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Ranching practices interactively affect soil nutrients in subtropical wetlands

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ABSTRACT

Growing demand for food from finite agricultural lands requires the optimization of agricultural management, including the potential interactive effects of these practices on ecosystems. We experimentally examined the interactive and temporal effects of three ranching practices (pasture management intensity, livestock grazing, and prescribed fire) on soil nutrients in 40 geographically-isolated seasonal wetlands. Wetlands were embedded in a subtropical ranch, and the long-term experiment used a factorial design with wetlands as experimental units. Soils (0–15 cm) were collected three times over 9 years; at experiment start (2007), one year after prescribed burns started (2009), and seven years later (2016). Samples were analyzed for soil bulk density, organic matter (OM), total nitrogen (N), carbon (C), and phosphorous (P). A lag effect was observed in response to fire; differences were not observed in 2009, but were detected in 2016 after multiple fire cycles had occurred. Rangeland practices showed 2- and 3-way interactive effects, especially for total P and N stocks. Total P increased most in the wetlands embedded within highly managed, grazed, and burned pastures ($2.31 \pm 0.76\ \mathrm{g\,m^{-2}\,yr^{-1}}$), consistent with legacy effects of historical fertilizer application, cattle activity, and ash deposit due to fire. Wetlands in semi-natural and burned pastures had the lowest rates of soil N storage ($5.13 \pm 7.33\ \mathrm{g\,m^{-2}\,yr^{-1}}$) compared to all other treatments ($24.5 \pm 10.8\ \mathrm{g\,m^{-2}\,yr^{-1}}$). Total C stocks were not significantly impacted by ranching practices throughout the study. In summary, ranching practices can additively and interactively alter soil nutrient stocks after a time lag, and legacy effects of P application still impact wetlands decades later. Our study is one of few focused on ranchland wetlands and shows that wetlands in highly managed, grazed, and/or burned pastures can sequester soil P and N, playing an important role in nutrient processing for agricultural landscapes and watersheds.

1. Introduction

The Food and Agriculture Organization (2011) projects that by 2050, food production will need to increase by 70% to feed the growing population and more than 80% of the increase will be from intensification of current agricultural lands. Among agricultural lands, pastures (used for grazing livestock) are globally important because they occupy 25% of all land area that is not permanently frozen (Wright, 1990). Ranching practices, including pasture intensification, managed livestock grazing intensity and timing, and prescribed burns, can alter soil nutrient dynamics and ecosystem health (Swain et al., 2007; McGranahan et al., 2014). Pastures vary in their degree of human alteration (e.g., fertilization, irrigation/drainage, seeding), ranging from natural rangelands to highly managed pastures. Intensive pasture management historically results in land degradation, eutrophication, biodiversity loss, and an increase in greenhouse gas emissions (IPCC, 2014). Livestock grazing influences greenhouse gas emissions soil erosion and nutrient runoff, sometimes resulting in eutrophication of water bodies (Mckergow et al., 2012). Livestock grazing also increases incorporation of surface litter into the soil and root exudation, therefore cattle removal can result in decreased microbial biomass and mineralizable pools of C and N (Bardgett et al., 1999; Wang et al., 2006). Finally, prescribed fire is commonly used to reduce woody plants cover and to increase nutrient concentrations in soil, hence promoting high quality forage grasses (Griffin and Friedel, 1984; Boughton et al., 2015). Prescribed fire will also reduce N in the soil through volatilization (Reinhart et al., 2016). While the short-term effects of individual ranching practices have been studied in detail (e.g., Vermeire et al., 2014; Little et al., 2015; Mérő et al., 2015), few studies have considered the *long-term* and *interactive* effects that these practices have on

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ecosystems (Boughton et al., 2015).

Geographically-isolated seasonal wetlands are common in ranchlands worldwide and play an important role in soil nutrient sequestration (Gathumbi et al., 2005; McCauley et al., 2015; Dunmola et al., 2010; Cohen et al., 2016). Despite being geographically separated from other aquatic bodies, these wetlands are vast in number, act as hydrological conduits between rangelands and downstream water bodies, and serve a vital ecological role as sinks and transformers of carbon (C), nitrogen (N), and phosphorus (P) (McCauley and Jenkins, 2005; Reddy and DeLaune, 2008; McCauley et al., 2015; Cohen et al., 2016). Wetlands in pastures are focal points for ecological management of agricultural lands because wetlands are significant C reservoirs and potential C sinks (depending on local conditions) that can help mitigate global climate change (IPCC, 2014). Furthermore, N and P from fertilizer runoff and animal wastes can either be retained in wetlands and removed (e.g., denitrification), or else released downstream, resulting in eutrophication and algal blooms downstream (Reed-Andersen et al., 2000; Whigham and Jordan, 2003; Gathumbi et al., 2005). Therefore, functional wetlands within agrarian landscapes are essential to sustainable rangeland practices by serving as on-site water treatment systems and nutrient storage reservoirs, in addition to serving as biodiversity hotspots and livestock watering and forage sites (Dunne et al., 2007; Medley et al., 2015). The question then becomes a matter of evaluating the potential benefit of wetlands to agriculture and using that knowledge to optimize wetland ecological functions (McCauley et al., 2015).

This research used a long-term experiment to evaluate main and interactive effects of ranching practices (pasture management intensity, livestock grazing, and prescribed burns) on soil nutrients in wetlands. By analyzing data periodically collected over nine years, we sought to evaluate the lag time between the implementation of practices and observed effects. We hypothesized that there would be a lag time (< 2 years) before interactive ranching practices would alter soils based on previous studies and observations that suggested that subtropical regions generally show quicker soil responses (< 2 years) to management than other systems due to their high mean annual precipitation and primary productivity (Lugo and Brown, 1993; Oesterheld et al., 1999; Brando et al., 2016; Hu et al., 2016). Specifically, we expected: (i) greater organic matter (OM), total C, and N concentrations in soils of highly managed, grazed, and burned wetlands due to fertility, grazing (i.e., cattle “mulching” and trampling during inefficient grazing of emergent wetland vegetation), and vegetation responses to fire; and (ii) greater total P in highly managed wetlands, regardless of other management practices, due to a legacy effect of historical fertilizer application.

2. Materials and methods

2.1. Study area

This study took place in subtropical pastures of Florida’s northern Everglades, at the MacArthur Agro-Ecology Research Center (MAERC) at Buck Island Ranch (27°09′N 81°11′W). Buck Island Ranch is a 4170-ha cattle ranch and research laboratory with > 600 wetlands ranging in size from 0.007 to 41.9 ha and inundated up to 10 months out of the year (Boughton et al., 2015). Buck Island Ranch is in the greater Everglades watershed where eutrophication is a major concern and cattle ranching is regionally prevalent (Gathumbi et al., 2005; Smith et al., 2006). Historical pasture management practices led to two distinctive pasture types: semi-natural and highly-managed pastures. Highly-managed pastures (HMPs) were heavily ditched to drain pastures (Fig. 1) and fertilized annually from 1970 to 1987 with 52 kg ha^{-1} of NH_4SO_4 or NH_4NO_3 and 18 kg ha^{-1} of P_2O_5 and K_2O (Boughton et al., 2011). After 1987, P fertilization stopped, but N fertilization continues on a regular basis with 56 kg ha^{-1} of NH_4SO_4 or NH_4NO_3, usually every two years. In contrast, semi-natural pastures (SNPs) have never been fertilized and have lower ditching densities (Fig. 1). Due to modest elevation differences and pasture management practices, the vegetation differs between the two pasture types, and the underlying soil types are a mosaic of Endoaqualfs such as Bradenton, Felda, and Hicoria muck. Higher elevation areas are dominated by Alaquods like Myakka sands (Sperry, 2004). HMPs are dominated by introduced grasses (*Paspalum notatum*) and SNPs contain *P. notatum,* as well as native grasses like *Andropogon* spp., and *Panicum* spp. (USDA, 1989; Boughton et al., 2015).

2.2. Experimental design and soil sampling

A 2 × 2 × 2 complete factorial design was used to understand the interactive effects of three practices: pasture management (HMP or SNP), cattle removal (grazed or fenced), and prescribed burns (burned or unburned) on soils in wetlands embedded within each experimental pasture (Boughton et al., 2015). The eight different treatment combinations were each replicated five times for a total of 40 wetlands in a randomized block design that accounted for spatial differences (Fig. 1). The 40 wetlands were relatively similar in sizes and hydroperiod. All 40 wetlands were sampled during February/March 2007 before fencing and prescribed fire treatments were applied (i.e., representing only pasture effects). Soils were sampled and analyzed for bulk density, organic matter, total P, total C, and total N. Each wetland was split into 4 quadrants bounded by cardinal directions (N, E, S, and W), plus a central zone (5 zones total), and a marker was randomly placed in each zone. Two 0–15 cm soil cores were randomly collected near the marker within each zone and composited to account for heterogeneity of soils.

Differences in pasture management (HMP vs. SNP) had been in effect for almost 4 decades at the study start (2007), but wetland exclosures and experimental prescribed burns had not yet been implemented (however, prior to the experiment, wetlands were exposed to prescribed burns on an irregular basis as dictated by routine management of surrounding pastures).

Barbed-wire fences were installed around 20 randomly selected wetlands in February/March 2007 (10 per pasture type), directly after initial sampling, and left in place for the entire experiment. These fences successfully exclude cattle, though feral pigs could still enter wetlands and disrupt soils there. The grazed pastures were exposed to typical grazing pressure for a cow-calf operation in Florida and based on pasture condition. Throughout the nine years, grazed HMPs had an average stocking density of 2.56 cow ha^{-1} and a stocking rate of 16.7 animal unit month (AUM) ha^{-1}. On the other hand, grazed SNPs had an average stocking density of 1.14 cows ha^{-1} and 6.89 AUM ha^{-1}. Cattle activity was not tracked throughout the experiment other than through tracking stocking rates of individual pastures, but cattle have free access to wetlands within the same pasture and regularly use wetlands to forage and drink.

All 20 wetlands randomly assigned to the burned treatment experienced prescribed burns in February of 2008 and 2011. Twelve of 20 wetlands were burned again in February 2013, and the remaining 8 wetlands were burned in March 2014 (permitted burns are seasonal and weather-dependent). The 40 wetlands were resampled using the above protocol in February 2009 and May 2016.

2.3. Sample analysis

Each bulk soil sample (0–15 cm depth) was weighed and ~100 g from each duplicate sample per quadrant was composited for a total sub-sample weight of 200 g. The composite samples were oven dried in a ThermoFisher Heratherm oven (ThermoFisher Scientific, Waltham, MA) at 70 °C for 72 h and weighed again, where the difference in weights indicated gravimetric moisture content and final weight was used to calculate soil bulk density. Afterwards, the oven dried samples were ground with a SPEX Sample Prep Mixer Mill 8000 M (Metuchen, NJ) for organic matter (OM) content and total C and N analysis on an Elementar Vario Micro Cube (Elementar Americas Inc., Mount Laurel,