CLIMATE CHANGE RESOURCE CENTER

Grassland Carbon Management

Preparers

Todd Ontl, Northern Institute of Applied Climate Science, US Forest Service, Houghton, MI.
Maria Janowiak, Northern Institute of Applied Climate Science, US Forest Service, Houghton, MI.

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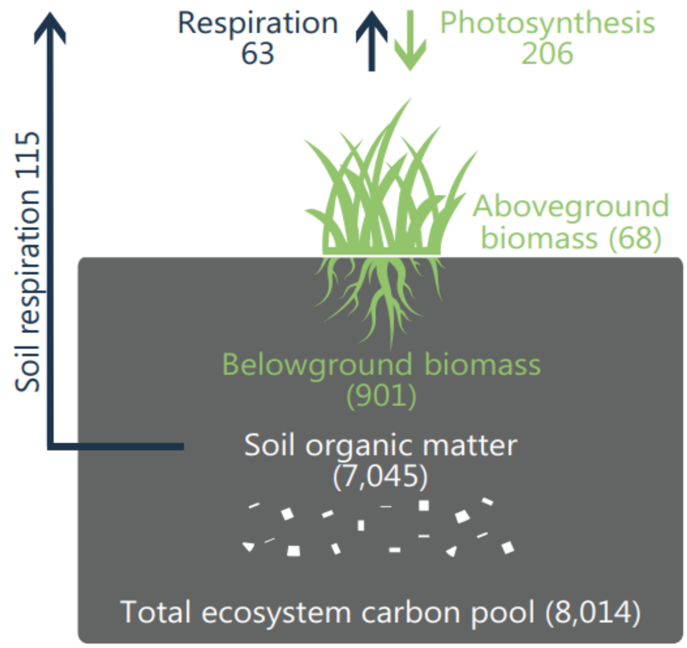
Introduction

Grasslands cover approximately 25% of the Earth's land surface (approximately 3.4 billion ha) and contain roughly 12% of the terrestrial carbon stocks (1,2). Grasslands are dominated by herbaceous (nonwoody) vegetation and so—unlike forests—carbon within living aboveground vegetation is a small proportion of the total ecosystem carbon pool. Additionally, this aboveground biomass carbon is relatively short-lived due to harvest, grazing, fire, and senescence. In contrast, the perennial grasses that dominate grasslands are characterized by extensive fibrous root systems that often make up 60-80% of the biomass carbon in these ecosystems. This belowground biomass may extend several meters below the surface and contribute abundant carbon to soils, resulting in deep, fertile soils with high organic matter content. Because of this, soil carbon makes up approximately 81% of total ecosystem carbon found in grasslands (1). The tight linkage between soil carbon and belowground biomass results in similar responses of these carbon pools to variation in annual precipitation and temperatures at broad spatial scales. Because plant productivity is limited by precipitation in grasslands, carbon stocks are highest in regions where rainfall is the greatest, such as the tallgrass prairie in the humid temperate region of the United States. Similarly, grassland carbon stocks decrease with increasing annual temperatures due to greater evapotranspiration (3).

Figure: Carbon stocks and fluxes in in the shortgrass steppe ecosystem, Colorado. Units are in grams per square meter. Carbon stocks are denoted in parentheses and shown in grams per square meter. Fluxes are associated with arrows and shown in grams per square meter per day. Data from Burke et al. 2008 (21).

Issues

Grasslands are used intensively for food and forage production globally because of their high natural soil fertility. Carbon stores within grasslands are sensitive to management and are thus vulnerable to losses in soil carbon. Land degradation—which is a long-term decline in plant productivity and the associated soil and water functions that support it—is widespread in grasslands in part due to soil carbon losses. More than 20% of the world's croplands are degraded, as are 20-25% of the grasslands (4). These losses in soil carbon are attributed to several factors, particularly decreased carbon inputs to the soil. Activities such as harvesting plant biomass significantly decreases the amount of carbon contributing to soil organic matter from removal of aboveground biomass. Likewise, changes of plant species to favor species with greater aboveground production—such as the conversion from natural grassland to cropland or improved pasture—significantly reduces the belowground biomass in roots.



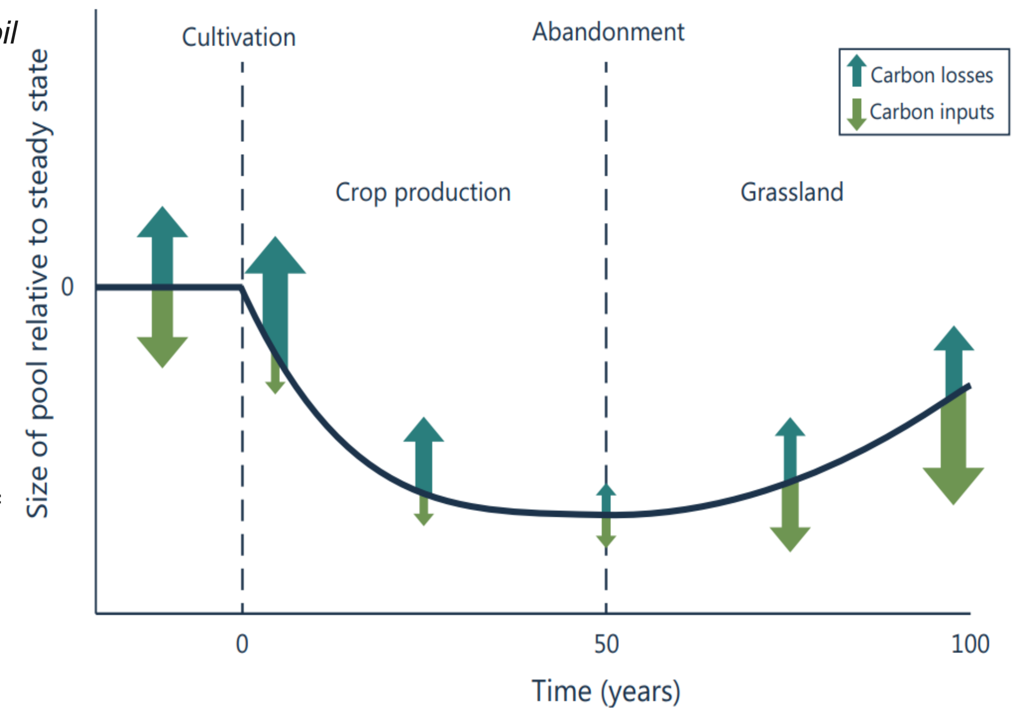


Figure: Impacts of cultivation and conversion to crop production and subsequent abandonment and succession to grassland vegetation on carbon inputs (green arrows), outputs (blue arrows) and soil carbon stocks (line) over time. Modified from Burke et al. 1995 (20).

Approximately 20% of the world's grasslands have been converted to cultivated crops (5). Soil disturbance, such as cultivation, is a common management practice in annual row crop production that leads to greatly accelerated losses of organic matter. In the Midwest, many soils have lost 30-50% of carbon (25 to 40 metric tons of carbon per hectare) from conversion to agriculture (6). These losses occur primarily through the disturbance of soil. Soil disturbance disrupts soil structure, exposing organic carbon to decomposition from soil microbes and invertebrates and increases soil temperature and aeration, enhancing the activity of decomposers. Disturbance can also greatly increase soil erosion, leading to deposition elsewhere on the landscape and additional losses of carbon as CO_2 to the atmosphere (7,8).

Prescribed fire and grazing management are practices often utilized in grassland management, and have important effects on species composition. Grassland ecosystems evolved with frequent fire and grazing, both of which are often important for maintaining the desired species composition and ecosystem function. The implications of fire and grazing intensity on carbon stocks in grassland ecosystems depends on many factors, highlighting the complex interactions between plant, soils, and climate that are important for carbon sequestration. For example, the exclusion of fire can lead to encroachment of woody shrubs in grasslands (9). This change in species composition can reduce soil carbon pools in wetter grasslands, however, soil carbon stocks in more arid ecosystems may increase with encroachment (10). Results from other studies have shown the opposite response, with woody encroachment from fire suppression in wetter grasslands increasing in soil carbon (11), suggesting the importance of other factors such as soil textures. Likewise, grazing impacts on soil carbon can depend on interactions between soils, plant species, and climate. On sites with higher rainfall, grazing generally increases soil carbon on sandy, coarse-textured soils, while clay soils respond with weak increases to strong decreases in soil carbon. For arid grasslands, the opposite seems true: fine-textured clay soils show the largest increase in soil carbon to grazing relative to sandy soils (12). These patterns in response to proper grazing management suggest a general trend towards increases in soil carbon, which a global analysis estimates as an increase in carbon stocks averaging 2.9% (13). Greater water-holding capacity of clay soils may increase this benefit in arid systems (14), while compaction of clay soils may restrict roots and actually reduce soil carbon over time in wet systems where soil moisture is not limiting (15).

Options for Management

Grassland carbon loss impacts many critical functions within ecosystems, such as reducing water-holding capacity, increasing the potential for wind and water erosion, and diminishing soil fertility. Best management practices for maintaining or restoring carbon in grasslands should, at a minimum, reduce soil disturbance to optimize these soil and water processes. Practices beneficial for carbon management include the reduction or cessation of tillage or minimizing the duration of bare soils by planting cover crops when cultivation is necessary (for example, when planting food plots for wildlife prior to seeding native species for restoration). Determining proper stocking rates for grazed lands in order to prevent overgrazing is critical for maintaining both desired species composition and adequate plant cover and biomass input to soils. Similarly, the use of prescribed fire can prevent woody or undesirable species from invading grasslands, and in some systems, reduces the litter layer to increase plant productivity (16). Like stocking rates on grazed lands, the benefits of prescribed fire depend on the frequency of its use. Because nitrogen is lost from volatilization with fire, grasslands burned too frequently can show poor plant productivity and low tissue nitrogen levels, indicative of low soil nitrogen levels (17). Grasslands impacted by a history of cultivation, overgrazing, fire suppression actions, or other disturbances to soils or plant communities can be restored through removal or careful management of the disturbance, and if plant cover or composition has been impacted severely, seeding of native species appropriate for the site.

Restoration of degraded grasslands by limiting soil disturbance, proper grazing management, thoughtful use of prescribed fire, or planting native species with deep root systems increases grassland carbon stocks by enhancing soil carbon inputs through plant productivity and limiting soil carbon losses. Seeding of grass or legume species into degraded grasslands can improve belowground production, and—in the case of legumes—improve soil fertility through nitrogen fixation. Fertilization and irrigation can have strong positive impacts to plant production and soil carbon stocks (13), although these practices are mostly applied in grasslands managed as pasture. Changes in ecosystem carbon from these management practices will vary, with the greatest gains expected to occur in cool humid climates and lowest in warm arid climates (18). The recovery of soil carbon is typically a slow process, taking many decades to centuries, depending on the carbon balance of the system (4). Despite these slow changes, the global potential for carbon sequestration from restoring degraded grasslands is significant, with the possibility to sequester approximately 3 Gt C per year—equivalent to reducing atmospheric CO_2 by 50 ppm over 50 years (19). In addition to restoring degraded grasslands to improve carbon storage, grassland management strategies should recognize the critical goal of maintaining grassland cover and preventing degradation to conserve the ability of that land to continue sequestering carbon.

How to cite

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Recommended Reading

Briggs, J.M.; Knapp, A.K. 1995. Interannual variability in primary production in tallgrass prairie: climate, soil moisture, topographic position, and fire as determinants of aboveground biomass. American Journal of Botany. 82(8): 1024–1030.

Burke, I.C.; Mosier, A.R.; Hook, P.B.; Milchunas, D.G.; Barrett, J.E.; Vinton, M.A.; McCulley, R.L.; Kaye, J.P.; Gill, R.A.; Epstein, H.E. 2008. Soil organic matter and nutrient dynamics of shortgrass steppe ecosystems. Ecology of the Shortgrass Steppe: A Long-Term Perspective. 306-341.

Burke, I.C.; Yonker, C.M.; Parton, D.S.; Schimel, W.J.; Cole, C.V.; Flach, K. 1989. Texture, climate, and cultivation effects on soil organic matter content in US grassland soils. Soil Science Society of America Journal. 53: 800–805.

Knapp, A.K., Briggs, J.M., Collins, S.L., Archer, S.R., Bret -Harte, M.S., Ewers, B.E., Peters, D.P., Young, D.R., Shaver, G.R., Pendall, E.; Cleary, M.B. 2008. Shrub encroachment in North American grasslands: shifts in growth form dominance rapidly alters control of ecosystem carbon inputs. Global Change Biology, 14(3), 615–623.

Lal, R. 2002. Soil carbon dynamics in cropland and rangeland. Environmental Pollution. 116: 353–362.

Lal, R.: Kimble, J.M.; Follett, R.F.; Cole, C.V. 1998. The potential of U.S. cropland to sequester carbon and mitigate the greenhouse effect. Chelsea, MI: Ann Arbor Press. 128 p.

Tools

Global Carbon Atlas

The Global Carbon Atlas gives audiences a number of ways to visualize carbon dioxide emissions and flux data, and to compare between countries and regions over time (1960 – 2012). Its products are grouped into three main categories that are intended for users with varied technical backgrounds. All products are based on current datasets and models contributed by scientists and research institutions (see Contributors).

NASA - CASA Global CQUEST - Carbon Query and Evaluation Support Tools
This application from NASA provides datasets and a viewer for geographic data that support large-scale carbon inventory. The datasets combine NASA remote sensing technology, ecosystem process modeling, and field-based measurements to characterize impacts on the carbon cycle.

Videos

https://www.fs.usda.gov/ccrc/videos/grasslands-and-carbon-processes-and-trends
https://www.fs.usda.gov/ccrc/videos/potential-soil-carbon-sequestration

References

1. Adams, J.M.; Faure, H.; Faure-Denard, L.; McGlade, J.M.; Woodward, F.I. 1990. Increases in terrestrial carbon storage from the Last Glacial Maximum to the present. Nature 348: 711–714.
2. Ojima, D.S.; Dirks, B.O.; Glenn, E.P.; Owensby, C.E.; Scurlock, J.O. 1993. Assessment of C budget for grasslands and drylands of the world. Water, Air and Soil Pollution. 79:95–109.
3. Burke, I.C.; Yonker, C.M.; Parton, D.S.; Schimel, W.J.; Cole, C.V.; Flach, K. 1989. Texture, climate, and cultivation effects on soil organic matter content in US grassland soils. Soil Science Society of America Journal. 53: 800–805.
4. Bai, Z.G.; Dent, D.L.; Olsson, L;Schaepman, M.E. 2008. Proxy global assessment of land degradation. Soil Use and Management 24: 233–234.
5. Ramankutty N.; Evan, A.T.; Monfreda, C.; Foley, J. 2008. Farming the planet: 1. Geographic distribution of global agricultural lands in the year 2000. Global Biogeochemical Cycles 22: GB1003. DOI: 10.1029/2007GB002952
6. Lal, R. 2002. Soil carbon dynamics in cropland and rangeland. Environmental Pollution. 116: 353–362.
7. Lal, R. 1995. Global soil erosion by water and carbon dynamics. In: Kimble, J.M.; Levine, E.R.; Stewart, B.A., eds. Soils and Global Change. Boca Raton, FL: CRC Press: 131–142;
8. Lal, R.: Kimble, J.M.; Follett, R.F.; Cole, C.V. 1998. The potential of U.S. cropland to sequester carbon and mitigate the greenhouse effect. Chelsea, MI: Ann Arbor Press. 128 p.
9. Knapp, A.K., Briggs, J.M., Collins, S.L., Archer, S.R., Bret -Harte, M.S., Ewers, B.E., Peters, D.P., Young, D.R., Shaver, G.R., Pendall, E.; Cleary, M.B. 2008. Shrub encroachment in

North American grasslands: shifts in growth form dominance rapidly alters control of ecosystem carbon inputs. Global Change Biology, 14(3), 615–623.

10. Jackson, R.B.; Banner, J.L.; Jobbágy, E.G.; Pockman, W.T.; Wall, D.H. 2002. Ecosystem carbon loss with woody plant invasion of grasslands. Nature. 418(6898): 623–626.
11. Tilman, D.; Reich, P.; Phillips, H.; Menton, M.; Patel, A.; Vos, E.; Peterson, D.; Knops, J. 2000. Fire suppression and ecosystem carbon storage. Ecology. 81(10): 2680–2685.
12. McSherry, M.E.; Ritchie, M.E. 2013. Effects of grazing on grassland soil carbon: a global review. Global Change Biology. 19(5): 1347–1357.
13. Conant, R.T.; Paustian, K.; Elliot, E.T. 2001. Grassland management and conversion into grasslands: effects on soil carbon. Ecological Applications 11(2): 343–355.
14. Steffens, M.; Kölbl, A.; Totsche, K.U.; Kögel-Knabner, I. 2008. Grazing effects on soil chemical and physical properties in a semiarid steppe of Inner Mongolia (PR China). Geoderma. 143(1): 63–72.
15. Sigua, G.C.; Coleman, S.W. 2010. Spatial distribution of soil carbon in pastures with cow-calf operation: effects of slope aspect and slope position. Journal of Soils and Sediments. 10: 240–247.
16. Briggs, J.M.; Knapp, A.K. 1995. Interannual variability in primary production in tallgrass prairie: climate, soil moisture, topographic position, and fire as determinants of aboveground biomass. American Journal of Botany. 82(8): 1024–1030.
17. Blair, J.M. 1997. Fire, N availability, and plant response in grasslands: a test of the transient maxima hypothesis. Ecology 78(8): 2359–2368.
18. Lal, R. 2004. Soil carbon sequestration impacts on global climate change and food security. Science 304(5677): 1623–1627.
19. Lal, R. 2009. Challenges and opportunities in soil organic matter research. European Journal of Soil Science 60(2): 158–169.
20. Burke, I.C.; Lauenroth, W.K.; Coffin, D.P. 1995. Soil organic matter recovery in semiarid grasslands: implications for the conservation reserve program. Ecological Applications 5(3), 793-801.
21. Burke, I.C.; Mosier, A.R.; Hook, P.B.; Milchunas, D.G.; Barrett, J.E.; Vinton, M.A.; McCulley, R.L.; Kaye, J.P.; Gill, R.A.; Epstein, H.E. 2008. Soil organic matter and nutrient dynamics of shortgrass steppe ecosystems. Ecology of the Shortgrass Steppe: A Long-Term Perspective. 306-341.

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