Catalyzing Adaptive and Resilient Food Systems

Where to look for adaptation and mitigation synergies?

Tim Crews
The Land Institute

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Annals of Botany **108**: 407–418, 2011
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ANNALS OF BOTANY Founded 1887

VIEWPOINT

Breeding crop plants with deep roots: their role in sustainable carbon, nutrient and water sequestration

Douglas B. Kell[1,2,*]

Global Change Biology

Global Change Biology (2016) **22**, 1315–1324, doi: 10.1111/gcb.13178

Soil carbon sequestration and biochar as negative emission technologies

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Article **Nature**

Potential for large-scale CO_2 removal via enhanced rock weathering with croplands

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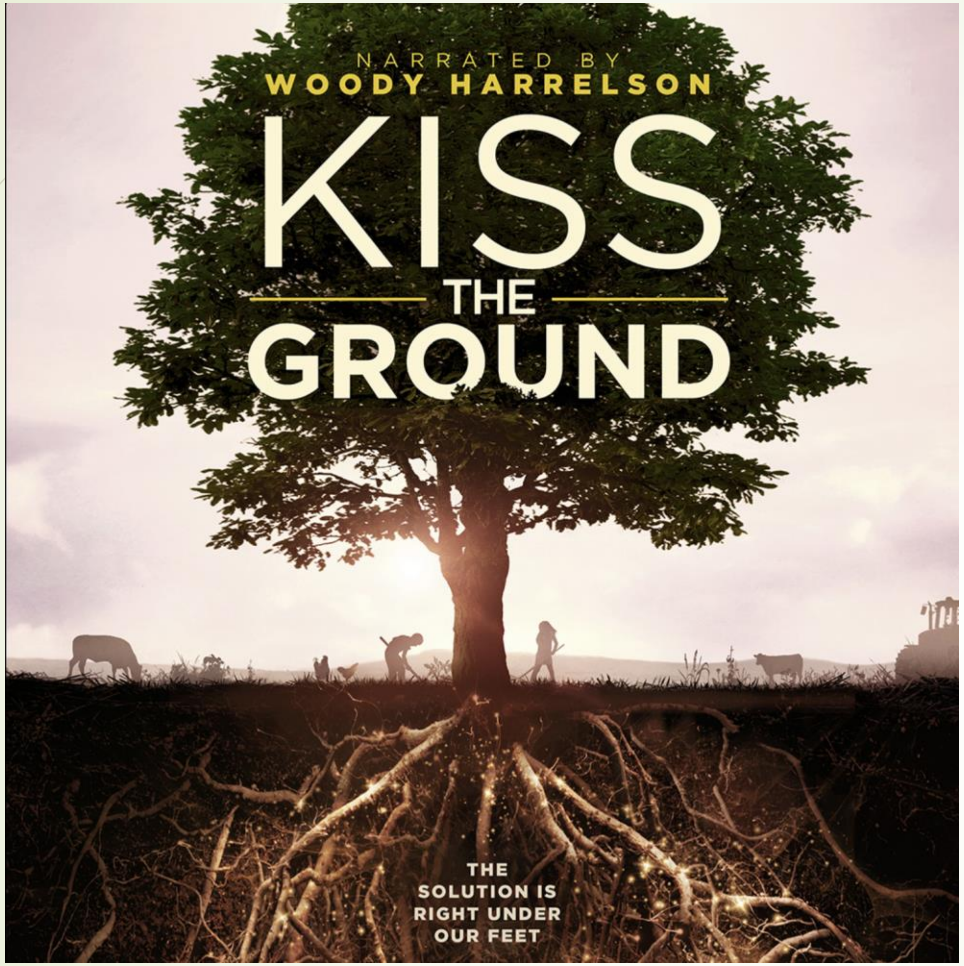

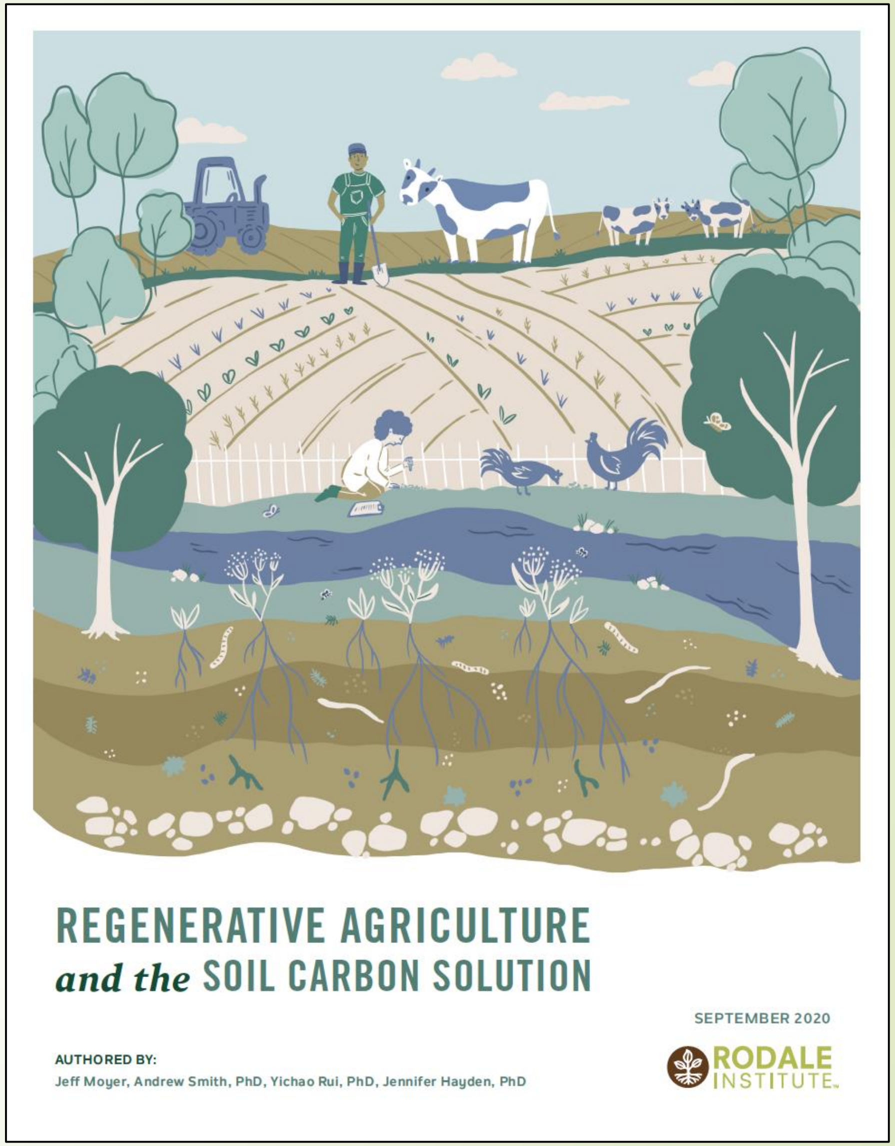

Soil Carbon Exuberance

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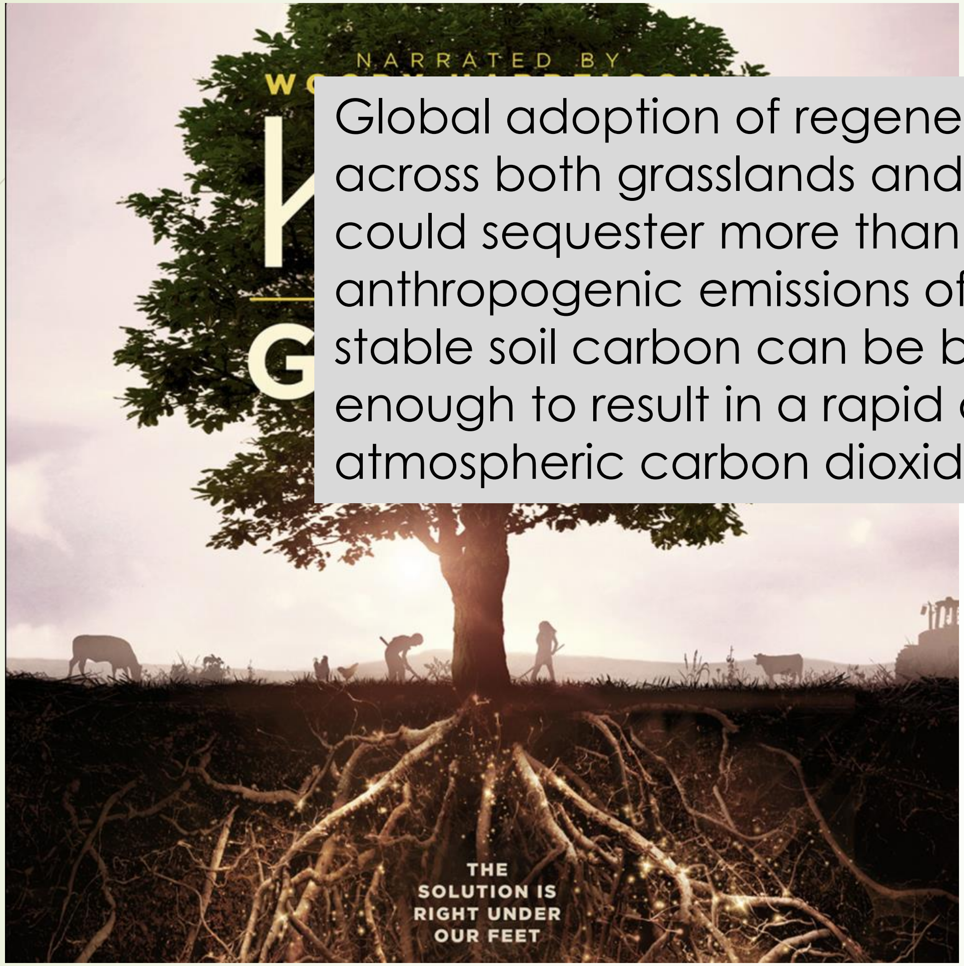

Global adoption of regenerative practices across both grasslands and arable acreage could sequester more than 100% of current anthropogenic emissions of CO_2 and that stable soil carbon can be built quickly enough to result in a rapid drawdown of atmospheric carbon dioxide.

Soil Carbon Exuberance

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CIVIL EATS

FOOD + POLICY FARMING HEALTH ENVIRONMENT DONATE

Does Overselling Regenerative Ag's Climate Benefits Undercut its Potential?

A new white paper from the Rodale Institute and the Carbon Underground says that regenerative practices, if adopted around the world, could sequester all annual carbon dioxide emissions. Critics warn the scientific data doesn't support these claims, and may oversell the benefits.

"Regenerative agriculture is a powerful drawdown, both to reduce emissions and add new carbon sinks. But preposterous claims that are easily debunked only undermine the message that regenerative agriculture is one of the few areas that can (potentially) solve around 10 percent of climate change."

Jon Foley, Project Drawdown

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Photo: Jim Richardson

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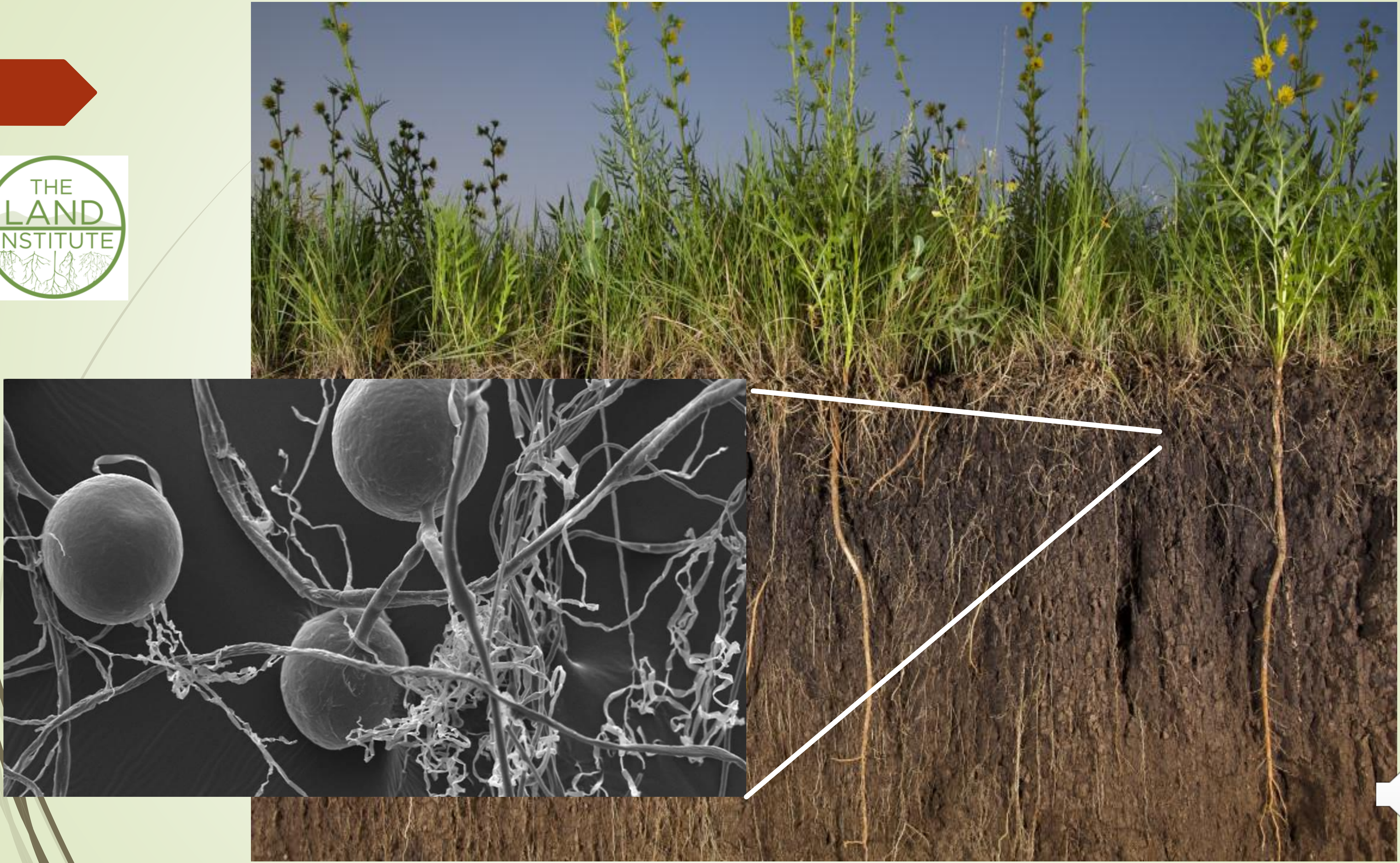

Photo: Jim Richardson

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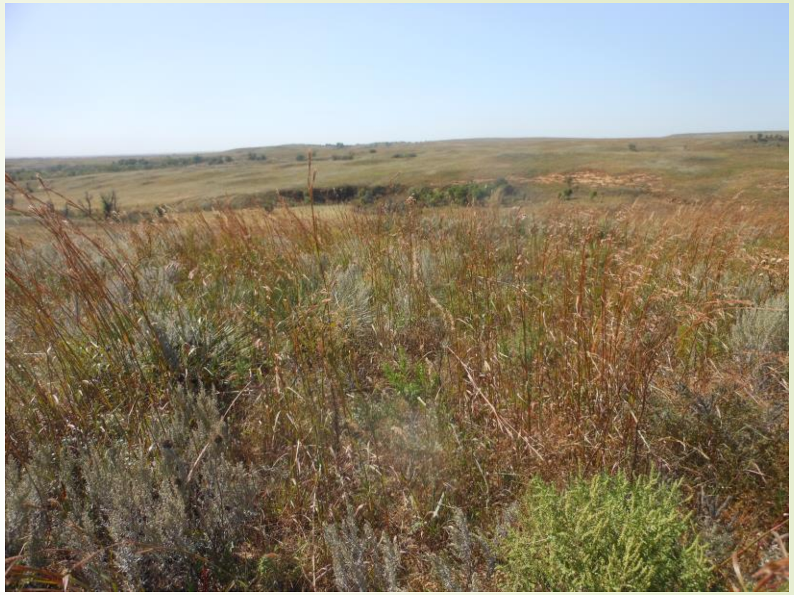

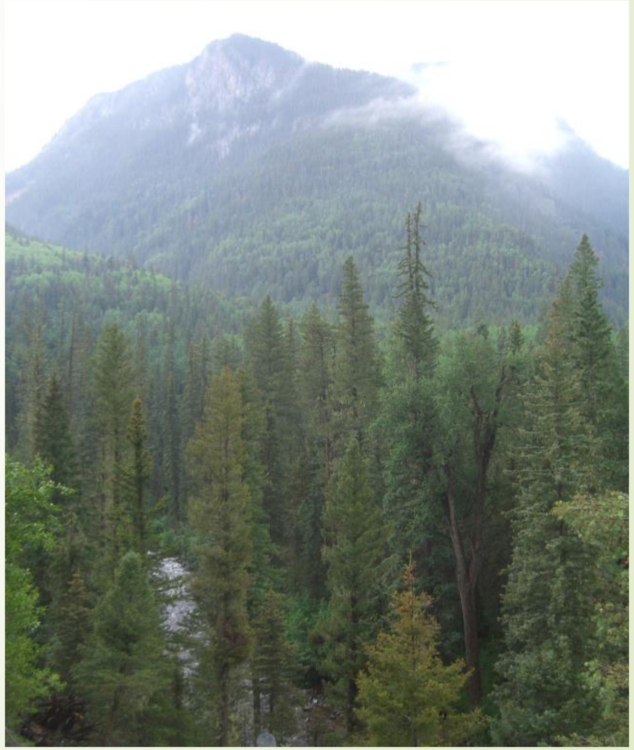

Disturbance defines our annual grain agroecosystems

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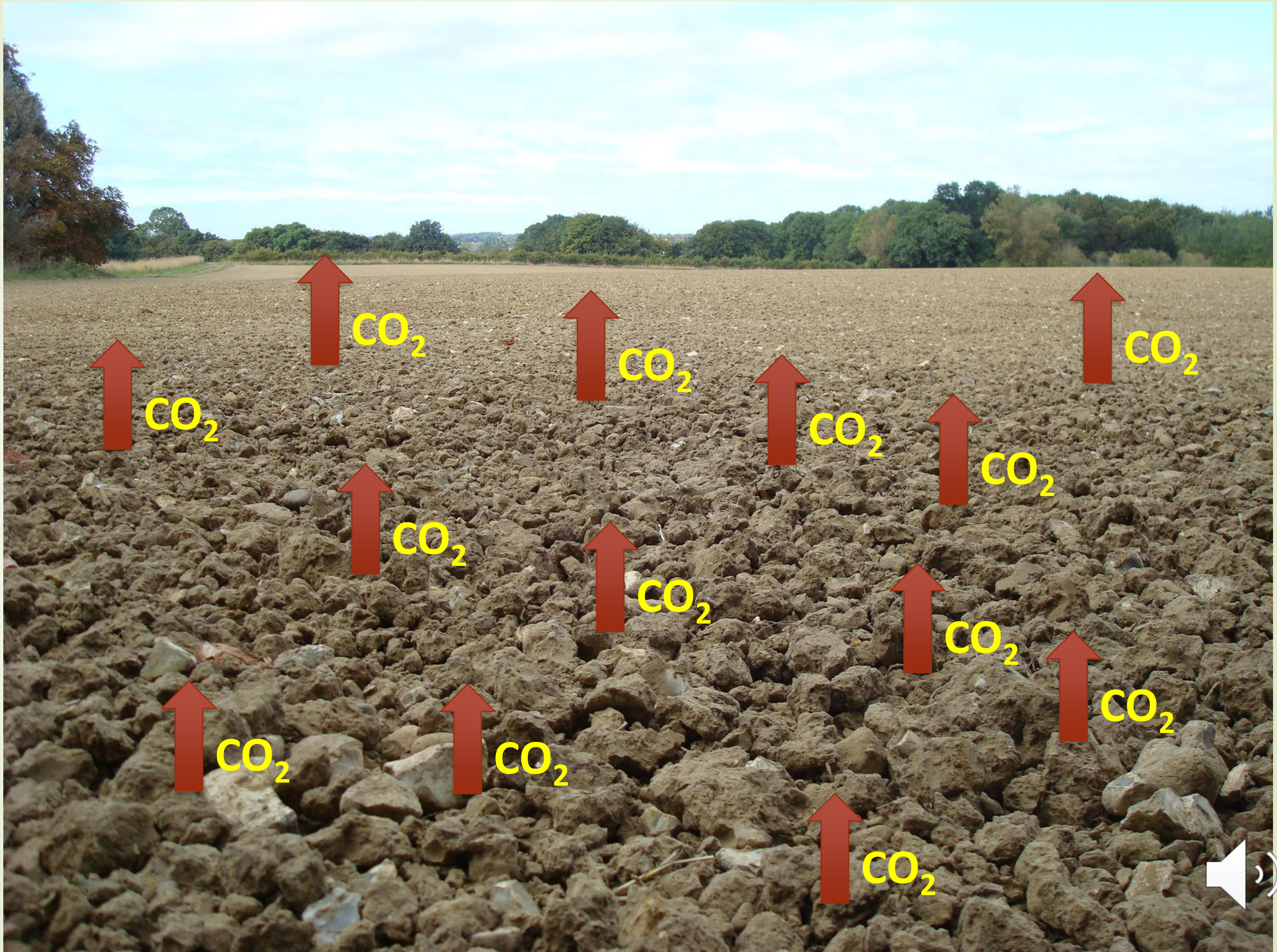
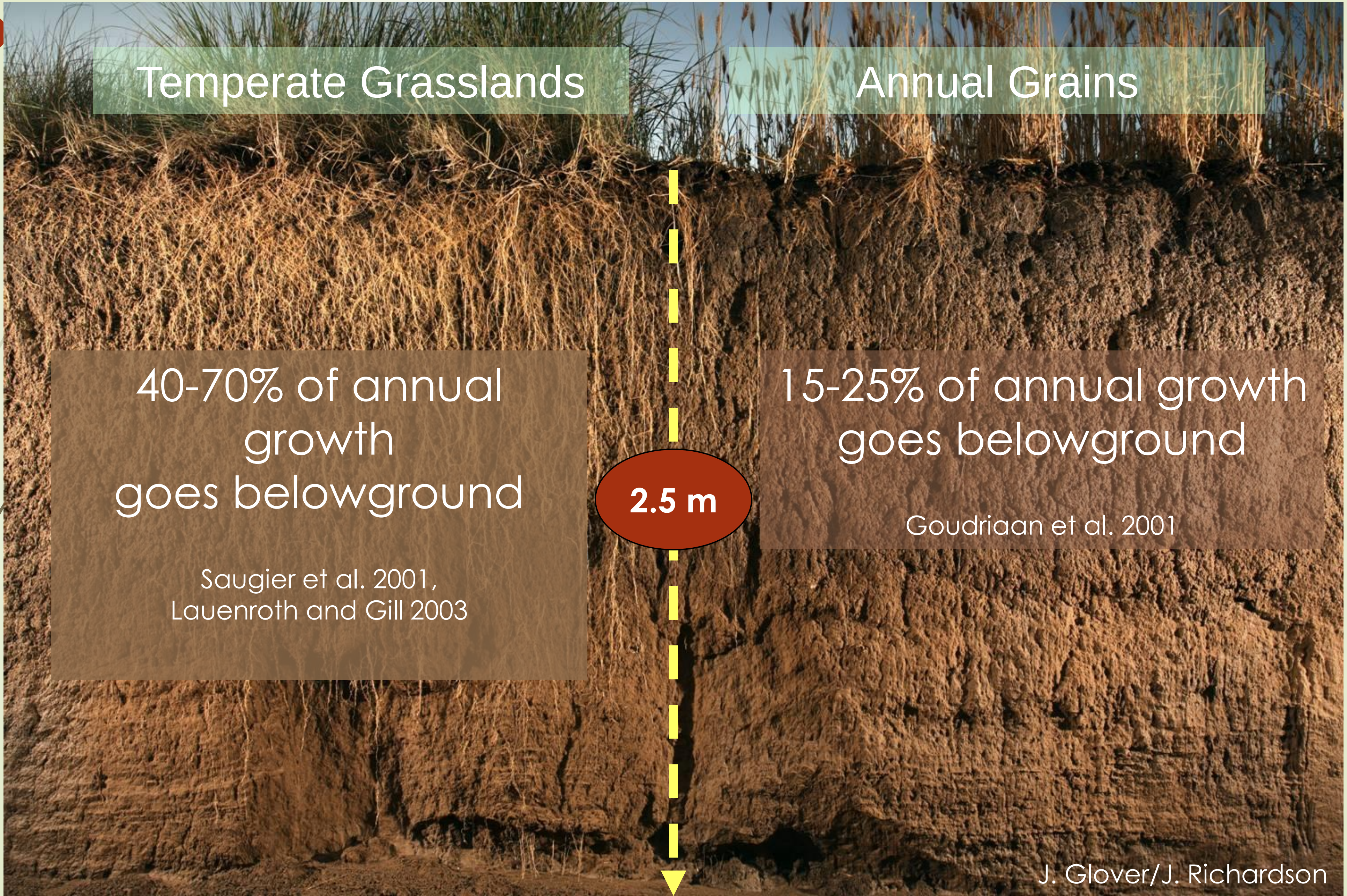
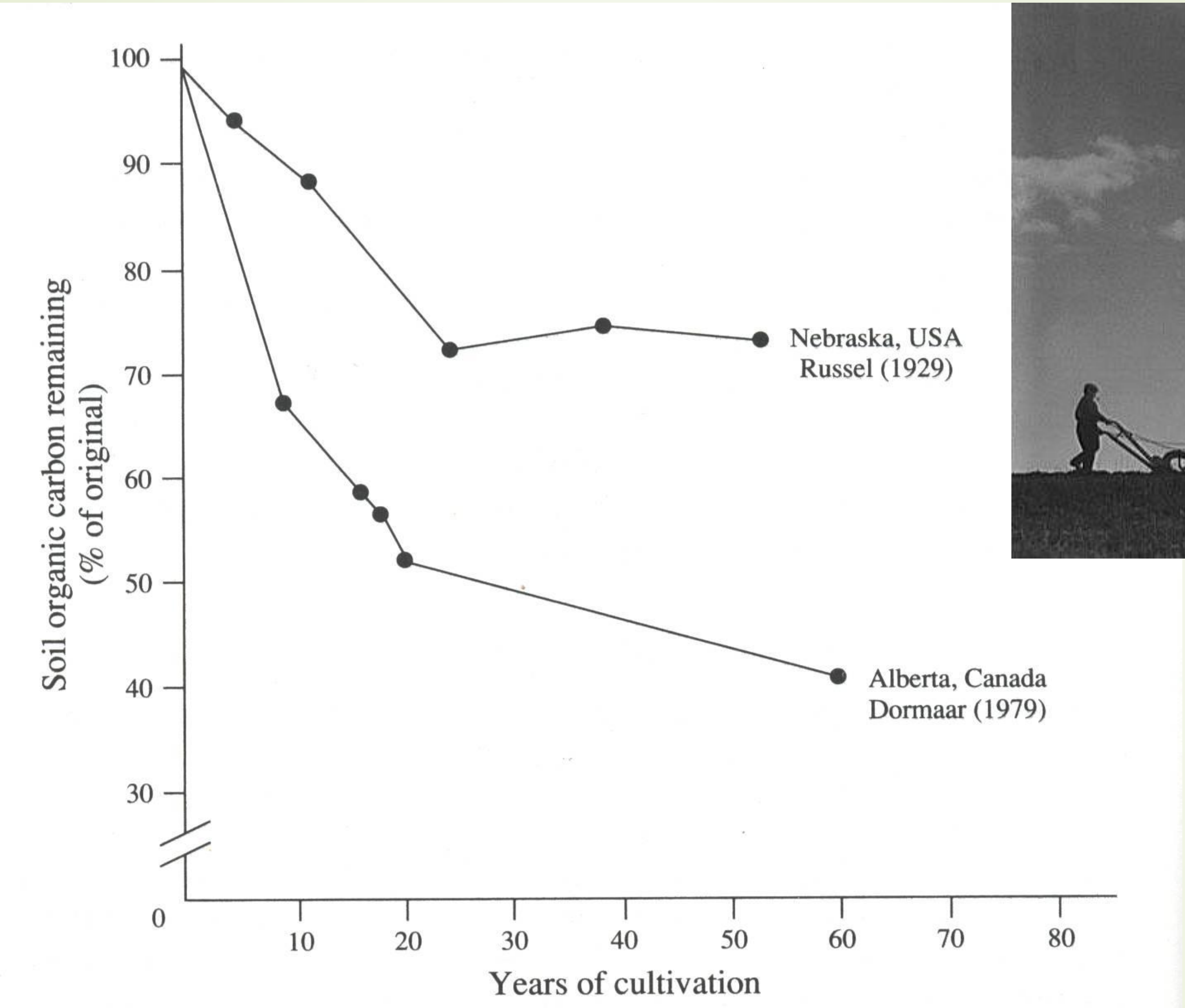


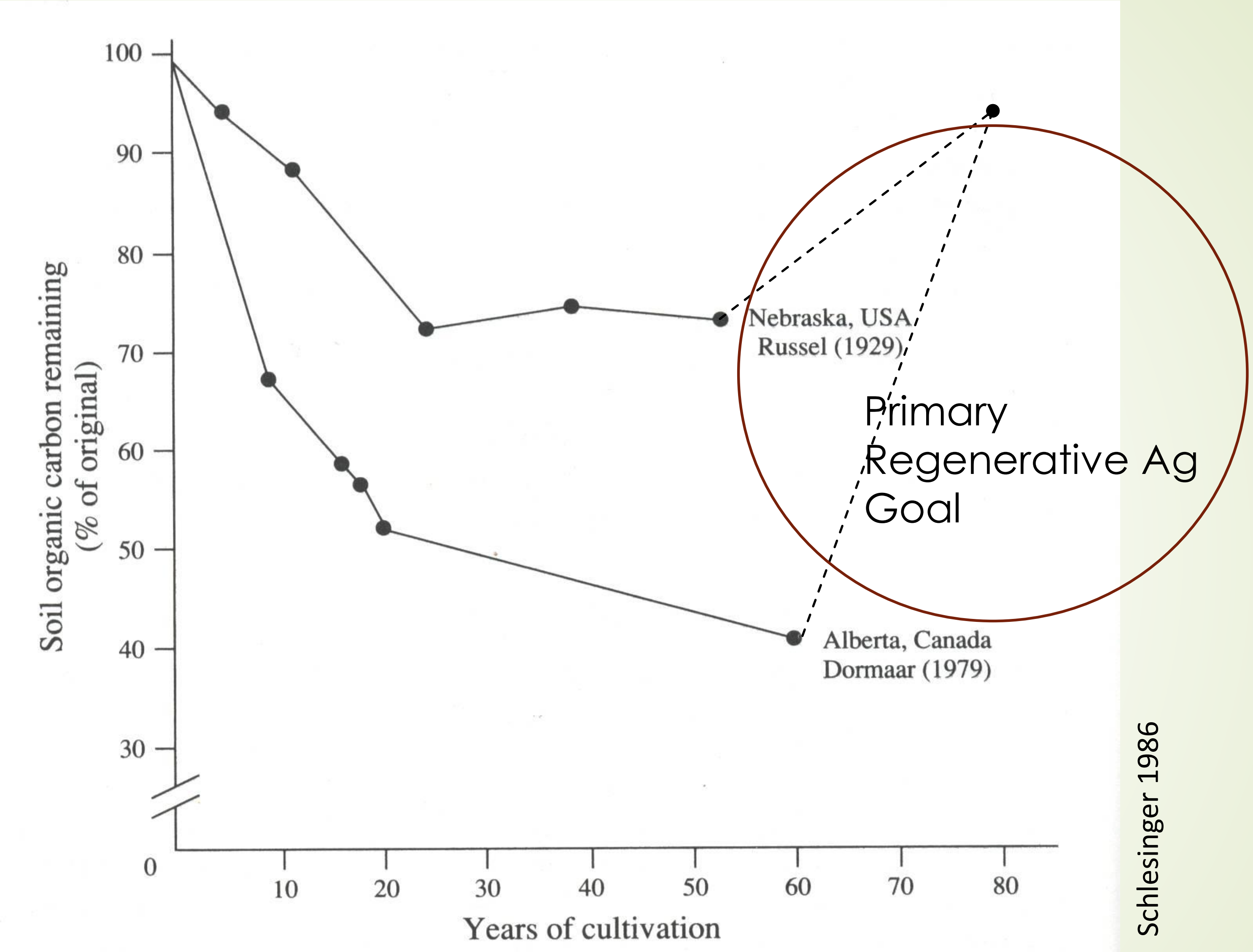
Belowground Allocation (% of NPP)





Schlesinger 1986

Loss of soil carbon to the atmosphere with plow conversion of perennial plant communities to annual agriculture.



Schlesinger 1986

Regenerative agriculture is intent on improving soil health which
Is in part defined by re-building lost soil carbon

TABLE 1 | Examples of agricultural management actions that can increase organic carbon storage and promote a net removal of CO_2 from the atmosphere and the main mode of action on the soil C balance (from Paustian, 2014).

Management practice	Increased C inputs	Reduced C losses
Improved crop rotations and increased crop residues	✓	
Cover crops	✓	
Conversion to perennial grasses and legumes	✓	✓
Manure and compost addition	✓	
No-tillage and other conservation tillage		✓
Rewetting organic (i.e., peat and muck) soils		✓
Improved grazing land management	✓	

Paustian et al. 2019

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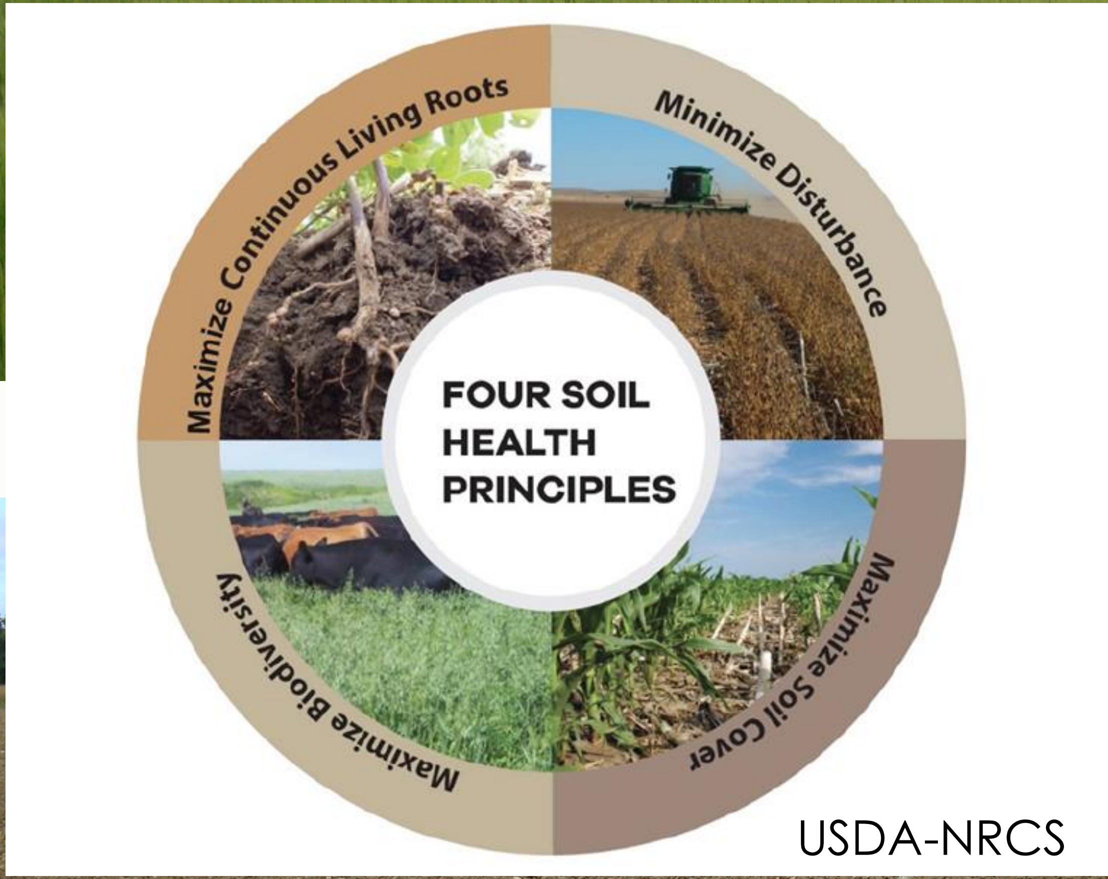
Paustian et al. 2019


Maximize Continuous Living Roots
Minimize Disturbance
FOUR SOIL HEALTH PRINCIPLES
Maximize Biodiversity
Maximize Soil Cover
USDA-NRCS

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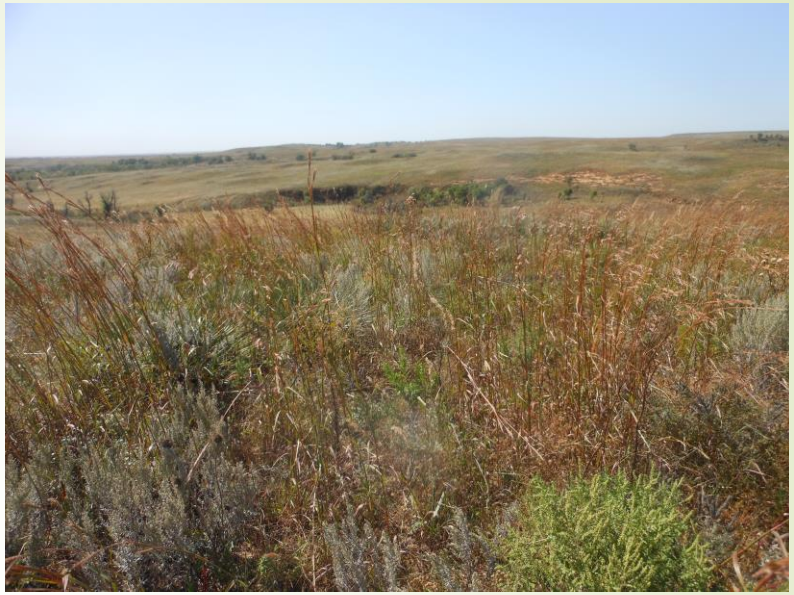

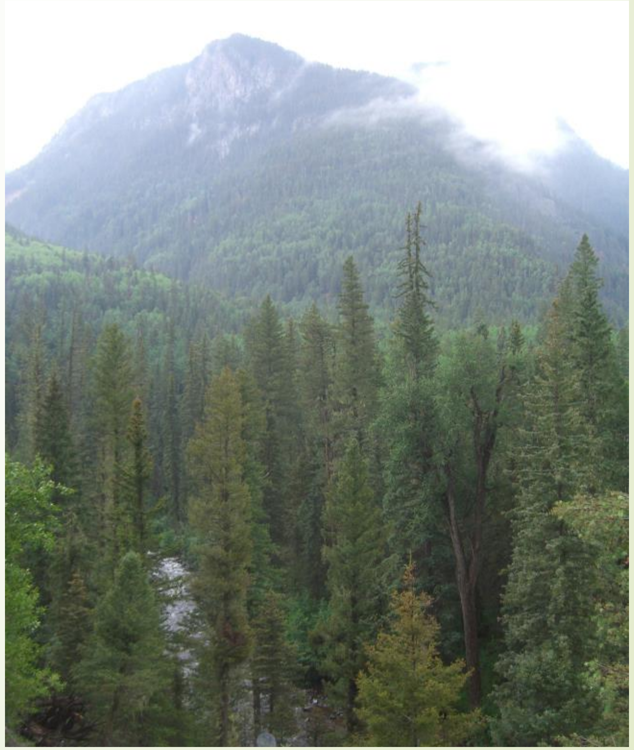

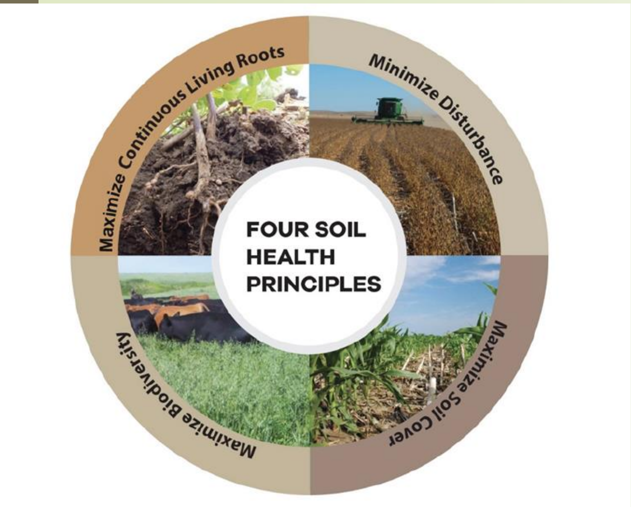
Maximize Continuous Living Roots
Minimize Disturbance
FOUR SOIL HEALTH PRINCIPLES
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Maximize Biodiversity

Table 2. Summary of field-based estimations of soil carbon accumulation rates in the conversion of annual agriculture to perennial grassland or perennial bioenergy crops.

Study Type	Geographic Areas	Mean C Accumulation t ha^{-1} year^{-1}	Depths [1] Sampled (cm)	No. Studies or Sites Included	Reference
Annual crops to perennial pasture or restored native grassland					
Meta-analysis	Central Europe, N. America, Russia	0.72	0–30	273	[93]
Meta-analysis	Russia	0.96	20	45	[95]
Meta-analysis	Tropical to temperate	0.33	5–300	39	[96]
Meta-analysis	Americas, U.K., Australia	1.01	NR [2]	23	[97]
Review	N. Midwest USA	0.44–0.5	25	39	[98]
Review	W. Canada	0.59	NR	17	[99]
Chronosequences	Illinois, USA	0.43	100	16	[100]
Review	France	0.50	NR	-	[101]
Review	NR	0.3–1.0	NR	-	[102]
Annual crops to perennial bioenergy crops					
Meta-analysis	NR	1.14–1.88	0–150	23	[103]
Meta-analysis	N. & S. America, Europe				
Miscanthus	S. Africa, Asia	1.09	100	13	[89]
Switchgrass		1.28	100	40	[89]

[1] When a range is reported, it indicates that multiple soil depths falling within the range were included in the study;
[2] NR = not reported.

Crews and Rumsey 2017

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330-1,888 kg C ha^{-1} yr^{-1}

Crews and Rumsey 2017

Perennial wheat

Perennial sorghum

Perennial rice

Wide hybridization

annual crop x perennial relative

Perennial rice terraces—Yunnan, China, 2019

de novo Domestication

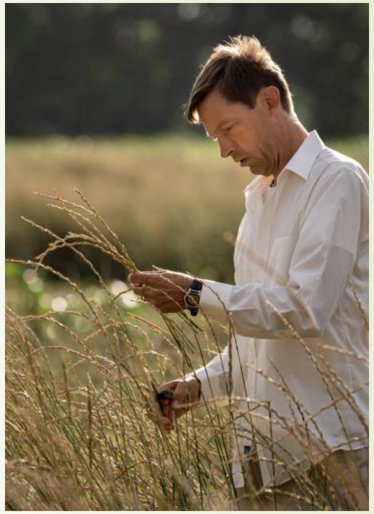
Oilseeds

Silphium
Silphium integrifolium

Legumes

Sainfoin
Onobrychis vicifolia

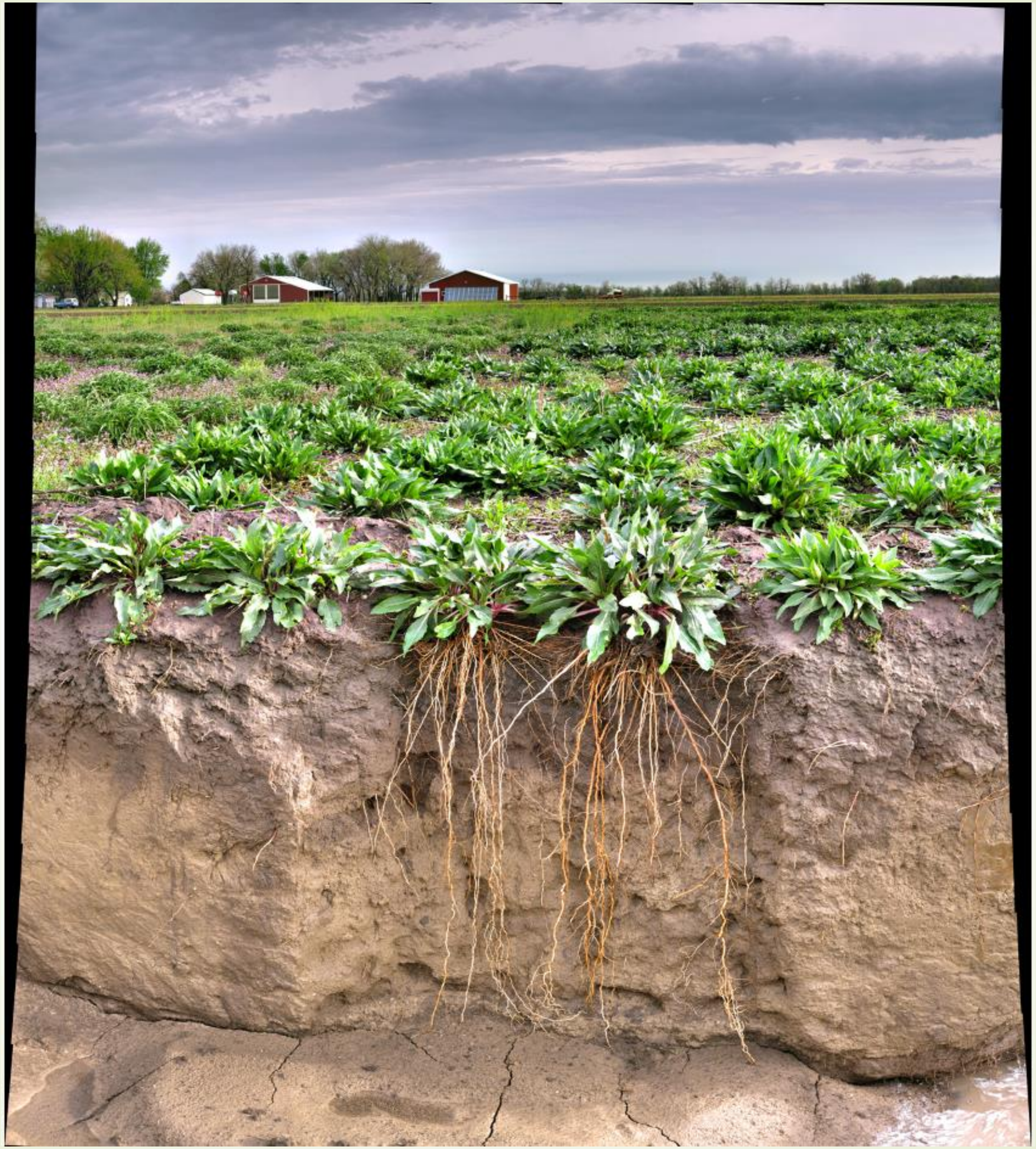
Wheatgrass



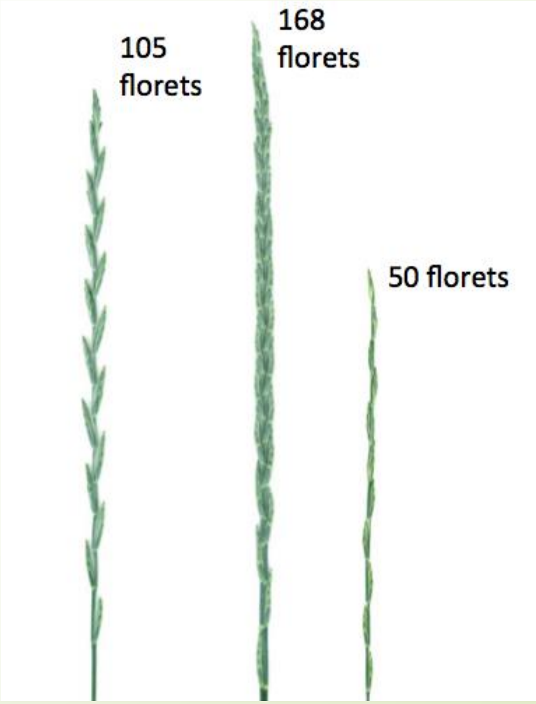
Kernza®
Thinopyrum intermedium

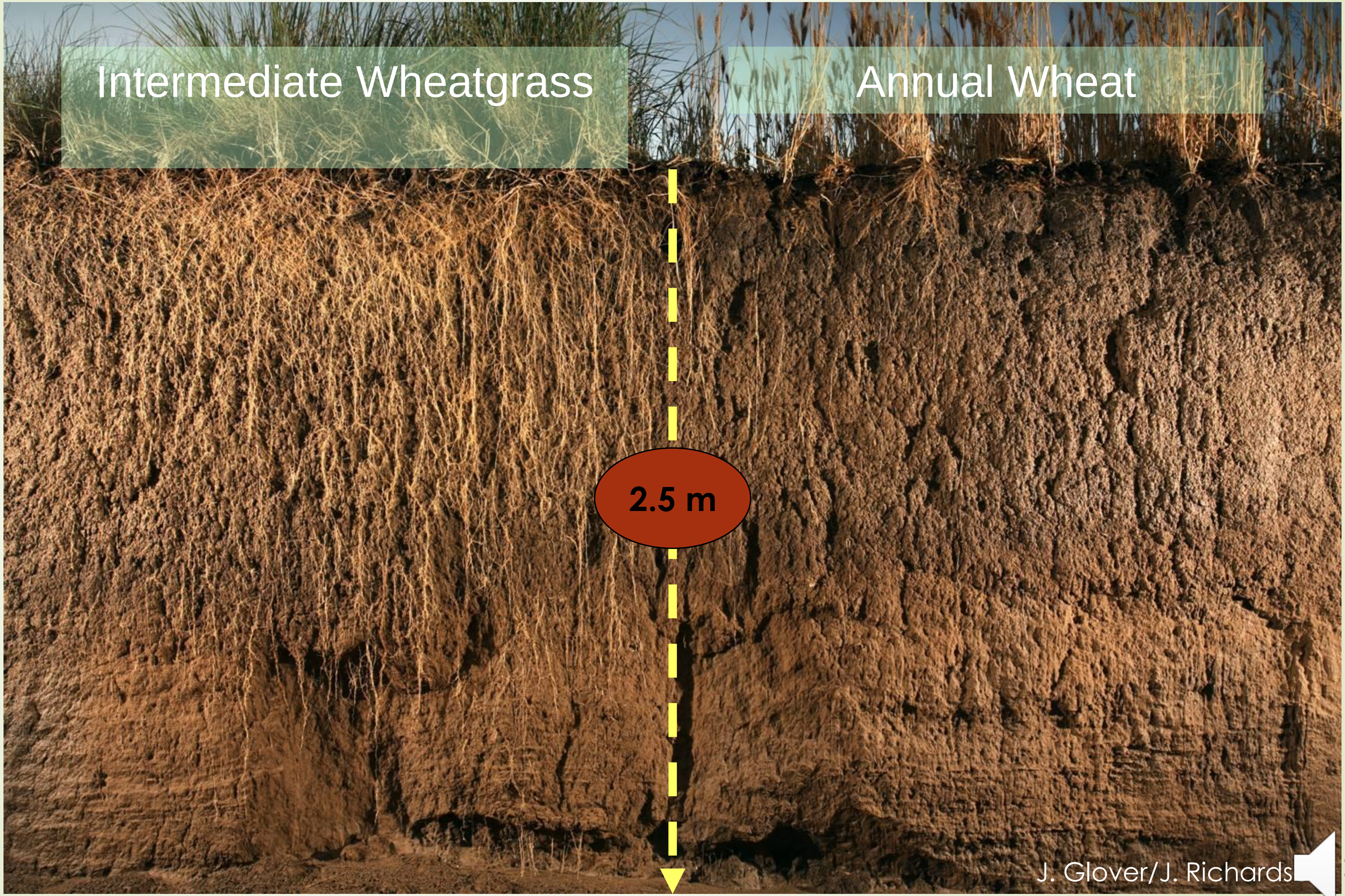
Photos: Scott Seirer

Silphium integrifolium
oilseed



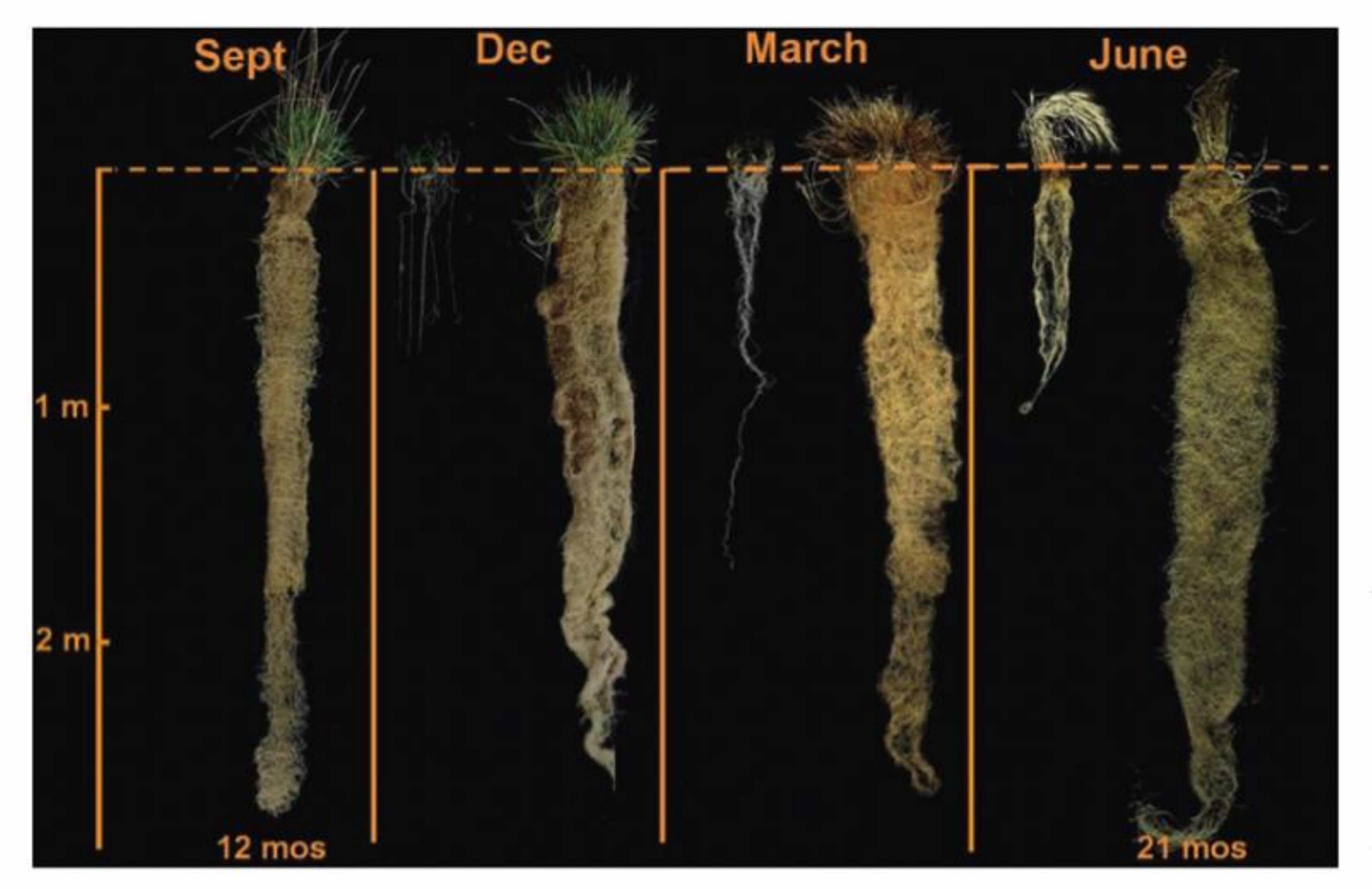
Breeding nursery of intermediate wheatgrass (*Thinopyrum intermedium*) that produces "Kernza®" perennial grain



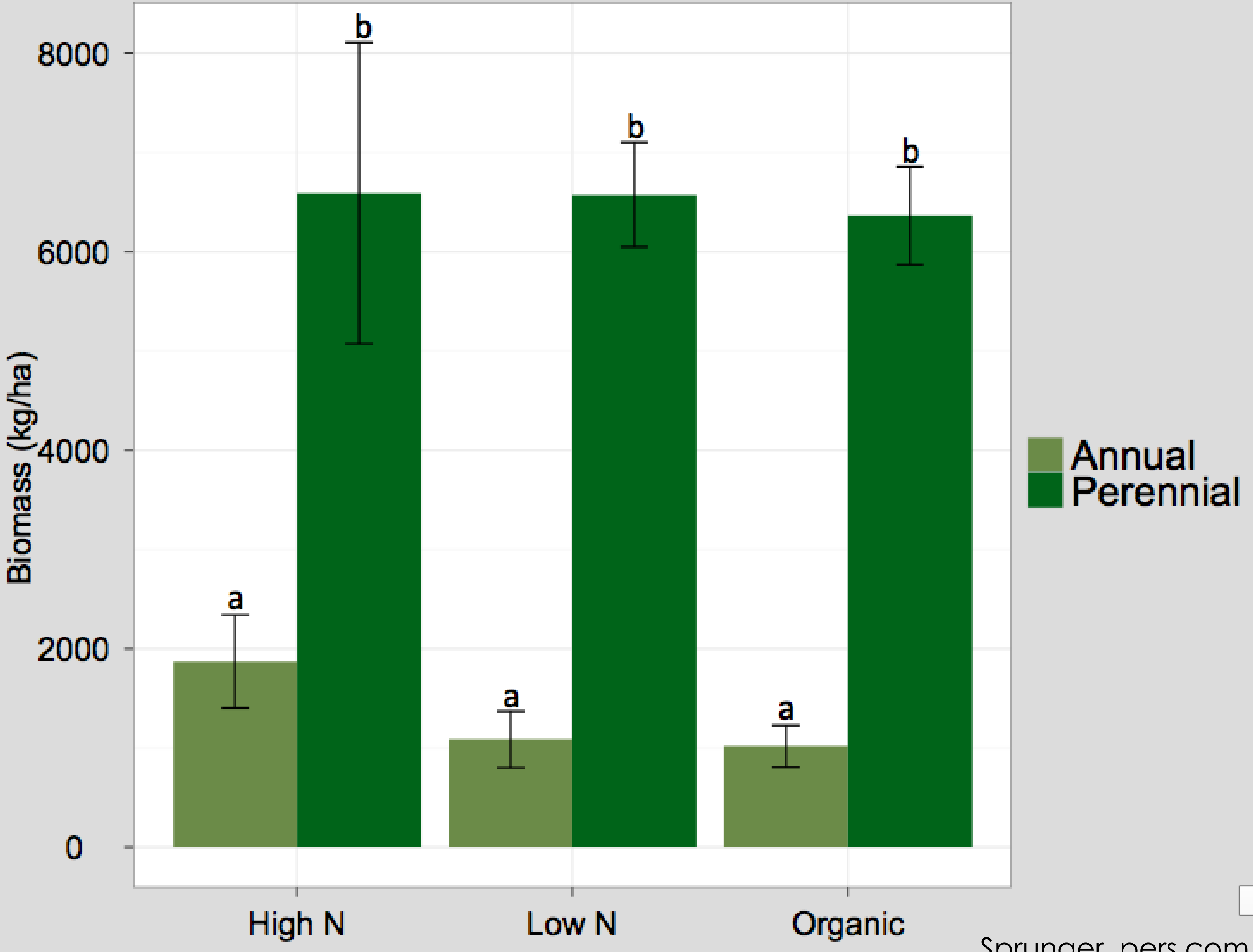

Intermediate Wheatgrass
Annual Wheat
2.5 m
J. Glover/J. Richards

Rooting extent of Intermediate wheatgrass (*Thinopyrum intermedium* or Kernza®) compared to annual winter wheat over four seasons

Perennial

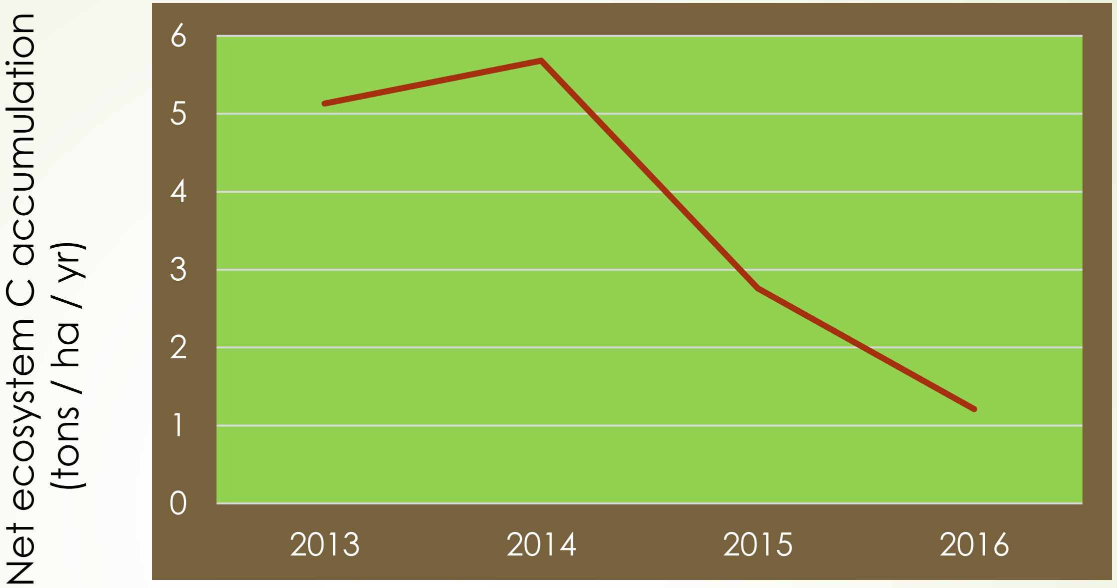


Total Root Biomass of annual wheat and perennial Kernza®

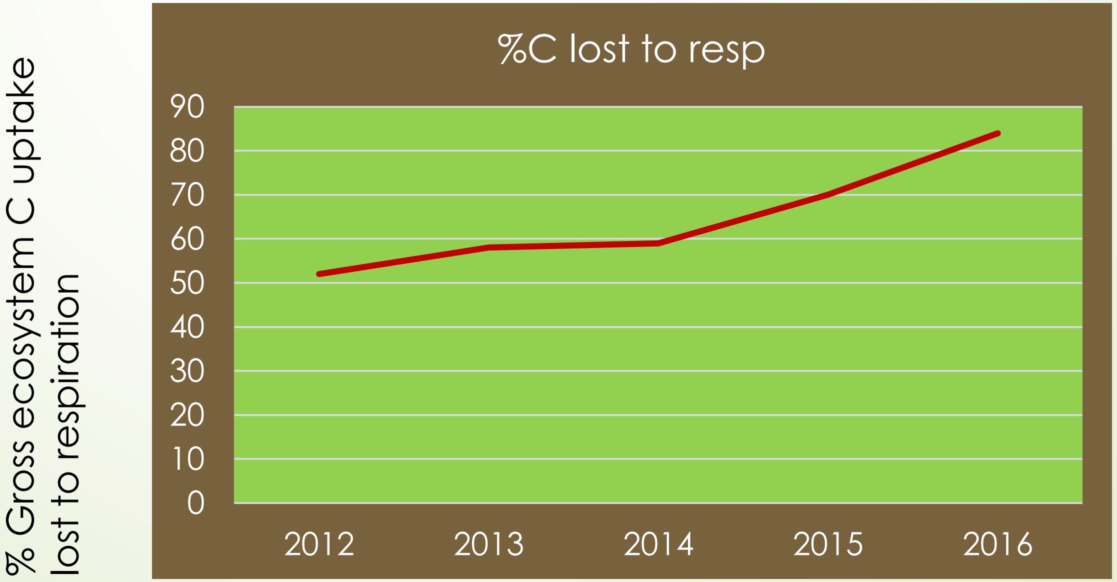


Sprunger, pers com

Ecosystem carbon accumulation and % respiration losses measured in a Kernza® (*Thinopyrum intermedium*) field in Salina, Kansas over five years by eddy co-variance



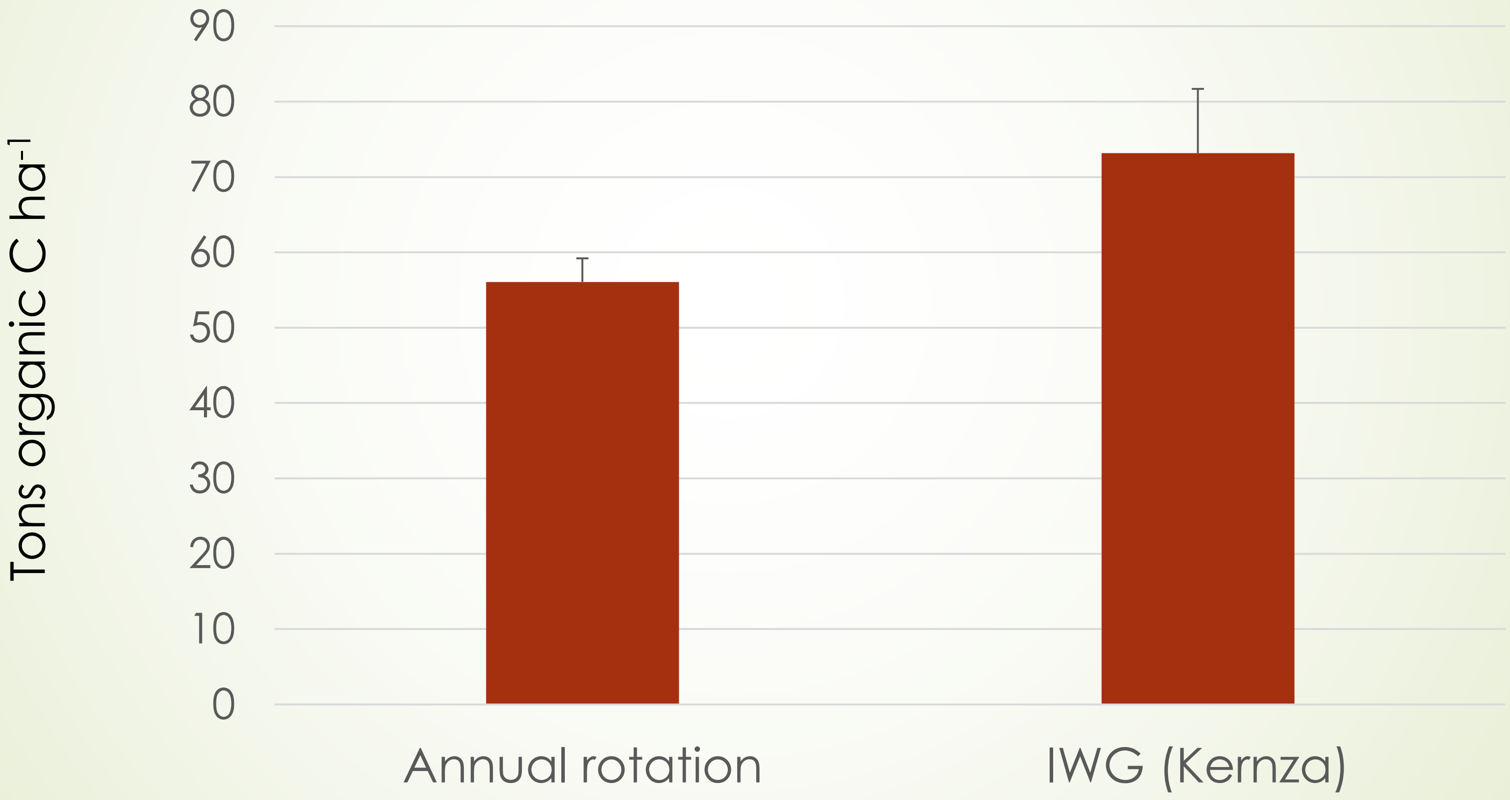
14.7 tons/ha (total)
3.7 tons/ha/yr
Range 5.68-1.21



de Oliveira et al. 2018

Differences in soil organic carbon per hectare to ~80 cm After 16 years of annual and perennial cropping

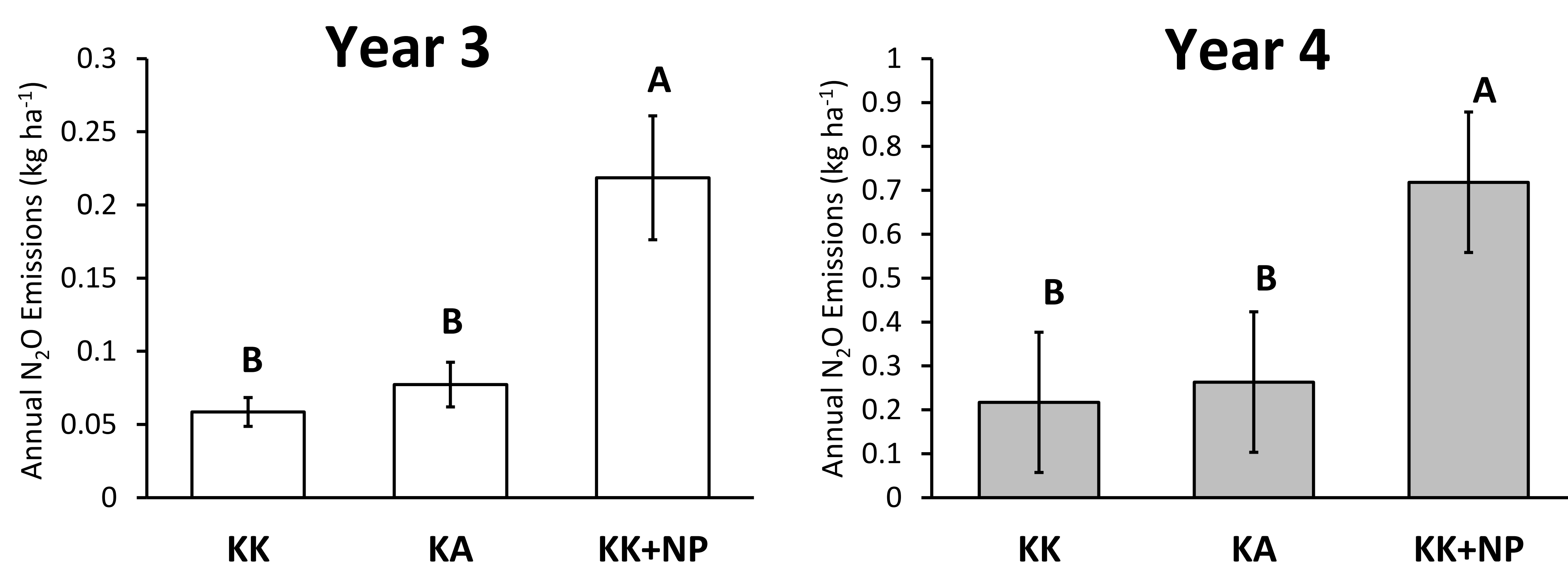
Kernza accumulation rate is 1.06 t yr^{-1} more than annual rotation



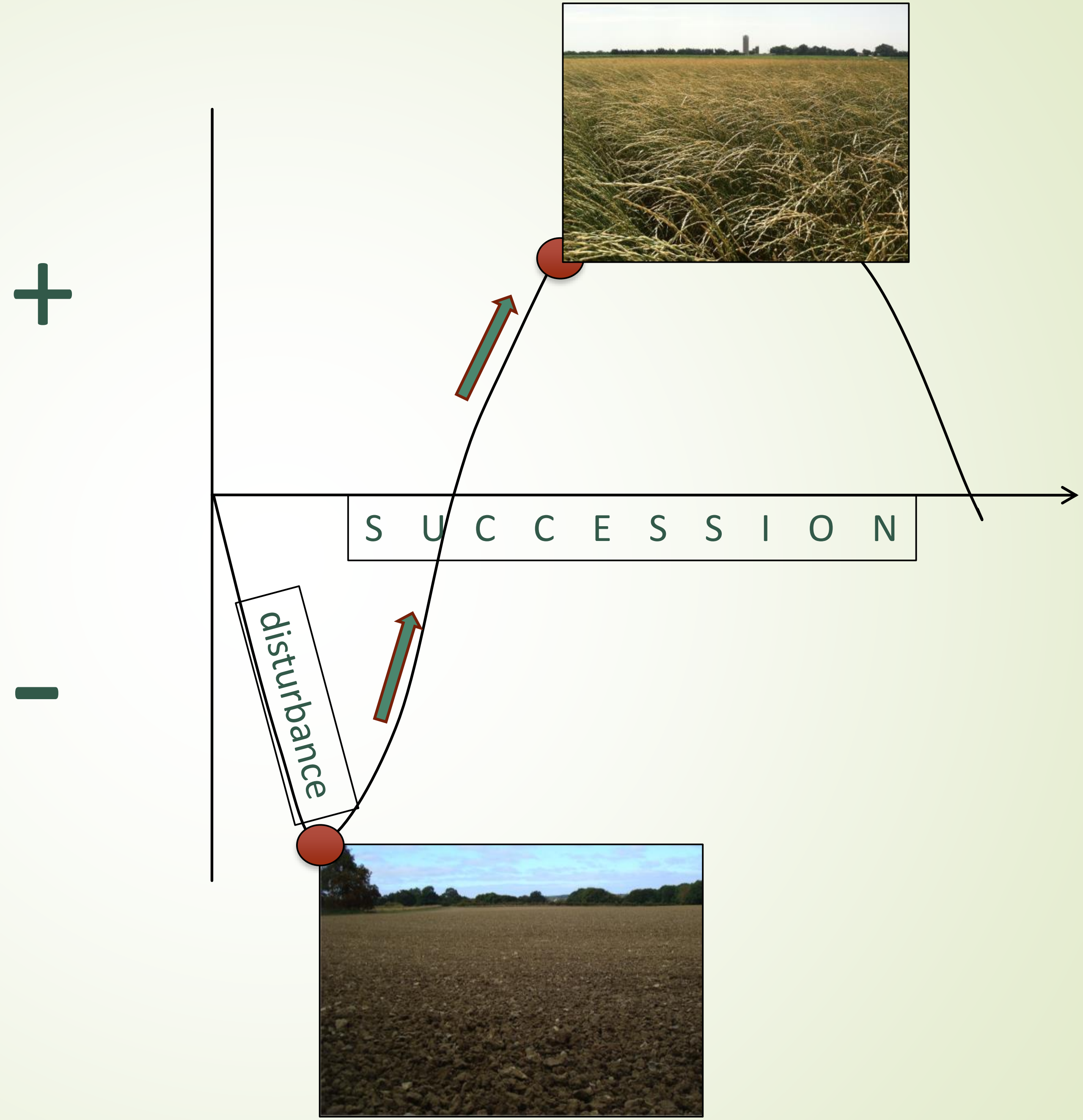
Crews, unpublished

Intermediate wheatgrass (Kernza®) – Alfalfa biculture

N2O emissions during two growing seasons in unfertilized Kernza-Kernza (KK), Kernza-alfalfa (KA), and fertilized Kernza-Kernza (KK+NP) plots



Soil formation and structure
Carbon accumulation
Nutrient retention



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Natural Ecosystem | Agriculture

Perennial-High Diversity	Annual-Low Diversity	Perennial-Moderate Diversity
		
Ecosystem Services	**Ecosystem Dis-services**	**Ecosystem Services**
Soil formation	Soil erosion	Soil formation
Maximizes soil organic matter	Reduces soil organic matter	Maximizes soil organic matter
Resistant to pathogens and insects	Vulnerable to pathogens and insects	Resistant to pathogens and insects
Nutrients retained	Unintentional nutrient losses	Regulated nutrient losses
Weed establishment suppressed	Weeds establish easily	Weed establishment suppressed
High functioning soil microbiome	Low functioning soil microbiome	High functioning soil microbiome
High precipitation use efficiency	Low precipitation use efficiency	High precipitation use efficiency
No fossil fuel dependence	Heavy fossil fuel dependence	Reduced fossil fuel dependence

Thank You

Photo: Jim Richardson

Diversity Delivers Ecosystem Services