Soil Carbon Sequestration through Rangeland Management

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Introduction

Rangeland ecosystems managed for livestock production represent the largest land-use footprint globally, covering more than one-quarter of the world's land surface (Asner et al. 2004). In California, rangelands cover an estimated 17 million hectares or approximately 40 % of the land area (FRAP 2003). Rangeland soils hold considerable potential to store carbon (C) and offset greenhouse gas emissions (Lal 2004). Management practices can have direct effects on C storage, such as those that alter soil chemical or physical characteristics, and indirect effects such as changes in plant morphology or life history, moisture, or microbial activity (Jones and Donnelly 2004; Steenwerth et al. 2002; Stromberg and Griffin 1996). These management-induced changes to C cycling at local scales can affect the global C cycle (Conant et al 2001; Schimel et al. 1990). Future legislation and C markets are likely to provide economic incentives for rangeland managers to change practices, yet research on how to optimize C sequestration in rangelands is limited (Derner and Schuman 2007). ***We propose to test the effects of key management practices on C sequestration and greenhouse gas dynamics in California rangeland ecosystems.***

A preliminary survey conducted in northern California confirmed that rangelands have considerable potential to sequester C in soils through changes in management practices. However, we lack comprehensive data that directly compares different management approaches under controlled conditions. Furthermore, to determine the potential for management to mitigate climate change and provide value added through future C markets we need to better understand the magnitude of, and controls on GHG fluxes from these ecosystems. We will use experimental manipulations replicated within and across bioclimatic zones, and scale our results to the state level using a well-tested ecosystem model. Our research will determine the effects of management approaches on the pools and mean residence times of soil and plant C (i.e. permanence), as well as effects on carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) fluxes across the soil-atmosphere interface. Our research will also explore the mechanisms responsible for the patterns observed, which should facilitate management planning across the diversity of rangeland ecosystems. Below we briefly summarize our results to date and our proposed approach and project outcomes.

Regional patterns in soil carbon pools

We are currently completing a soil C survey in two counties in northern California encompassing approximately 260 km^2. Replicate soil samples were collected at multiple depth increments to 1 m depth at 35 sites (n = 1050 samples). Sites were selected to control for slope and bioclimatic conditions. Sampling was stratified to include intensive (dairy and silage) and extensive (moderate and rotational grazing) management, annual and perennial plant cover, and the dominate soil orders. We also sampled four fields that had been treated once with a vertical subsoiler to increase water infiltration, paired with an untreated control. Management practices included organic amendments, intensive (dairy) and extensive (other) grazing practices, and subsoiling.

Soil C pools ranged from approximately 50 to 140 Mg C ha^{-1} to 1 m depth, with a mean of 99 ± 22 (sd) Mg C ha^{-1}. Differences among sites were due primarily to C concentrations, which exhibited a much larger coefficient of variation than bulk density at all depths. There were no statistically significant differences among the dominant soil orders. The very wide range of soil C content across sites, which were similar with regard to soil type, slope, climate, and cover type strongly suggests an important effect of management. Subsoiling appeared to significantly increase soil C content in the top 50 cm, even though subsoiling had only occurred for the first time the previous Nov (Fig. 1a). Organic amendments also appeared to greatly increase soil C pools (Fig 1b), and was the dominant factor that distinguished soil C pools in intensive and extensive land uses.

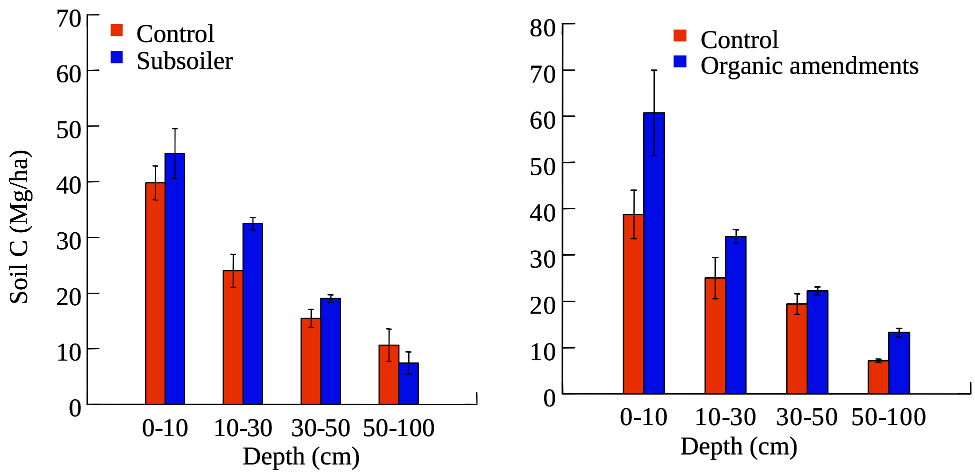

Figure 1. (a, left): Patterns in soil C content by depth following subsoiling and in control fields. Data are means and standard errors of five paired control and treatment combinations. The subsoiler had been used in fields the previous fall. (b, right): Effects of organic amendments on soil C pools in west Marin County.

There are several important co-benefits of soil C sequestration. Changes in management practices that increase soil organic matter content (which is 50% C) are also likely to improve soil fertility, decrease erosion, increase soil water holding capacity, and increase productivity and sustainability. There is a clear need for better management practices that both improve the long-term sustainability of rangeland ecosystems and sequester C for climate change mitigation.

Approach

Our research sites will be located in Marin and Yuba counties, CA. Sites in Marin are on private and state-owned land that were part of the original C survey; in Yuba County we will be working at the Sierra Foothills Research and Extension Center (SFREC). We chose these sites to encompass a range in mean annual precipitation and forage quality and quantity (higher in the Marin sites and lower at SFREC). We have used the results from our C survey together with data compiled for the literature to identify management practices that have considerable potential to increase soil C. We will apply the following management approaches in a replicated complete block design:

(1) Current best practices (from NRCS, moderate grazing with seasonal rotation)
(2) Short duration high intensity grazing.
(3) Vertical subsoiling
(4) Compost addition

Subsoiling and compost application will be use in separate and combined treatments under both grazing scenarios for a total of eight experimental treatments. Treatments (within blocks) will be

 *Cited references available upon request replicated at both Marin and SFREC sites. We will use the current best management practices (treatment 1) as a control. Short duration grazing with high stocking rates has been proposed as a means to sustain forage production (Manley et al. 1997) and decrease the invasion of weedy species (Bruijn and De Bork 2006). The effects of this grazing approach on C and greenhouse fluxes are unknown. We will use the Yeoman's plow for the subsoiling treatments. This technique involves pulling a device with 3-6 vertical blades spaced at 75 cm intervals that produce a 4 cm wide cut in the soil to approximately 20-30 cm depth. The technique has been used in Australian grasslands to increase water infiltration and to remove impermeable soil layers. For the compost treatment we will use locally generated green waste compost (plant debris and manure) applied to the surface to a depth of 2.5 cm. The compost is part of a new project in Marin county to recycle green waste while increasing agricultural production. We will estimate the C pools and greenhouse gas fluxes at the site of compost production and after application to rangeland plots. This, together with a lifecycle analysis currently being generated in the county will provide a full accounting of the relative costs and benefits of this approach.

Our goals are to determine the potential to sequester C in soils, while increasing the productivity and sustainability of rangelands. Thus our primary measurements will include above- and belowground net primary production, forage quality, and plant life history traits (e.g. annual versus perennial biomass). We will monitor patterns in soil moisture and temperature using automated sensors, and make high frequency measurements of CO_2, N_2O, and CH_4 across the soil-atmosphere interface. As indices of soil C sequestration and controlling mechanisms we will measure soil C pools and soil C fractions. To determine the mean residence time of C in soils we will use ^{14}C analyses of C fractions throughout the soil profile. This key measurement will help us understand the degree of permanence of sequestered C. Soil nutrient concentrations and net nitrogen fluxes will be measured as indices of soil fertility. To scale our results to regional and global rangelands we will use the Century Soil Organic Matter Model. Century has been used extensively in rangeland ecosystems to explore the effects of management and climate on C and N pools and fluxes (Parton et al. 1994).

Project outcomes

Our research will determine how changes in key management practices can increase rates of C sequestration in soils. The study will also identify mechanisms contributing to C storage or loss, and provide a full soil GHG budget. Our collaborative team includes scientists from academia, government, the private sector, and non-profit organizations. The research will be led through the U.C. Berkeley in close collaboration with U.C. Davis, the Marin Agricultural Land Trust, and U.C. Cooperative Extension. Public outreach, extension, and education will be provided in collaboration with Marin Organic, the Environmental Defense Fund, Sierra Foothills Research and Extension Center, Marin Resource Conservation District, and the Marin Agricultural Commission. These groups provide valuable outreach and education to ranchers and the general public adding an integral component to this research. We are also teaming up with national scientific networks to compare and contrast our results with research in other regions. Our integrated research will provide the basis for better land use decisions and public policy, and provide a cost-effective, safe approach to mitigate climate change.

*Cited references available upon request