Carbon footprint of high-yielding irrigated alfalfa production in California

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Proposal for U.S. Alfalfa Farmer Research Initiative, National Alfalfa & Forage Alliance

Justification

Agriculture is a major contributor to global greenhouse gas (GHG) emissions and climate change. Food systems are estimated to account for more than one-third of total GHG emissions from human activity, which includes all phases of crop and animal production, food processing and transport, and direct and indirect land use change. Across the world, governments and the private sector are developing ambitious plans to decrease the carbon footprint of crop and livestock production systems. For example, the USDA Agricultural Innovation Agenda seeks to cut the environmental footprint of US agriculture in half by 2050 while increasing production by 40%, including a net reduction in current GHG emissions.

Alfalfa production systems play a critical role in the economic and environmental sustainability of US agriculture. Alfalfa is the most important high-quality forage which supports the dairy and livestock sectors and generates the third or fourth highest direct farm-gate revenue after corn, soybean, and (sometimes) wheat. As a perennial legume, alfalfa also provides multiple ecosystem services related to soil quality, wildlife habitat, pest control, reduced nutrient losses, erosion protection, and lower GHG emissions (Guyader et al, 2016). However, few studies have directly quantified the carbon footprint of alfalfa production. The scope of prior work has often included an analysis of many feed components for dairy or meat production over large regions (Thoma et al, 2013; Adom et al, 2012; Eshel et al, 2014; Hawkins et al, 2015; Veltman et al, 2018), limiting the ability transfer research findings into practical use on livestock or forage operations.

To help meet new climate-smart agriculture goals for the US, there is an urgent need to understand the management factors contributing to GHG emissions from alfalfa production and how soil carbon storage may offset these emissions. Alfalfa has the potential to provide key climate benefits compared to other forage or row crops due to differences in carbon and nitrogen (N) cycling (Little et al, 2017). In the long-term, identifying alfalfa's comparative advantages could help increase revenue for growers through on-farm payments for GHG mitigation, supporting the financial viability of perennial forages which provide important ecosystem services that are currently not valued in livestock value chains.

Alfalfa has been shown to have a lower carbon footprint than grain, silage, or oilseed crops because it greatly reduces nitrogen (N) fertilizer inputs (Camargo et al, 2013). Addition of N fertilizer represents the single greatest contributor to GHG emissions in crop production, reaching up to 64% in maize systems (Kim et al, 2014). Thus, decreasing fertilizer use not only for alfalfa but also the N requirements for subsequent crops could further reduce GHG emissions, but this benefit is often overlooked in previous studies (Costa et al, 2020). Another advantage is the combination of reduced tillage and deep rooting systems providing high carbon inputs throughout the year, which can significantly increase soil carbon stocks (Liu et al, 2016). Unlike frequently-planted annuals, alfalfa is likely to build carbon and N reserves over time (Putnam, 2016), yet prior work has not always considered this mitigation potential. Hence, new research is required to account for these systems-level effects in a holistic analysis. The net impact of different GHG sources including fuel and energy use, external inputs, and soil nitrous oxide (N_2O) emissions can be determined using lifecycle analysis (LCA), an increasingly common tool to quantify agricultural sustainability.

New programs are emerging to financially support farmers for sequestering carbon or avoiding GHG emissions, but these require a foundation of science-based evidence for different cropping systems in different regions. There is a current USDA-funded project to conduct an LCA for primarily rainfed alfalfa production in the US Midwest. However, we are not aware of any work investigating these issues for irrigated systems in the Western US, despite irrigated alfalfa accounting for roughly half of total US production. Irrigation has strong impacts on carbon footprint because it influences both energy use and crop productivity. For instance, irrigation energy accounted for approximately 42% of total GHG emissions for corn in Nebraska (Grassini and Cassman, 2012). This percentage is likely to differ depending upon whether the irrigation system is pressurized (as in Nebraska) vs. gravity-fed (as in many western systems). Additionally, due to the large yield increases achieved with irrigation, a key question is whether the increased productivity is worth the additional GHG emissions. A recent study for alfalfa in Italy reported net benefits of irrigation, with yields increasing to a greater degree than energy use (Bacenetti et al, 2018). In contrast, irrigation combined with fertilization resulted in higher GHG emissions in an arid region of China, representing a tradeoff with yield (Wang et al, 2021).

California consistently ranks among the top states in total forage and total alfalfa production. Alfalfa acreage is almost entirely irrigated, producing among the highest US yields due to favorable soils, climate, management, and genetics. The $7 billion dairy industry is highly dependent upon alfalfa production in the state. However, variation in rainfall and increasing frequency of drought are limiting water availability, causing a decline in alfalfa acreage throughout much of the Western U.S. Meanwhile, production costs for land, labor, and inputs continue to increase, putting pressure on growers to maximize economic returns to available irrigation water. Considering these constraints to on-farm profitability, one opportunity for increasing revenue is to quantify the ecosystem services alfalfa provides and link these to new market opportunities.

California represents the best-case study for this example because of its strong state-based efforts to decrease GHG emissions from agriculture and other sectors. Under the Healthy Soils Program, California growers can receive an incentive of $100-400 per acre to convert annual cropland to an irrigated forage such as alfalfa to achieve the goal of reducing GHG emissions and increasing soil carbon. Recently, USDA has invested $1 billion to jumpstart the development of markets for climate-smart commodities at the national level, indicating that such programs could be expanded to other regions. Importantly, alfalfa's potential for soil carbon storage is estimated to be 2-3 times higher than no-till or cover crops, two of the main regenerative agriculture practices to participate in carbon markets for commodity grain crops.

Objectives

This project will conduct an LCA of high-yielding irrigated alfalfa production in California based on representative management practices. Different sources of GHG emissions will include energy use for fuel and irrigation, embodied emissions in agrochemicals, importance of biological N_2 fixation, estimates of soil N_2O emissions and soil carbon storage, and reduced N fertilizer requirements for the subsequent crop. Project activities will address the following objectives:

1. Quantify the carbon footprint of alfalfa production for three main growing regions in California (Intermountain, Central Valley, and Low Desert). These represent a 3-4 cut system, 5-9 cut system, and 8-12 cut system with distinct varieties, management practices, and environments relevant to the much larger regions of Intermountain West and Southwestern US.
2. Identify the major drivers of GHG emissions and construct mitigation scenarios to explore opportunities for further decreasing carbon footprint without lowering crop productivity. This could include reducing fuel use, increasing irrigation efficiency, changing cutting systems or varieties, or applying soil amendments to build soil carbon. Scenarios will leverage results from previous and ongoing field research in California, emphasizing changes in management with the biggest impact.
3. Perform extension and outreach with alfalfa growers and industry to raise awareness about management practices influencing GHG emissions in California, and explore the feasibility of participating in ecosystem service markets due to the anticipated low carbon footprint.

Methodology

This project will follow recommended international guidelines for implementing LCA in agricultural systems. Guiding frameworks will include the scientific approach developed for LCA 14044 series standards (2006) and UN FAO LEAP (2017) livestock feed methodology. A key strength of our proposal is that Dr. Joel Talliksen from the University of Minnesota will serve as an advisor in developing our LCA framework and sharing methodologies from his current project in the US Midwest (see letter of support for details). This standardization will allow for better comparison of findings across studies, and lay the foundation for a national LCA effort using consistent criteria for different regions. The scope of our project is irrigated alfalfa in California, but this framework can be readily extended to other regions through future research and NAFA partnerships.

In nearly all states where it is grown, alfalfa is rotated with other crops (corn, wheat, cotton, specialty crops, etc.). In our study, a 4- or 5-year alfalfa crop followed by a single year of a rotation crop will be chosen as the model system, after consultation with growers in the three different regions. This way, the carbon and N benefits of alfalfa for the full 'system' can be compared over multiple decades under various climate scenarios, including impacts on the subsequent rotation crop. Representative yields will be obtained from historical UC variety trial data (over 200 location years), and county and state records.

Data analysis and LCA modeling will be conducted with the OpenLCA software. Management practices for each growing region will be obtained from existing UC Davis Cost of Production studies. Potential gaps in data will be filled using results from previous UC field studies or industry input to establish realistic benchmarks. Energy use for different irrigation systems will be estimated using USDA protocols. Soil N_2O emissions will be estimated using IPCC emission factors. The carryover benefits of alfalfa for reducing N fertilizer requirements of the subsequent crop (e.g. tomatoes or wheat) will be derived from previous UC field experiments. Soil carbon storage will be estimated using COMET farm, which reports aggregated results for different counties in California based on the process-based biogeochemical model DayCENT. This quantification methodology is currently used by the California Department of Food and Agriculture's Healthy Soils Program, which provides incentives for management practices that build soil carbon and reduce GHG emissions.

Once the LCA framework has been constructed and the biggest sources of emissions identified, we will create different scenarios for further minimizing emissions. These scenarios will target management factors that constitute the biggest share of carbon footprint, such as irrigation energy use or fuel consumption for harvesting, etc. We will also conduct a sensitivity analysis to test the robustness of results based on different assumptions required for LCA modeling.

This project has strong industry support from the California Alfalfa & Forage Association, a NAFA member (see attached letter). Results from the LCA, when near completion, will be offered to representative farmers for review and ground-truthing in terms of the impacts of different common practices. Our findings will be shared with the farming community at regularly occurring UC Davis field days and extension events, the Western Alfalfa & Forage Symposium, our Alfalfa Website, and through the Alfalfa & Forage News Blog. Results will also be published in peer-reviewed journals.

USAFRI Research Priority addressed

The priority addressed in this proposal is New Uses and Market Development. Throughout the country, there is rapid growth in programs from the government and private sector which provide economic incentives for reducing GHG emissions from commodity crop and livestock production. While alfalfa currently provides soil, water, and climate benefits, these sustainability advantages are generally not recognized or accounted for in the current marketplace. Quantifying the carbon footprint (whether positive or negative) of alfalfa through rigorous research is an important step in developing links with different environmental markets currently being developed.

One example is soil carbon markets where there is an incredible amount of investment. Ecosystem service markets such as Eco-Harvest have also recently been announced for commodity crop production. Similarly, industry efforts like the U.S. Dairy net zero initiative are working to achieve net GHG neutrality with the goal of "establishing new markets and revenue opportunities and transforming the way farms of all sizes can improve their environmental footprint and benefit from untapped revenue potential on farm." Major commodity crops such as corn, soybean, and wheat as well as specialty crops (especially almond) have embarked on detailed research documenting carbon storage with the same goal. This proposal will help document the environmental benefits of alfalfa production systems using quantitative LCA methodology, helping support the long-term objective of increasing on-farm income and profitability through ecosystem service payments for building soil carbon and reducing GHG emissions.

Timeline

This is a two-year project with a start date of Sep 1, 2022 and end date of Aug 31, 2024. Data collection for alfalfa management in California and development of an LCA framework will occur in year 1.

Methods and preliminary results will be shared with growers and agricultural stakeholders during the second half of year 1 and throughout year 2 via the extension activities described above. Analysis and writing of 1-2 manuscripts for peer-reviewed publication will occur during year 2.

Budget and budget justification

The total budget request for this project is $98,200 over two years. The majority of funds will support a postdoctoral scholar at 60% time working under the supervision of Cameron Pittelkow and Dan Putnam. This postdoc will lead all project activities, including developing the LCA framework based on the template provided from the US Midwest project, collecting representative management data for alfalfa production in California, analyzing GHG components to identify biggest drivers, constructing mitigation scenarios to leverage insights from previous field studies, conducting a sensitivity analysis of results, and developing presentations and writing manuscripts for peer-reviewed publication.

The postdoc and both PIs will collectively present findings to industry and agricultural stakeholders to meet the extension objectives of this project. Travel funds are requested to present at NAFA meetings and the international ASA-CSSA-SSSA conference during year 2. Purchasing a background LCA database subscription is required each year to gain access to inventory data and standardized coefficients for carbon footprint analysis. Funds are also requested to publish results in an open-access journal so they can be shared widely with the international agricultural community.

Category	Item/activity	Year 1	Year 2	Total
Personnel	Postdoc salary	35,870	36,947	72,817
	Benefits	7,712	8,171	15,883
Travel	NAFA meeting	1,000	1,000	2,000
	ASA-CSSA-SSSA conference		1,500	1,500
Materials and supplies	LCA background database	2,000	2,000	4,000
	Open-access publication		2,000	2,000
TOTAL*				98,200

*UC Davis Sponsored Programs will review the final budget proposal and values may adjust slightly.

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Key personnel vitae

Attached below

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