

# Improving crop nitrogen uptake prediction in OverseerFM through iterative soil-crop coupling and recalibration

Andrew REVILL<sup>1\*</sup>, Edith KHAEMBAH<sup>2</sup>, Brendon MALCOLM<sup>2</sup>, Hamish BROWN<sup>2</sup>, Jean-Paul TAVERNET<sup>1</sup>, Steve GELLATLY<sup>1</sup> and Mark-John BRUWER<sup>1</sup>

<sup>1</sup>*Overseer Limited, Wellington 6011, New Zealand*

<sup>2</sup>*Bioeconomy Science Institute, Lincoln, New Zealand*

\*Corresponding author: [andrew@overseer.org.nz](mailto:andrew@overseer.org.nz)

## Abstract<sup>1</sup>

OverseerFM is widely used for farm nutrient budgeting in New Zealand. Earlier versions under-predicted crop nitrogen (N) uptake for some crops under moderate to high soil N supply, leaving more residual N in the simulated soil profile and limiting the model's ability to represent the environmental benefits of catch crops and other cropping systems. To address this, field data from 37 experiments across a range of crop types and regions were used to recalibrate crop parameters. Two updates were introduced: a luxury N uptake factor to represent additional uptake when N supply exceeded baseline requirements, and an iterative monthly coupling between crop uptake and soil mineral N supply. Together, these changes reduced under-prediction of above-ground N uptake and improved agreement with observations across diverse crops, including reduced prediction error in an independent validation dataset. Soil-mineral-N prediction error also decreased in one rotation dataset, although substantial discrepancies remained. The revised model therefore provides a stronger basis for representing N capture by catch crops, while winter-period uptake and nitrate leaching require further validation.

**Keywords:** catch crops, nitrogen uptake, calibration, OverseerFM, nutrient budgets

## Introduction

OverseerFM is widely used in New Zealand for farm nutrient budgeting, and its representation of crop N uptake affects estimates of crop N removal, residual soil mineral N and nitrate-leaching risk. Crop N uptake is calculated from yield: product, residue and root dry matter are multiplied by fixed crop-specific N concentrations and distributed monthly using accumulated thermal time (Brown 2020). Across 11 winter-sown catch-crop trials, previous versions represented low-N conditions adequately but under-predicted uptake when 200–400 kg N/ha was applied as

urea to simulate urine patches (Khaembah et al. 2023). In a 2015 Lincoln oat trial, final uptake under 400 kg N/ha was under-predicted by 50–90 kg N/ha, depending on sowing date. This could leave more simulated mineral N and over-estimate leaching, although the leaching error was not quantified. The limitation matters for catch crops, which capture N vulnerable to leaching after winter forage grazing and can reduce nitrate leaching by approximately 20–50% relative to fallow soil (Carey et al. 2016; 2023; Malcolm et al. 2020; 2022).

This study aimed to improve prediction of crop N uptake in OverseerFM. Because the uptake equations are shared across crops, changes developed for catch crops also affect other crop types; the evaluation therefore included forage, fodder, grain and vegetable crops.

## Materials and Methods

### Study design and data sources

Historical Bioeconomy Science Institute experiments were compiled for model calibration and independent validation because the original data, metadata and methods were available, allowing traceable configuration of the simulations. The database comprised 37 experiments, 79 datasets and 261 treatments conducted across six New Zealand regions between 1988 and 2023. Crops included catch crops (oats, ryecorn, wheat, barley and triticale), grain crops (maize, wheat and barley), whole-crop or fodder crops (maize and fodder beet), legumes (peas, beans and lentils), oilseed rape, and vegetables (potato, onion, broccoli, pak choi and lettuce). All experiments had been previously published or reported, with references for the calibration datasets provided in Tables 1 and 2.

### Calibration and validation datasets

Calibration experiments included an N-rate gradient from which a baseline and higher-N treatment suitable for characterising luxury uptake could be identified.

<sup>1</sup>The authors wish to disclose that in the preparation of this manuscript, ChatGPT v5.4 was utilised to help provide editorial suggestions around manuscript structure and readability. The authors were the ultimate editors of the manuscript and take full responsibility for the accuracy of the information presented.

**Table 1** Set 1 experiments used to calibrate baseline N uptake and the luxury uptake factor. Applied N rates are the observed treatments; the forage-oat baseline was interpolated between the 0 and 400 kg N/ha treatments.

| Crop     | Region/location      | Year | Applied N (kg/ha; baseline, higher-N) | Last N application date | References                                 |
|----------|----------------------|------|---------------------------------------|-------------------------|--------------------------------------------|
| Broccoli | Canterbury/Lincoln   | 2021 | 0, 120                                | 4 May 2021              | (Khaembah et al. 2023; Searle et al. 2024) |
| Kale     | Canterbury/Lincoln   | 2011 | 300, 500                              | 29 Dec 2011             | (Chakwizira et al. 2015)                   |
| Maize    | Canterbury/Lincoln   | 2012 | 50, 400                               | 31 Jan 2013             | (Teixeira et al. 2014)                     |
| Oat      | Canterbury/Lincoln   | 2015 | 0, 400                                | 1 Jul 2015              | (Malcolm et al. 2016)                      |
| Pak choi | Canterbury/Lincoln   | 2020 | 0, 140                                | 15 Jan 2021             | (Khaembah et al. 2023; Searle et al. 2024) |
| Potato   | Canterbury/Lincoln   | 2019 | 200, 400                              | 6 Jan 2020              | (Khaembah et al. 2023; Searle et al. 2024) |
| Potato   | Canterbury/Lincoln   | 2021 | 206, 412                              | 7 Jan 2022              | (Searle et al. 2024)                       |
| Onion    | Canterbury/Lincoln   | 2021 | 0, 240                                | 22 Dec 2021             | (Searle et al. 2024)                       |
| Onion    | Hawke's Bay/Hastings | 2022 | 0, 230                                | 20 Dec 2022             | (Searle et al. 2024)                       |
| Lettuce  | Hawke's Bay/Hastings | 2021 | 0, 75                                 | 18 Oct 2021             | (Searle et al. 2024)                       |

The baseline was the lowest N rate beyond which further N additions did not increase final yield or biomass; it was an operational within-experiment reference rather than a recommended N rate. The higher-N treatment remained on the yield plateau while crop N accumulation increased. Classification therefore used the within-experiment yield and uptake response, not an absolute applied-N threshold. Measured soil mineral N was not consistently available across Set 1 and was not used to confirm surplus supply; ‘higher-N’ denotes additional crop N accumulation beyond that required to increase yield or biomass. Other experimental conditions were common across N-rate treatments, although non-N factors may have constrained absolute yield.

The primary calibration dataset (Set 1) required replicated treatments, at least three in-season measurements of crop N accumulation, and sampling that included the early-to-mid vegetative phase. Experiments with only one or two N-uptake dates were insufficient to characterise the uptake trajectory and were retained for validation. Set 1 (Table 1) calibrated both baseline and luxury N uptake.

Higher-N treatments were applied as single or split applications according to the original experimental design; reports the date of the final N application for each Set 1 experiment. The 0 kg N/ha oat treatment was N-limited and was therefore not used directly as the baseline. Instead, a synthetic above-ground N-uptake series was interpolated between the observed low- and high-N oat curves using a blending coefficient of  $\alpha = 0.523$  derived from the non-oat Set 1 experiments; only the interpolation coefficient was informed by other crops.

The supplementary calibration dataset (Set 2; Table

2) comprised experiments with suitable baseline treatments but no clearly identifiable higher-N luxury-uptake treatment and was therefore used only to refine the baseline uptake curves. All remaining experiments, which were excluded from parameter fitting, formed the independent validation dataset (Set 3). These included single-rate studies, N-gradient studies lacking an identifiable baseline or higher-N treatment, and studies with only one or two N-uptake dates. Set 3 covered cereal grain and forage crops, vegetables, root and bulb crops, legumes and oilseed rape, and included variation in N rate, irrigation, species or cultivar, establishment method, sowing date, plant population and spacing across six regions, multiple soil types, and the period 1988–2023.

**Simulation set-up and limitations**

Experiments were simulated in OverseerSci, a flexible test environment using the same model engine as OverseerFM. Because OverseerFM represents management monthly rather than by exact date, sowing by the 15th was assigned to that month and later sowing to the next; harvest by the 15th was assigned to the previous month-end and later harvest to the current month-end. This approximation could shift crop development and resource inputs by up to 16 days relative to observations. Its effect was not quantified separately and may contribute to timing discrepancies in simulated development and N uptake.

**Parameter recalibration**

Recalibration used a Python implementation of the Overseer crop code (Brown 2020) for parameter fitting. Total crop N demand is the sum of product, stover and root dry matter multiplied by crop-specific

**Table 2** Set 2 experiments used to supplement baseline N-uptake calibration. PG denotes crops established after winter-forage grazing.

| Crop             | Region/location      | Year | Applied N (kg/ha) | References                               |
|------------------|----------------------|------|-------------------|------------------------------------------|
| Maize (grain)    | Canterbury/Lincoln   | 2012 | 250               | George et al. 2013; Teixeira et al. 2014 |
| Maize (silage)   | Waikato/Tamahere     | 2023 | 275               | Chakwizira et al. 2025                   |
| Oat forage       | Southland/Winton     | 2020 | PG                | Malcolm et al. 2021                      |
| Oat forage       | Southland/Wreys Bush | 2021 | PG                | Malcolm et al. 2022                      |
| Oat forage       | Canterbury/Te Piritā | 2018 | PG                | Carey et al. 2019                        |
| Potato           | Auckland/Pukekohe    | 2000 | PG                | Martin et al. 2001                       |
| Ryecorn forage   | Southland/Winton     | 2020 | PG                | Malcolm et al. 2021                      |
| Ryecorn forage   | Southland/Wreys Bush | 2021 | PG                | Malcolm et al. 2022                      |
| Triticale forage | Canterbury/Te Piritā | 2018 | PG                | Carey et al. 2019                        |
| Wheat (grain)    | Canterbury/Lincoln   | 2017 | 200               | Chakwizira et al. 2023                   |
| Wheat (grain)    | Canterbury/Lincoln   | 2020 | 150               | Khaembah et al. 2023; Searle et al. 2024 |

N concentrations; seasonal biomass and N uptake follow accumulated thermal time. Four parameters were fitted: product N concentration,  $X0_{coeff}$ ,  $b_{coeff}$  and luxury factor  $L$ . Product N concentration sets demand magnitude;  $X0_{coeff}$  defines the thermal-time proportion at which half the biomass has accumulated;  $b_{coeff}$  controls the steepness of the sigmoidal biomass curve; and  $L$  defines the crop-specific upper bound on uptake above baseline under surplus N supply ( $L = 1$  indicates no additional luxury uptake). Realised uptake may be lower because simulated soil mineral N constrains it.

Baseline crop N demand at time  $t$  is:

$N_{base}(t) = \sum_i [DM_i(t) \times C_{N,i}]$ ,  $i$  = product, stover, root  
where  $DM_i(t)$  is dry matter in crop pool  $i$  and  $C_{N,i}$  is its crop-specific N concentration. Product N concentration therefore affects the magnitude of crop N demand.

Monthly biomass accumulation follows the existing Overseer sigmoidal curve (Brown 2020):

$$P_{Biomass}(T_t) = \frac{1}{1 + \exp\left(-\frac{T_t - X0_{biomass}}{b_{biomass}}\right)} \times \frac{1}{RelMaxDM_{Harv}}$$

where  $T_t$  is accumulated thermal time and  $RelMaxDM_{Harv}$  is the relative maximum biomass achieved at harvest.  $X0_{coeff}$  and  $b_{coeff}$  enter the curve through:

$$X0_{biomass} = (T_{t_{planting}} + T_{t_{harvest}}) \times \frac{X0_{coeff}}{RelT_{t_{harvest}}}$$

$$b_{biomass} = X0_{biomass} \times b_{coeff}$$

Potential luxury uptake is bounded by:

$$TotalCropN_{lux}(t) = TotalCropN_{base}(t) \times L$$

where  $TotalCropN_{lux}(t)$  and  $TotalCropN_{base}(t)$  are the potential luxury and baseline trajectories, respectively, and  $L$  is the crop-specific upper bound.

Simulated soil mineral N may subsequently constrain realised uptake.

Parameters were estimated by nonlinear least squares, minimising the summed squared difference between observed and predicted total crop N uptake across all sampling dates. Baseline fitting used Sets 1 and 2 with  $L = 1$ . For paired Set 1 baseline and higher-N treatments, product N concentration,  $X0_{coeff}$  and  $b_{coeff}$  were fitted jointly across both treatments, whereas  $L$  was fitted only to the higher-N treatment. Multiple experiments of a crop shared one parameter set.

### Iterative crop-soil mineral N coupling

To reconcile crop uptake with soil mineral N supply, the crop and background soil-N components were coupled at the monthly model time step. This monthly iteration does not imply that field observations were available monthly: crop N-uptake sampling frequency varied among experiments, and measured soil mineral N was available only for a subset and at variable frequencies. The crop component first calculated potential uptake, bounded by:

$$N_{pot,t} = N_{base,t} \times L$$

where  $N_{base,t}$  is baseline crop N uptake and  $L$  is the luxury-uptake bound. The background soil-N component then constrained potential uptake to the maximum supported by simulated soil mineral N:

$$N_t^{(k)} = \min(N_{pot,t}, N_{supply,t}^{(k)})$$

**Table 3** Fitted parameters and NSE before and after recalibration for Sets 1 and 2 (means; SD in parentheses). Product N is product N concentration; X0coeff and bcoeff are biomass-curve coefficients; L is the luxury uptake factor; dashes indicate that L was not estimated for Set 2.

| Set | Crop                   | Product N (%) | X0coeff     | bcoeff      | L           | NSE (previous) | NSE (calibrated) |
|-----|------------------------|---------------|-------------|-------------|-------------|----------------|------------------|
| 1   | Broccoli <sup>1</sup>  | 3.25 (0.37)   | 0.41 (0.02) | 0.11 (0.06) | 1.15 (0.14) | 0.835          | 0.96             |
| 1   | Kale <sup>2</sup>      | 1.79 (0.08)   | 0.34 (0.02) | 0.23 (0.04) | 1.21 (0.06) | 0.103          | 0.982            |
| 1   | Lettuce <sup>1</sup>   | 1.72 (0.20)   | 0.34 (0.02) | 0.12 (0.05) | 1.50 (0.13) | 0.455          | 0.871            |
| 1   | Maize <sup>3</sup>     | 1.49 (0.13)   | 0.40 (0.05) | 0.27 (0.21) | 1.33 (0.09) | 0.714          | 0.864            |
| 1   | Oat <sup>4</sup>       | 1.30 (0.10)   | 0.36 (0.02) | 0.12 (0.03) | 1.54 (0.12) | 0.676          | 0.932            |
| 1   | Onion <sup>1</sup>     | 1.81 (0.11)   | 0.48 (0.03) | 0.11 (0.06) | 1.03 (0.07) | 0.843          | 0.949            |
| 1   | Pak choi <sup>1</sup>  | 4.67 (0.37)   | 0.40 (0.07) | 0.10 (0.07) | 1.37 (0.12) | 0.658          | 0.96             |
| 1   | Potato <sup>1</sup>    | 1.58 (0.08)   | 0.43 (0.04) | 0.18 (0.05) | 1.21 (0.08) | 0.831          | 0.953            |
| 2   | Maize <sup>2</sup>     | 1.47 (0.00)   | 0.43 (0.00) | 0.40 (0.00) | -           | 0.79           | 0.998            |
| 2   | Maize <sup>3</sup>     | 1.49 (0.00)   | 0.40 (0.00) | 0.27 (0.00) | -           | 0.82           | 0.891            |
| 2   | Oat <sup>4</sup>       | 1.3 (0.59)    | 0.36 (0.14) | 0.12 (0.04) | -           | 0.146          | 0.979            |
| 2   | Potato <sup>1</sup>    | 1.58 (0.00)   | 0.43 (0.00) | 0.18 (0.00) | -           | 0.112          | 0.93             |
| 2   | Ryecorn <sup>4</sup>   | 1.3 (0.27)    | 0.42 (0.06) | 0.27 (0.03) | -           | 0.436          | 0.997            |
| 2   | Triticale <sup>4</sup> | 1.3 (0.00)    | 0.42 (0.00) | 0.27 (0.00) | -           | 0.281          | 0.983            |
| 2   | Wheat <sup>3</sup>     | 2.6 (0.68)    | 0.50 (0.17) | 0.25 (0.03) | -           | 0.272          | 0.933            |

End-use: <sup>1</sup>Vegetable, <sup>2</sup>Fodder, <sup>3</sup>Grain, <sup>4</sup>Forage (catch crop).

where  $N_t(k)$  is realised crop N uptake in month  $t$  at iteration  $k$  and  $N_{supply,t}(k)$  is the constraint from simulated soil mineral N.

Uptake was returned to both components and the constraint recalculated until convergence. Thus, the constraint reflects simulated soil N rather than applied N.  $L$  was fitted to observed crop uptake; measured soil N, available for only some experiments, was not included in the objective.

Iterations stopped when the maximum absolute change in monthly realised luxury-N factor between iterations was  $<5 \times 10^{-3}$ . A 10-iteration cap was imposed, with the last stable iteration retained if convergence failed. Sensitivity testing required a mean of 2.1 and maximum of three iterations; relative to a  $1 \times 10^{-5}$  reference, final soil-block N leaching differed by  $>1\%$  in only 0.04% of simulations and never by  $>2\%$ .

**Code implementation and verification**

Directly fitted values were used where available, with  $L$  estimated only for Set 1 crops; otherwise, proxies were assigned by crop end use. For  $X0_{coeff}$  and  $b_{coeff}$ , fodder, grain and vegetable crops used 0.33/0.18, 0.42/0.27 and 0.39/0.20, respectively. Bulb and fibre crops, lacking a calibrated end-use group, used overall means of 0.35/0.20. Green-manure crops (lupin, mustard, oat, phacelia, rape, ryecorn and turnip) used the fodder proxy; these were model categories, not

calibration datasets. Fitted  $L$  analogues included 1.33 for cereal grains, 1.15 for leafy brassica vegetables and 1.21 for root vegetables. Where no clear analogue was available, a proxy  $L$  value was used. Product N used the closest defensible crop equivalent or retained the OverseerFM default.

The resulting parameterisation and model changes were implemented in OverseerSci and tested for convergence and supply limitation under low soil mineral N. Because OverseerSci uses the OverseerFM engine, evaluation followed implementation in that engine rather than inference from Python fitting. Shared crop–soil coupling was evaluated beyond catch crops.

**Statistical evaluation**

Model performance was assessed using  $R^2$ , RMSE, NRMSE and NSE. RMSE quantified average error (kg N/ha), NRMSE scaled RMSE by mean observed uptake, and NSE measured performance relative to the observed mean. Values nearer 1 are better, with  $0.5 < NSE < 0.65$  generally acceptable (Smith et al. 1997; Ritter and Munoz-Carpena 2013).

**Results**

Recalibration improved model fit in both calibration sets (Table 3). In Set 1, NSE increased from 0.103–0.843 to 0.864–0.982; in Set 2, from  $-0.309$ –0.820 to 0.891–0.998. Fitted Set 1 values ranged from 1.30–

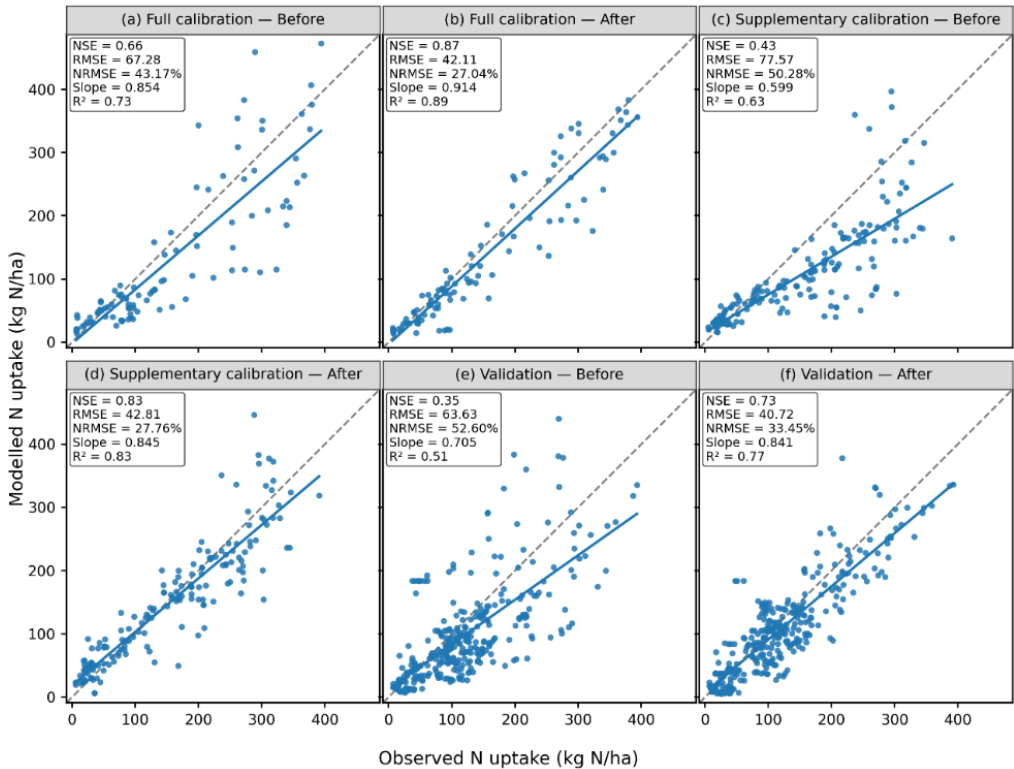


**Figure 1** Observed versus modelled above-ground N uptake for the pre-update and updated specifications across Sets 1–3. Dashed lines show the 1:1 relationship; blue lines show fitted regressions. Insets report NSE, RMSE, NRMSE, slope and R².

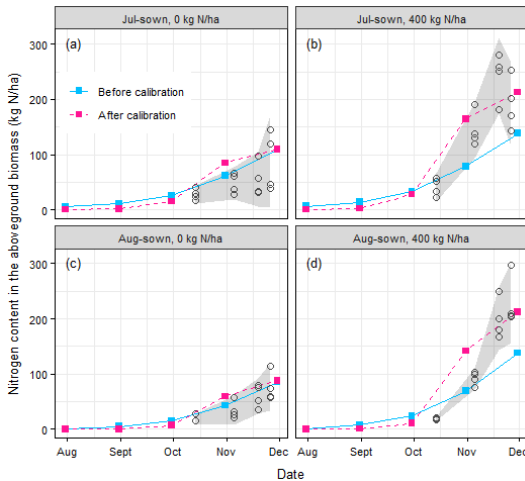


**Figure 2** Measured above-ground N uptake (circles) and Overseer predictions before recalibration (solid blue line and squares) and after recalibration (dashed pink line and squares) for July- and August-sown oats receiving 0 or 400 kg N/ha at Lincoln in 2015. Shaded ribbons show 95% confidence intervals. Data are from Malcolm et al. (2016).

4.67% for product N, 0.34–0.48 for X0coeff, 0.10–0.27 for bcoeff and 1.03–1.54 for L. Because the parameters were fitted jointly, their individual contributions to improved performance were not separated.

For grain crops, product N is the fitted harvested-grain N concentration used to calculate crop N demand. The wheat value of 2.6% was fitted jointly to the 2017 spring-wheat and 2020 winter-wheat datasets. Demand scales with simulated product dry matter, but earlier-sown, higher-yielding wheat was not specifically evaluated.

The updated specification improved above-ground N-uptake predictions across Sets 1–3 (Figure 1), reducing scatter and improving agreement with the 1:1 line. In validation, NSE increased from 0.35 to 0.73, RMSE decreased from 63.6 to 40.7 kg N/ha and NRMSE from 52.6 to 33.5%. Corresponding changes were 0.66 to 0.87, 67.3 to 42.1 kg N/ha and 43.2 to 27.0% for Set 1, and 0.43 to 0.83, 77.6 to 42.8 kg N/ha and 50.3 to 27.8% for Set 2.

The 2015 Lincoln forage-oat experiment illustrates changes in monthly uptake (Figure 2). The 400 kg N/ha urea treatment was applied on 1 July, coinciding with the July sowing and occurring one month before

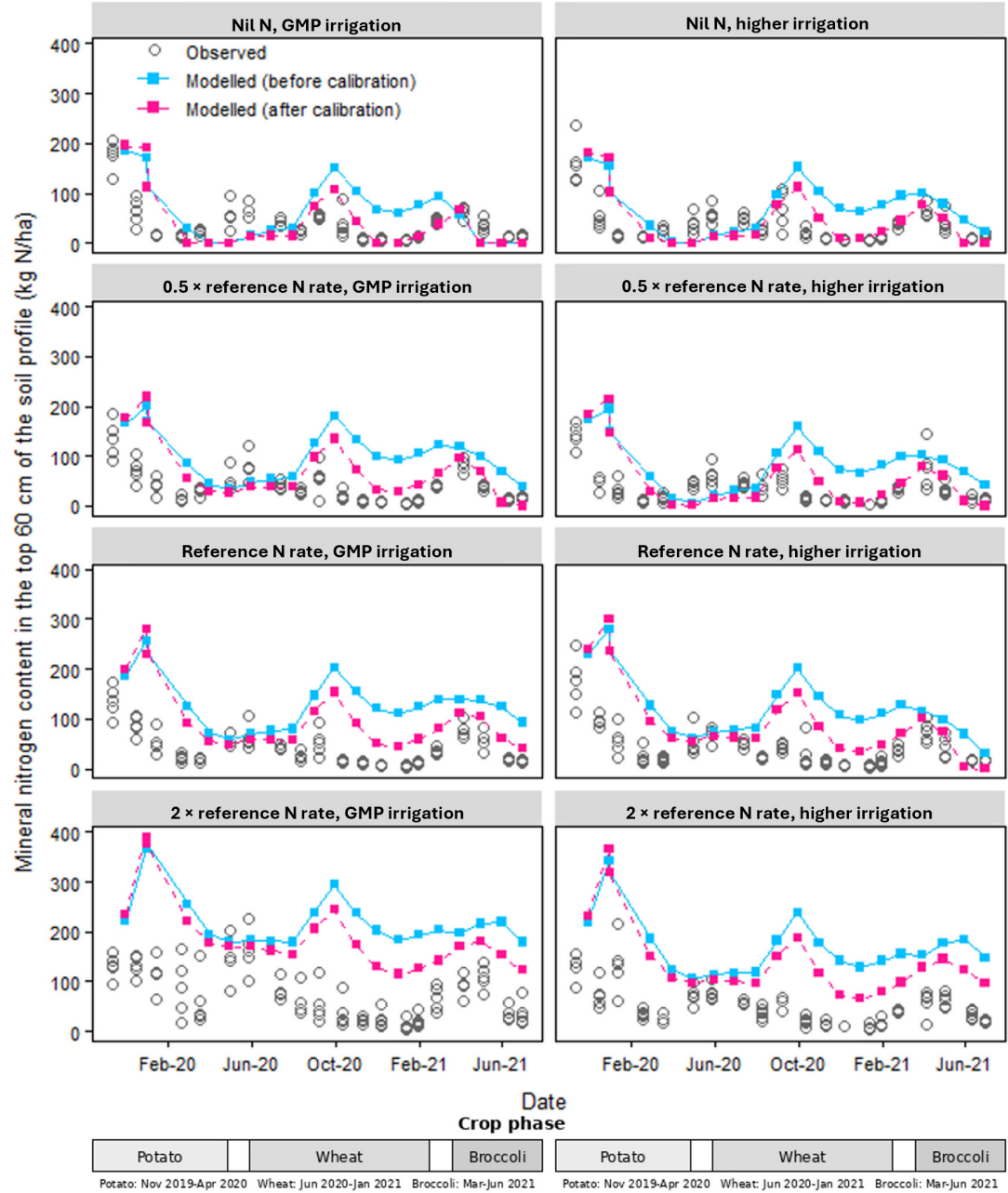


**Figure 3** Measured soil mineral N to 60 cm depth (circles; individual field replicates) and Overseer predictions before recalibration (solid blue) and after recalibration (dashed pink) in a potato–wheat–broccoli rotation. Crop phases were potato (Nov 2019–Apr 2020), wheat (Jun 2020–Jan 2021) and broccoli (Mar–Jun 2021). Observations were collected on specific dates, whereas model outputs are monthly. N treatments were nil, 0.5× reference N rate, reference N rate and 2× reference N rate under GMP and higher-irrigation schedules. February irrigation was 50 mm in both schedules and therefore did not define the higher-irrigation treatment. Data are from Searle et al. (2024).

the August sowing. The updated model better captured later-season uptake under 400 kg N/ha and improved agreement under 0 kg N/ha, although some late-season over-prediction remained. The July- and August-sown treatments had three and four N-uptake sampling dates, respectively, concentrated from October onwards. The experiment therefore does not independently test winter uptake; overall performance was assessed using the wider calibration and validation datasets.

In the potato–wheat–broccoli rotation (Figure 3), soil mineral N RMSE decreased from 58.2 to 46.1 kg N/ha and NSE increased from -1.38 to -0.49, although substantial discrepancies remained. Figure 3 therefore indicates reduced error in this rotation, not comprehensive validation. Seasonal drawdown more closely followed observations across N rates and the two irrigation treatments in this rotation experiment, although timing offsets remained because outputs are monthly whereas field measurements were date-specific.

## Discussion

The recalibrated coefficients and iterative crop–soil coupling improved the representation of crop N dynamics. Earlier versions under-predicted uptake under 200–400 kg N/ha urine-patch simulations, leaving more residual mineral N in the soil profile (Khaembah et al. 2023). Evidence was strongest for above-ground uptake (validation NSE increased from 0.35 to 0.73; RMSE decreased from 63.6 to 40.7 kg N/ha). Soil mineral N predictions also improved but remained less well represented, with substantial discrepancies indicating uncertainty in the coupled soil–crop N balance and in other soil processes. The revision links potential crop N demand to simulated soil mineral N so that realised uptake cannot exceed the supported supply.

Improved uptake provides a basis for better representation of catch-crop N capture. Catch crops can reduce nitrate leaching after winter forage grazing (Carey et al. 2016; Malcolm et al. 2020; 2022), whereas OverseerFM previously under-predicted uptake under high N loading (Khaembah et al. 2023). Crop uptake and soil N were evaluated in different experiments, so coupling was not validated with paired observations; winter uptake and leaching were also not tested. Paired crop-uptake, soil-N and leaching measurements are needed to quantify mitigation improvements.

Because Overseer uses a shared biomass-growth and N-uptake framework with crop-specific coefficients (Brown 2020), the changes also affect other crops. Figure 3 covers the complete rotation and cannot attribute discrepancies to potato, wheat or broccoli. Table 3 reports crop-specific uptake performance, but values are not directly rankable because datasets differ.

Performance varied, and proxy coefficients remain uncertain; the results support broader testing rather than equal performance across crops.

Remaining high-uptake variability may reflect input uncertainty, monthly timing assumptions and limited calibration coverage; their contributions were not quantified. Further work should expand crop-specific, high-uptake datasets and include paired crop and soil N measurements through the growing season and winter. The revision improves uptake prediction and supports continued OverseerFM development.

## Conclusions

The OverseerSci updates combined recalibrated crop coefficients with iterative crop–soil N coupling, improving crop N uptake and soil mineral N dynamics by constraining realised uptake to simulated availability. At the time of the study, the changes had not yet been released in production OverseerFM, but they are relevant beyond catch crops because the crop structure is shared.

The work supports better representation of rapid-N-capture systems, particularly forage-oat catch crops used to reduce residual soil N during periods of elevated leaching risk. It did not specifically evaluate winter uptake by established autumn-sown wheat or other winter-active crops, or use the farm-effluent redistribution loop. The findings therefore apply to crop-only systems, and further testing is required before the revised model can be generalised to these systems. The model can be refined as additional crop N-uptake data become available.

## ACKNOWLEDGEMENTS

We thank the Bioeconomy Science Institute teams and collaborators who generated and curated the trial datasets and contributed to equation formulations and coefficient updates. Overseer Limited supported OverseerSci implementation and verification. The Ministry for Primary Industries' Sustainable Land Management and Climate Change fund supported this project.

## REFERENCES

- Brown H. 2020. *The process for improving and expanding the OVERSEER® crop model*. A Plant & Food Research report prepared for: Overseer Limited. Milestone No. 88352. Contract No. 37427. Job code: P/445006. PFR SPTS No. 20147. 30 p.
- Carey PL, Cameron KC, Di HJ, Edwards GR, Chapman DF. 2016. Sowing a winter catch crop can reduce nitrate leaching losses from winter-applied urine under simulated forage grazing: a lysimeter study. *Soil Use and Management* 32: 329–337. <https://doi.org/10.1111/sum.12276>

- Carey P, Malcolm B, Maley S. 2019. *Catch crops to mitigate N loss after winter forage grazing: from plot to paddock*. In: Currie LD, Christensen CL eds. Nutrient loss mitigations for compliance in agriculture [Occasional Report No. 32]. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 10 p.
- Carey P, Malcolm B, Maley S. 2023. Tillage practice and sowing time affect yield, nitrogen uptake and profitability of catch crops sown after winter forage grazing in New Zealand. *New Zealand Journal of Agricultural Research* 66: 454-478. <https://doi.org/10.1080/00288233.2022.2097269>
- Chakwizira E, de Ruiter JM, Maley S. 2015. Effects of nitrogen fertiliser application rate on nitrogen partitioning, nitrogen use efficiency and nutritive value of forage kale. *New Zealand Journal of Agricultural Research* 58: 259-270. <https://doi.org/10.1080/00288233.2015.1016538>
- Chakwizira E, Moot DJ, Teixeira E. 2023. Quantifying morpho-physiological traits that describe canopy and biomass formation and partitioning processes for spring wheat genotypes grown under contrasting nitrogen supply. *New Zealand Journal of Crop and Horticultural Science* 51: 231-254. <https://doi.org/10.1080/01140671.2022.2028862>
- Chakwizira E, Sharp JM, Yang XM, Wallace D. 2025. Developing nitrogen use efficiency indicators for the arable sector: Maize silage. *Agronomy New Zealand*, In Press.
- George MJ, Teixeira EI, Herreman TF, Brown HE. 2013. Understanding nitrogen and water stress mechanisms on maize crops. *Agronomy New Zealand* 43: 27-32.
- Khaembah E, Brown H, Malcolm B. 2023. *Catch crops in Overseer: an evaluation of nitrogen content and uptake by cereal catch crops*. A Plant & Food Research report prepared for: Ministry for Primary Industries. Milestone No. 95360. Contract No. 40547. PFR SPTS No. 23976. 26 p.
- Malcolm B, Teixeira E, Johnstone P, Maley S, de Ruiter J, Chakwizira E. 2016. Catch crops after winter grazing for production and environmental benefits. *Agronomy New Zealand* 46: 99-108.
- Malcolm B, de Ruiter J, Dalley D, Carrick S, Waugh D, Arnold N, Dellow S, Beare M, Johnstone P, Wohlers M et al. 2020. Catch crops and feeding strategy can reduce the risk of nitrogen leaching in late lactation fodder beet systems. *New Zealand Journal of Agricultural Research* 63: 44-64. <https://doi.org/10.1080/00288233.2019.1704422>
- Malcolm B, Maley S, Teixeira E, Michel A, Taylor A, Scobie D, Dynes R. 2021. *Catch crops for cleaner freshwater – annual report 2021*. A Plant & Food Research report prepared for: Ministry for Primary Industries. Milestone No. 86738-M06. Contract No. 38723. Job code: P/444011/01. PFR SPTS No. 21237.
- Malcolm B, Cameron K, Beare M, Carrick S, Payne J, Maley S, Di H, Richards K, Dalley D, de Ruiter J. 2022. Oat catch crop efficacy on nitrogen leaching varies after forage crop grazing. *Nutrient Cycling in Agroecosystems* 122: 273-288. <https://doi.org/10.1007/s10705-022-10201-9>
- Martin R, Craighead M, Williams P, Tregurtha C. 2001. Effect of fertiliser rate and type on the yield and nitrogen balance of a Pukekohe potato crop. *Agronomy New Zealand* 31: 71-80.
- Ritter A, Munoz-Carpena R. 2013. Performance evaluation of hydrological models: statistical significance for reducing subjectivity in goodness-of-fit assessments. *Journal of Hydrology* 480: 33-45. <https://doi.org/10.1016/j.jhydrol.2012.12.004>
- Searle B, Brown H, Khaembah E, Sharp J, Maley S, Dellow S, van der Weyden J, Arnold N, Sorensen I, Husband E et al. 2024. *Sustainable Vegetable Systems - annual report 2024*. A Plant & Food Research report prepared for: Potatoes New Zealand Incorporated. Milestone No. 89147. Contract No. 38729. Job code: P/444006/05. PFR SPTS No. 26449B. 30 p.
- Smith P, Smith JU, Powlson DS, McGill WB, Arah JRM, Chertov OG, Coleman K, Franko U, Frolking S, Jenkinson DS et al. 1997. A comparison of the performance of nine soil organic matter models using datasets from seven long-term experiments. *Geoderma* 81: 153-225. [https://doi.org/10.1016/S0016-7061\(97\)00087-6](https://doi.org/10.1016/S0016-7061(97)00087-6)
- Teixeira EI, George M, Herreman T, Brown H, Fletcher AL, Chakwizira E, de Ruiter JM, Maley S, Noble A. 2014. The impact of water and nitrogen limitation on maize biomass and resource-use efficiencies for radiation, water and nitrogen. *Field Crops Research* 168: 109-118. <https://doi.org/10.1016/j.fcr.2014.08.002>