Back to the Future: Achieving Resilient, Sustainable Grasslands through Restoration of Ecological Norms

The Soil Health Properties of Native Grasslands

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Abstract
Due to an increased interest in soil health and the role soils can have in carbon sequestration, native grasslands are getting heightened attention. Native grasslands are known for their deep top-soils that develop over time through the accumulation of soil organic matter. The deep and fibrous root systems that make up two-thirds of the biomass of native grasslands are the primary contributors to the soil organic carbon (SOC) content of grassland soils. Increased SOC content has a cascading effect on soil health metrics through increasing water infiltration and water holding capacity, supporting diverse and abundant soil microbial life, and improving nutrient cycling.

Introduction
With an estimated 1% of native remnant prairies still in existence, the tallgrass prairies of the United States are one of the most endangered ecosystems on the planet (Samson & Knopf, 1994). Historically, the primary reason for their decline has been due to their tremendous soil health properties and the agricultural value that they represented, primarily for annual cropping systems (Packard & Mutel, 1997). However, the widespread conversion from perennial grasslands to agricultural use has led to a precipitous decline in soil health - including soil organic matter (SOM) loss, reduced aggregate stability, limited water holding capacity, nutrient depletion and increased wind- and water-induced soil erosion (Karlen et al., 2019). As soil health and the role of soils as a carbon-sink gains in popularity, new attention has been given to native grasses and the role they can play in promoting soil health.

Soil Carbon
Over the past two decades, the role of grasslands as a means to sequester carbon has encountered a heightened awareness (Bai & Cotrufo, 2022; Chambers et al., 2016). Grasses store two-thirds of their carbon underground, in their roots (Packard & Mutel, 1997), which form a dense fibrous network which can reach depths of five to eight feet (Keyser, 2021). Roots are an important contributor to soil carbon pools. Carbon - in the form of carbohydrates produced via photosynthesis - is leaked into the soil through root structures (Panchal et al., 2022). Roots themselves contribute to the carbon pool through dieback and turnover (Dietzel et al., 2017). As much as ninety-five percent of the organic matter inputs in grassland soils come not from the litter on the soil surface, but from roots (Rice & Owensby, 2000). Native grasses have been found to have a higher rate of decomposition compared to non-native forages, suggesting an increased rate of root sloughing and a favorable food source for soil microbes which culminates in greater derived SOC (Ashworth et al., 2021). Soil organic carbon has the slowest turnover rates in terrestrial ecosystems and thus soil carbon sequestration has the potential to mitigate CO_2 loading in the atmosphere (Deb et al., 2015). Soil organic carbon provides several other benefits, including improved soil structure, porosity and aggregation leading to water retention and quality (Benbi et al., 1998; Page et al., 2020), promoting healthy soil biology (Page et al., 2020), and plant nutrient availability (Page et al., 2020).

Water Cycle
The carbon sequestering benefits associated with the root systems of native grasslands have an equally important function – improving water quality and quantity (Teague & Dowhower, 2022). For every one percent increase in SOC, a two-to-greater-than-five-percent increase in water holding capacity can be expected (Olness & Archer, 2005). The increase in water holding capacity in grassland soils contributes to resiliency during times of drought. Several studies have shown that the root systems of native grasses increase water infiltration, presumably through the channels they create (Keyser, 2021). Many of the root channels are in the top twelve inches, where the bulk of the fibrous root system resides, however forty-three percent of the fine

root mass can be found below the plow layer (Chimento & Amaducci, 2015) with many of the channels reaching depths of five to eight feet (Keyser, 2021). Water infiltration is important both in times of flooding and in times of drought. During immense rainfall and flooding, large amounts of above ground biomass produced by native grasslands covers the soil surface, slowing down velocity of rainfall and the surface movement of water. This allows infiltration to occur and serves as a barrier to off-site movement of sediments and nutrients (Lee et al., 1998). For this reason, native grasses, such as switchgrass, are often used near agricultural fields as riparian buffer strips (Lee et al., 1998; Nelson et al., 2006).

Soil Microbial Diversity

The roots of grasslands play an important role in maintaining diverse microbial populations through their contributions to soil organic carbon and soil moisture. While some soil organisms feed directly on roots, the majority depend on soil organic compounds, such as carbon, for an energy source (Page et al., 2020; *Soil Organic Matter and Soil Biology*, 2020; Teague & Dowhower, 2022). Decomposition of organic matter, which supplies nutrients for plants, is performed primarily by bacteria and fungi (de Vries et al., 2006). Studies have shown native grasslands support more than double the amount of microbial biomass in comparison to paired cultivated soils (Mackelprang et al., 2018). This suggests the increased SOC found in native grasslands is supportive of microbial biomass.

Several native grass species have been found to be arbuscular mycorrhizal fungi (AMF) dependent (Koziol & Bever, 2017), making AMF a keystone species in native grasslands (Teague & Dowhower, 2022). Arbuscular mycorrhizal fungi have been shown to increase nutrient and moisture availability for plants (Teague & Dowhower, 2022), increasing resiliency to stressful conditions such as drought, leading to increased photosynthesis and water uptake (Begum et al., 2019). This relationship may play a role in the resiliency of native grass species. Studies have shown that the soils of native grasslands have higher ratios of AMF to saprophytic fungi when compared to cultivated sites (Mackelprang et al., 2018) and AMF enhances growth of C_4 grasses but not annuals or C_3 grasses (Wagle & Gowda, 2018). The lack of soil disturbance associated with perennial native grasslands presumably further promotes the development of AMF.

Changes related to soil water are particularly important for soil biology. Soil organisms live in water films surrounding soil particles. Different types of organisms prefer different moisture conditions for growth. Consequently, changing moisture content alters the composition of soil microbial populations. Soil water also influences the movement of soil organisms, making movement easier through pore spaces created through aggregation and roots (*Soil Organic Matter and Soil Biology*, 2020). The promotion of water absorption and retention associated with perennial grasslands, especially from species with extensive root systems, such as native grasses, facilitates soil biological health.

Studies have shown that exposed soil due to clipping, tillage and overgrazing have negative impacts on soil biology (Xue et al., 2016). The above ground biomass of native grasses also provides benefits to soil biology by limiting evaporation at the soil surface and keeping the soil at temperature ranges that are optimal for biological activity.

Nutrient Cycling

The role that native grasses play in SOC formation, the water cycle, and soil microbial health all culminate in improved nutrient cycling. Li et al. showed that native grassland reconstruction following agricultural production systems increased SOC, total nitrogen (N), and C:N ratio, with a remnant prairie exhibiting the highest SOC, total N and C:N ratio (Li et al., 2021). Within a native grassland system, fresh biomass inputs from roots results in more labile organic residues for microbes to utilize and transform into mineralizable carbon (MC) for plant uptake (Li et al., 2021). The increased MC, in turn, promotes greater microbial activities, which improves nutrient cycling (Li et al., 2017). Diversity in soil biology, supported through native grasslands and their associated root systems, increases the mineralization and availability of nutrients (Bellows, 2001; Teague & Dowhower, 2022). Franzluebbers et al. showed that grasslands with a late summer N fertilizer application showed no response if the soils had high levels of microbial activity (Franzluebbers, 2018). Keyser summarized that soils that had high levels of microbial activity were those that already had organic N sources that supported healthy microbial communities. In turn, the biology transformed the N into a form that made it available to the grass (Keyser, 2021).

Water too, plays an important role in nutrient cycling by dissolving and transporting nutrients throughout the soil. Water can also be a destructive force, negatively impacting the nutrient cycle through compaction, nutrient leaching and erosion (Bellows, 2001). Improved water infiltration, water holding capacity and water use efficiency associated with native grasslands support water's effectiveness in nutrient cycling.

Conclusions

The abundant and deep perennial root systems associated with native grasslands lead to the potential for soil carbon sequestration and provides a host of soil health benefits driven by an increase in SOC stocks. Soil organic carbon promotes the absorption and retention of water, making native grasslands more resilient both in times of drought and during flooding events when compared to annual cropping systems. In addition, native grasslands provide an improvement in run-off reduction and nutrient retention when compared to more shallow rooted cool season grasslands (Belden & Coats, 2004; Lee et al., 1998). Increased soil moisture is good for grassland productivity and also benefits soil microbial diversity. Increased soil biological health provides improved nutrient cycling – in turn providing a positive feedback loop by providing the native grasses and other grassland plants with the nutrients

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