Extended Abstract
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Paper/Poster Title	**Legume adaptation, risk and its interaction with soil management in grazing systems: a bioeconomic modelling approach**

Abstract prepared for presentation at the 98th Annual Conference of The Agricultural Economics Society will be held at The University of Edinburgh, UK, 18th - 20th March 2024.

Abstract	***200 words max***

Field research has identified that white clover was the perennial legume species that offered the greatest potential to improve livestock productivity across the eastern High Rainfall Zone of Southern Australia. Using an existing dynamic and stochastic whole farm bioeconomic model, the Sustainable Grasslands Model (v1.08), we modelled grazing systems in different agro-ecological zones across a north-south transect across New South Wales (NSW), to capture low-high rainfall, seasonal distribution of rainfall and species adaptation. The results across all sites indicate that both sheep meat and wool production in the high input systems are 3-4 times higher than the nil, and nearly 2 times higher than the low input system.
The findings highlight the differences between the agro-ecological zones in response to investments in soil fertility and maintaining white clover in the sward. Interactions between climatic variation and pasture productivity, persistence and quality, were the main drivers of economic performance. From a management perspective, there is little or nothing gained from low input systems to promote white clover persistence within the more marginal agro-ecological zones, due to their exposure to input price risk and reduced responses to improvements in soil fertility and re-sowing pastures.

Keywords	Farm profitability, persistence, soil acidity, phosphorus
JEL Code	Agricultural R&D; Agricultural Technology Q160 see: www.aeaweb.org/jel/guide/jel.php?class=Q)

Introduction	***100 – 250 words***

In the high-rainfall region of south-eastern Australia nitrogen (N) remains a key limitation to productivity in permanent pastures. Legumes, the key source of N in those mixed sward systems, generally lack persistence, especially under drought conditions or where grazing management is sub-optimal. Consistent with previous research, recent field research revealed that there is a relatively narrow range of viable species options available with the persistence required in permanent pastures. Despite being sensitive to drought, white clover (*Trifolium repens*) was found to be the perennial legume species that was most consistent across a broad range of environments and soil types and therefore offered the greatest prospect to improve livestock productivity. Additionally, the field research revealed that improving soil fertility, especially through elevated levels of soil pH and soil phosphorus (P), improved legume productivity and persistence.
The aim of this work is to define the impacts on whole farm profitability of addressing soil pH deficits with lime and adding phosphorus fertiliser to improve white clover persistence

and permanent pasture production across a range of agro-ecological zones. To define the farm level impacts there is a need to consider the dynamic interactions between climatic variability, soil fertility management, pasture legumes and whole-farm profitability.

Methodology	***100 – 250 words***

Using an existing dynamic and stochastic whole farm bioeconomic model, the Sustainable Grasslands Model (v1.08), we modelled grazing systems in different agro-ecological zones across a north-south transect across New South Wales (NSW), to capture low-high rainfall, seasonal distribution of rainfall and species adaptation. The model was calibrated using field trial data from the *LPP project - Extending the boundaries of legume adaption through better soil management*, and applied to four case study sites located in the Northern Tablelands (Guyra), Central Tablelands (Orange), Southern Tablelands (Gunning) and Monaro (Cooma) regions of NSW. Using a typical self-replacing Merino system, all sites are modelled to transition from a common initial state in response to three alternative input systems: nil, low (targeting soil pH_{Ca}: 4.8-5.2; 0.65-0.5 x Critical Soil P; minimum 2% white clover) and high (targeting soil pH_{Ca}: 5-5.5; 1.2-1.1 x Critical Soil P; minimum 2-4% white clover). Each input system uses these decision rules to trigger capital and maintenance applications of lime and phosphorus fertiliser, and pasture re-sowing when there are low levels of white clover in the sward. Expected 'best practice' stocking rates and grazing rules are applied to each whole farm system and case study site. The maximum sustainable stocking rate for each site and system are identified over a 10-year simulation horizon to ensure systems maximise profitability while remaining sustainable in response to any changes in soil fertility and subsequent pasture production.

Results	***100 – 250 words***

The results across all sites indicate that both sheep meat and wool production in the high input systems are 3-4 times higher than the nil, and nearly 2 times higher than the low input system. Similarly, across all sites the high input systems achieved the highest gross margins in the long-run ($1067-$1359 ha^{-1}), followed by the low input ($626-$758 ha^{-1}) and nil systems ($338-$440 ha^{-1}). Cooma had the lowest and most variable gross margins, the highest and least variable were at Guyra and Orange, with Gunning being in-between. Analysis of annual cash flows indicates the large capital investment required at the start of a transition, especially when adopting high input systems. However, in the long-run, the nil systems will generate annual cash flows that are only 15-20% of that achieved under the high input systems, with the low input systems generating around 50% of the high input system. Using Net Present Value to define the aggregated 10-year impact of adopting different systems, it indicates that the high input system achieves the highest economic performance at all sites. The high input systems provided marginal gains of $368-$547 ha^{-1} yr^{-1} above that of nil, and $264-$288 ha^{-1} $year^{-1}$ more than low input systems. A sensitivity analysis of outcomes to fertiliser and lime prices shows that rankings did not change, although the impacts were larger for the riskier high input systems.

Discussion and Conclusion	*100 – 250 words*

The findings highlight the interactions between climatic variation and pasture productivity, persistence and quality, which were found to be the main drivers of economic performance. The case study sites that benefited the least from investment were the riskier environments. This corresponds well to the climatic variability experienced at each site, with drier more variable climates gaining the least from investments into soil fertility and perennial legumes. From a management perspective, there is little or nothing gained from low input systems within the more marginal agro-ecological zones, due to their exposure to input price risk and reduced responses to improvements in soil fertility and re-sowing pastures. The results indicate that high input systems consistently achieved higher economic performance, with the effective rate of return positively correlated with the amount of rainfall within a region, but negatively correlated with its variability.

Some of the results expected and previously reported in literature where not observed in this study, e.g. low soil fertility effects severely degrading ground cover and causing soil erosion. This is likely to be a result of the imposed biomass-based grazing rules and the recursive identification of profit maximising sustainable stocking rates for each specific input system and site. The applied multi-criteria approach to comparing input systems and stocking rates provides a more rigorous assessment of economic benefits and avoids the situation whereby the economic performance of an input system can be inflated through over-stocking and deriving economic benefit through resource degradation without incurring the full costs of degradation.