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Validated simulation of a long-term experiment reveals a pathway for improved crop productivity

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Abstract: Long-term farming system experiments, when paired with well-validated dynamic farming system models, offer a powerful approach to evaluate the production and environmental impacts of novel agricultural innovations. A current deficiency is the lack of adequate comprehensive validations for long-term crop sequences that capture the dynamics of soil and crop responses without resetting soil conditions, especially for soil mineral nitrogen (Min-N). This reduces confidence in scenario analyses aimed at improving agricultural productivity and sustainability given the central role played by nitrogen (N) dynamics.

We validated the APSIM Classic model (Holzworth et al. 2014) using data from a 30-year crop sequence experiment in NSW, Australia, which included wheat, canola, lupin and field pea (Kirkegaard and Lilley 2023). The simulations used variety-specific parameters and field operations aligned with the field experiment management practices. To initialise soil organic matter pools, we used detailed measurements from Kirkby et al. (2016) across the full rooting depth (1.6 m), rather than relying on surface layer data and default values for deeper layers. This approach enabled accurate simulation of nitrogen mineralisation and immobilisation, particularly at depth, where models often underestimate N availability, and maintained long-term model performance without the need for periodic resetting. The model accurately reproduced observed dynamics of soil water, Min-N, crop biomass, and grain yield across the entire sequence.

We used the validated APSIM model to simulate a range of agronomic innovations aimed at improving productivity and sustainability. These scenarios included perfect summer weed control, and earlier sowing of both wheat and canola based on seasonal rainfall-driven sowing opportunities. We also tested a range of improved nitrogen management strategies which included fixed topdressing rates, seasonally optimised rates, and a novel "N bank" approach that adjusts fertiliser inputs based on soil N and rainfall-driven potential. These simulations revealed how changes in weed control, sowing time, and N management could change system performance over the long term. The model predicted potential increases in average annual crop productivity of 1.2 t/ha (30 %), water-use-efficiency (WUE) of 2.0 kg/ha/mm (30%) and nitrogen-use-efficiency (NUE) of 13 kg/kg (21%). It also predicted reductions in N leaching of 8 kg N/ha (-33%) and soil organic matter loss of 3.1 t/ha (31%) in the top 10 cm.

Our study (Lilley and Kirkegaard 2024) represents a rare example of model validation that captures the dynamics of soil water, Min-N, biomass and grain yield in a long-term diverse crop sequence. This validation provides confidence in scenario analyses of agronomic innovations and their production and environmental consequences.

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