NATIONAL CENTER FOR CASE STUDY TEACHING IN SCIENCE

From Prairies to Corn Fields for Fuel: A Tale of Lost Carbon

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Part I – Land-Use Change Due to Corn Ethanol Push

The plow ripped through the thick skin of the prairie, uprooting the native grasses, shrubs, and flowers that protected the soil. Ducks, geese, and other birds cried in alarm and flew away from the plow's wake. Small mice and voles scurried from their nests before they were run over by the tractor's tires. The plow went around for another pass, fully burying the plants with a rough layer of soil on top. Discs and other metal machinery also passed over the field, leaving a smooth seed bed, perfect for planting a corn crop.

Farmer Robert Malsam is one of many farmers, who together since 2010, plowed up more than one million acres of native prairie in the Dakotas and Nebraska to plant corn for ethanol. In a 2013 Associated Press article, Malsam said, "It's not hard to do the math there as to what's profitable to have. Farmers can make about $500 an acre planting corn. I think an ethanol plant is a farmer's friend (Brokaw and Gillum, 2013)."

Why has corn ethanol production become so profitable? The rapid expansion of biofuel production began in 2007 when the U.S. Congress set a production goal of 36 billion gallons of non-petroleum biofuel to be used in the nation's transport fuel mix by 2022 and subsidized producers and refiners to produce the non- petroleum biofuel. The federal goverement also required companies to blend billions of gallons of corn ethanol into gasoline (Figure 1). As a consequence, from 2010–2012, the number one use for corn in the U.S. was fuel.

Figure 1. Prairie is terminated and soil is inverted with a moldboard plow, corn is planted, and then corn is harvested for conversion to ethanol.

Scientists, some farmers, and other citizens are concerned about potential environmental impacts that result when prairie grasslands are converted to corn fields. In the same Associated Press article, Professor Chris Wright, who studies land conversion at South Dakota State University, said: "The conversation about land preservation should start now before it becomes a serious problem." When prairie land conversion occurs, the resulting landscape is less diverse and has less wildlife habitat. Additionally, large reservoirs of long-stored carbon in the soils of those converted fields release that carbon back to the atmosphere in the form of carbon dioxide.

Where did all of that carbon go that was in the prairie? What are some consequences of this large loss of carbon from prairie grassland systems?

Questions

1. Why is it important to consider carbon loss from prairie grasslands after land conversion to cornfields for ethanol when you think of sustainability?

2. Without doing any additional research at this point, why do you think carbon is lost from prairie grassland ecosystems when they are plowed under and planted to cornfields?

Part II – Carbon in Prairie Grasslands and Plowed Cornfields

The potential pool of carbon stored in soils can be quite large, depending on environmental conditions and how ecosystems are managed. In fact, on average, the soil carbon pool is thought to be about twice the size of the atmospheric carbon pool. How does the soil in a prairie grassland compare with soil in a corn field?

Soil in an undisturbed grassland tends to have a dark, rich layer of organic matter called the A-horizon, which can be a meter deep or more (Figure 2a) on top of mineral soil layers and then bedrock. The carbon-rich organic matter in the A-horizon builds up over millenia as living organic matter dies and is decomposed, or broken down, by microbes into smaller and smaller pieces. Soil organic matter is 50% carbon. Over time, some of those small soil particles, less than 2-mm in size, are bound in water stable soil aggregates that protect them from decomposition. Black carbon pieces from historic fires are slow to decompose and are frequently found in prairie grassland soil. Finally, recalcitrant organic polymers, called humus, which are not easily decomposed by microbes, accumulate in the soil. Soil in a field cultivated with a plow tends to lack that dark color seen in prairie grassland sod and so has much less organic matter (Figure 2b). The soil also tends to be more easily eroded and has poorer soil structure.

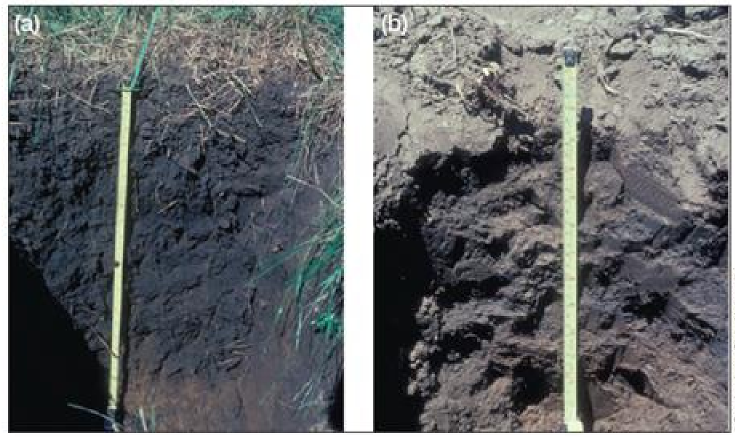


Figure 2. Soil profiles from (a) an undisturbed grassland and (b) a field cultivated with a plow. *Source:* Republished with permission of *Ecological Society of America*, from DeLuca and Zabinski, 2011; permission conveyed through Copyright Clearance Center, Inc.

Questions

1. When prairie grassland is plowed, how does the soil environment and structure change?

2. Keeping the first question in mind, after prairie grassland is plowed, what explains the observed large release of carbon dioxide out of the soil and back into the atmosphere?

Part III – Don't Forget About the Plants

Although cornfields and prairie grasslands are both composed of plants, they are very different places. Each spring after soils are plowed, farmers like Farmer Malsam plant corn in neat rows and the corn seedlings rapidly grow in height over the course of the summer, often reaching over five feet in height in a good year! In early autumn, the sound of dried out corn leaves rustling against one another can be quite lovely to a farmer's ears. The late afternoon sun lends a soft, golden light to the stalks. That is mostly what is seen and heard before the combine harvester comes through and collects the grain to be sold for fuel or feed.

In the prairie, where Professor Wright likes to take a stroll in autumn, the perennial prairie grasslands would be thick, lush, and green and starting to slow down to their winter dormancy period. Insects would buzz. Birds would chirp. Some birds would migrate over winter but then they would return. Mammals would scurry about before hibernating until spring. The following spring, the grassland plants would break dormancy and start growing once again.

When you think about loss of carbon from native prairie grasslands after conversion to corn fields, it is important to remember that carbon is also added to each ecosystem in the form of plant biomass. It is the balance between carbon addition and loss in an ecosystem that determines whether an ecosystem has a net loss of carbon and serves as a source for atmospheric carbon, or whether an ecosystem has a net gain of carbon and serves as a sink for atmospheric carbon. Native prairie grasslands are considered to be carbon sinks. Scientists estimate that an average of 47.5% of organic carbon is lost in upper soil layers when native prairie grasslands are converted to corn fields (DeLuca and Zabinski, 2011); you considered why in Part II of this case study. We should also ask whether there are any differences in how much carbon is added back into the system each year by native grassland plants compared with corn plants.

In other words, how do these two plant communities compare in the amount of biomass they produce in a year and how much of that is retained within each system? One way to think about the productivity of a community of plants is to measure net primary production (NPP). NPP is the amount of carbon acquired during photosynthesis minus the carbon lost in respiration. Any left-over carbon remains in the biomass of the plant. Total NPP includes NPP for aboveground (ANPP) and belowground (BNPP) biomass, or "shoots and roots."

Grassland and corn plants have very different root structures, which contribute to annual BNPP. Perennial grassland plants have deep, extensive, fibrous root systems (Figure 3b) relative to annual plants (Figure 3a). Thus, it is common for perennial plants, which can live year after year, to allocate more carbon belowground to their roots, compared to annual plants, such as corn. ANPP also differs between grassland and corn plants, as you will see in the data below.

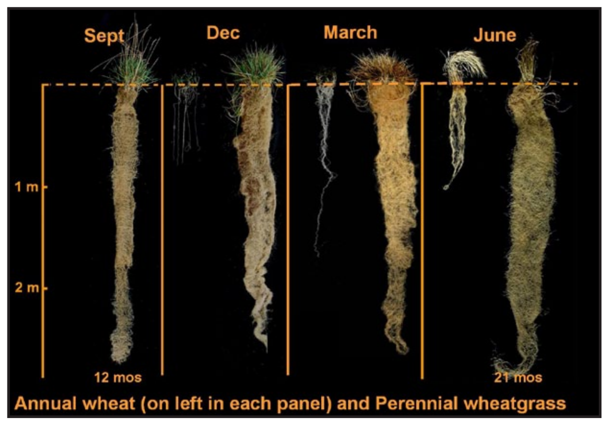


Figure 3. Root systems beneath an annual plant, wheat (left side of each panel) and a perennial wheatgrass plant (right side of each panel). Wheat roots grow to a maximum depth of 1 m, while perennial grass roots can reach depths greater than 2 m. (*Image credit:* Jerry Glover, https://commons.wikimedia.org/wiki/File:4_Seasons_Roots.jpg, CC BY 3.0.)

Kansas Tall Grassland Prairie

Scientists at Konza Prairie Natural Area in Kansas measured ANPP in prairie grassland in early fall in both 1994–1995 in unburned, control plots that were left undisturbed. No inputs were added to the prairie. On average, they found average ANPP for the prairie grassland to be 9 Mg ha^{-1} yr^{-1} (Blair, 1997).

Iowa Corn

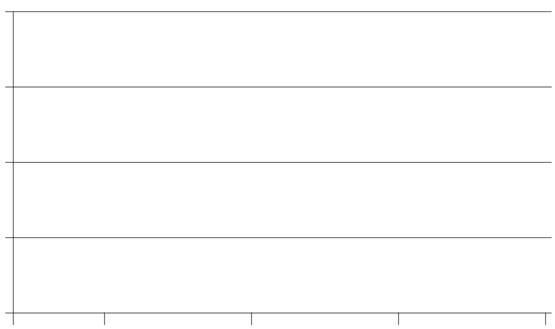
Scientists in Iowa measured ANPP for corn at full maturity from 1985–1998, just prior to grain harvest (Table 1). Each year they applied nitrogen at different rates in different fields (Table 1). The site received tillage, or was plowed before planting.

Table 1: Average ANPP for corn at Kanawha Experimental Site under different fertilizer treatments.

	Corn ANPP (Mg ha^{-1} yr^{-1}) by fertilizer treatment			
Experimental Site	0 kg (N/ha)	90 kg (N/ha)	180 kg (N/ha)	270 kg (N/ha)
Kanawha	8.0	10.3	11.5	11.3
Data Excerpted: Russell et al., 2009				

Exercise – Plot

Using Table 1, plot the relationship in the box below between corn ANPP and increasing fertilizer rate applied to the fields at Kanawha Experimental Site. Which should be the independent and which should be the dependent variable on the graph? Describe the relationship.



Independent variable:

Dependent variable:

Description:

Questions

1. Is the addition of synthetic nitrogen fertilizer to corn fields to boost yields sustainable? (*Hint:* How is nitrogen fertilizer made?)

2. Which fertilizer treatment might corn ANPP be most fair to compare with prairie grassland ANPP? Why? Is corn or prairie grassland ANPP higher on average (be sure to specify which fertilizer treatment you used)?

3. The data in Table 1 was collected just prior to corn harvest. Assuming about 1/2 of aboveground corn biomass is removed from the field during grain harvest, does a similarly sized field of corn or a grassland prairie have the potential to add more carbon back to the soil in a year? What if roots were included?

4. What are potential limitations to examining the ANPP data above to represent prairie grasslands and corn fields in the U.S. for comparing plant biomass inputs in these systems?

Part IV – Integrating Soil, Plant, and Atmospheric Carbon Pools

Carbon cycling in grasslands (or any ecosystem) can be depicted as a series of pools and fluxes of carbon. A carbon flux, drawn as an arrow, shows how much carbon over time moves from one pool to another pool. A pool can be thought of as a storage reservoir for a particular element like carbon and can be drawn as a box. Most pools have at least one flux entering and one flux exiting them. When fluxes of carbon move from pool to pool in an ecosystem, this represents a cycle. One can focus on a portion of the carbon cycle (such as we are doing here) or on the entire global carbon cycle.

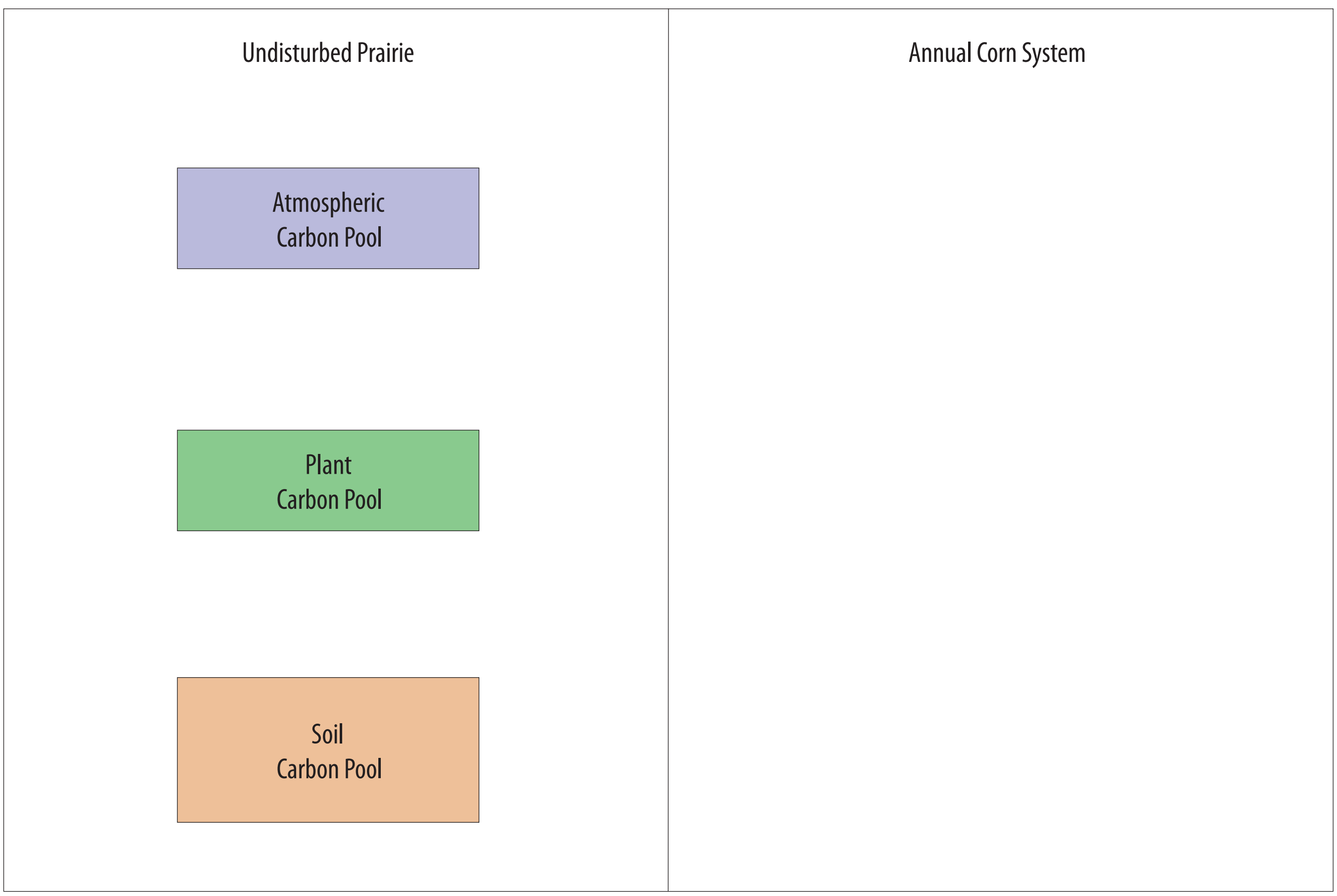
Exercise – Pool and Flux Drawings

A. On the left-hand side of Figure 4 below, under the heading "Undisturbed Prairie," draw the fluxes (arrows) of carbon between the pools (boxes) in the undisturbed prairie grassland. (Box sizes reflect the relative sizes of pools.)

B. Again on the left-hand side, describe the form(s) of the carbon for each pool that is drawn (e.g., CO_2, organic-C).

C. On the right-hand side of Figure 4, under the heading "Annual Corn System," draw boxes (pools) and arrows (fluxes) for a newly planted, fertilized corn system following plowing of prairie grassland. Use the size of the boxes you draw to indicate whether the pools are larger or smaller in the corn system compared with the grassland system; in other words, bigger boxes on the right would indicate a larger pool in the corn system. Similarly, use thickness of the arrows you draw to indicate the relative size of flux; a thinner arrow should indicate smaller flux and a thicker arrow should indicate greater flux in the corn system as compared with the prairie grassland system. *Note:* Not all pools or fluxes necessarily change size. Use the information in the rest of this case study and your notes on carbon cycling and decomposition to help you.

Figure 4. Comparison of carbon cycling in undisturbed prairie grassland vs. corn field. Box sizes reflect relative sizes of pools.



D. Describe why you increased or decreased the size of a pool or flux for the corn field relative to the prairie grassland and whether you think the corn field is a sink or source of carbon.

Implications

Professor Wright emphasized that discussion about conservation of prairie grasslands should be happening right now, but it is not. Prairie grasslands offer plant, animal, and insect diversity in the landscape plus store large amounts of carbon, as we explored in this case. How much are those services worth, ecologically, economically, or socially? Are they worth enough to compete with corn that Farmer Malsam said could be sold for $500 per acre in autumn 2013?

Questions

1. If farmers did not convert prairie grasslands to cornfields, stored carbon could be preserved. One government program offered to farmers who set aside land is called the CRP program, or Conservation Reserve Program. After researching this, describe it and share pros and cons of this program for farmers. Does the program adequately help farmers when corn prices are high? What other benefits or services do intact grasslands provide beyond the monetary CRP compensation provided to farmers?

2. For farmers who are going to convert prairie grasslands to cornfields, are there different ways to manage corn fields in their crop rotations to help mitigate losses of carbon from the system after land conversion or even become a sink of carbon over time? Do a little research to answer this question if you have not learned about different, perhaps more sustainable, methods to grow corn and other crops. Describe at least two management options.

References

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