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# Cows, carbon, and conservation

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**Key words**: carbon market; cow-calf; ecosystem modelling; life cycle analysis

**Abstract**

Managed grazing lands cover ~25% of global land area. Carbon stored in grazing land soils (top 1 m) represent 20% of total global soil organic carbon (SOC) stocks with a potential annual SOC sequestration rate of 0.5 ton C $ha^{-1}$ $yr^{-1}$. Conversely, grazing animals produce greenhouse gases (GHG). Although the US beef industry has made significant advances in reducing its environmental footprint, extensive grazing operations (e.g., the cow-calf and stocker phases) are responsible for ~ 70% of the GHG emissions from the beef value chain. Multiple stakeholders are interested in the potential effect carbon market participation may have on the financial status of the beef industry and its cascading effects to conservation and climate mitigation. Producers are interested in carbon markets to diversify income sources and drive increased profitability. Financially viable producers support diverse industries, ranging from fertilizer, feed, equipment, and beyond. Conservationists are also interested in carbon markets as a tool to fund the protection of grazing lands to benefit conservation goals. The question remains how extensive grazing operations can engage in carbon markets. We utilized life cycle analysis and an ecosystem model to understand net carbon sequestration at Archbold Biological Station's Buck Island Ranch, a commercial cow-calf grazing operation in Many ranchers are being approached by carbon credits brokers aiming to trade ranch carbon credits in carbon markets. If effective, these markets ensure globally reduced atmospheric greenhouse gas concentrations when buyers pay sellers for reduced emissions or increased sequestration. For Buck Island Ranch to credibly be paid for carbon sequestration, new management reducing emissions or enhancing sequestration is needed, even though the ranch is presently a net carbon sink. Credible carbon markets include the concept of additionality which refers to the need for payments to result in newly avoided emissions or increased sequestration beyond what would have already been occurring without the payment. Emissions could be reduced either from cattle or the environment. Inhibiting cattle methane through feed additives shows promise in the dairy industry (Belanche et al. 2020) and may be useful for pasture-based systems. Increasing soil C stocks is more difficult because many producers are already implementing effective SOC management (Silveira et al. 2024). To have a meaningful impact on climate change, ideally contracts should span at least several decades (Dynarski et al. 2020).

. Life cycle analysis estimated annual average emissions as 11,294 Mg CO2 eq. The ecosystem model estimated annual soil organic carbon sequestration as 12,391 Mg eCO2/year. Sequestration offset emissions with 1,097

metric tons CO2e remaining. A preliminary survey of ranchers' (n=23) interest in carbon markets showed barriers to enrolling in carbon markets were lack of awareness of existing programs, lack of information on programs, and not receiving credit for existing practices. Lastly, we explored the possibility for ranchers to participate in carbon markets considering common program credibility concerns.

**Introduction**

There is increasing interest in management of grazing lands for carbon sequestration. At the same time, there is also interest in reducing greenhouse gas (GHG) emissions from cattle on grazing lands as 70-80% of the US beef industry's GHG emissions result from the cow-calf phase of the beef life cycle, which is managed on grazing land (Rotz et al. 2019). It is critical to accurately quantify carbon uptake and emissions from grazing lands to manage carbon sequestration and reduce emissions.

Economic incentives through carbon markets are an emerging tool for conservation of grazing lands. Producers are interested in carbon markets to diversify income sources and increase productivity (Silveira et al. 2024). The potential for carbon to affect the financial status of the beef industry through carbon market participation has cascading effects to conservation. Ranching can benefit conservation goals by providing wildlife habitats, connectivity and wildlife corridors, and preserving multiple ecosystem services ranging from water quantity and quality, open space, and recreation. Therefore, maintaining economically viable ranches is an important conservation strategy. However, there is a lack of information about the producer community's interest in these programs and the barriers or incentives to participating.

Understanding baseline ranch-scale carbon emissions and uptake is the first step towards ranch participation in carbon markets. For ranch operations, life cycle assessment (LCA) is a method for evaluating environmental impacts associated with the production of goods (Rotz et al. 2019). Ecosystem process-based models can be used to quantify ecosystem carbon dynamics but these models must be validated (Zhou et al. 2021).

Here we: 1) quantify all carbon emissions from a representative ranch operation with LCA; and 2) utilize a process-based ecosystem model validated with *in-situ* ground measurements to understand ecosystem carbon emissions and uptake. To address the need for producer community interest in carbon markets we conducted a survey.

**Methods**

This study took place at Archbold Biological Station's Buck Island Ranch, located in south-central Florida, USA, a 4249-ha cow-calf operation with ~3,000 cattle. The ranch contains 1,953 ha of cultivated pastures planted with *Paspalum notatum* and 2,290 ha of semi-native grasslands dominated by a mixture of native grasses (*Andropogon* spp, *Coleataenia* spp, *Axonopus* spp) and *P. notatum*. The climate is subtropical with a mean annual temperature of 22ºC (1998-2021) and mean annual precipitation is 132 cm.

The carbon footprint was calculated by way of LCA employing the Beef EA model (Alltech E-$CO_2$, Stamford, United Kingdom), a bespoke tool employed in both research and industry. Independently accredited to be compliant with carbon footprint standards globally (ISO, 2018), the model is rooted in the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories. Emissions modelling follows the IPCC Tier 2 Framework (IPCC, 2006; 2019), however facilitates incorporation of site-specific Tier 3 data when available. This approach enabled detailed account of cows' dietary intake, for example, and incorporation of higher granularity data from an ecosystem model (described below) for estimates of $CH_4$ and $N_2O$ arising from cows' deposition at pasture.

The system boundary was defined as cradle-to-gate, covering emissions arising in all inputs and processes through the supply chain and on-farm, up to the point at which the product cattle left the ranch. Operations data were collected for the period from 2015 to 2020 and GHG emissions estimated for each of the six calendar years. This included account of all ranch inputs (e.g. fertilizer, lime, pesticide, herbicide, feed use), fuel and electricity use, animal excreta and applications to the land, and enteric fermentation by cattle.

We quantified total ranch emissions in two ways: *Scenario 1*) including enteric methane and calculating direct and indirect $N_2O$ loss and manure $CH_4$ by LCA Tier 2 method, but not including ecosystem methane; and *Scenario 2*) including enteric methane using LCA approach and including ecosystem methane, $N_2O$ and manure $CH_4$, all calculated using an ecosystem model (*ecosys*). Not including ecosystem methane as in Scenario 1 is typical of LCA practices that consider this source a process of the natural ecosystems.

The process-based model *ecosys* was utilized (Zhou et al. 2021). This model implements biogeophysical and biogeochemical principles to simulate water, energy, carbon, and nutrient cycles over the soil-plant-atmosphere continuum at hourly time steps. The model estimates photosynthesis, autotrophic and heterotrophic respiration, and soil nitrous oxide emissions and soil emissions caused by field-level responses to environmental forcing and practice data (e.g., manure input and fertilizer). Other model inputs included animal use days for all pastures and fertilizer inputs. The initial soil carbon stock was derived from the gSSURGO database. Data from on-site groundwater wells was incorporated to ensure accuracy of the hydrology of the site, where groundwater typically rises to the surface in the wet season and recedes in the dry season. The model gross primary productivity (GPP), ecosystem respiration (Reco), and ecosystem methane were validated using eddy covariance data comparisons to model estimates. Soil carbon increases were modeled for 1 m depth of soil.

We did not include wetlands, ditches, or woodlands, but focused on pastures as the largest land use on the ranch and the landscape primarily utilized for beef production. Future work will incorporate the entire ranch ecosystem as a third scenario.

***Producer Survey***

We conducted a survey of beef producers in Florida to determine interest in carbon markets for pasture-based beef production. The survey asked about the incentives and barriers to practicing climate-smart agriculture and participating in carbon markets (Campbell et al. 2019). We obtained a sample of beef producers through the data procurement company DTN. We collected responses using online survey software Qualtrics between June 2023 and October 2024 and offered a $15 Amazon eCard as compensation. This survey was approved by the Archbold Ethics Review Committee, #2023-001.

**Results**

Throughout the six-year period, total annual emissions for scenario 1, averaged 6,294±1095 (stdev) metric tons CO2eq between 2015 - 2020 (Table 1). This resulted in an emissions intensity value of 20.97 kg CO2 eq/kg of live weight. In scenario 2, annual average emissions were 11,294 metric tons CO2 eq. Emissions intensity was 38.53 kg CO2 eq/kg live weight. Annual emissions were driven by variability in enteric fermentation, fertilizer use, and ecosystem emissions.

***Ecosystem Model***

The site-level simulations showed that the *ecosys* model captured both the magnitude and seasonal patterns of carbon fluxes measured by an onsite eddy covariance tower (i.e., ecosystem gross primary production (GPP), and ecosystem respiration (Reco)) with $R^2$ equal to 0.8 and 0.79, for GPP and Reco, respectively. The eddy covariance tower net ecosystem productivity (NEP) was -2.39 ± 0.41 Mg C $ha^{-1}$ $yr^{-1}$. The *ecosys* model estimated the annual average C sequestration rate was 1.84 Mg C/ha/year. At the ranch scale, the annual increase in SOC was 12,391 metric tons eCO2/year.

***Net Carbon Balance at the Ranch Scale***

In Scenario 1, the net carbon balance was -6,097 metric tons CO2eq. Net emissions intensity was on average -20.31 kg CO2eq/kg live weight for calves leaving the ranch. In Scenario 2, the annual average sequestration exceeded annual average emissions by 1,097±3026 metric tons CO2eq. This resulted in an average net emissions intensity of as -3.65 kg CO2eq/kg live weight for calves leaving the ranch.

Table 1. Carbon emission and sequestration analysis from Buck Island Ranch from 2015 – 2020. Results are generated with LCA and the process-based ecosystem model *ecosys*. All units are in metric tons CO2eq, except otherwise noted.

| | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** | **Average** |
|---|---|---|---|---|---|---|---|
| Fertilizer | 0.0 | 430.0 | 0.0 | 336.5 | 127.4 | 0.0 | 149.0 |
| Herbicide | 0.7 | 0.0 | 3.5 | 3.2 | 0.5 | 1.1 | 1.5 |
| Supplemental Feed | 368.4 | 200.8 | 250.3 | 404.3 | 198.1 | 239.2 | 279.9 |
| Farm Machinery Use | 140.9 | 141.0 | 91.1 | 135.5 | 153.1 | 150.4 | 135.3 |
| Farm Electricity Use | 37.3 | 30.7 | 20.3 | 28.8 | 13.4 | 36.6 | 27.9 |
| Direct N2O (*ecosys model*) | 645.5 | 763.1 | 318.0 | 459.9 | 530.3 | 524.6 | 540.2 |
| Indirect soil N2O (*ecosys model*) | 17.1 | 30.9 | 2.3 | 0.7 | 1.6 | 0.0 | 8.8 |
| Enteric fermentation | 5,826.5 | 6,126.2 | 3,883.6 | 4,595.8 | 5,142.9 | 4,405.4 | 4,996.7 |
| Manure methane (LCA method) | 56.2 | 60.9 | 38.4 | 44.1 | 51.1 | 41.4 | 48.7 |
| Soil methane emissions (*ecosys model*) | 7,793.8 | 7,270.5 | 2,915.0 | 3,775.6 | 3,912.8 | 4,625.4 | 5,048.9 |
| Carbon credit/ deduction | 137.8 | -0.5 | 64.2 | 70.0 | -60.6 | 444.9 | 109.3 |
| Scenario 1: Total emissions per year w/manure CH4 (LCA) | 7,230.3 | 7,783.1 | 4,671.7 | 6,078.8 | 6,157.7 | 5,843.6 | 6,294.2 |
| Scenario 2: Total emissions per year with *ecosys* Soil Methane emissions | 14,967.9 | 14,992.7 | 7,548.4 | 9,810.3 | 10,019.4 | 10,427.6 | 11,294.4 |
| Calf live weight sold | 303.3 | 323.2 | 185.0 | 249.5 | 376.7 | 363.5 | 300.2 |
| Scenario 1: Emissions intensity(kg CO2eq/kg LW) | 23.8 | 24.1 | 25.3 | 24.4 | 16.4 | 16.1 | 21.0 |
| Scenario 2: Emissions intensity(kg CO2eq/kg LW) | 49.4 | 46.4 | 40.8 | 39.3 | 26.6 | 28.7 | 38.5 |
| Soil Carbon sequestered (*ecosys model*) | 12,391.1 | 12,391.1 | 12,391.1 | 12,391.1 | 12,391.1 | 12,391.1 | 12,391.1 |
| Net Carbon Scenario 1 | -5,160.8 | -4,608.1 | -7,719.4 | -6,312.4 | -6,233.4 | -6,547.5 | -6,096.9 |
| Net Carbon Scenario 2 | 2,576.8 | 2,601.6 | -4,842.8 | -2,580.9 | -2,371.7 | -1,963.6 | -1,096.8 |
| Net Carbon Intensity Scenario 1(kg CO2 eq/kg LW) | -17.0 | -14.3 | -41.7 | -25.3 | -16.6 | -18.0 | -20.3 |
| Net Carbon Intensity Scenario 2 (kg CO2 eq/kg LW) | 8.5 | 8.1 | -26.2 | -10.4 | -6.3 | -5.4 | -3.7 |

***Producer Survey***

We received a total of 23 survey responses. The results from these respondents are not meant to be representative of all Florida beef producers and are not generalizable. Respondents engaged in climate-smart practices to improve soil condition (n=20), maximize profitability (n=20), and increase yield and/or productivity of the land (n=19). Nearly all respondents (n=20) conducted soil test-based fertilizer applications and rotational grazing (n=19). Barriers to engaging in climate-smart agriculture included lack of or not enough knowledge about practices (n=10, n=9 respectively) and the uncertainty about the impact on farm business (n=8). The primary barriers to participating in carbon markets reported were lack of awareness of and information on existing programs (n=10, n=9 respectively) and no credit for existing practices of past use (n=9). When asked about incentives to participate, payments for past practices (n=14) and no out of pocket program costs (n=14) were top responses.

**Discussion**

Here we showed that a typical ranch in the humid subtropics, is on average, a net sink of carbon. The modelling approach we employed can be utilized to determine baseline carbon footprints and assess management interventions to mitigate emissions or increase soil carbon sequestration. The model estimate of 1.8 Mg C ha $^{-1}$ yr$^{-}$

$^{1}$ (1 m depth) was in line with sequestration estimates measured by soil sampling (20 cm depth: 0.9 Mg C ha $^{-1}$ yr$^{-1}$) and eddy covariance (1.1 -1.4 Mg C ha $^{-1}$ yr$^{-1}$) (Silveira et al. 2024).

Many ranchers are being approached by carbon credits brokers aiming to trade ranch carbon credits in carbon markets. If effective, these markets ensure globally reduced atmospheric greenhouse gas concentrations when buyers pay sellers for reduced emissions or increased sequestration. For Buck Island Ranch to credibly be paid for carbon sequestration, new management reducing emissions or enhancing sequestration is needed, even though the ranch is presently a net carbon sink. Credible carbon markets include the concept of additionality which refers to the need for payments to result in newly avoided emissions or increased sequestration beyond what would have already been occurring without the payment. Emissions could be reduced either from cattle or the environment. Inhibiting cattle methane through feed additives shows promise in the dairy industry (Belanche et al. 2020) and may be useful for pasture-based systems. Increasing soil C stocks is more difficult because many producers are already implementing effective SOC management (Silveira et al. 2024). To have a meaningful impact on climate change, ideally contracts should span at least several decades (Dynarski et al. 2020).

Producers are interested in these programs but lack information about climate smart practices, carbon markets and the best way to engage. They are concerned about the lack of acknowledgment for the benefits of existing practices and require more information about how participating in carbon markets affects farm business.

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