Edmar Teixeira[1,2]

Sylvain Leduc[3]; Florian Kraxner[3]; Piera Patrizio[3,4]; Jing Guo[5]; Richard Yao[6]; David Palmer[6]; Paul Johnstone[1]; Thomas Sowersby[1]; Richard Edmonds[1]; Shane Maley[1]; Abha Sood[7]; Derrick Moot[2]

edmar.teixeira@plantandfood.co.nz

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Design and analysis of novel food systems through biophysical/techno-economic spatial modelling: A case study with plant-based protein from lucerne crops in New Zealand

[1] The New Zealand Institute for Plant and Food Research Limited (PFR; New Zealand)
[2] Lincoln University (LU, New Zealand)
[3] The International Institute for Applied Systems Analysis (IIASA; Laxenburg, Austria)
[4] Imperial College London (ICL, UK)
[5] Manaaki Whenua – Landcare Research, New Zealand (MW-LR; New Zealand);
[6] Scion – New Zealand Forest Research Institute Limited (Scion; New Zealand)
[7] The National Institute of Water and Atmospheric Research (NIWA)

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The New Zealand Institute for Plant and Food Research Limited

Background

- Food value chains (FVC) are inherently complex systems which will likely be subjected to compounding environmental and economic pressures in the coming decades. These include climate change, stricter environmental regulations and societal demands for healthier, more nutritious and sustainably produced food options.
- Systems analysis methods that dynamically capture interactions within and across FVC sub-components, including biophysical (e.g. climate, genotypes and soils) and socio-economic (e.g. processing technologies and markets), can support the design of more sustainable and resilient food systems for future conditions.
- We describe the initial conceptualisation and preliminary results of a systems analysis framework developed to evaluate sustainability and optimise resource allocation in novel FVC at the agricultural landscape scale.
- We test the framework through a case study focusing on the assessment of a new plant-based protein value-chain from lucerne crops (*Medicago sativa*) across New Zealand (Figure 1).
- Globally, there is increasing demand for high quality protein for human consumption, and the use of perennial legume crops, such as lucerne, with high protein quality and high yield potentials may positively contribute to future global protein supply.
- To quantitatively assess benefits and trade-offs of this new FVC, we spatially integrate protein-yield simulations from a process-based agricultural model into a techno-economic model, considering georeferenced production-resource datasets across New Zealand.

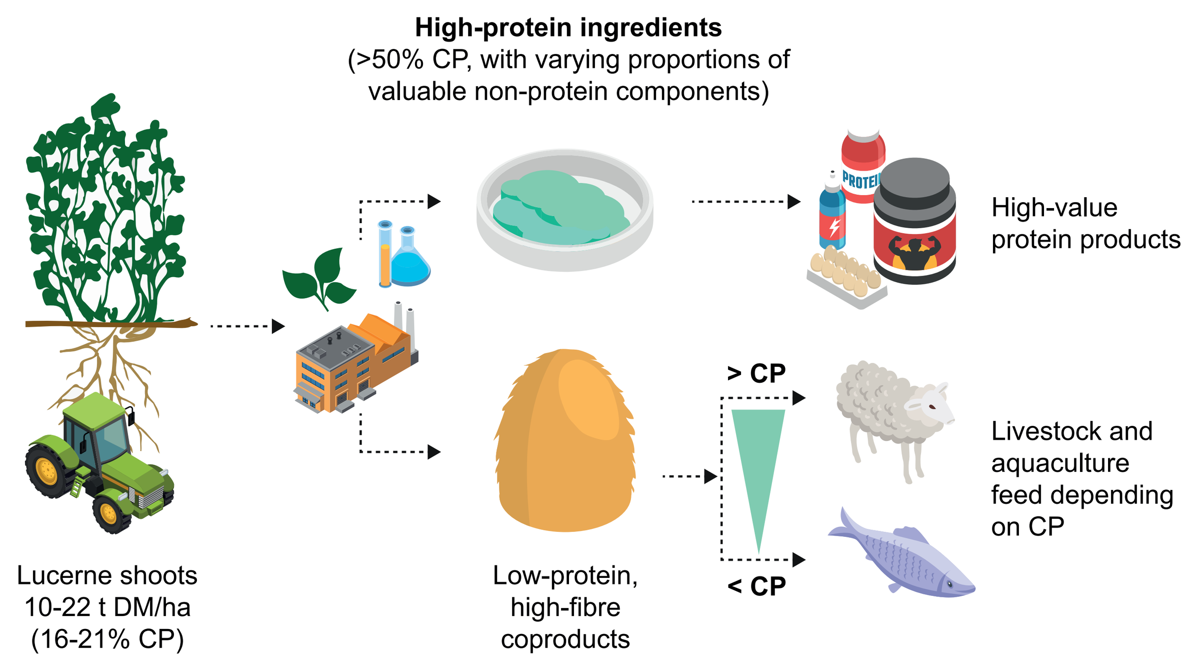

Figure 1: Conceptual representation of the case study showing a novel value chain for lucerne-based protein for human consumption considering high and low crude protein (CP) concentrates.

Methodological approach

- The systems analysis pipeline under development is shown in Figure 2.
- Lucerne production systems responses to climate, management and genotype choices are parameterised in the Agricultural Production Systems sIMulator (APSIM) Next Generation (Holzworth et al., 2018, 2014).
- The APSIM-NextGen lucerne prototype (Yang et al., 2021) dynamically integrates processes from plants and soils to simulate lucerne above-ground biomass and protein yields in this case study.
- The model is spatially applied within a High Performance Computing Environment (HPC) of the ATLAS (Assessment Tool for Landscape Agricultural Systems) framework (Teixeira et al., 2020). Only lands estimated as 'suitable' for lucerne growth, based on a sequence of filtering criteria, are considered in simulations (Figure 3).
- Within HPC, ATLAS generates 30-year biomass and protein yield distributions (and other crop/soil impact metrics) at 5 km resolution in response to daily weather data for historical climate (or climate change) scenarios, and considering different soil-types/water-supply (rainfed or irrigated) combinations across New Zealand.
- ATLAS spatial 'outputs' are then assimilated as 'input' by the techno-economic model BeWhere (www.iiasa.ac.at/models-and-data/bewhere), developed at IIASA.
- BeWhere is currently being parameterised for New Zealand to integrate national georeferenced datasets on production resources (e.g. transport network, infrastructure and labour spatial allocation).
- In the next stage of the project, BeWhere will be used to spatially estimate optimal plant-based protein processing unit locations, processing capacity, production costs and emissions across New Zealand, considering main products and coproducts (Figure 1).

Preliminary results

- Preliminary results are now available for the midlife stage of the project (Stage 3 in Figure 2). Specifically, ATLAS spatial outputs are being now tested before the BeWhere modelling stage is resumed.
- In addition, an initial mapping of land suitability for lucerne was developed across New Zealand (Figure 3).
- For suitable areas, lucerne above-ground yields (Figure 4), considering both high and low water availability conditions, showed a strong spatial pattern with mean values declining from >20 t DM/ha in the north to <10 t DM/ha in the south.
- Physiologically, APSIM indicates that this spatial pattern is mainly driven by a reduction in canopy development and net carbon assimilation for total plant biomass (shoots and roots) growth, as temperatures decline at higher latitudes.
- For rain-fed conditions and soils with low water holding capacity, yield decline was particularly intense in the drier climates of the east coast and central South Island, where drought stress is exacerbated.

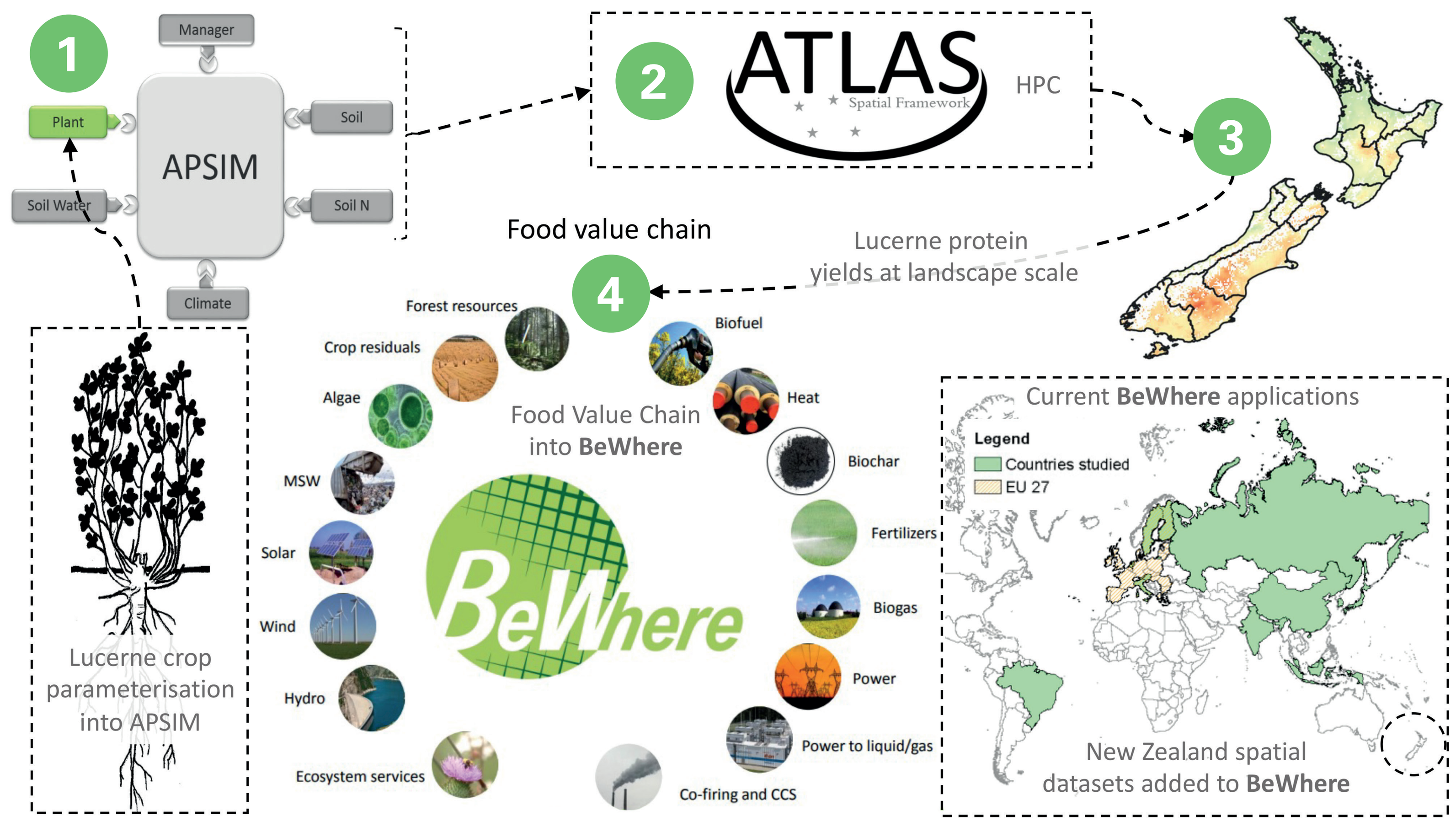

Figure 2: The workflow to assess value-chain scale impacts of new agricultural activities. The analysis pipeline follows the steps: (1) Lucerne cropping systems are parameterised in the Agricultural Production Systems sIMulator (APSIM); (2) APSIM simulations are tested and moved to a High-Performance Computing environment (HPC) in the ATLAS (Assessment Tool for Landscape Agricultural Systems) framework; (3) Landscape scale protein yield simulations across New Zealand are produced; and (4) BeWhere assimilates spatial protein yield data from ATLAS and georeferenced datasets from New Zealand to then optimise food value chains. This is added as a new domain alongside current energy-sector related options.

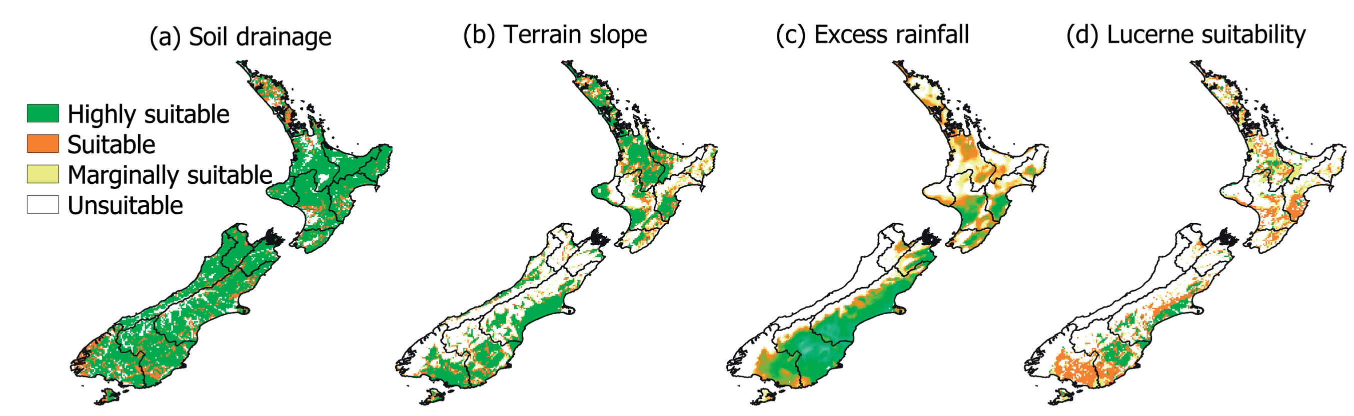

Figure 3: Criteria used to define suitable areas for lucerne growth across New Zealand.

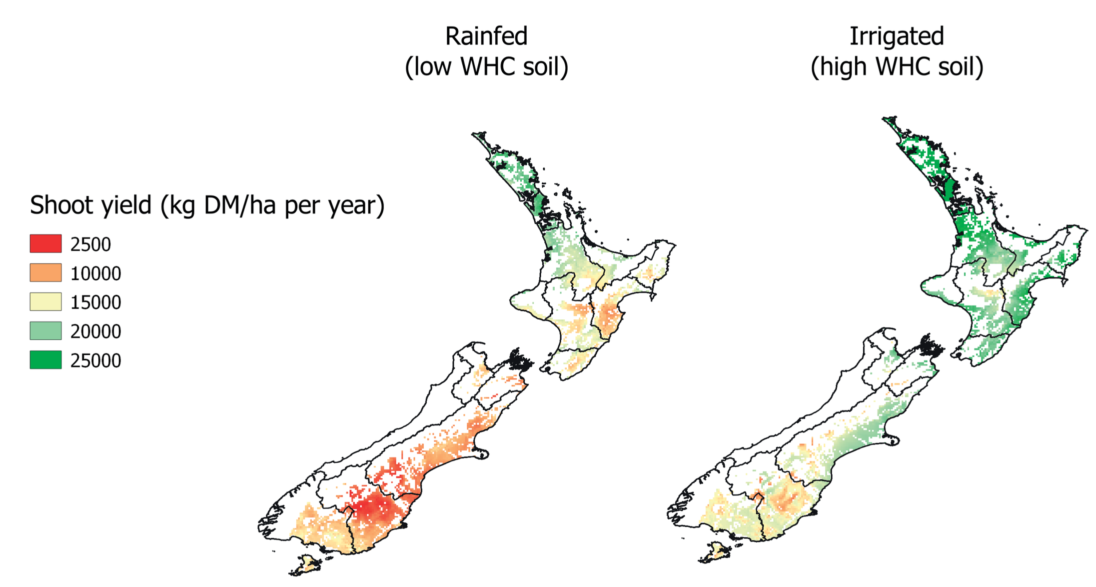

Figure 4: Potential above-ground lucerne yield (30-year mean) simulated by the APSIM-Next Generation Lucerne Prototype within the ATLAS framework, considering rain-fed conditions at low (75 mm) water holding capacity (WHC) and irrigated conditions at high (525 mm) WHC at 2 m depth profile across New Zealand.

Final remarks and next steps

- The observed spatial patterns in lucerne protein productivity, including inter-annual variability changes, are likely to be transferred to economic and environmental aspects of the value-chain system.
- Techno-economic implications of such cropping system responses will be evaluated using BeWhere in the next stage of this work (i.e. Step 4 in Figure 2).
- This will provide insights into biophysical and socio-economic sustainability metrics for the novel FVC, including costs and optimal spatial allocation of production resources, such as siting of plant-protein processing units across New Zealand.

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