Opportunities to Increase Soil Carbon Sequestration in Subtropical Grazing lands

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1

Outline

1. Definitions
2. Soil organic carbon (SOC)
   - Carbon inputs into the soil
   - Factors controlling SOC stocks
   - How to measure SOC
   - Limitations and opportunities to increase SOC

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2

Definitions:

Carbon pools/stocks are reservoirs that have the capacity to store and release C

Carbon fluxes: refer to the amount of C exchanged among different pools

Carbon inventory: it involves estimation of stocks and fluxes of C in a given area over a given period and under a given management system

Sequestration: the transfer and storage of atmospheric CO_2 to other pools, such as soil or plant biomass (Lal, 2008)

Turnover time: the lifespan of soil C. It is colloquially used to describe the average length of time C compounds remain in the soil before being lost via leaching or respiration

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3

Definitions:

Recalcitrant: refers to SOC pools that are resistant to microbial and enzymatic degradation due to its chemical structure. Microbes selectively degrade organic matter based on its ease of oxidation, leaving behind organic matter that is increasingly difficult to break down (Sollins et al., 1996).

Stability/stabilization: refers broadly to SOC resistance to decay, whether that results from humification, selective preservation of recalcitrant organic matter, and physicochemical interactions such as adsorption to mineral surfaces and occlusion within soil aggregates (Knorr et al., 2005; von Lutzow et al., 2006)

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4

Major C Pools:

1. Biomass : it includes living above-ground and below-ground biomass, and litter

2. Soil C pools: inorganic ($CaCO_3$) and organic forms. Total C = SIC + SOC

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5

Soil Organic Matter (SOM)

- SOM is a complex and varied mixture of organic substances under different stages of decomposition (i.e., fresh litter to stable humus)

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6

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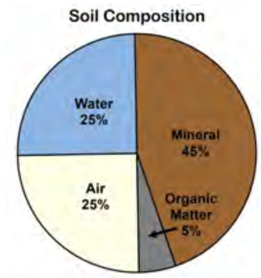
- Most soils contain relatively small amounts of SOM (1-5%) but its effects on soil physical, biological, and chemical properties are profound



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7

Soil Organic Matter

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- Most soils contain relatively small amounts of SOM (1-5%) but its effects on soil physical, biological, and chemical properties are profound
- It strongly affects physico-chemical and biological properties of soils such as cation exchange capacity, soil structure, water infiltration rate, water holding capacity, soil erodibility and conservation, and pesticide sorption
- Increasing SOM in agricultural soils improves soil health and global food security while drawing down atmospheric CO_2

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Carbon inputs into the soil

- Plants are the main source of soil organic matter
- When plant residues are added to the soil, organic compounds undergo decomposition

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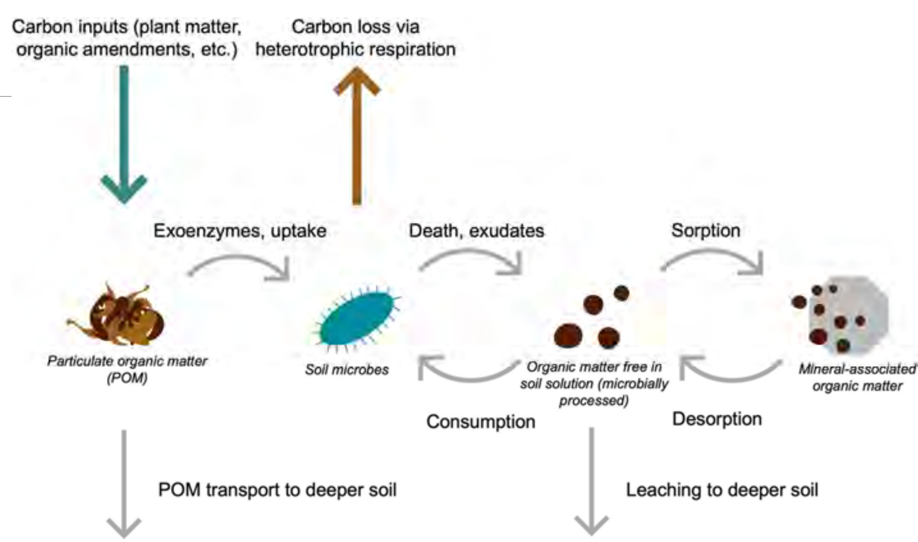
Conceptual illustration of soil C flows



Source: Dynarski et al. 2020. Dynamic stability of soil carbon: reassessing the "permanence" of soil carbon sequestration. Front. Environ. Sci. 13. https://doi.org/10.3389/fenvs.2020.514701

10

Carbon inputs into the soil

- Plants are the main source of soil organic matter
- When plant residues are added to the soil, organic compounds undergo decomposition
- Quantity and quality of plant litter control the rate of decomposition
- Sugars, starches, and protein decompose rapidly, while cellulose, fats, waxes, and lignin decompose very slowly

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11

Carbon inputs into the soil

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- Quantity and quality of plant litter control the rate of decomposition
- SOC = Balance between C inputs and outputs

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12

Factors Controlling Soil C Sequestration

C INPUTS
- Above- and below-ground biomass residues
- Animal excreta
- Organic fertilizer

SOC

C OUTPUTS
- Decomposition
- Erosion/leaching
- Harvest

Climate, landscape position, **soil type**

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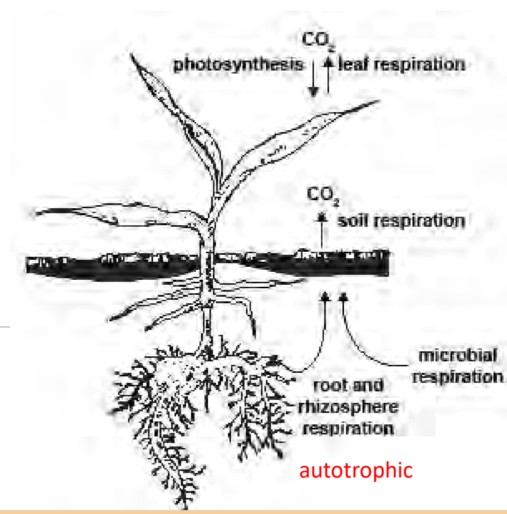
13

Carbon loss: biotic (respiration) and abiotic factors (erosion, leaching)



heterotrophic

Soil respiration is often used as an indicator of microbial activity, but may not correlate well with SOC.

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14

Factors affecting SOC stocks

1. Climate (temperature and precipitation)

- For each decrease of 10ºC in annual temperature, average SOC stocks increases 2-3 times
- C:N ratio of SOC increase as temperature decrease

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15

Factors affecting SOC stocks

2. Soil Texture/Soil Type

- SOC stocks is 2-4 times greater in fine-textured soils than coarse-textured soil
- Clay minerals: soil with 2:1 expanding layer silicates have more SOC than 1:1 soils

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16

Table A.1 **Estimated mass of carbon in the world's soils (excluding glacier-covered areas)**

Soil orders	Area k.km2	Area %	Organic C t/ha	Organic C global Gt	Organic C % global	Inorganic C Gt
Alfisols	13,159	10.1	69	90.8	5.3	43
Andisols	975	0.8	306	29.8	1.8	0
Aridisols	15,464	11.8	35	54.1	3.2	456
Entisols	23,432	17.9	99	232.0	13.7	263
Gelisols	11,869	9.1	200	237.5	14.0	10
Histosols	1,526	1.2	2,045	312.1	18.4	0
Inceptisols	19,854	15.2	163	323.6	19.0	34
Mollisols	9,161	7.0	131	120.0	7.0	116
Oxisols	9,811	7.5	101	99.1	5.8	0
Spodosols	4,596	3.5	146	67.1	3.9	0
Ultisols	10,550	8.1	93	98.1	5.8	0
Vertisols	3,160	2.4	58	18.3	1.1	21
Other soils	7,110	5.4	24	17.1	1.0	5
TOTALS	130,667	100.0		1,699.6	100.0	948

Note: five soil orders (Entisols, Gelisols, Histosols, Inceptisols, and Mollisols) account for some 72% of all the organic carbon in the world's soils. Gelisols alone account for between 14% and 24.5% of the total. There is, however, a large measure of uncertainty in the data.

72% OC in world's soils

17

Factors affecting SOC stocks

3. Management Practices

- Cropping system (i.e., annual vs perennial; harvest regimen)
- Fallowing (plowed or left unseeded for a season or more)
- Tillage
- Fertilization
- Grazing management

In native soils, SOC stocks are determined by the soil type (texture, clay mineral) and climatic conditions (temperature, precipitation). **In cultivated soil**, management plays an important role on SOC stocks

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18

How to measure SOC?

- Carbon exists in the soil in many forms but for the purposes of measurement and analysis the three main forms are: organic, inorganic, and charcoal soil carbon
- All three forms are important but SOC is often used as an indicator of soil health
- There are several methods to determine SOC:
  - Laboratory methods
  - Remote sensing (aerial photography, drone imagery, satellite data)
  - Modeling
- Each method has its advantages and disadvantages regarding convenience, accuracy, and cost

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19

Quality of SOC

- Recently there has been increasing interest in classifying various types or fractions of SOC such as active, labile, particulate, occluded, light, or heavy, with various residence or turnover times ascribed to the various fractions
- The most common approach to characterize SOM “quality” is to recognize different portions or pools of SOC that vary in their susceptibility to microbial metabolism

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20

Conceptual Soil C Pools

Most earth system models use a soil model consisting of one to three conceptual C pools based on their presumed chemical composition and turnover times. Attempts to measure the modellable C pools had minimal success

Chemical composition, physical structure of soil and chemical associations with soil minerals affect the turnover times of SOC pools

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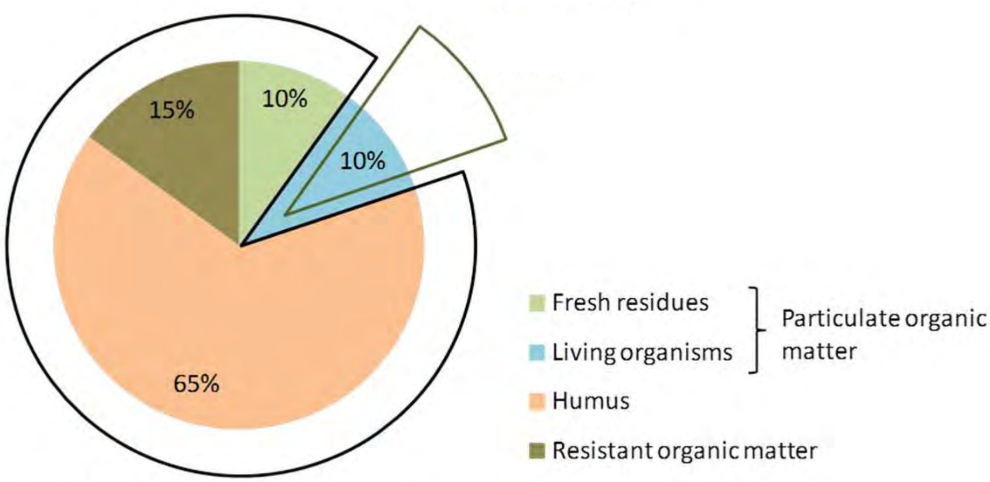
21



The different SOC pools not only differ in size but are also composed of different materials with different chemical and physical properties and different decomposition times

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Limitations

- Lack of financial benefits and policies that encourage SOC sequestration. Increases in soil C should be positively correlated with productivity

- Projections of temperature and precipitation across the USA during the next 50 yr anticipate a 1.5 to 2°C warming and slight increase in precipitation (Izaurralde et al., 2011)

- Changes in management that lead to increases in SOC sequestration may also increase emissions of GHG

- Time and space scale - Carbon sequestration is a long-term process, difficult to measure

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Opportunities

- Grazing land management practices intended to promote C sequestration increase productivity and tend to make systems more resilient to climate variation and, consequently reduce the impacts of drought and flood

- These practices could result in the sequestration of 10.5 to 34.3 million metric tons C yr^{-1} (Follett et al., 2001). Each ton of C stored in soils removes ~ 3.67 tons of CO_2 from atmosphere (Fynn et al., 201); ~38 to 126 million tons CO_2 yr^{-1}

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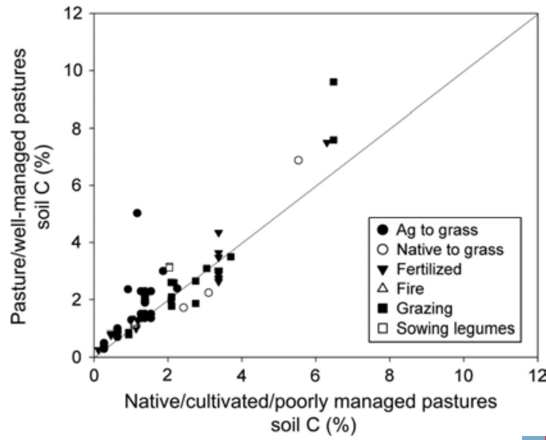
24

Management practices that promote SOC



Management practices characterized as "improved" increased SOC by an average of 26% (4-76%) or 0.47 Mg C·ha^{-1}·yr^{-1}

MORE CARBON INPUT IS THE MAIN CONTROL ON SOIL C

Source: Conant et al. (2017).
332 data points across 64 publications

25

Management practices that promote SOC

1. Fertilization

- Improve above- and below-ground production
- Change species composition and quantity/quality of C inputs
- Unintended environmental consequences (N_2O emissions, nutrient losses)

26

Silveira et al, 2017

27

Long-term (13 yr) SOC responses (0 to 20 cm) to different tall fescue (*Festuca arundinacea* Schreb.) fertilization strategies[1]

Fertilization	SOC	Particulate organic C
	__________ g m^{-2} __________	
Low fertilization (120-13-50 lb N-P-K per acre yr^{-1})	3759 b	1393 b
High fertilization (300-33-124 lb N-P-K per acre)	4034 a	1553 a

~7% increase in SOC

[1]Source: Franzluebbers and Stuedemann (2005).

28

Management practices that promote SOC

1. Fertilization
2. Introduction or reintroduction of grass or legume species

29



1. Adewopo, J.B., Silveira. M.L., Xu, S., Gerber, S., Sollenberger, L.E., and Martin, T. 2015a. Long-term grassland management intensification impacts on particle-size soil carbon fractions: evidence from ^{13}C natural abundance. *Soil Science Society of America Journal*, 79:1198-1205.
2. Adewopo, J.B., Silveira, M.L., Xu, S., Gerber, S., Sollenberger, L.E., and Martin, T.A. 2015b. Management intensification effects on autotrophic and heterotrophic soil respiration in subtropical grasslands. *Ecological Indicators* 56:6-14
3. Adewopo, J.B., Silveira, M.L., Xu, S., Gerber, S., Sollenberger, L.E., and Martin, T. 2014. Management intensification impacts on soil and ecosystem carbon stocks in subtropical grasslands. *Soil Science Society of America Journal* 78:977-986.
4. Silveira, M.L., Xu. S., Adewopo, J.B., Franzluebbers, A.J., and Buonadio, G. 2014. Grazing land intensification effects on soil C dynamics in aggregate size fractions of a Spodosol. *Geoderma* 230-231:185-193.
5. Xu, S., Silveira, M.L., Ngatia, L.W., Normand, A.E. , Sollenberger, L.E. , Reddy, K.R. 2017a. Carbon and nitrogen pools in particle-size fractions as affected by sieving method and land use intensification. Geoderma 305:70-79.
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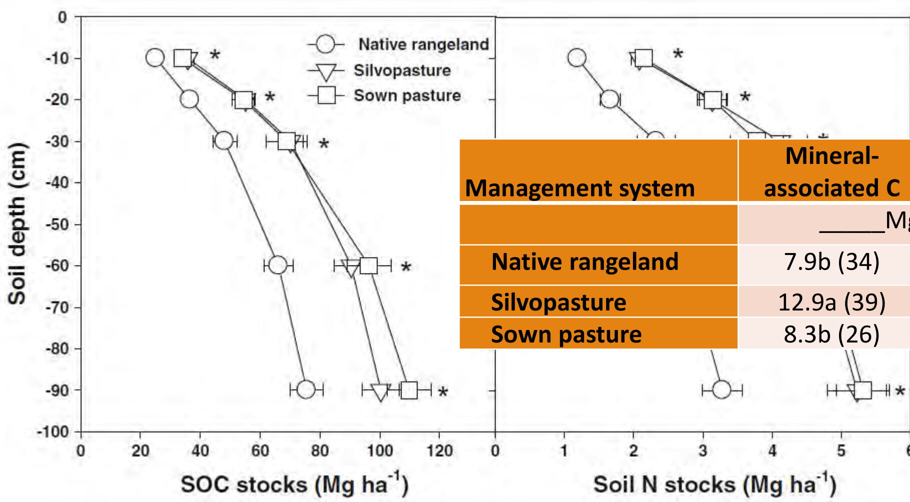
7. Xu, S., Silveira, M.L., Inglett, K.S., Sollenberger, L.E., and Gerber, S. 2016. Effect of land-use conversion on ecosystem C stock and distribution in subtropical grazing lands. *Plant and Soil,* 399:233-245.

30

Long-term (>25 yr) impacts of grazing land intensification on SOC stocks (0-100 cm)

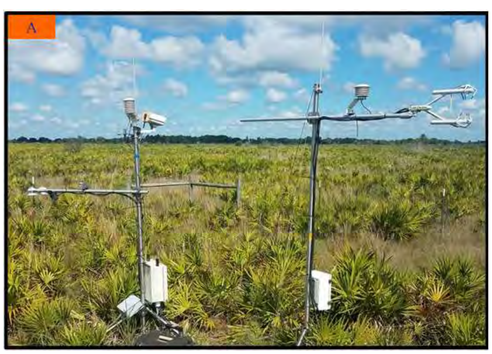


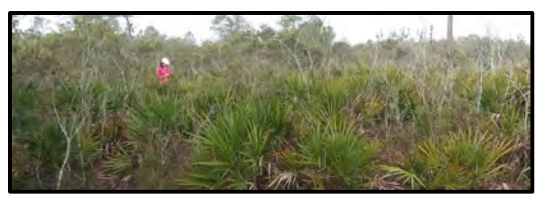
Management system	Mineral-associated C	Particulate organic C
	_____Mg ha -1 _____	
Native rangeland	7.9b (34)	15.9b (66)
Silvopasture	12.9a (39)	20.0ab (61)
Sown pasture	8.3b (26)	23.2a (74)

Source[1]: Adewopo et al., 2014; Xu, et al., 2016

31

Impacts of grazing land intensification on ecosystem C stocks





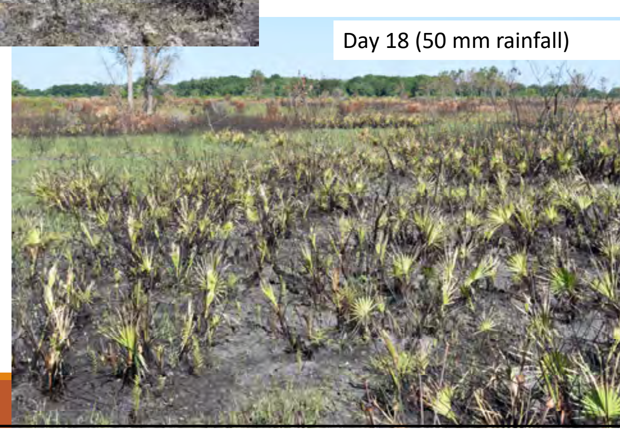
32

March 26, 2021

33

Day 0

Day 5



Day 18 (50 mm rainfall)

34

Day 5 –native grasses

Day 18

35

Impacts of grazing land intensification on ecosystem C stocks

Long-Term Agroecosystem Research


Agricultural and Forest Meteorology
Volume 311, 15 December 2021, 108682

Carbon dynamics and soil greenhouse fluxes in a Florida's native rangeland before and after fire

Rosvel Bracho, Maria Lucia Silveira, Raoul Boughton, Joao M.D. Sanchez, Marta M. Kohmann, Carolina B. Brandani, Gerardo Celis

CONCLUSIONS

- Pine flatwoods are C sinks even in year when prescribed burning occurred
- During a 4-yr burning cycle, net ecosystem production can reach -1287 g C m^{-2} yr^{-1} with an average of -322 g C m^{-2} yr^{-1}
- Pine flatwoods vegetation is well-adapted to burning and can recover its photosynthetic capacity in 60 days following a prescribed burning event

Response variable	Year			
	2016	2017	2018	2019
	g C m^{-2} yr^{-1}			
Gross primary production	-1854	-1749	-1861	-2033
Ecosystem respiration	1445	1422	1492	1851
Net ecosystem production	-409	-327	-369	-182

36

Management practices that promote SOC

1. Fertilization
2. Sowing improved grass or legume species
3. Grazing management
   - **Positive** : Derner et al., (1997); Schuman et al., (2001); Franzluebbers and Stuedemann (2003); Franzluebbers et al., (2012)
   - **Negative** : Bauer et al. (1987); Derner et al. (1997); April and Bucher (1999); Conant and Paustian (2002)
   - **Neutral**: Milchunas and Laurenroth (1993); Manley et al., (2005)

37

Total C and N content in bulk soil samples from pastures under different stocking densities (Liu et al., 2011; Silveira et al., 2013)

Stubble Height†	Total C	Total N	Particulate C	
cm	--------------- Mg ha^{-1}	--------------		% total
24	26	1.7	10.4	34
16	23	1.5	8.6	29
8	24	1.5	8.3	27
SE	3	0.2	1.1	2.6
Polynomial Contrast	NS‡	NS	L*	L*

†Stocking density treatments were based on target stubble height. ‡NS = not significant ($P > 0.1$). L = linear; * = $P \leq 0.05$

38

Final Remarks

- Management practices intended to promote SOC sequestration can also increase productivity and environmental quality (soil and water quality); however, they need to be examined at a local/regional scale
- The direction and magnitude of SOC responses to management depend on the duration and intensity of these practices, region, and current SOC levels. Because of the degraded status of many grazing land soils, there is a high potential for positive environmental co-benefits as a result of implementation of improved grazing land management practices
- Despite positive effects on SOC, grazing land management practices may in some cases have little to no benefits in terms of the GHG balance or ecosystem services
- Importance of baseline measurements (SOC before any changes occur): BAU vs. "Improved"

39

THANKS

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40