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Grasslands and Carbon: Processes and Trends

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Grasslands and Carbon: Processes and Trends

Rebecca McCulley*

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Slide 1. Grasslands and Carbon

Hi, my name is Rebecca McCulley. I'm a professor at the University of Kentucky and a grassland ecologist and I'm here today to talk about grasslands and carbon and the way they store and process carbon.

Grasslands and Carbon: Processes and Trends

Forest and Grassland Carbon in North America: a shortcourse for land managers

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Slide 2. Acknowledgments

I'd like to thank various people that provided slides for this talk and funding sources that have supported a bulk of knowledge that we know on this topic.

Acknowledgements

- Dr. Ingrid Burke, University of Wyoming
- Dr. Eugene Kelly, Colorado State University
- Dr. John Blair, Kansas State University



Slide 3. Learning Objectives

There are three primary learning objectives I'd like for listeners to take home from this talk. The first is that grasslands differ from forests in many ways, but from a carbon perspective they store a much greater proportion of the carbon that they take in in any given year in belowground components, so, either the roots or in soil carbon pools. Therefore, the way to manage grasslands for carbon is to get it belowground and keep it there. Disturbances such as drought, fire, grazing, and tillage are important in grasslands and can ultimately determine the carbon balance of these systems.

Learning Objectives

- Grasslands differ from forests in that a greater proportion of carbon is stored belowground (in roots and soils).
- Therefore, managing for maximizing C storage in these systems focuses on getting C into the soil and keeping it there.
- Disturbances such as drought, grazing, fire, and tillage can significantly impact grassland C balance.

* This document transcribes the presentation given by Dr. McCulley. The presentation is part of General Technical Report NRS-93, "Forest and grassland carbon in North America: A short course for land managers." The full report, comprised of 15 presentations, is in DVD format and can be obtained at <http://nrs.fs.fed.us/pubs/order/40110>. The presentations and related materials can also be accessed at <http://www.fs.fed.us/ccrc/carboncourse/>

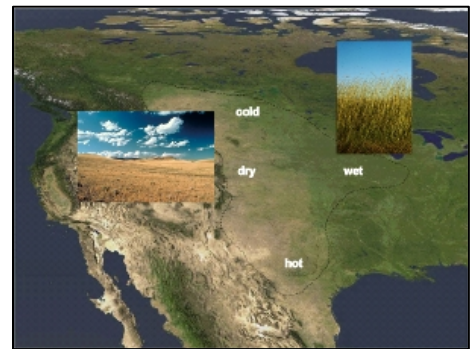
Slide 4. Grasslands

Grasslands make up about 30 percent of the North American surface. I'm going to talk primarily about the Great Plains grasslands, which you see outlined in black here, but there are many different types in North America. We have desert grasslands in the Southwest, Arizona, and New Mexico. We have Mediterranean grasslands along the coast of California, and in the eastern parts of the United States we have managed grasslands or pastures. Different species are present in each of these locations and dictate the way that these systems respond. I'd also like to mention that grasses are a pretty significant component of the Intermountain Basin of the West. So we think of these as shrub steppe systems, but grasses make up a significant component there.



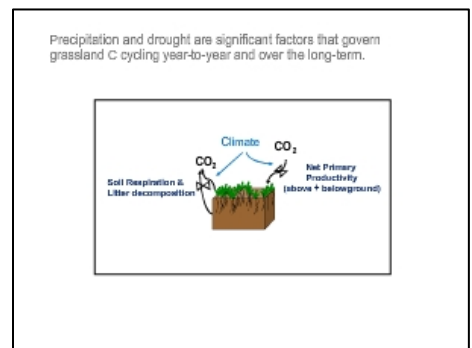
Slide 5. Weather Regions

The sites that I'll talk about a lot today are in the Great Plains. The Central Plains Experimental Range is also known as the Shortgrass Steppe Long Term Ecological Research site at the base of the Rocky Mountains in Colorado. These are dry grassland systems and somewhat cold. The Great Plains, in general, are dictated by big temperature gradients, cold near Canada, warm in Texas, and big precip gradients from dry at the base of the Rockies to wet as we move towards the east. The eastern site that you'll hear me reference quite a bit today is the Konza, also Long-term Ecological Research Station.



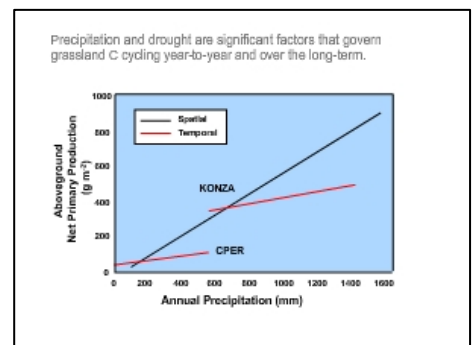
Slide 6. Precipitation and Drought

What we know about grasslands, whether they're managed grasslands in the East, Mediterranean grasslands in the West or the Central Great Plains is that they're all very responsive to precipitation and drought. These are climate variability and rainfall is significant in this region, in all of these regions, and ultimately dictates the amount of carbon dioxide that the plants can remove from the atmosphere and store as either above- or belowground production. Rainfall is also an important control on the loss of carbon from belowground pools through soil respiration and ultimately also litter decomposition.



Slide 7. Aboveground Chart

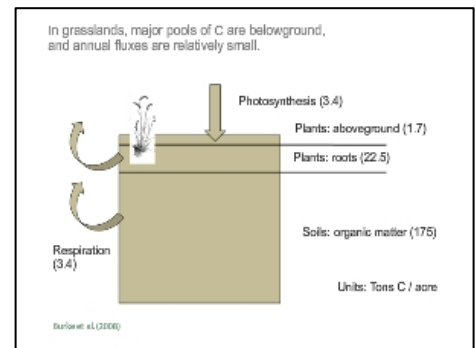
We know this because of a long-term history of collecting aboveground production data across the Great Plains. So what you're seeing in the graph here is aboveground plant production on the Y versus annual precipitation on the X. You can see the black line represents the average plant production, aboveground plant production, across a range of about 50 sites in the Great Plains that obviously experience a wide range in precipitation. And you can see that generally this is a linear trend. The



more rainfall a grassland gets, typically the more aboveground production it has. However, at any individual site, while we still see linear increases, such as the red lines here shown at Konza and Central Plains Experimental Range, the slope of that relationship is lower, which indicates that over time, so at an individual site at Konza, it gets about 900 mm of rainfall a year on average, but you can see that it can experience as much as 1400 mm of rainfall a year and as few as 600. In a wet year Konza, the aboveground production, the grass, responds by increasing production, but it doesn't do so as much as a grassland that regularly receives 1400 mm of rainfall a year. So there's some inertia in the system. Fortunately, that inertia is also there during drought years though, so you can see both at Konza and at the Central Plains Experimental Range, in very dry years the red line is actually above the black line. So these same systems tend to be a little bit buffered for some reason, which are yet to be able to explain, to these climatic variability. So climate is important.

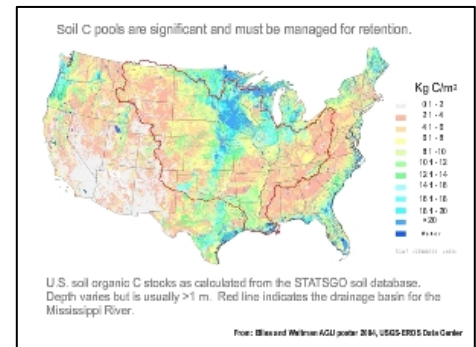
Slide 8. Belowground C Pools

In grasslands we know, I've said the first take home message is that the majority of carbon is stored belowground, and I hope this figure demonstrates that. These are values from a short steppe system, so the CPER¹. Photosynthesis and respiration are essentially balanced here and there are very small fluxes. Moreover, aboveground plant biomass, while I've shown you we have good data for that, very sensitive to precipitation, fairly easy to measure in these grassland systems. It's an extremely small stock of carbon in these systems. Most of carbon is stored in the roots. You can see 22.5 tons of carbon per acre, and a huge portion of it is actually in the soil organic matter down there.



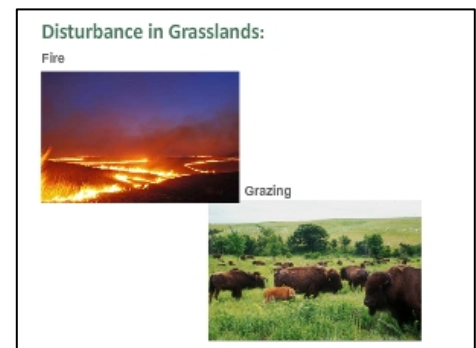
Slide 9. Soil C Pools

Soil carbon pools are significant. You've heard a lot about soil carbon pools in prior talks and you'll hear more about them as you go through the course. Here is the figure for the United States, and it has Mississippi drainage basin outlined in red. You put the Central Plains on there, you can see there is a wide variety in carbon storage. Relatively low in the dry western portion of the Great Plains, and it usually increases as we move into what we today think of as the Corn Belt, so very significant carbon stores in these areas.



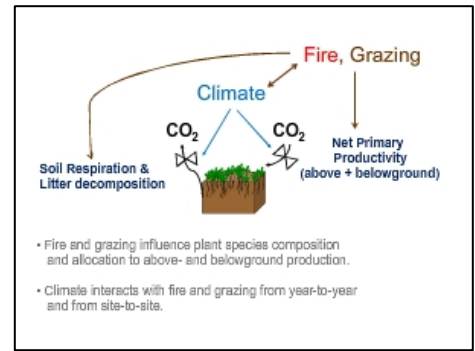
Slide 10. Disturbance in Grasslands

Plant production and the soil carbon stores can be impacted by common disturbances in grasslands such as fire and grazing.



Slide 11. Climate, Fire, and Grazing

Fire and grazing interact to affect the carbon cycle, primarily by altering plant species composition, as well as even within an individual species, the allocation patterns, how much carbon goes above- versus belowground. They obviously also interact with climate, where during dry years you might have systems more prone to fire and also during dry years, less available grazing, so some alterations in grazing patterns.



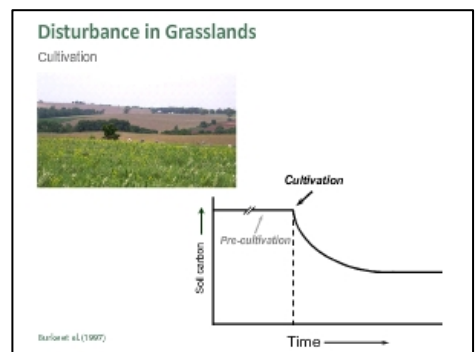
Slide 12. Fire and Grazing Over Time

If we look at pictures of the way these two disturbance factors can alter the plant community composition, on the left you see a picture from Konza, our eastern tall grass prairie system, where annual fire, there's a fire every spring, converts the system into basically a monoculture of very productive warm season grasses that allocate a lot of energy belowground, a lot of carbon belowground. While in the bottom panel of that figure on the left, you can see Konza experiencing fire only once every 4 years, and you can see it looks very different. There's a lot more spatial heterogeneity in the vegetation and structure, and a lot of this is actually woody plant encroachment that happens when you reduce fire frequency in this system. On the right you can see the effects of grazing, and this is desert grassland at the Santa Rita Experimental Range in Arizona. At the initiation of grazing in the early 1900s, you can see this was a desert grassland. It has a lot of grass present, and you can tell by the mountains in the back that this is a repeat time photo, so the photo on the top at the initiation of grazing and the photo on the bottom 30 to 40 years post grazing, and you can see that the grazing has drastically reduced the amount of grass cover and significantly increased the amount of woody plant cover in these systems. That has an effect on the carbon balance.



Slide 13. Cultivation

Another common disturbance in grasslands is cultivation, and here is a picture of native grass prairie relic in the front and active cultivation all around it from Missouri. Cultivation is a significant disturbance to the soil carbon pool. You can see in the graphic at the bottom, soil carbon at precultivation and then a general decline postcultivation. This works because plows move soil and invert soil. When they do that they alter the structure of the soil and the protection of soil organic matter from aggregates. They increase water and oxygen availability, and generally increase the temperature. All of these things stimulate decomposition of that soil carbon and loss back to the atmosphere.



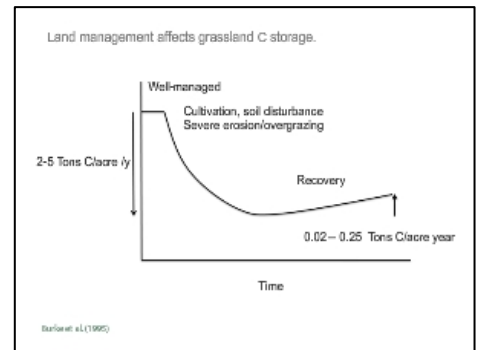
Slide 14. Disturbance

Cultivation though, can also influence the amount of soil carbon in soil particles period, that are lost through erosion. Whether wind erosion as the top picture depicts it was wide spread and common in the Great Plains during drought years in the thirties and forties, but we also have significant water erosion that can happen from the eastern wetter portions of the plains. But cultivation is not alone in impacting erosion. We can have grazing, especially in the semiarid West, increasing bare areas and making these systems much more prone to both wind and water erosion. You also have fire, especially in the West, that can also promote erosion.



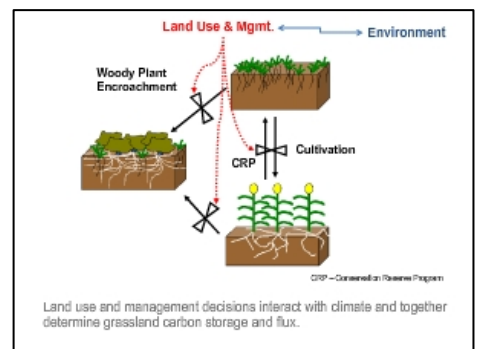
Slide 15. Land Management Affects Grassland Storage

So, if we look at land management, these different land management choices and effects on grassland carbon storage, you can see well-managed grasslands have a certain amount of carbon that they store. We come in and choose to disturb these systems either pretty severely through cultivation or significant soil disturbance, and those pools start to drop dramatically. We overgraze, reduce our plant production inputs, create erosion, and all of those things are going to lead to pretty significant declines. Long-term cultivation in the United States has resulted in about 30 to 50 percent soil carbon losses in many of these systems. As land managers though, we have the ability to change the way we manage these systems to try to sequester carbon back into the soil and belowground pools, and that's depicted here on the recovery line, and that might look like removing cultivation, reducing cultivation. It might also mean changes in our grazing regime or alterations in our fire regime. One thing to point out here though is while there is recovery and we are able to get carbon back into these pools, they're very stable pools for the most part, which is good. They'll go away for a long time. Recovery is very slow. So if you look at the rate of change that happens, the slope of the downward line here is quite high, where the positive recovery line the slope is very low. So it takes hundreds of years to get these pools to completely recover.



Slide 16. Chart

So land use management obviously is, in part, dictated by the environment and must be sensitive to climatic change and variability with the environment. But we have the ability to convert these grassland systems into woody systems by overgrazing and/or elimination of fire or reductions in fire. This has an effect on carbon balance. In almost every case, woody plants moving into grasslands increases aboveground carbon storage. Woody plants store a lot of carbon aboveground and grasses do not, we know that. The effect on the belowground pools is a little bit more variable, and there's a lot of science that still has to be done to understand when we gain and lose soil carbon pools with woody plant conversion. A more direct and more universal response is seen in the conversion of grassland systems into annual cropping systems. These almost always result in large losses of carbon. However, as managers we have the opportunity, and we inherit cultivated landscapes to go in and replant perennial grasses through programs such as the Conservation Reserve Program, the Grassland Reserve Program, or various WHIP2 type programs



that are administered by the NRCS³, and you can see significant gains in soil carbon through that type of management effort.

Slide 17. Climate Variability and Change

So to leave a few points and then a final take home message here.

Climate variability and change is significant in these systems.

Grasslands are adapted to that. They have evolved, in a large part, with significant variability and precipitation. These things dictate and control fire season and frequency, which influence the grazing

management and grazing patterns on the landscape, and both of these things can ultimately influence plant species composition change. And actually I wanted to spend just a second on the plant species

composition change. This particular picture is of the Intermountain West, and while you may not be able to see

it real well, the darker area on the right is a native shrub steppe system and the lighter area on the left is an annual grass invaded, so cheat grass invasion that's currently happening in this area. That type of conversion is significant. It has interactions with both climate and fire frequency, and it has implications for carbon cycle. So these complex interactions, by influencing the type of vegetation on the landscape, the allocation of that carbon above- and belowground that comes with those species changes, impacts grassland carbon balance. But obviously when we're managing and we're making decisions about our fire and grazing management

frequencies, we're also probably considering other services that these grasslands provide. Things like species diversity, conservation and aesthetic goals, ranching and livelihood options, and other things that I might not have listed here. So if we look just at the woody plant component, and I've told you woody plants store more carbon aboveground than grasses. So you might say, well if I'm just going to manage these areas for carbon storage then perhaps I should let them all go to woody plants. And that might be a choice for carbon storage, but I think you would no longer have a grassland to manage. So if you want to maintain a grassland, then you're going to have to balance these various factors.

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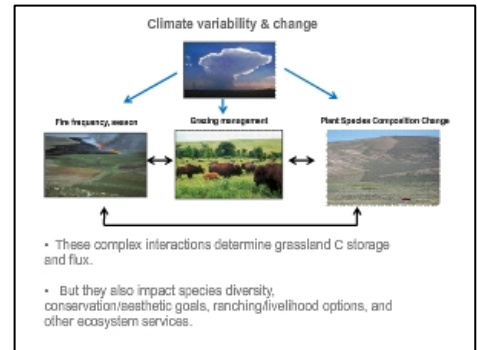
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Slide 18. Management Considerations

So finally, if you do choose to manage grasslands for carbon storage,

keep the soil in place and keep it covered, minimize soil disturbance,

use fire and grazing to stimulate plant production and carbon inputs to

the soil. But this management is going to have to be sensitive to and

responsive to changes in climate that we experience today and are

likely to experience in the future, and additional desires or pressures on

the landscape. Thank you.

Management Considerations for Carbon Storage in Grasslands:

- 1) Keep the soil covered and in place (minimize soil disturbance).
- 2) Use fire and grazing to stimulate plant production and C inputs to the soil, but management must be sensitive and flexible to climatic variability and additional desires for the landscape.

Footnotes

¹CPER=Central Plains Experimental Range

²WHIP=Wildlife Habitat Incentives Program

³NRCS=Natural Resources Conservation Service