Soil carbon and climate change

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Outline:

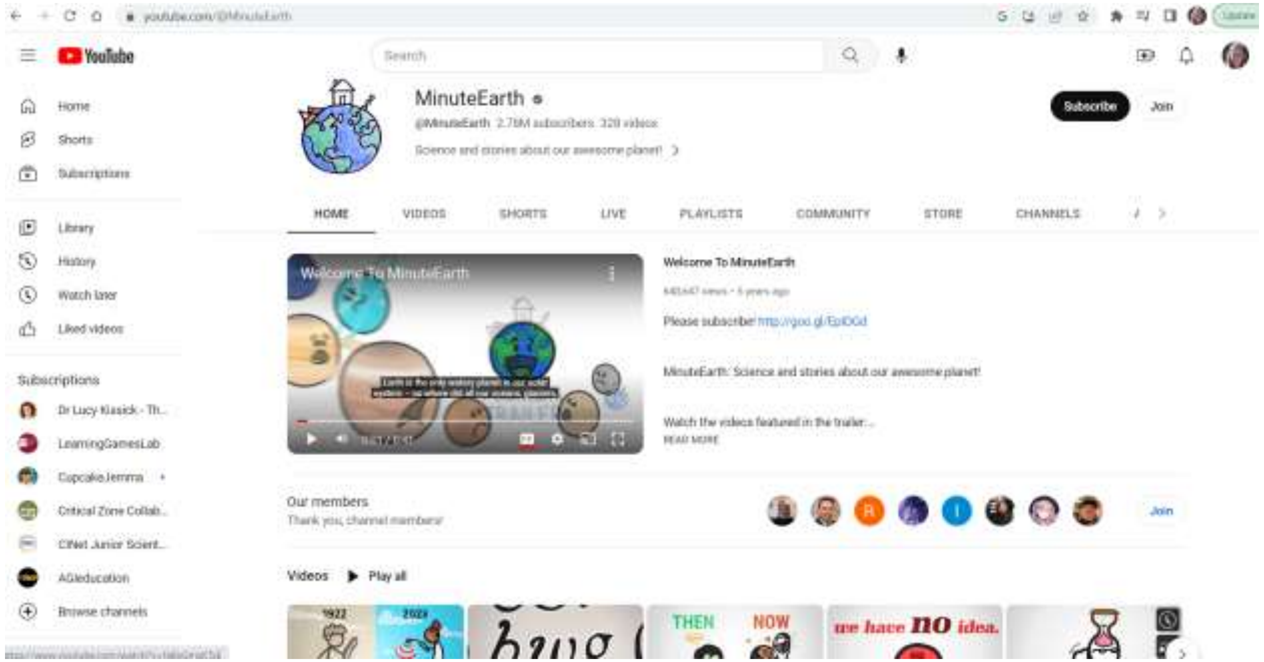
- What is climate change?
- Carbon budget and the global carbon cycle
- Soil carbon
- Feedback loops
- Carbon storage in soils
- Atmospheric carbon
- How soil carbon can impact climate change

Climate change refers to the long-term shirs in temperature and weather patterns, mainly caused by human activities, especially the burning of fossil fuels. (United Nations)

Here is a short video that illustrates what climate change is and how humans are impacting climate:

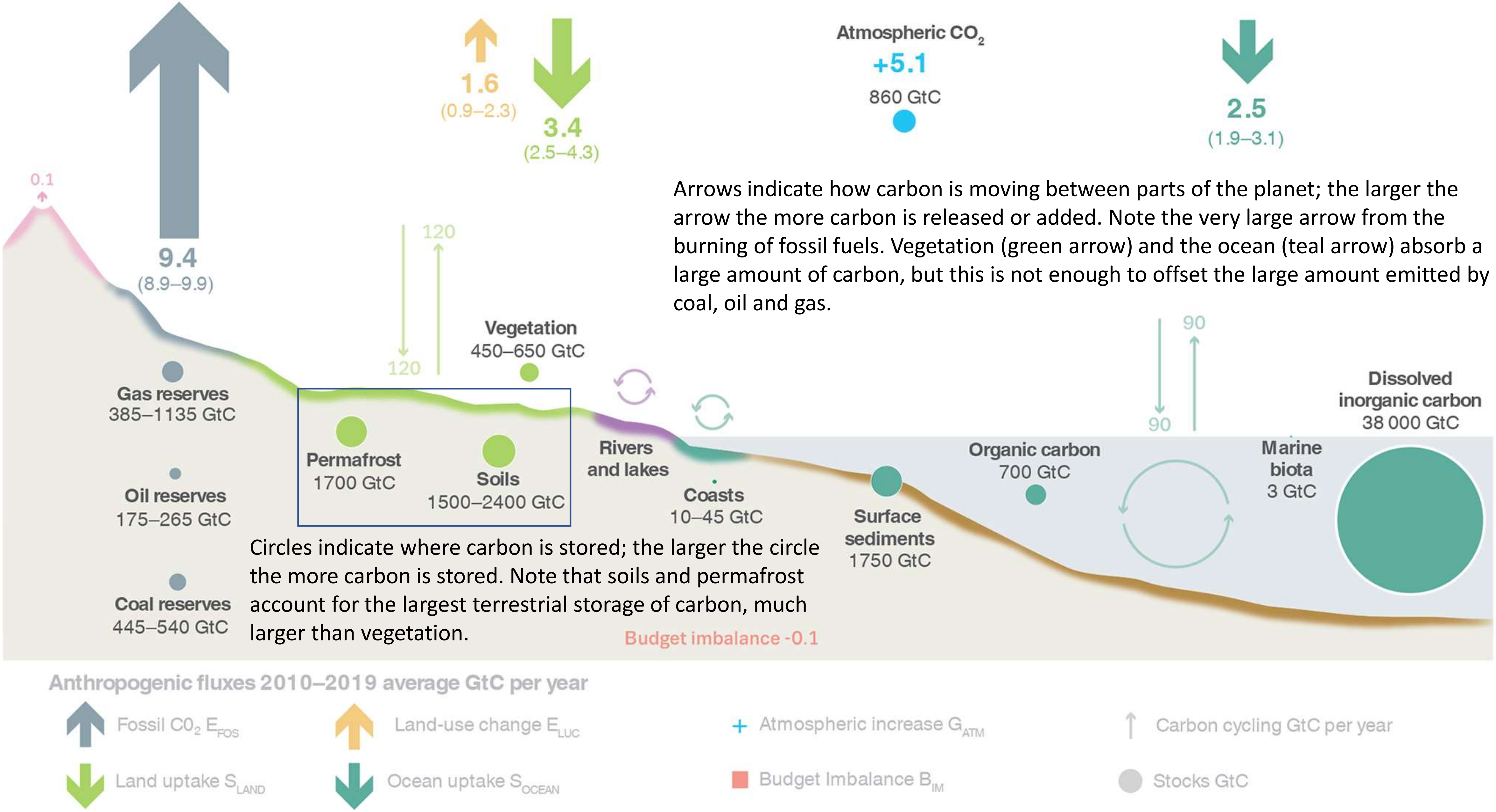
[Minute Earth – Climate Change]

Additional short videos related to climate change and how the Earth works can be found on the YouTube Channel "Minute Earth"



The global carbon cycle

Friedlingstein et al., 2020



Arrows indicate how carbon is moving between parts of the planet; the larger the arrow the more carbon is released or added. Note the very large arrow from the burning of fossil fuels. Vegetation (green arrow) and the ocean (teal arrow) absorb a large amount of carbon, but this is not enough to offset the large amount emitted by coal, oil and gas.

Circles indicate where carbon is stored; the larger the circle the more carbon is stored. Note that soils and permafrost account for the largest terrestrial storage of carbon, much larger than vegetation.

Carbon Budget – Conceptual Diagram

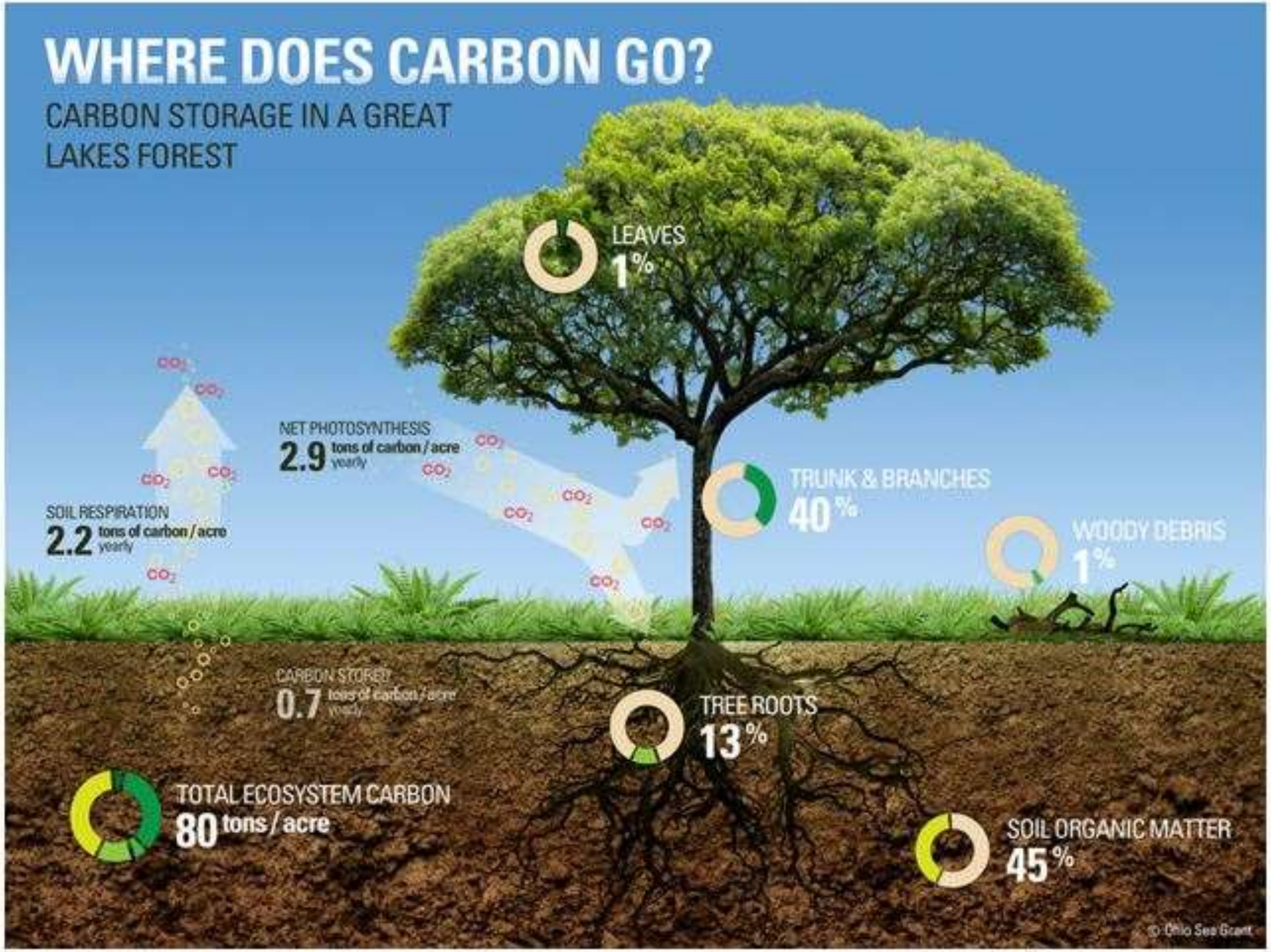


Image courtesy of Ohio Sea Grant

Vegetation absorbs CO2 from the atmosphere during photosynthesis and stores the carbon in leaves, trunks, branches and roots.

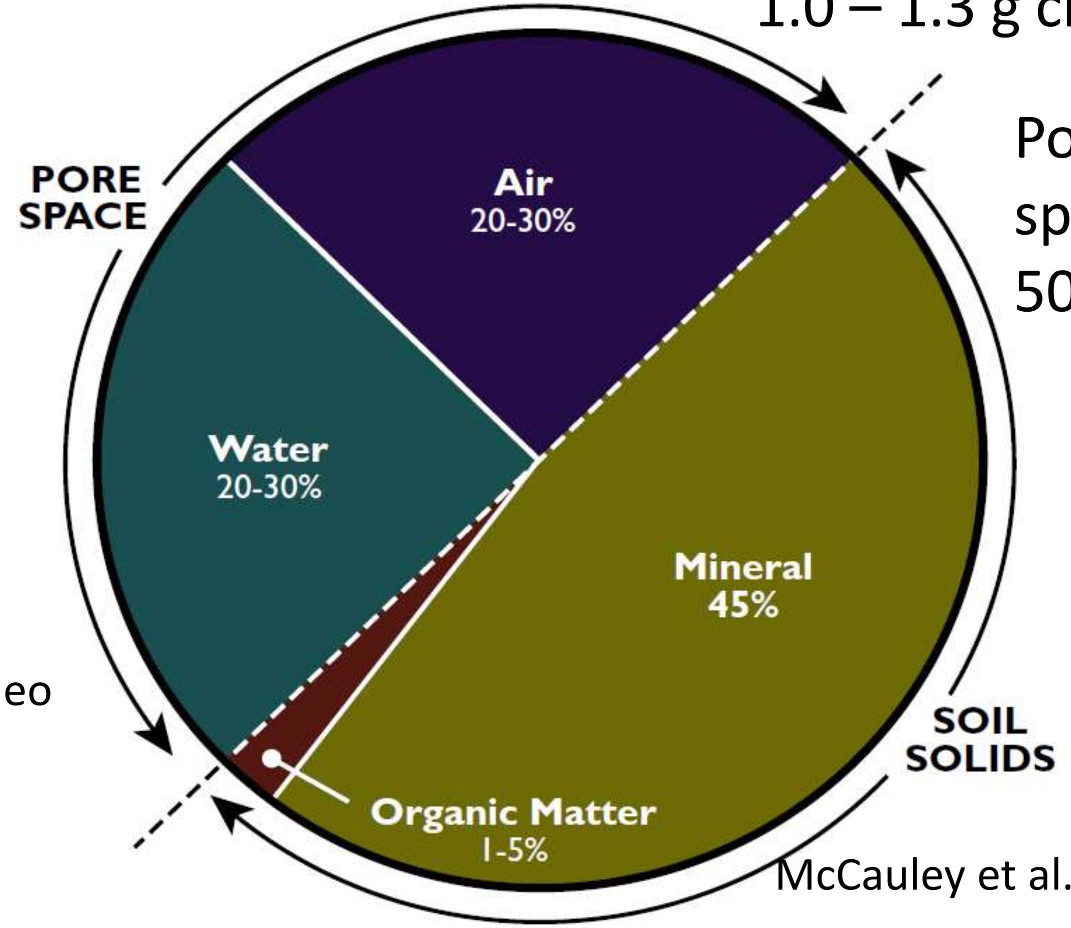
Some CO2 is released back to the atmosphere by soil respiration, or the breathing of soil microorganisms.

Almost half of the carbon in a forest is stored in the soil.

Soil organic matter is typically 1 – 5% of the total soil volume and varies depending on environmental conditions and land use.

Density = 1.0 – 1.3 g cm^{-3}

Pore space = 50%

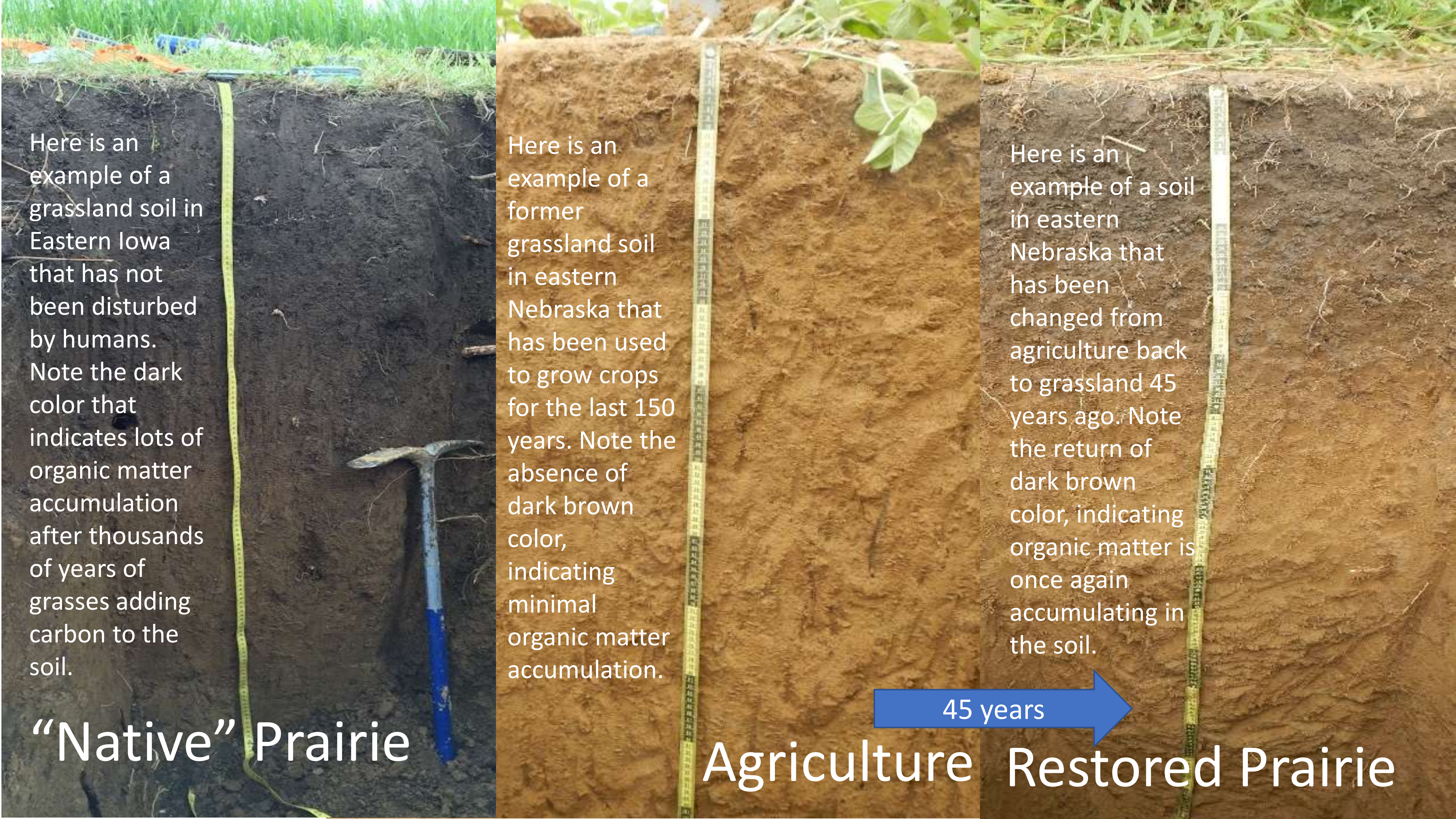


McCauley et al., 2005

Here is a link to a video about life in the soil: [Minute Earth – is Soil Alive?]


"Native" Prairie

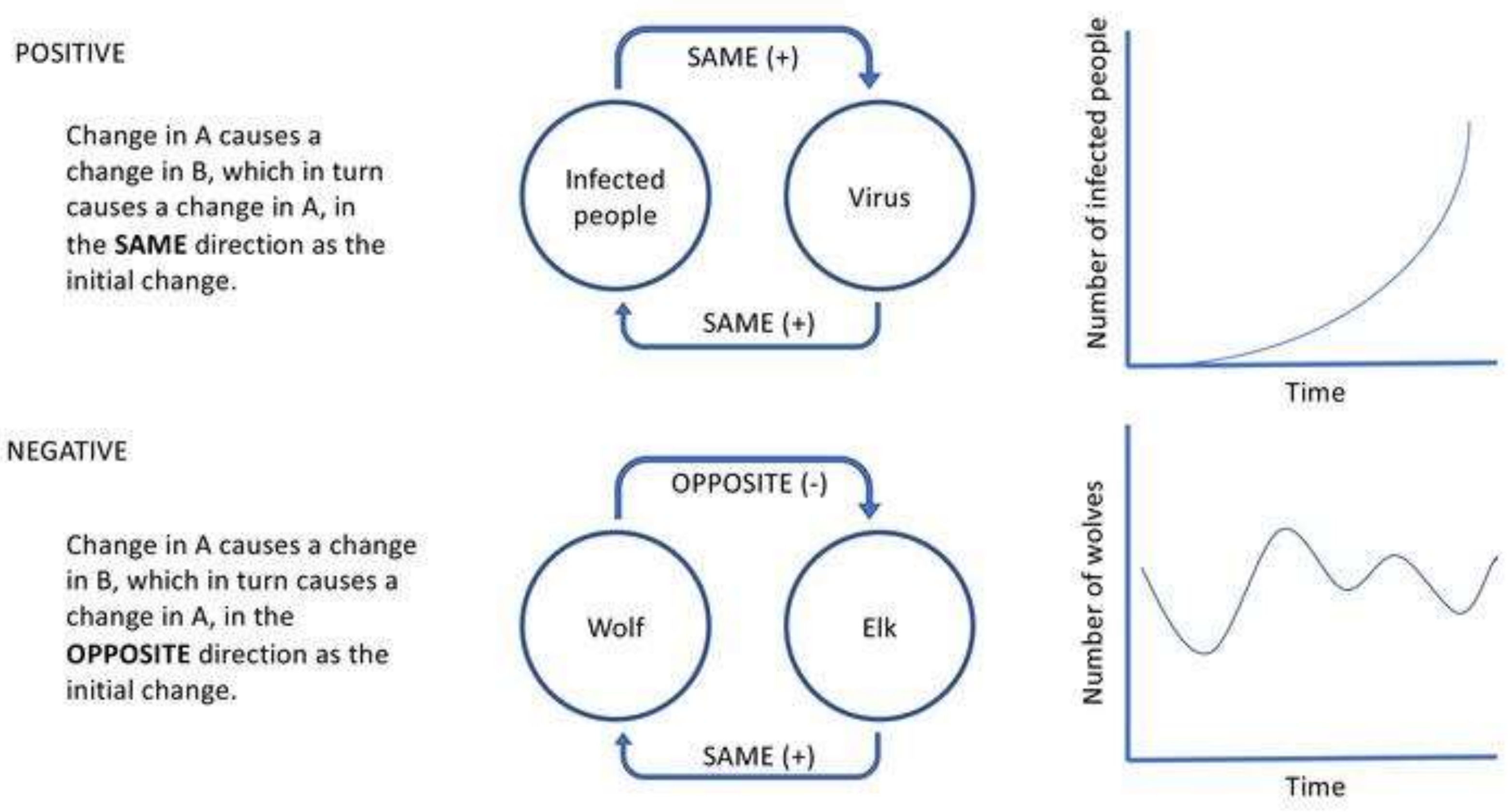

Agriculture


Here is an example of a grassland soil in Eastern Iowa that has not been disturbed by humans. Note the dark color that indicates lots of organic matter accumulation after thousands of years of grasses adding carbon to the soil.
"Native" Prairie
Here is an example of a former grassland soil in eastern Nebraska that has been used to grow crops for the last 150 years. Note the absence of dark brown color, indicating minimal organic matter accumulation.
Agriculture
45 years
Here is an example of a soil in eastern Nebraska that has been changed from agriculture back to grassland 45 years ago. Note the return of dark brown color, indicating organic matter is once again accumulating in the soil.
Restored Prairie

Feedback Loops – an important part of climate change

Feedback loops are circuits of change and response to change:

- *positive feedback loops* usually amplify the change
- *negative feedback loops* typically diminish the effects of change



Releasing more CO_2 into the atmosphere traps more heat, which causes increasingly warmer temperatures.

An increase in temperature can increase the amount of cloud cover, which could reduce incoming solar radiation by reflecting radiation back to space, limiting warming.

Diagram by Thomas F. Shipley. *serc.carleton.edu*

Feedback Activity: Try this activity with a small group to explore how some disturbances (switching from a written word to pictures) result in enhanced change (positive feedback) while other disturbances result in minimal change (negative feedback). You will need a small notepad and pencil for each person.

1. Start by thinking of a word (i.e.: summer, mountain, cake, flower…)
2. Write the word on the front page
3. Pass the paper to the person on your right
4. Look at the word, then flip the top page over and illustrate the word
5. Pass the drawing to the person on your right
6. Look at the drawing only, flip the page and write the word you think the drawing represents
7. Pass the word to the person on your right
8. Look at the word only, flip the page and illustrate the word
9. Repeat until your original paper is returned to you (or at most 10 times if your group is larger)
10. Find your original word and review all pages: are your pages an example of a positive or negative feedback loop?

Soil carbon is best stored in wet, cold conditions that limit decomposition by organisms. Depressions and low spots in the landscape are also good places to store carbon, as these are places where erosion tends to accumulate soil and organic material and trap water.

Here is a link to a video about permafrost: Permafrost video

Carbon and land use change graphing activity: Use data below from the paper at right to graph soil carbon under forest and agriculture land use and discuss how land use could impact carbon storage and soil properties.

				Total SOC (kg/m2)	(sum((OC%*BD*dz)/1(
Agriculture					
depth (cm)	dz (cm)	Bulk Density (g/cm3)	clay %	Organic Carbon (%)	**SOC (kg/m2)**
5	5	1.63	19	1.1	0.897
15	10	1.63	21	0.6	0.978
25	10	1.61	17	0.6	0.966
35	10	1.37	23	0.5	0.617
45	10	1.7	19	0.1	0.170
65	20	1.64	11	0.1	0.164
93	28	1.65	7	0.1	0.231
125	32	1.58	9	0.1	0.253
147	22	1.66	9	0.0	0.146
175	28	1.74	6	0.0	0.195
180	5		7	0.0	0.000
				Total SOC (kg/m2)	**4.62**

Forest						
Horizon	depth (cm)	dz (cm)	Bulk Density (g/cm3)	clay %	Organic Carbon (%)	**SOC (kg/m2)**
A	7	7	1.09	12	3.1	2.365
AB	17	10	1.03	16	1.1	1.082
Bt1	30	13	1.27	22	0.4	0.627
Bt2	46	16	1.3	22	0.3	0.520
Bt3	56	10	1.52	24	0.3	0.380
Bt4	67	11	1.73	24	0.2	0.324
Bt5	83	16	1.73	18	0.2	0.471
BC	97	14	1.6	12	0.1	0.112
C1	123	26	1.73	8	0.1	0.225
C2	150	27	1.52	8	0.1	0.205
C3	180	30	1.62	6	0.1	0.243
					Total SOC (kg/m2)	**6.55**

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Rates of soil mixing and associated carbon fluxes in a forest versus tilled agricultural field: Implications for modeling the soil carbon cycle

Kyungsoo Yoo,[1] Junling Ji,[2] Anthony Aufdenkampe,[3] and Jonatan Klaminder[4]

Received 22 January 2010; revised 15 October 2010; accepted 3 November 2010; published 10 February 2011.

[1] In natural ecosystems, bioturbation is an essential component of soil formation, whereas tillage drives soil mixing in agricultural soils. Yet soil mixing is commonly neglected in modeling soil organic carbon (SOC) as it responds to land use changes. Here, in order to determine mixing-driven carbon fluxes, we combine a mass balance model with measurements of ^{210}Pb activities and SOC contents. Soil mixing rates by tillage decrease from 3.4 ± 2.3 cm yr^{-1} at the surface to 0.8 ± 0.2 cm yr^{-1} at a depth of ~20 cm, causing the SOC stored in the upper 25 cm of the soil to be physically turned over via mixing annually. In contrast, the bioturbation-driven soil mixing velocity at the forest increases from 0.6 ± 0.1 cm yr^{-1} at the surface to 2.7 ± 0.5 cm yr^{-1} at a depth of ~10 cm, which results in physically turning over SOC in the A horizon via mixing on years to decadal time scales. Therefore, SOC fractions with different susceptibilities to decomposition may have significantly different physical trajectories within the soils over their lifespans, and thus the assumption of C-cycling models that all SOC fractions experience identical environmental conditions is unlikely to be realistic. Carbon sinks, excesses of plant carbon inputs over decomposition carbon losses, are found within the top portion of the A horizons. These carbon excesses are transferred, via mixing, to the lower portion of the A horizon, where they are decomposed. By quantifying mixing-derived SOC fluxes, this study shows a previously unrecognized complexity in understanding SOC dynamics associated with land use changes.

Citation: Yoo, K., J. Ji, A. Aufdenkampe, and J. Klaminder (2011), Rates of soil mixing and associated carbon fluxes in a forest versus tilled agricultural field: Implications for modeling the soil carbon cycle, *J. Geophys. Res.*, *116*, G01014, doi:10.1029/2010JG001304.

1. Introduction

[2] Soil mixing is a ubiquitous but hidden process from the perspective of soil organic carbon (SOC) budgeting. In places where erosion and leaching losses of organic carbon are not significant components of carbon fluxes, soil carbon storage is ultimately determined by the balance of plant carbon input and decomposition. In this view of SOC storage, soil mixing is an internal process within soil systems, and therefore its impacts on SOC storage have been explicitly removed from the research window. So far, most SOC cycling studies have focused on relating biological processes to physical and chemical properties of soils such as moisture and temperature [e.g., *Amundson*, 2001] and mineralogy [e.g., *Masiello et al.*, 2004]. Limited knowledge about how mixing processes affect the SOC cycle is of concern because mixing is an essential characteristic of topsoils enriched with organic carbon. An A horizon is defined as a soil horizon where humified organic matter is intimately mixed with mineral fractions or having properties resulting from cultivation or other disturbances. Despite the universal nature of soil mixing and its critical role in forming A horizons where most SOC studies focus, the impacts of soil mixing in vertically redistributing net ecosystem productivity have not been explicitly considered in assessing biosphere-atmosphere carbon exchange [*Baldocchi*, 2008] and in soil chronosequence studies to understand how SOC storages respond to land use changes [*Amundson*, 2001; *Schlesinger*, 1986].

[3] This contribution is to pry open the black box by quantifying (1) the rates where SOC is redistributed by soil mixing and (2) how the depth-dependent SOC mixing compares to overall SOC budgets. In addressing these goals, we focus on two common soil mixing mechanisms, tillage in cultivated croplands and bioturbation in forests, which place this study in the context of land use changes and the associated changes in SOC storage.

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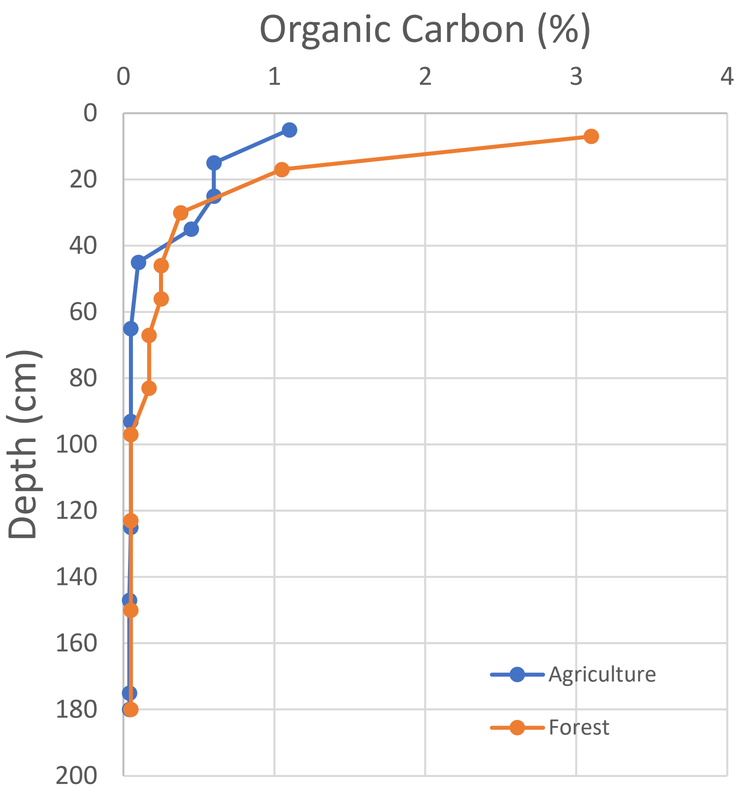
0148-0227/11/2010JG001304

Carbon and land use change graphing activity

Use data from publications to help students practice data visualization and interpretation skills



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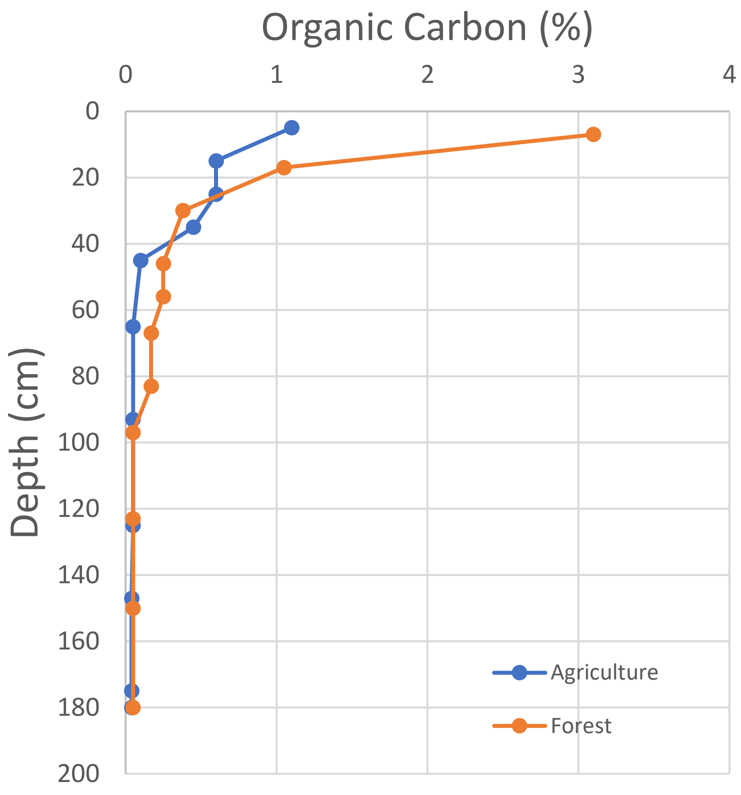
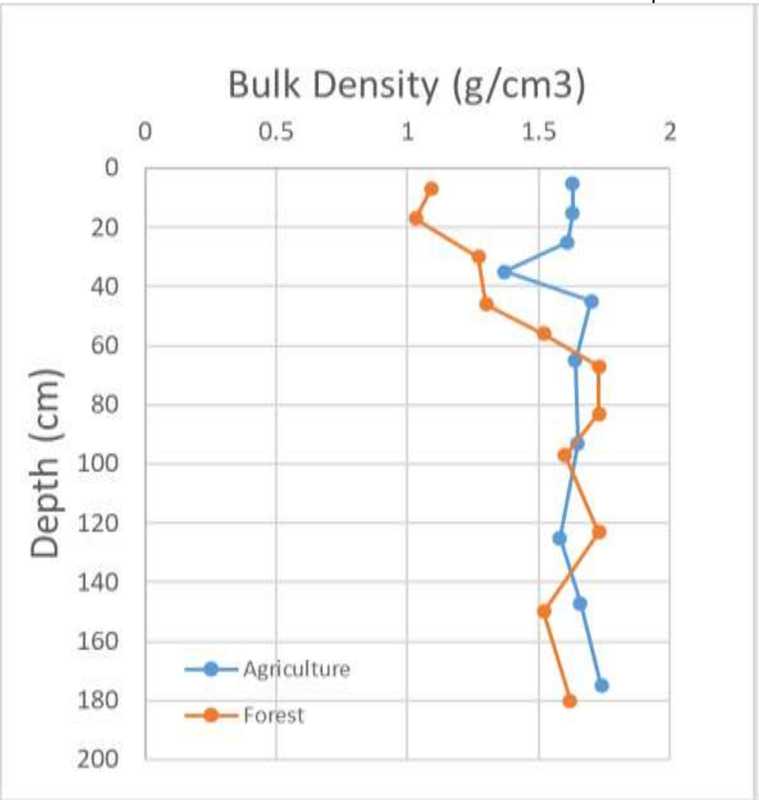
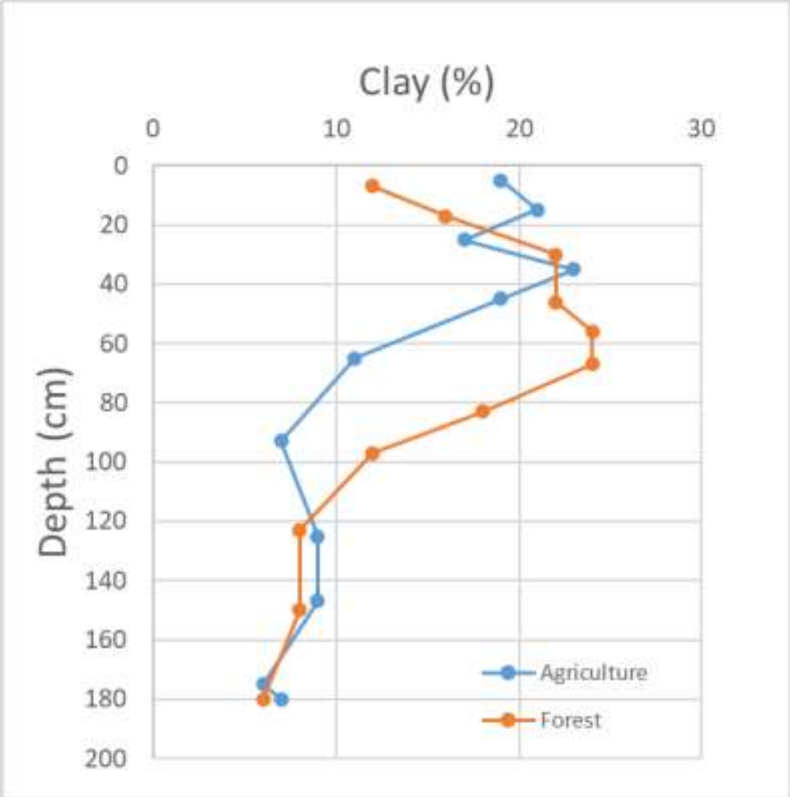
Organic carbon: Note the much higher accumulation of organic carbon in surface soils under forest compared to agriculture; at depth the soils store similarly low amounts of carbon.

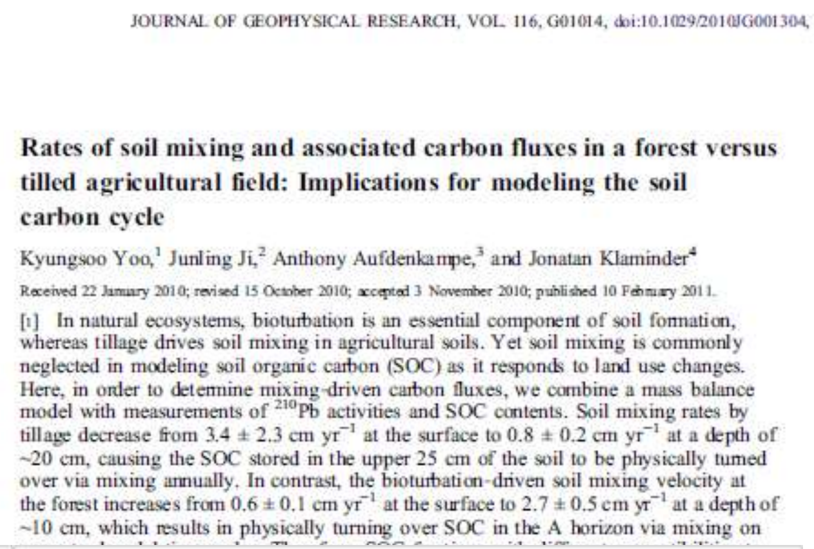
Bulk density: Forest soil has lower bulk density than agriculture, likely due to roots that loosen the soil in the forest and compaction due to tillage and tractors used under agricultural land management.

Clay content: In forest soils, clay washes deeper into the soil while under agricultural management the upper soil mixes together soil and keeps clay near the surface.





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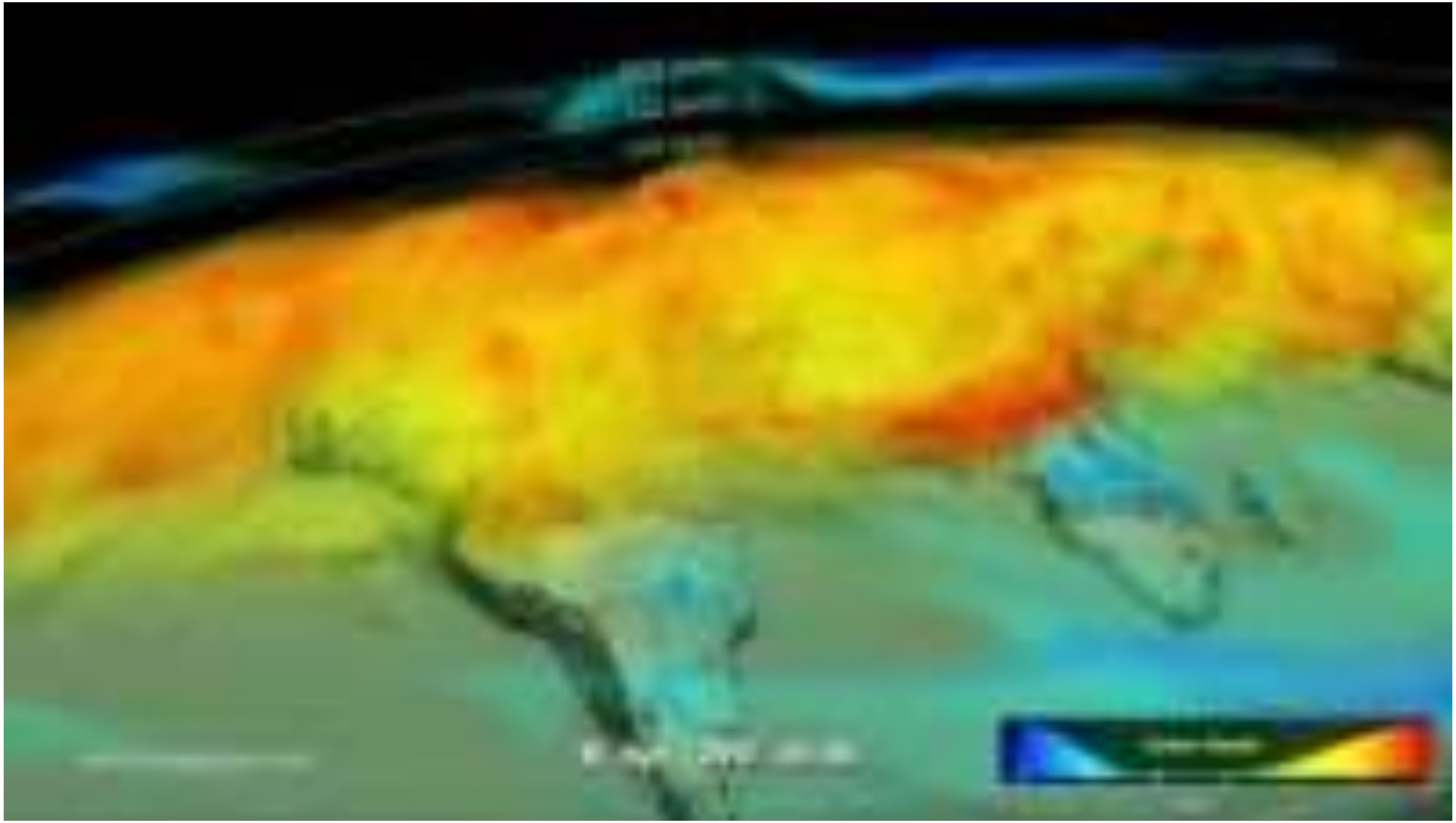
Atmospheric carbon dioxide varies throughout the year due to seasonal changes in vegetation photosynthesis. Watch this NASA visualization to see how atmospheric CO_2 varies.



Soils can help minimize the impact of increased atmospheric CO_2 by storing carbon in the subsurface, illustrated by the video below.

FAO United Nations