Highlights

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Soil Carbon Sequestration in Grazinglands: Societal Benefits and Policy Implications

Ronald F. Follett and Debbie A. Reed

Sequestration of soil organic carbon in grazinglands provides important societal benefits and is potentially influenced by existing and future policies and legislation. USDA conservation and farmland protection and restoration programs and climate change policies for grazinglands that encourage retention and enhancement of grazingland soil carbon stocks are discussed. Planning efforts to improve rangeland management can have greater impact if done at the watershed, state, or local level and with active participation by land managers and owners. Important opportunities exist to sequester soil carbon in grazingland soils if mandatory reductions are included in future greenhouse gas emissions strategies.

Productivity, Respiration, and Light-Response Parameters of World Grassland and Agro-Ecosystems Derived From Flux-Tower Measurements

Tagir G. Gilmanov, L. Aires, Z. Barcza, V. S. Baron, L. Belelli, J. Beringer, D. Billesbach, D. Bonal, J. Bradford, E. Ceschia, D. Cook, C. Corradi, A. Frank, D. Gianelle, C. Gimeno, T. Gruenwald, Haiqiang Guo, N. Hanan, L. Haszpra, J. Heilman, A. Jacobs, D. A. Johnson, M. B. Jones, G. Kiely, Shenggong Li, V. Magliulo, E. Moors, Z. Nagy, M. Nasyrov, C. Owensby, K. Pinter, C. Pio, M. Reichstein, M. J. Sanz, R. Scott, J.-F. Soussana, P. C. Stoy, T. Svejcar, Z. Tuba, and Guangsheng Zhou

The role of grasslands, wetlands, and agroecosystems as sinks or sources for atmospheric CO_2 remains uncertain. Data from 118 global flux-tower sites (316 site-years) partitioned into gross photosynthesis and ecosystem respiration using light–temperature response methods were analyzed. On average, 80% of the sites were apparent sinks for atmospheric CO_2, with mean net uptake of 700 g $CO_2 \cdot m^{-2} \cdot yr^{-1}$ for intensive grasslands and 933 g $CO_2 \cdot m^{-2} \cdot yr^{-1}$ for croplands. However, part of these sinks is accumulated in crops and forage and harvested, transported, and decomposed in off-site carbon pools, so that these ecosystems are not necessarily increasing their carbon stock.

Climate-Driven Interannual Variability in Net Ecosystem Exchange in the Northern Great Plains Grasslands

Li Zhang, Bruce K. Wylie, Lei Ji, Tagir G. Gilmanov, and Larry L. Tieszen

There have been few long-term studies investigating interannual variability in carbon exchange and its responses to climatic change across Northern Great Plains grasslands. A model based on remotely sensed data was developed and run to achieve synoptic estimates of the variability in carbon exchange. Estimates characterize both temporal dynamics and geographic patterns of sink and source activity. Our study shows that Northern Great Plains grasslands were a weak carbon source during 2000–2006, which included three drought-affected years. The quantitative analysis provides insights into how this grassland ecosystem will respond to future climate under a variety of environmental conditions.

New Parameterization of a Global Vegetation Model for Steppe Ecosystem From Southern Siberian In Situ Measurements

Nicolas Vuichard, Philippe Ciais, Luca Belelli-Marchesini, and Riccardo Valentini

Global vegetation models need to be carefully compared with multiple-scale observations in order to ensure they provide accurate large-scale estimates of carbon, water, and

energy fluxes. We developed a new parameterization for the ORCHIDEE model for steppe ecosystems with 3-year observations of productivity and a phenological index at a steppe site in Central Asia. These new parameters improve annual productivity and seasonal variability estimates that contribute to realistic ecosystem respiration and net carbon balance fluxes. This work will help better quantify the carbon balance of the Central Eurasian steppe in response to future climate change.

Diurnal and Seasonal Patterns in Ecosystem Carbon Dioxide Fluxes and Their Controls in a Temperate Grassland

Anita C. Risch and Douglas A. Frank

Daily CO_2 flux patterns are important in determining total ecosystem CO_2 gains and losses. CO_2 fluxes and environmental factors were measured over 24 hours once per month from May to September in a grazed moist grassland in Yellowstone National Park. Absolute values of all fluxes were greatest in midsummer, and lowest in spring and fall. Daily and seasonal variations in CO_2 flux were related to available light, temperature (air and soil), and soil moisture. Continued anthropogenic increases in greenhouse gas emissions that could change the intensity of radiation, temperature, and precipitation may strongly affect patterns in CO_2 uptake and release.

Net Carbon Fluxes Over Burned and Unburned Native Tallgrass Prairie

Dale J. Bremer and Jay M. Ham

Land management practices such as burning may affect carbon sequestration in rangeland soils. For 2 years we measured exchanges of carbon with the atmosphere in burned and biennially burned tallgrass prairie ungrazed by ungulates. In a wet year when both sites were burned, small amounts of atmospheric carbon were sequestered. In a dry year when only one site was burned, both sites lost carbon to the atmosphere, but the burned site lost twice as much. Over the entire 2-year study, both sites lost carbon. Data suggest that annual burning of rangelands promotes soil carbon loss compared to less-frequently burned rangeland.

Land Use Influences Carbon Fluxes in Northern Kazakhstan

Jorge F. Perez-Quezada, Nicanor Z. Saliendra, Kanat Akshalov, Douglas A. Johnson, and Emilio A. Laca

Carbon and water fluxes were measured on four land-use types common in the Kazakh steppe. Abandoned and native grassland gained CO_2, crested wheatgrass was near equilibrium, and wheat and barley cropping lost CO_2. The lower gross primary production on crested wheatgrass and native land, compared to grain cropping and abandoned land, was compensated by positive carbon gain attained through a longer growing season. About 19% of annual ecosystem respiration occurred during the nongrowing season. Carbon lost by cultivation of native lands is partially being restored when fields are left uncultivated and native grasslands are often net carbon sinks.

Carbon Stocks and Fluxes in Rangelands of the Río de la Plata Basin

José M. Paruelo, Gervasio Piñeiro, Germán Baldi, Santiago Baeza, Felipe Lezama, Alice Altesor, and Martín Oesterheld

Information from field studies, remote sensing estimates, and modelling exercises were summarized and interpreted to describe carbon stocks and fluxes across the environmental gradients of the temperate rangeland of the Río de la Plata grasslands in South America. Average estimates of belowground net primary production (NPP) were more variable and higher than aboveground NPP. Plant biomass contributed an average 13% to total carbon stocks, the largest amount coming from belowground biomass. Aboveground green biomass represented less than 7% of the plant carbon. Soil organic carbon (SOC) was concentrated in the recalcitrant pool whereas the active soil pool represented only 6.7% of the SOC.

Pathways of Grazing Effects on Soil Organic Carbon and Nitrogen

Gervasio Piñeiro, José M. Paruelo, Martín Oesterheld, and Esteban G. Jobbágy

We reviewed studies on grazed and ungrazed sites to determine the effect of grazing on soil organic carbon (SOC). Although grazing had variable effect on SOC, several general patterns were observed. Root biomass, a primary control of SOC formation, was higher in grazed than ungrazed grasslands at the driest and wettest sites, but lower at sites with intermediate precipitation. Soil organic matter (SOM) and carbon:nitrogen ratios frequently increased under grazed conditions, suggesting potential nitrogen limitation for SOM formation under grazing. Nearly all sites located in the intermediate precipitation range showed decreases or no changes in SOC.

Nutrient Limitations of Carbon Uptake: From Leaves to Landscapes in a California Rangeland Ecosystem

Benjamin Z. Houlton and Christopher B. Field

Owing to human activities, CO_2 concentrations have risen steadily in the atmosphere since the industrial revolution. We reviewed literature of nutrient limitations to terrestrial CO_2 uptake across a range of scales in a California rangeland ecosystem. Soil nutrients, especially nitrogen and phosphorus, broadly limit the capacity of this ecosystem to store additional carbon. This implies that carbon storage within

California rangelands will be rather limited in the future, and stakeholders should consider interactions between soil nutrients and carbon cycles when assessing the strength of terrestrial carbon sinks in diverse landscapes.

Soil Carbon Pools in California's Annual Grassland Ecosystems

Whendee L. Silver, Rebecca Ryals, and Valerie Eviner

Rangelands cover a large land area globally and have considerable potential for soil carbon (C) sequestration. We used the literature to explore patterns in soil C storage in annual grass-dominated rangelands in California. Annual grasslands had more deep C ($\geq$1 m) than expected, and C pools did not vary with temperature, precipitation, or soil type. Woody plants increased C by ~ 40 mg $\cdot$ ha^{-1} to 1-m depth. The annual grasslands had similar soil C storage capacity as temperate perennial grasslands and offer an important resource for mitigation of greenhouse gas emissions and climate change.

Managing Sources and Sinks of Greenhouse Gases in Australia's Rangelands and Tropical Savannas

Garry D. Cook, Richard J. Williams, Christopher J. Stokes, Lindsay B. Hutley, Andrew J. Ash, and Anna E. Richards

Deforestation has been the largest cause of greenhouse gas emissions in Australia, followed by direct emissions from livestock. Livestock emissions are substantial and are best reduced by a whole-property approach decreasing emissions per unit area, rather than per animal. Improved fire management in northern and central Australia provides further opportunities to reduce methane and nitrous oxide emissions. Income from greenhouse gas abatement can provide resources for better land management and increase livelihoods of indigenous people in remote settlements.

Improving Estimates of Rangeland Carbon Sequestration Potential in the US Southwest

Joel Brown, Jay Angerer, Shawn Salley, Robert Blaisdell, and the late Jerry W. Stuth

Effective policies and programs promoting soil carbon sequestration require credible estimates of potential carbon uptake associated with specific practices and land types. However, slow rates of carbon turnover make field measurement of sequestration potential difficult and expensive. We tested the applicability of a widely used model (CENTURY) and online tool (COMET VR) to credibly estimate soil carbon in response to land use and management options. The approach worked relatively well for grassland soils and soils converted from cropland to perennial grass. The model was less credible when applied to common practices on arid soils. We propose an integrated field measurement and model-based system to improve reliability of soil carbon estimates.

Supplying Carbon Sequestration From West African Rangelands: Opportunities and Barriers

Leslie Lipper, Celine Dutilly-Diane, and Nancy McCarthy

Estimates for potential carbon sequestration through improved rangeland management in pastoral West Africa are evaluated. Per-hectare amounts are low, but the aggregate potential is high. Carbon emission can be reduced by minimizing or avoiding land degradation, rehabilitating degraded lands, and increasing above- and belowground biomass. These management practices have potential to promote sustainable agricultural development and poverty reduction by significantly reducing carbon emissions. High transaction costs can be a problem associated with carbon markets and they can minimize adoption of improved rangeland management practices.