practices discussed for increasing SOM have implications for crop productivity. Reducing tillage commonly results in increased productivity in dryland situations. Harvest of some crop residues may lower and increase productivity in dryland and irrigated situations, respectively. Cover crops or double-cropped forages may lower or increase productivity, depending on soil water and N availability. Crop rotation effects are generally positive for crop yield. Reduced erosion is expected to eventually favor crop productivity.

Regular manure or biosolid application can be an important source of nutrients, contribute to water stable soil aggregation, and supply organic material to the soil. Manure application will likely contribute to increased SOM when it is below ACSS and erosion is controlled, and maybe more than application of similar amounts of organic material with higher C:N ratios. Manure application is likely to be less effective than increased root growth for sustained increases in SOM and ACSS.

Conclusion

Increasing SOM throughout Nebraska is agronomically and environmentally desirable but not always feasible for given climate, soil, and management conditions, as SOM moves towards a steady-state level. The greatest opportunity for increasing SOM is when it is below the ACSS but to move above current ACSS requires a significant change in management.

Most important may be to reduce SOM loss through erosion control. If erosion is controlled, practices that increase root biomass are next in importance for increasing SOM. Reducing tillage, retention of crop residue in the field, increasing root biomass production, incorporation of some crop residue for irrigated continuous corn, and manure use are addressed as practices for increasing SOM. Some of these practices are likely to improve land productivity sufficiently to make the practices net no-cost options.

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