# The nexus between rotation profits and emissions: the impact of legumes?

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**Abstract**
Mitigating greenhouse gas emissions is an increasing priority for Western Australian grain producers. This study investigates the environmental and economic viability of integrating lupins and legume pastures into crop rotations at three locations in Western Australia's grainbelt. Modelling simulations using the Economic Valuation of Alternative Land Use Sequence (EVALUS) model were conducted at each location to examine the gross margins and emissions associated with including lupins and legume pastures in current rotations. Findings indicate that replacing canola with lupins consistently reduces emissions at all locations. However, retention of canola over lupins generally boosts profits, highlighting the need to develop other more sustainable and profitable alternatives to canola. Inclusion of legume pastures rather than lupins yields mixed results. A phase of pasture with legumes in the sward provides fixed nitrogen to subsequent cereal crops and thus reduces the need for applied fertiliser and educes attendant emissions. However, the trade-off is increased farm level emissions (Scope 1) from livestock grazing in the pasture phase, thus increasing overall farm-level emissions in several analysed scenarios. Modelling results demonstrate how land use diversification can support business resilience and profitability but also highlight the pressing need for technological and biological innovation to mitigate agricultural emissions. The results illustrate that continued research and policy support is needed to drive sustainable and profitable practices in dryland agriculture in Western Australia.

**Keywords**
Modelling, Gross Margins, Emissions, Legumes

## Introduction

Agriculture in Western Australia (WA) contributes approximately 12% to the state's total emissions (DCCEEW, 2024). Within agriculture, broadacre cropping accounts for 15% of agricultural emissions, as identified by Curnow et al. (2022). However, recent research suggests that the carbon footprint of broadacre cropping is underestimated due to differences in emission inclusions (d'Abbadie & Machon, 2024). Fertilizer and chemical use, along with livestock in mixed farming systems, have been identified as the primary drivers of these emissions (Taylor et al., 2022; Kharel et al, 2022; d'Abbadie & Machon, 2024).

Incorporating legume crops into rotations has been shown to reduce emissions from subsequent cereal crops in specific WA locations (Barton et al., 2013). Additionally, Kharel et al. (2022) have discussed the benefits of legume pastures in rotations. However, the adoption of new emission factors has significantly altered the emissions profile of cropping systems.

This study aims to evaluate the economic and environmental impacts of including legume pastures and lupin crops (*Lupinus angustifolius*) in rotations. By conducting a comprehensive analysis across multiple locations and systems, and considering various emission sources, this research seeks to provide robust recommendations for sustainable crop rotations in WA.

## Methods

To capture the diverse geographic, soil, and climatic variations within WA's grainbelt, three study sites were strategically selected. The locations represent high, medium, and low rainfall areas as described in Farmanco (2022), Planfarm (2022) and GIS (2016). Key characteristics of the locations are listed in Table 1.

Comprehensive data on production inputs, crop diversity, yields, stocking rates, input expenses, revenue streams, and emission profiles for each location were drawn from Kharel et al. (2022) and d'Abbadie et al. (2023), encompassing the period 1994-2023.

**Table 1: Description of locations selected.**

| Location | Latitude | Longitude | Mean Growing Season Rainfall (mm) [1994-2023] | Soil type considered |
|---|---|---|---|---|
| Northampton | -28.356652 | 114.633531 | 348 | Deep Sand |
| Wongan Hills | -30.888478 | 116.716978 | 252 | Deep Sand |
| Merredin | -31.484890 | 118.280894 | 205 | Shallow Sandy Duplex |

The economic and emission impacts of various crop rotations were evaluated using the Economic Valuation of Alternative Land Use Sequence (EVALUS) model (Kharel et al., 2023). This model employed 15 years of randomized 1994-2023 weather and price data, including 30 iterations of different 15-year sequences to generate robust findings. The model evaluates the land use sequence considering their carry-over effects on soils, nitrogen application, acidity and diseases, within other environmental effects.

The estimation of greenhouse gas (GHG) emissions for the different rotations was based on the current methodology from the National inventory report (DCCEEW 2024), using the GHG frameworks developed by the Primary Industries Climate Change Centre's (Lopez et al. 2024a, Lopez et al. 2024b).

The study examined six different crop rotations:

- CCK: Cereal - Cereal - Canola
- CCKP: Cereal - Cereal - Canola - Legume Pasture
- CPCK: Cereal - Legume Pasture - Cereal - Canola
- CPPP: Cereal - Legume Pasture - Pasture - Pasture
- CCL: Cereal - Cereal - Lupin
- CCLP: Cereal - Cereal - Lupin - Legume Pasture

In these rotations, 'C' represents cereal, 'K' represents canola, 'P' represents legume pasture, and 'L' represents lupin. For Northampton, the cereal considered was only wheat, while for the other locations wheat followed by barley was selected. The first four rotations were designed to compare the inclusion of legume pastures in the rotation. The last two rotations aimed to evaluate the impact of lupins, both individually and in combination with legume pastures. The legume pasture phases assumed the presence of livestock in the system. Additionally, if livestock were present, it was assumed that they grazed the crop stubble.

## Results

*Finding 1: Legumes in the rotation yield mixed results regarding net margin and emissions.*

The inclusion of legume pastures in crop rotations yielded mixed economic outcomes across the selected locations. As illustrated in Figure 1, integrating legume pastures generally reduced the rotational net margin. This decrease is attributed to the lower proportion of high-value crops in the rotation compared to pastures. However, it is important to highlight that those rotations with a higher proportion of crops exhibited greater variability in economic returns. This variability underscores the potential benefit for mixed farm producers to maintain livestock within their operations, as it provides a more stable and consistent cash flow regardless of seasonal fluctuations.

In the northern sandy location of Northampton, the inclusion of lupins in the rotation either increased or maintained net margins, demonstrating the economic viability of lupins at this location. Conversely, in the lower rainfall environment of Wongan Hills and Merredin, lupins did not offer any significant economic benefit. This lack of economic gain at drier locations suggests that alternative crops or management strategies may be more appropriate to enhance rotational profitability in these environments.

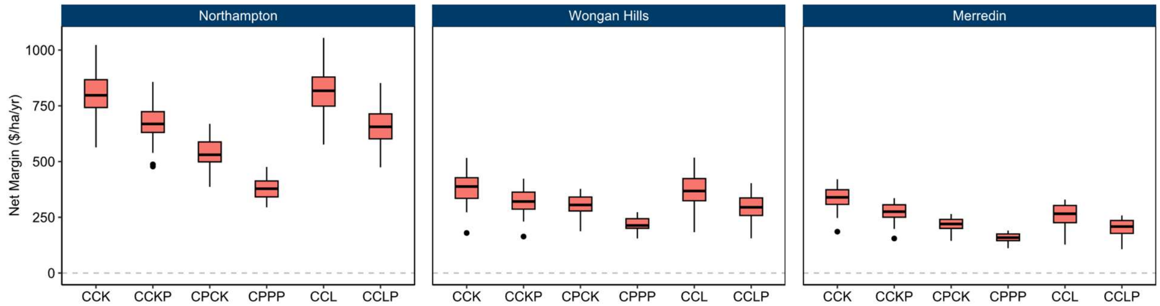


**Figure 1: Net margin ($ per hectare of rotation per year) for the six different rotations at the three selected locations for the period 1994-2023.**

As shown in Figure 2, incorporating legume pastures into crop rotations increased emissions on a per hectare basis at all locations. This is due to the inclusion of livestock in the system. However lower stocking rates may in practice generate different results to the ones modelled in this study as suggested by Plunkett et al (2023). This study's findings also contrast with those reported by Kharel et al. (2022) who identified locations where adding livestock could potentially reduce emissions. The discrepancy between our findings and those of Kharel et al. (2022), however, is primarily due to the adoption of new emission factors in this current study which more comprehensively accounts for livestock emissions.

In contrast to the findings for legume pasture, the inclusion of lupins in crop rotations consistently decreased emissions. Replacing canola with lupins resulted in reduced emissions at all locations examined. This substitution also leads to increased gross margins, mostly in the northern sandy location of Northampton. At other lower rainfall locations, while lupins contribute to lower emissions, they do not significantly increase rotational gross margins.

These findings highlight the need for region or location-specific strategies when integrating legumes into crop rotations. The environmental benefit of lupins, particularly their potential to reduce greenhouse gas emissions, underscores their suitability as a more sustainable crop alternative. However, the economic viability of inclusion of lupins or legume pastures varied by location, suggesting that further research and development are necessary to provide rotational options that deliver positive environmental and economic outcomes.

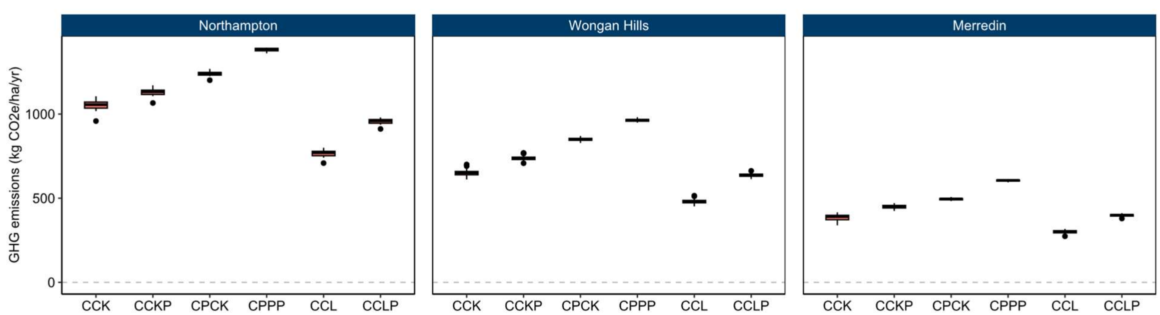


**Figure 2: Average greenhouse gas (GHG) emissions (in kg $CO_2e$ per hectare of rotation per year) for the six different rotations at the three selected locations.**

*Legumes in the rotation reduces cereals emissions intensities*

As illustrated in Figure 3, incorporating legumes into crop rotations reduces the emission intensities of subsequent cereal crops. This reduction is primarily due to the increased nitrogen availability provided by legumes, which lessens the need for synthetic nitrogen applications in subsequent cereal crops. Consequently, the carbon footprint of these cereals is reduced.

It is important to note that, due to allocation methodologies, the GHG benefits associated with including legumes in rotations cannot be directly attributed to the legumes themselves but rather to the cereal crops that follow them (Sevenster et al. 2023). This highlights the critical role of legumes in enhancing the sustainability of cereal production through their nitrogen-fixing capabilities and their overall contribution to lower GHG emissions in cereal cultivation.

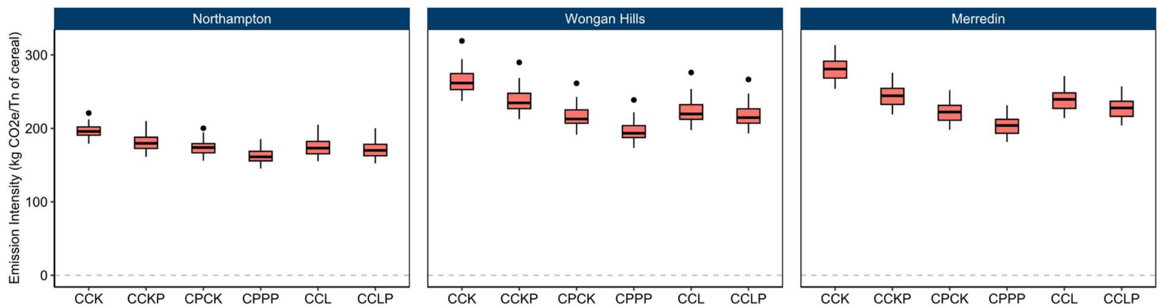


**Figure 3: Emissions intensities for cereals [wheat and barley] (in kg $CO_2$e per tonne of cereal) for the six different rotations at the three selected locations.**

## Conclusion

The inclusion of legumes in crop rotations at three locations in the grainbelt of Western Australia yields mixed economic and environmental results. While legume pastures reduced cereal emission intensities by enhancing nitrogen availability, they also increased overall rotational emissions due to livestock grazing. Although effective in reducing emissions and increasing margins at a higher rainfall location with sandy soil, lupins did not boost rotational gross margins at the other two drier locations.

Farmers should consider their specific soil, rainfall and business constraints when optimizing their farm profitability and emissions. Policy incentives focused on reducing cereal emission intensities should be carefully designed to avoid increasing total farm emissions.

Continued research and innovation are crucial to develop sustainable and profitable agricultural practices that balance the economic viability of farming against the need for environmental stewardship in agriculture.

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