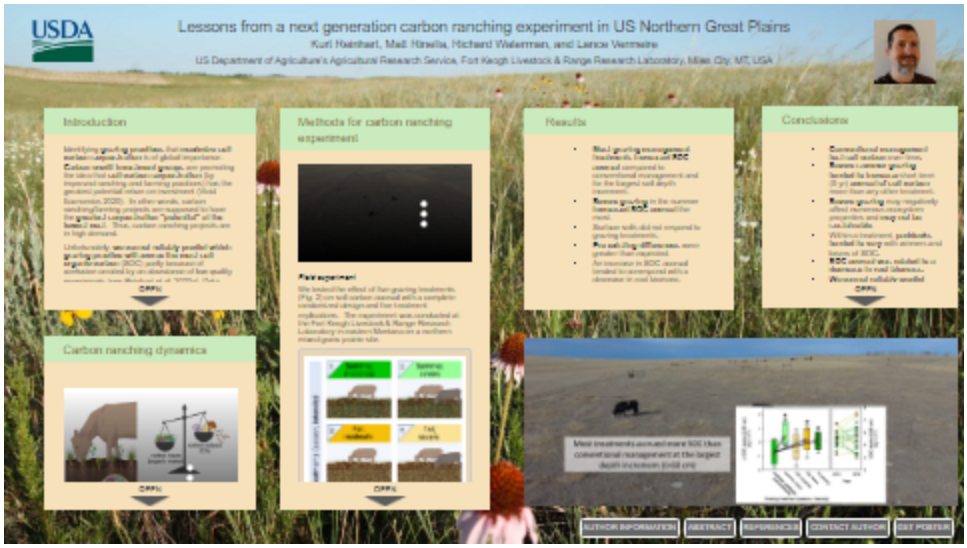
Lessons from a next generation carbon ranching experiment in US Northern Great Plains

Kurt Reinhart[1], Matt Rinella[1], Richard Waterman[1], and Lance Vermeire[1]

[1]US Department of Agriculture's Agricultural Research Service, Fort Keogh Livestock & Range Research Laboratory, Miles City

January 24, 2023

Lessons from a next generation carbon ranching experiment in US Northern Great Plains



Kurt Reinhart, Matt Rinella, Richard Waterman, and Lance Vermeire

US Department of Agriculture's Agricultural Research Service, Fort Keogh Livestock & Range Research Laboratory, Miles City, MT, USA

PRESENTED AT:

INTRODUCTION

Identifying **grazing practices** that **maximize soil carbon sequestration** is of global importance. **Carbon credit investment groups** are promoting the idea that **soil carbon sequestration** (by improved ranching and farming practices) has the greatest potential return on investment (Vivid Economics 2020). In other words, carbon ranching/farming projects are supposed to have the **greatest sequestration "potential" at the lowest cost**. Thus, carbon ranching projects are in high demand.

Unfortunately, **we cannot reliably predict which grazing practice will accrue the most soil organic carbon** (SOC) partly because of confusion created by an abundance of low-quality experiments (see Reinhart et al. 2022a). Data quality has likely suffered because adequate treatment replication requires a lot of land, meaningful scale introduces heterogeneity among replicates, and pre-existing differences are rarely taken into account. **Here we tested the effects of five grazing treatments on SOC stocks with a gold standard randomized controlled trial with pre-treatment data at a semiarid grassland** (Reinhart et al. 2022b). We also tested for relationships between plant (root biomass, plant species composition) and soil properties (mass, nitrogen concentration) and SOC accrual.

CARBON RANCHING DYNAMICS

[VIDEO] https://res.cloudinary.com/amuze-interactive/video/upload/vc_auto/v1667414691/agu%20fm2022/F1-70-CA-E6-72-F4-8F-FA-15-0D-06-2C-8A-9C-83-AA/Video/grazing_SOC_dynamics_opy04b.mp4

Grazing by large ruminants can impact several biotic and abiotic soil (and plant) properties (e.g. Reinhart et al. 2022a) which can affect whether soil organic carbon (SOC) accrues or is mineralized.

Many are promoting the notion of increasing soil carbon sequestration by applying optimal grazing management (e.g. Bai & Cotrufo 2022). This typically refers to the wishful belief in a win-win scenario where management can simultaneously increase production of forage and SOC stocks. The starting logic is simple--an increase in forage production will increase inputs of particulate organic matter (PAOM) to the soil. However, an increase in PAOM may stimulate microbial mineralization of the more persistent SOC fractions (i.e. mineral accociated organic matter or MAOM). Thus, we cannot reliably predict whether an increase in PAOM inputs will ultimately increase or decrease SOC stocks.

What livestock management practice is likely to increase SOC accrual? Grazing management systems tend to vary stocking density and the time a pasture is rested between livestock grazing events. Other nuances of grazing management are the timing of grazing and management heterogeneity (e.g. are practices static yr-to-yr). **The probablity that a change in management will increase SOC stocks is difficult to predict** and will depend on the starting conditions, system, etc.

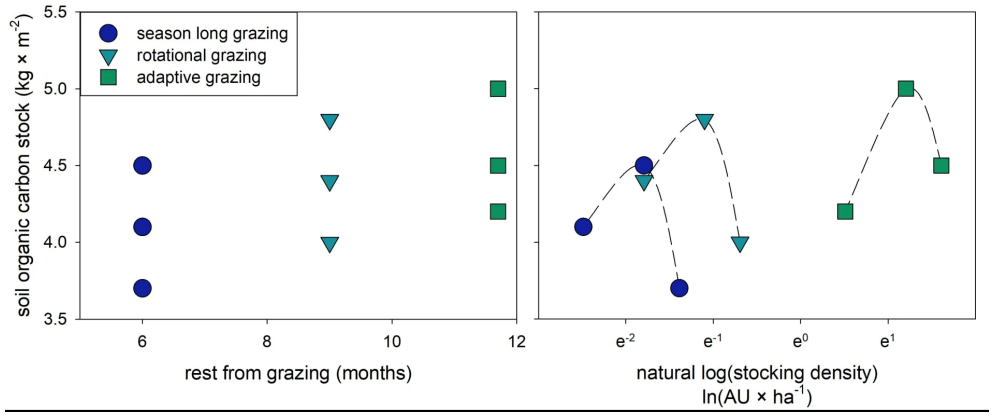


Fig. 1 Predicted variation in soil organic carbon stocks with variation in 1) rest from grazing, 2) stocking density, and 3) grazing practice. Adaptive grazing refers to high-density short-duration rotational grazing.

METHODS FOR CARBON RANCHING EXPERIMENT

[VIDEO] https://res.cloudinary.com/amuze-interactive/video/upload/vc_auto/v1667339460/agu%20fm2022/F1-70-CA-E6-72-F4-8F-FA-15-0D-06-2C-8A-9C-83-AA/Video/S1014796_Trim_17sec_y5heze.mp4

Field experiment

We tested the effect of five grazing treatments (Fig. 2) on soil carbon accrual with a complete randomized design and five treatment replications. The experiment was conducted at the Fort Keogh Livestock & Range Research Laboratory in eastern Montana on a northern mixed-grass prairie site.

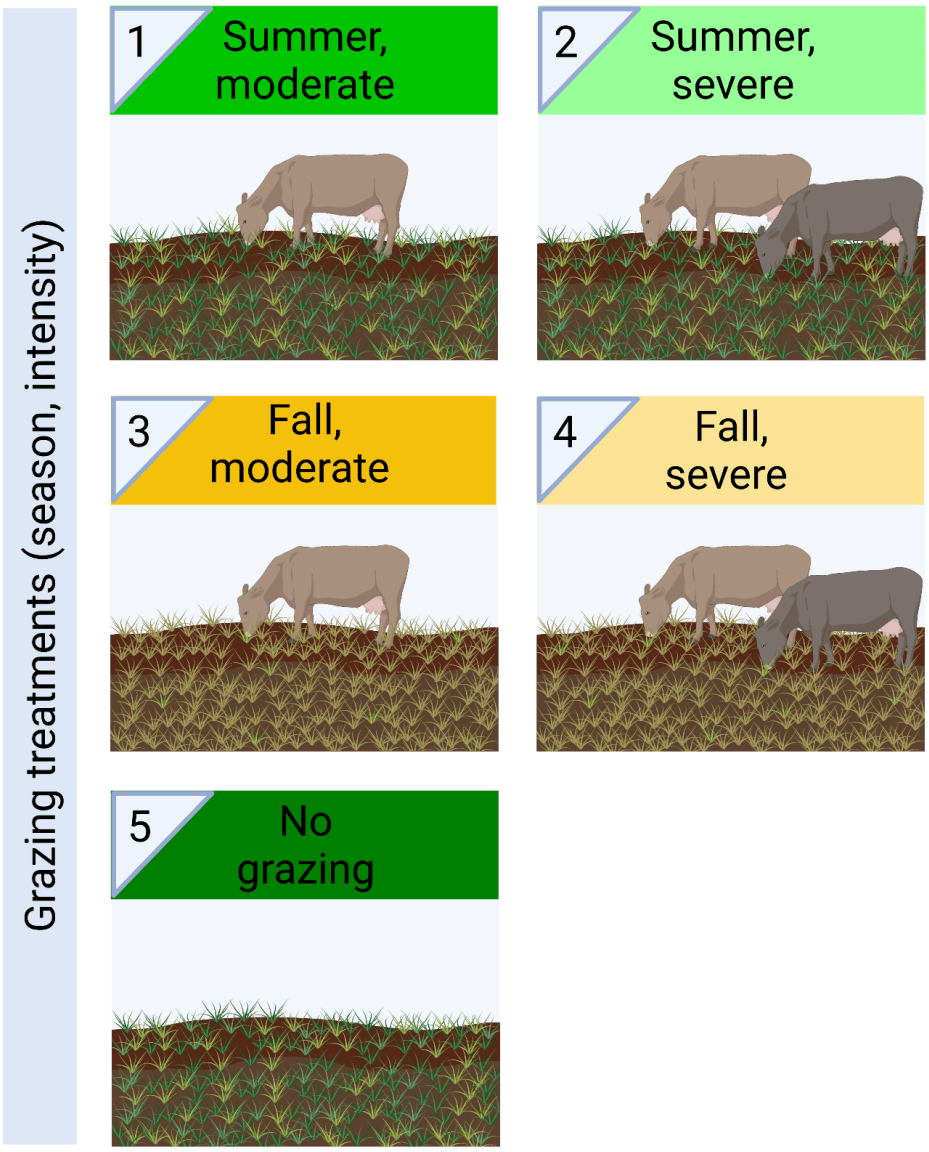


Fig. 2 Field experiment with five grazing treatments. Grazing in summer and at moderate levels (#1) is the conventional approach to management. Created with BioRender.com

Experiment had 20 large paddocks (60 x 30m, see video above) and 5 small ungrazed paddocks (4.8 x 4.8m).

Soil sampling & processing

Soil was cored pre-treatment (2013) and after 5-yrs of grazing treatments (2018) from permanent Ez plots (Fig. 3). Each experimental unit (i.e. paddock) had one Ez plot.

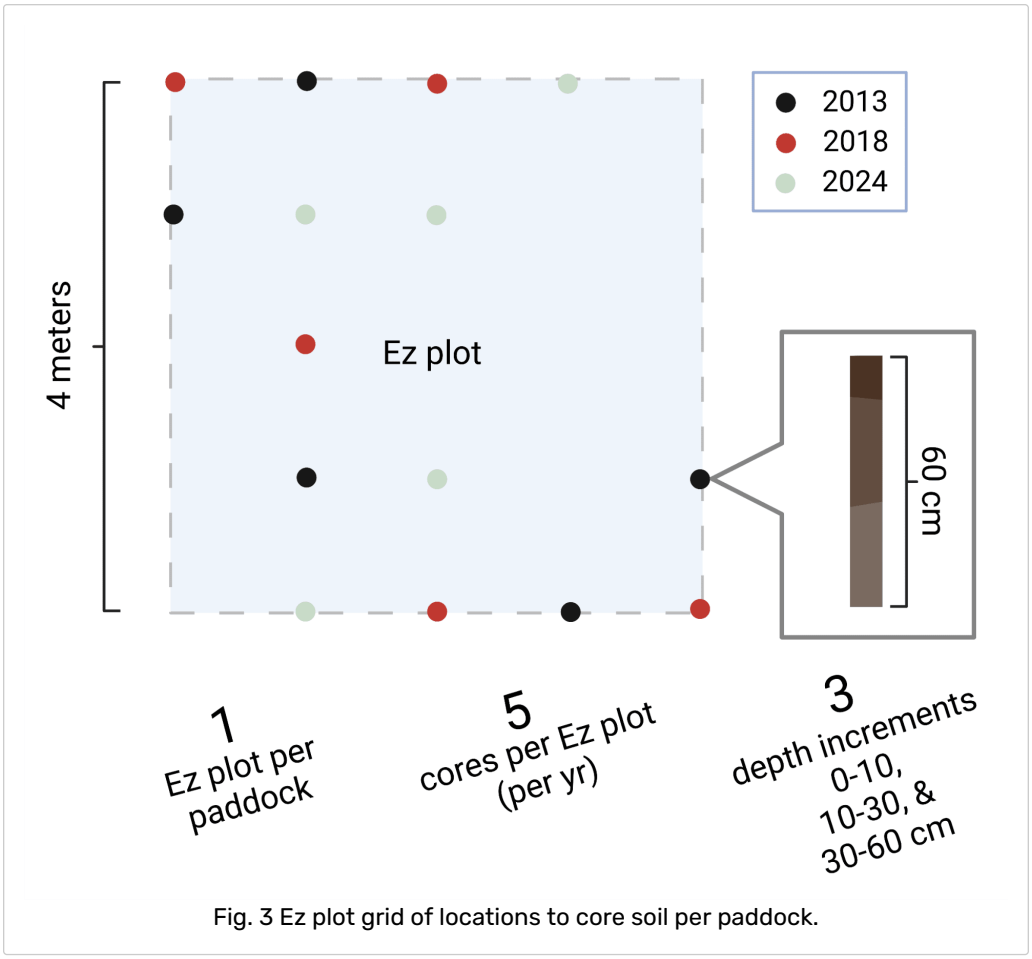


Fig. 3 Ez plot grid of locations to core soil per paddock.

Each core was separated into depth increments in the field. Samples were processed further in the laboratory. We determined each increment's bulk density, total carbon, and inorganic carbon (Fig. 4).

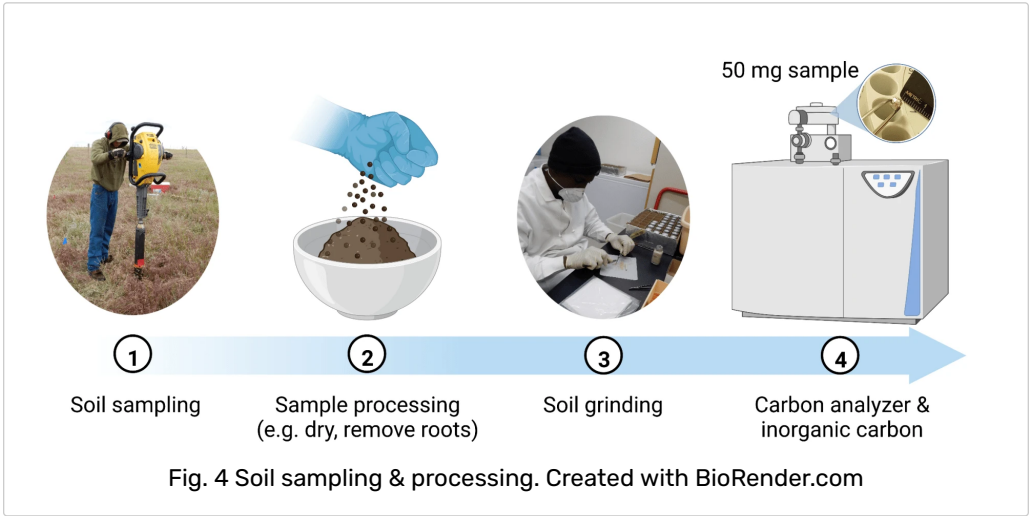


Fig. 4 Soil sampling & processing. Created with BioRender.com

These data were used to estimate routine metrics of SOC stocks (e.g. SOC kg x m^{-2}, 0-30 cm depth increment).

Data analysis

We used R and lme4 to perform a linear mixed effects analysis of the relationship between grazing treatment and year on SOC stock metrics.

RESULTS

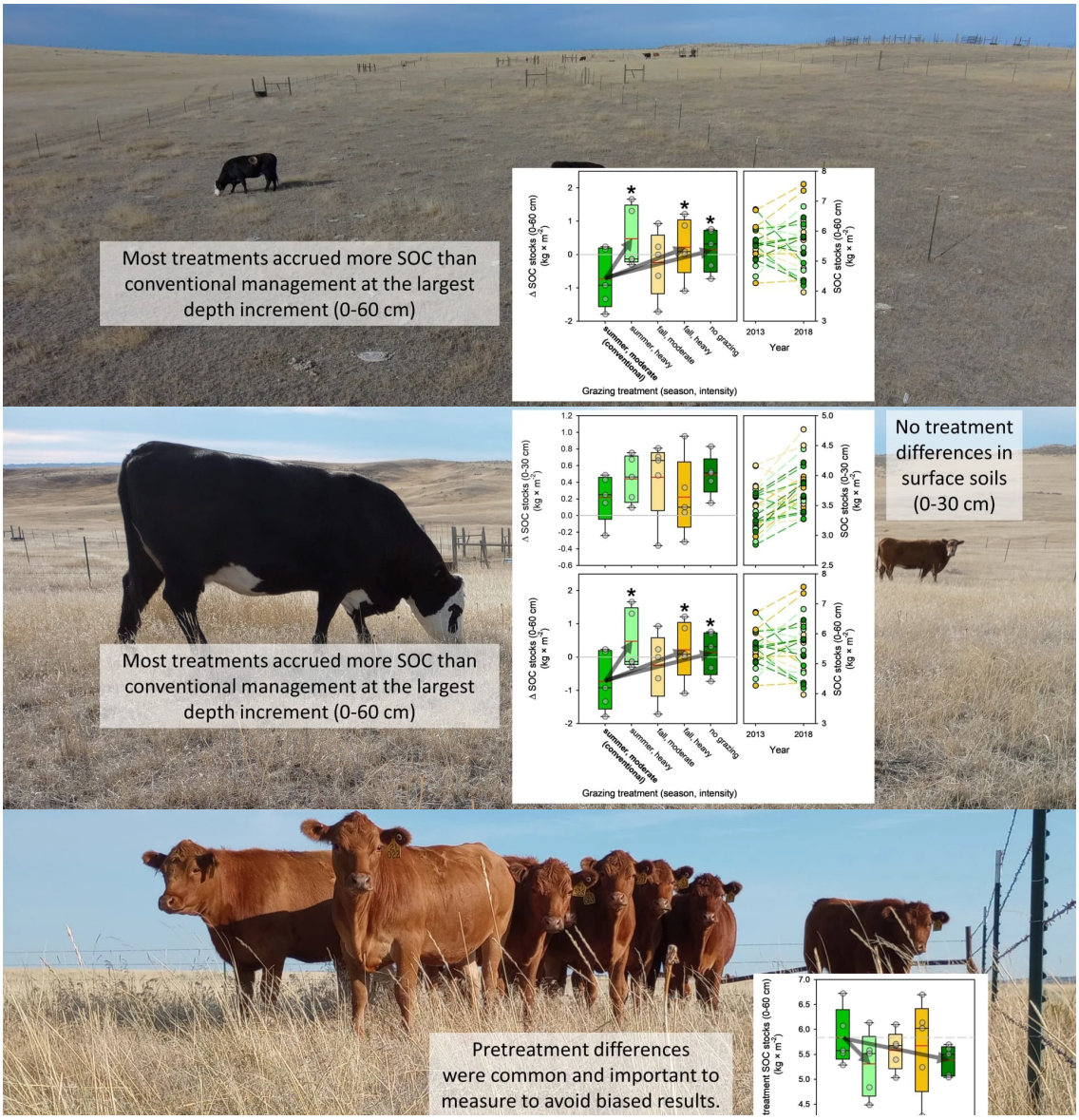
- **Most grazing management treatments increased SOC accrual** compared to conventional management and for the largest soil depth increment.
- **Severe grazing** in the summer **increased SOC accrual** the most.
- Surface soils did not respond to grazing treatments.
- **Pre-existing differences** were greater than expected.
- An increase in SOC accrual tended to correspond with a decrease in root biomass.

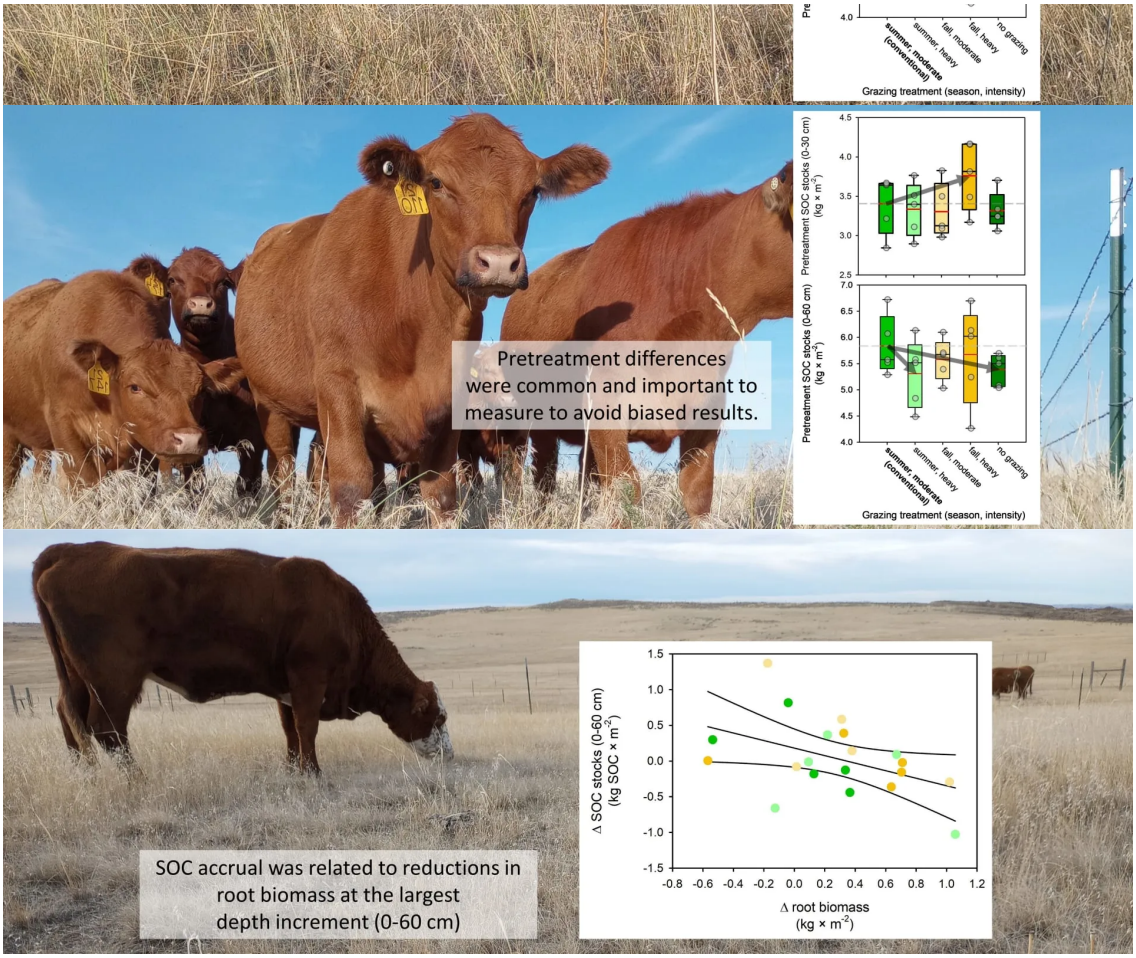
CONCLUSIONS

- **Conventional management lost soil carbon** over time**.**
- **Severe summer grazing tended to increase** short-term (5-yr) **accrual of soil carbon** more than any other treatment.
- **Severe grazing** may negatively affect numerous ecosystem properties and **may not be sustainable**.
- Within a treatment, **paddocks tended to vary** with winners and losers of SOC**.**
- **SOC accrual was related to a decrease in root biomass.**
- **We cannot reliably predict which grazing management practice will maximize SOC accrual** for a given system and/or time period.
- Most carbon ranching studies are poorly replicated and lack pre-treatment data (Reinhart et al. 2022a). Variation in our data highlight how **poorly designed experiments are at risk of reporting misleading results**.

Our findings support the low rating given to most carbon ranching projects by a carbon credit monitoring group (CarbonPlan (https://carbonplan.org)).

- **SOC permanence** is a major problem of carbon farming and carbon ranching projects--**no SOC is truely protected from microbial mineralization**.




Pretreatment differences were common and important to measure to avoid biased results.
Pretreatment SOC stocks (0-30 cm) (kg × m⁻²)
Pretreatment SOC stocks (0-60 cm) (kg × m⁻²)
summer, moderate (conventional)
summer, heavy
fall, moderate
fall, heavy
no grazing
Grazing treatment (season, intensity)
SOC accrual was related to reductions in root biomass at the largest depth increment (0-60 cm)
Δ SOC stocks (0-60 cm) (kg SOC × m⁻²)
Δ root biomass (kg × m⁻²)

AUTHOR INFORMATION

Kurt Reinhart[1], Matt Rinella[1], Richard Waterman[1], and Lance Vermeire[1]

1 U.S. Department of Agriculture's Agricultural Research Service, Fort Keogh Livestock & Range Research Laboratory, Miles City, MT, USA

ABSTRACT

Identifying grazing practices that maximize food production and soil carbon sequestration is of global importance. Currently, we cannot reliably predict which grazing practice will accrue the most soil organic carbon (SOC) partly because of confusion created by an abundance of low-quality experiments. Data quality has likely suffered because adequate treatment replication requires a lot of land, meaningful scale introduces heterogeneity among replicates, and pre-existing differences are often not taken into account. Here we tested the effects of five grazing treatments on SOC stocks with a gold standard randomized controlled trial with pre-treatment data at a semiarid grassland. Treatments were no grazing, severe summer grazing, moderate fall grazing, severe fall grazing, and the conventional approach of moderate summer grazing. We also tested for relationships between plant (root biomass, plant species composition) and soil properties (mass, nitrogen concentration) and SOC. After applying treatments for 5-yr, the no grazing and severe summer and fall grazing treatments accrued 0.85 to 1.22 kg × m^{-2} (0–60 cm soil depth) more SOC than conventional moderate summer grazing and represent appreciable (i.e. >4 per mille per yr) increases in SOC stocks. Sustainable accrual of SOC may depend on management heterogeneity. Accrual of SOC was likely driven by a reduction in SOC mineralization related to increased soil density and nitrogen, decreased root biomass, and change in plant species composition. Our findings counter the prevailing view that plant material inputs are the primary driver of SOC accrual in grazing lands. In other words, SOC accrual was mainly associated with indicators of decreased SOC mineralization (C outputs). Robust generalizations on grazing practices that will reliably and sustainably maximize the rate of SOC accrual for a specific system, climate and timeline are still lacking, but further focus on factors affecting SOC mineralization will facilitate their development.

(https://agu.confex.com/data/abstract/agu/fm22/3/9/Paper_1124993_abstract_1013707_0.jpg)

REFERENCES

Bai, Y., and M. F. Cotrufo. 2022. Grassland soil carbon sequestration: Current understanding, challenges, and solutions. Science 377:603-608.

Reinhart, K. O., H. S. Sanni Worogo, and M. J. Rinella. 2022a. Ruminating on the science of carbon ranching. Journal of Applied Ecology 59:642-648.

Reinhart, K. O., M. J. Rinella, H. S. Sanni Worogo, R. C. Waterman, and L. T. Vermeire. 2022b. Lessons from a next generation carbon ranching experiment. Geoderma. https://doi.org/10.1016/j.geoderma.2022.116061 (https://doi.org/10.1016/j.geoderma.2022.116061)

Vivid Economics. 2020. An investor guide to negative emission technologies and the importance of land use. London, United Kingdom.