Trade-offs between farm profit and greenhouse gas emission reduction

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Abstract

To develop sustainable sheep production, there is a need to stack multiple mitigation interventions on the one land parcel, such as grazing management associated with soil organic carbon (SOC) accrual and feed additives for enteric methane reduction. The study, thus, aimed to investigate trade-offs between farm profit and greenhouse gas (GHG) emission reduction associated with those interventions.

We used soil carbon data measured in a long-term field experiment in New South Wales and data of net emissions (associated with using different feed additives) on two sheep farms (440 ha and 3786 ha), representative for small-scale and larger-scale farms. Then, a mixed-binary nonlinear programming model was applied to identify combinations of grazing management and feed additives to maximise farm profit and minimise net GHG emissions.

The results of both farms indicated that the most appropriate grazing management and feed additives varied depending on farmer's objective was profit or emission reduction or both. If profit was key goal, combination of multi paddock-fast rotation-high stocking rate and 1% walnut shell biochar would be adopted. In contrast, 15 paddock-slow rotation-low stocking rate and flexible grazing stacking with 0.2% Bovaer would be considered to minimise net emissions. If the objective was to maximise profit and minimise net emissions simultaneously, results of adopting multiple grazing management varied depending on farm size. The small-scale farm tended to adopt 15 paddock-slow rotation-low stocking rate and flexible grazing, while the larger-scale farm implemented 15 paddock-fast rotation-high stocking rate and flexible grazing. Furthermore, carbon price was a driver of farmer's decisions on mitigation interventions. The larger-scale farm would change to adopt 15 paddock-slow rotation-low stocking rate and flexible grazing when carbon price was equal or more than $AU50/tonne CO2-equivalent. Thus, policies and legislative process relevant to increases in carbon price should be considered.

Introduction

There is a need to adopt mitigations for sustainable production that balance economic viability with environmental responsibility. Farm management relevant to soil carbon (Meyer et al. 2018) and feed additives (Gerber et al. 2015) are key for GHG emission reduction. While each mitigation has its strengths, combinations of grazing and feed management may provide greater benefits by enhancing emission reduction, improving soil health and boosting farm profitability. This study aims to determine what combination of feed additives and grazing management results in the lowest net farm GHG emissions while maximising profit.

Methods

In terms of data source, measured data of soi carbon sequestration was from a field experiment (Simmons, pers. comment.) at the Orange Agricultural Institute, New South Wales, Australia; while simulated data of sheep production (sheep productivity, feed volume, sheep age, total GHG emissions and emission intensity) were calculated through GrassGro software and SB-GAF tool. Farm characteristics (revenues of selling sheep and wool, land management cost, selling cost, stock management cost, pasture cost, supplement cost, and fixed costs) was collected though two real commercial sheep farms, 430 ha and 3786 ha. Consistent with Pham-Kieu et al. (2024), we extrapolated experimental data to the farm scale and combined with sheep production, then a invoked programming modelling approach.

We developed three mixed-binary nonlinear programming models to identify optimal combinations of grazing treatments – feed additives, grazing area allocation, the number of sheep sold and their age. These models aimed to maximize farm profit, minimize net GHG emissions, or achieve a balance between the two objectives. While the models differed in their objective functions, they shared a similar set of constraints. We assumed that farmers would maintain consistent grazing and feed management practices over a six-year period for a single sheep flock. Then the models were formulated below:

	Model I	Model II	Model III
Objective function	Max Sheep profit	Min Net GHG emissions	Max Profit = Sheep profit + environmental income
Subject to all constraints	- Constraints of SOC accrual - Constraints of sheep productivity and enteric methane reduction - Constraint of total GHG emissions - Constraints of stocking rate and sheep numbers - Constraints of revenue and production costs		

Results

Optimal grazing and feed management

When profit was prioritised on two farms (Model I), they would raise more sheep (approximately 1.5 times larger than those of Model II), achieved higher sheep profit and released higher emission intensity (Fig.1). While 15 paddock-fast rotation-high stocking rate was dominated on larger farm, there was a split between grazing area subject to this treatment and 30 paddock-fast rotation-high stocking rate on small farm (Fig.2). Despite generating greater profit, large farm had an emission intensity of approximately 0.6 tCO2-e/DSE higher than small farm. In contrast, if the primary goal was to reduce GHG emissions, higher emission reduction and lower profit were realised with flexible grazing and 15 paddock-slow rotation-low stocking rate. For trade-off between profit and emissions, similar adoption was considered on small farm, while combination of 15 paddock-fast rotation-high stocking rate and flexible grazing was adopted on large farm. Such grazing regimes led to higher emission intensity (about 0.4 tCO2-e/DSE higher) and lower environmental income (around $AU3/DSE less) compared with small farm. 1% biochar was used to maximise profit, while 0.2% Bovaer was considered to minimise net emissions or achieve both goals on 2 farms.

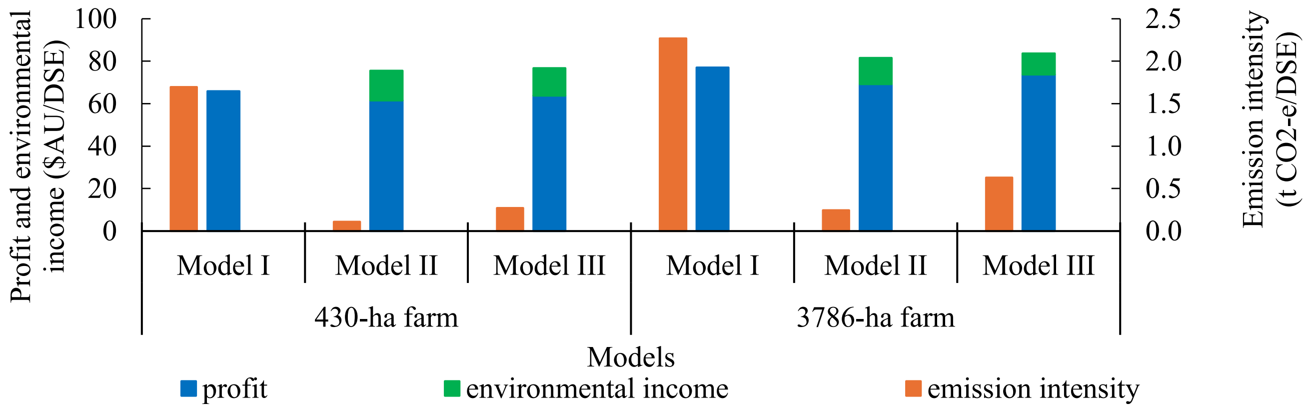

Fig. 1. Farm profit and emission intensity over 10-year simulation for three models subject to adoption of grazing treatments and feed additives

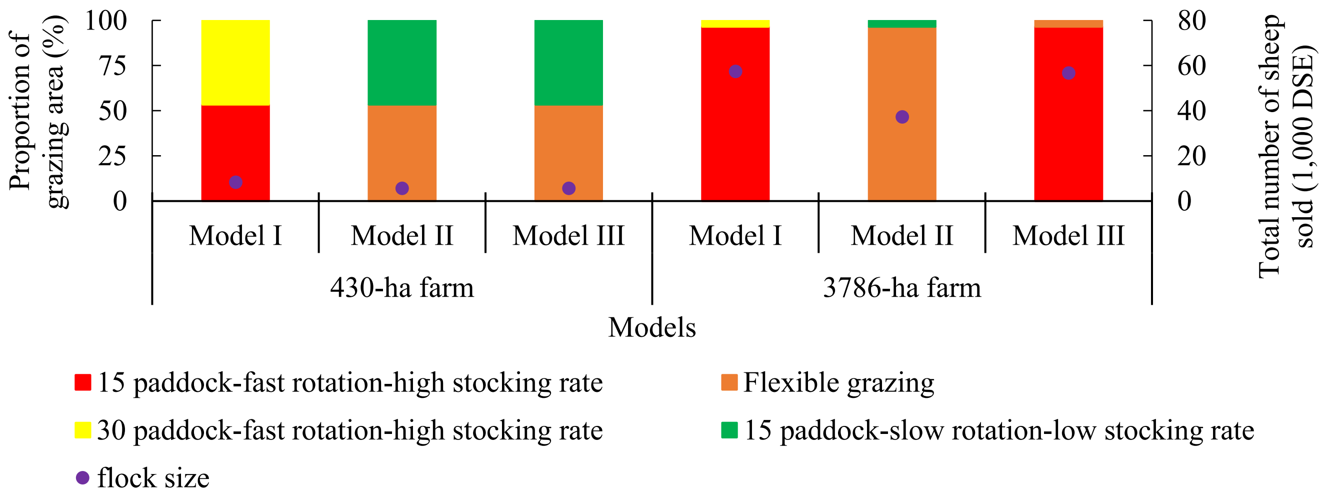

Fig. 2. Grazing management scenarios examined in the study and simulated number of sheep sold.

Impacts of carbon price on farm decision-making

When carbon price increased, small-scale farmer tended to sell sheep at early age, but did not alter their decisions on adopting grazing and feed management. In contrast, large-scale farmer adjusted their grazing management, shifting from 15 paddock-fast rotation-high stocking rate to 15 paddock-slow rotation-low stocking rate with flexible grazing dominated the grazing area, although they did not change feed management or the timing of sheep sales.

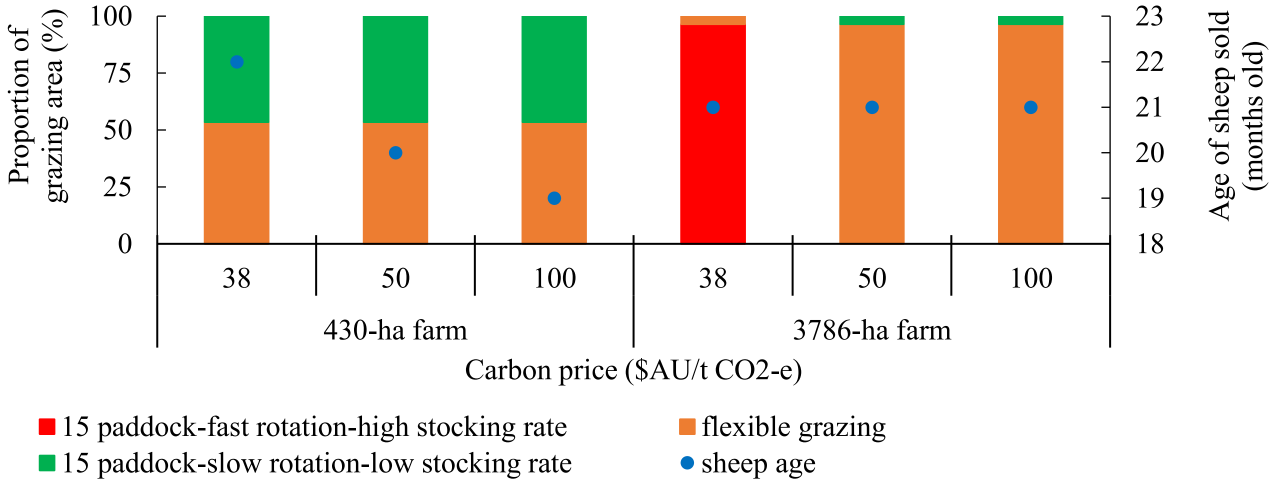

Fig. 3. Impacts of carbon price on grazing area allocation and emission intensity on farms.

Discussion

Align with Beauchemin et al. (2022), we found that combinations of grazing and feed management varied depending on farmer's objectives, even though these combinations bring greater results in emission reduction than any single management (Fujisaki et al. 2018; Harrison 2021). Fast rotation-high stocking rate with 1% biochar was most conducive to profit-aim, while flexible grazing and slow rotation-low stocking rate with 0.2% Bovaer was more conducive to emission-aim. Fast rotation-high stocking rate, though preferred for profit, is detrimental to SOC in the long term as it would negatively impacts on pasture productivity, decreasing above- and below-ground biomass and reducing SOC (Bilotto et al. 2023). In contrast, flexible grazing or slow rotation-low stocking rate (Rouquette 2015; Badgery et al. 2017) can reduce grazing pressure, promote forage growth, and increase both above and below-ground biomass, contributing to greater SOC accrual. Although multiple paddock systems can optimise pasture use and promote environmental sustainability (Jorns et al. 2023), the 30-paddock system was not preferable on large farm due to its high costs and substantial infrastructure requirements. For feed additives, biochar was preferable for profitability due to its ability to improve animal productivity (Mirheidari et al. 2019) and its lower cost compared with other feed additives, wheares Bovaer was more effective in reducing enteric methane emissions (Martínez-Fernández et al. 2014). Asparagopsis was excluded from all models due to its high cost.

Consistent with Pham-Kieu et al. (2024), our results indicated that trade-offs between profit and emission reduction was context-dependent, varying across farm size. Large-scale farmer tended to favour grazing treatments with lower infrastructure cost since they focus on optimising efficiency and minimising infrastructure investment to reduce overall production costs. Small-scale farmer, however, split the adoption of low- and high-cost treatments, likely due to higher potential for environmental income. As farmers would alter management relating to mitigation when potential profit was greater than their current activities, increased carbon price may attract more participants to join carbon credit markets and mitigate net emissions on their farms. However, the extent of these changes may depend on farm size, as large-scale farmer is likely to be responsive with price fluctuation. This could be due to their greater capacity to absorb risks, access to resource, or more substantial economic incentives. In contrast, the small farm may have limited financial resources and less flexibility to make major changes unless the financial benefit is clearly significant. Hence, future policies and legislation should thus consider mechanism to increase carbon prices and create opportunities to realise economic, environmental, social and cultural co-benefits associated with carbon farming practices.

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References

Badgery, W, Millar, G, Broadfoot, K, Martin, J, Pottie, D, Simmons, A & Cranney, P 2017, 'Better management of intensive rotational grazing systems maintains pastures and improves animal performance', *Crop and Pasture Science*, vol. 68, no. 12, pp. 1131-1140.

Beauchemin, KA, Ungerfeld, EM, Abdalla, AL, Alvarez, C, Arndt, C, Becquet, P, Benchaar, C, Berndt, A, Mauricio, RM, McAllister, TA, Oyhantçabal, W, Salami, SA, Shalloo, L, Sun, Y, Tricarico, J, Uwizeye, A, De Camillis, C, Bernoux, M, Robinson, T & Kebreab, E 2022, 'Invited review: Current enteric methane mitigation options', *Journal of Dairy Science*, vol. 105, no. 12, pp. 9297-9326.

Bilotto, F, Christie-Whitehead, KM, Malcolm, B & Harrison, MT 2023, 'Carbon, cash, cattle and the climate crisis', *Sustainability Science*, vol. 18, no. 4, pp. 1795-1811.

Fujisaki, K, Chevallier, T, Chapuis-Lardy, L, Albrecht, A, Razafimbelo, T, Masse, D, Ndour, YB & Chotte, J-L 2018, 'Soil carbon stock changes in tropical croplands are mainly driven by carbon inputs: A synthesis', *Agriculture, Ecosystems & Environment*, vol. 259, pp. 147-158.

Gerber, PJ, Mottet, A, Opio, CI, Falcucci, A & Teillard, F 2015, 'Environmental impacts of beef production: Review of challenges and perspectives for durability', *Meat Science*, vol. 109, pp. 2-12.

Harrison, MT 2021, 'Climate change benefits negated by extreme heat', *Nature Food*, vol. 2, no. 11, pp. 855-856.

Jorns, TR, Derek Scasta, J, Derner, JD, Augustine, DJ, Porensky, LM & Raynor, EJ 2023, 'Adaptive multi-paddock grazing management reduces diet quality of yearling cattle in shortgrass steppe', *The Rangeland Journal*, vol. 45, no. 4, pp. 160-172.

Martínez-Fernández, G, Abecia, L, Arco, A, Cantalapiedra-Hijar, G, Martín-García, AI, Molina-Alcaide, E, Kindermann, M, Duval, S & Yáñez-Ruiz, DR 2014, 'Effects of ethyl-3-nitrooxy propionate and 3-nitrooxypropanol on ruminal fermentation, microbial abundance, and methane emissions in sheep', *Journal of Dairy Science*, vol. 97, no. 6, pp. 3790-3799.

Meyer, RS, Cullen, BR, Whetton, PH, Robertson, FA & Eckard, RJ 2018, 'Potential impacts of climate change on soil organic carbon and productivity in pastures of south eastern Australia', *Agricultural Systems*, vol. 167, pp. 34-46.

Mirheidari, A, Torbatinejad, NM, Shakeri, P & Mokhtarpour, A 2019, 'Effects of walnut shell and chicken manure biochar on in vitro fermentation and in vivo nutrient digestibility and performance of dairy ewes', *Tropical Animal Health and Production*, vol. 51, no. 8, pp. 2153-2160.

Pham-Kieu, M, Ives, S, Badgery, W & Harrison, MT 2024, 'Tensions between private and public benefit associated with carbon farming', *Sustainable Production and Consumption*, vol. 49, pp. 387-397.

Rouquette, FM 2015, 'Grazing Systems Research and Impact of Stocking Strategies on Pasture–Animal Production Efficiencies', *Crop Science*, vol. 55, no. 6, pp. 2513-2530.