



DairyUP
Unlocking potential

Final Report

P4 Feedbase for Intensive Systems



Dairy UP (Phase I) was a \$16 million, five-year industry driven project with a portfolio of 10 research, development and adoption projects collectively aiming to realise three primary objectives:

- Increase Productivity and Profitability by unlocking the potential of milk, the cow and water,
- De-risking the industry and
- Developing new markets.

A key part of Dairy UP was a coordinated network of partner farms across New South Wales (and beyond) providing valuable insights into real world application of new practices, including the challenges and benefits of new innovative technologies.

Dairy UP made a big contribution to dairy research and development rejuvenation, (attracting new researchers, PhD students and Industry investment).

Dairy UP was funded through the Australian and NSW Government’s Bushfire Industry Package – Sector Development Grant (BIP-SDG) program, with cash co-contributions from Dairy Australia, The University of Sydney’s Dairy Research Foundation, Local Land Services, Norco, Leppington Pastoral Co Ltd and Dairy NSW; and in kind contributions by all the above organisations plus NSW DPI (Biosecurity and Food Safety; Agriculture), Scibus, Australia Fresh Milk Holding Ltd, Dairy Connect and NSW Farmers.

This project was delivered jointly by University of Sydney’s Dairy Research Foundation, Scibus, Department of Primary Industries and Regional development.

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Delivery organisations



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I. Executive Summary

Contained housing systems are becoming increasingly common in the Australian dairy industry, driven by substantial investments in large-scale operations where total mixed ration (TMR, system 5) feeding is becoming a practical reality. These systems rely heavily on maize silage as a primary dietary component to reduce feed costs and to maintain production efficiency. In this context, the P4 “Feedbase for Intensive Systems” project, funded under the Dairy UP program, was established to 1) improve the accuracy of prediction of maize silage yield through calibration and validation, 2) real-time monitoring and modelling of crops, 3) improving quality, and 4) new directions in brown midrib (BMR) maize research and development, thereby supporting informed decision making by Australian dairy farmers.

P4a — Calibration and Validation of APSIM and Remote Sensing for Maize Silage Yield and Quality:

Maize silage is a key component of TMR used for dairy production in intensive system. Maize yield forecasting is important for feed planning in commercial farms which is usually implemented by modelling and remote sensing. APSIM model is used extensively to monitor yield of grain crops, and its library has 90 calibrated grain type genotypes. However, there is no silage type genotype in APSIM library. Thus, the aim of this study was to calibrate and validate data by creating maize silage library in APSIM using detailed plot and paddock level maize silage based data to simulate silage crop growth, development, and biomass partitioning across a wide range of genotype, management, and environmental conditions. Remote sensing was done by sentinel2, which was used to predict APSIM biomass. A robust APSIM parameterisation was developed for silage-specific maize genotypes, enabling accurate simulation of crop growth, phenology, biomass accumulation, and partitioning. The calibrated parameters were then used to validate maize silage rather than grain maize, grown at paddock level. Harvest index (HI) was identified to use a key proxy for silage nutritive value. The research established a framework to combine APSIM simulations with remote sensing for dynamic, in-season monitoring of maize growth, yield and quality.

P4b — Integration of APSIM with remote sensing data: APSIM is not effective to capture field variability of crop status in real time. In contrast, remote sensing provides spatial and temporal coverage of a paddock, able to detect real time canopy conditions and biomass using various indices under good weather and crop canopy conditions. However, remote sensing does not simulate physiological processes during crop growth stages such as at grain filling and other growth stage. Thus, it was hypothesised that integrating APSIM with remote sensing data may enable dynamic yield forecasts and quality predictions. Yield and quality data were collected from 11 farms in year 1 (y1, 2022-23) and 6 farms in y2 (y2, 2023-24) from four regions of NSW. The aim was to integrate APSIM with satellite data to improve yield and quality predictions and enhance dairy farmers’ ability to monitor and manage crop growth in real time. Both APSIM ($R^2 = 0.86$) and integrated APSIM-remote sensing ($R^2 = 0.77-0.81$) using sentinel2 NDVI through fAPAR were able to predict biomass, and HI particularly in y2 ($R^2 = 0.84$) across diverse environment confirming their suitability as a robust tool for silage production systems

P4c — Redefining nutritive value of maize silage through more precise evaluation: This subproject investigated the nutritive value of WCMS and addressed the long-standing observation that silages with contrasting starch contents often exhibit similar energy values. A comprehensive literature review and experimental evidence showed that increasing starch in WCMS reduces fibre digestibility by reducing rumen pH. Rapid starch fermentation lowers rumen pH, suppressing cellulolytic microbes and limiting fibre breakdown, while starch digestibility remains largely unaffected. To better represent this dynamic, a two-compartment digestion model was proposed, separating grain (starch) and stover (fibre) components rather than treating WCMS as a

homogeneous feed. This approach provides a more accurate framework for evaluating silage quality and energy supply. The findings have significant implications for ration formulation and silage management, supporting more precise feeding strategies, cost-effective and improving efficiency in intensive dairy systems.

P4d — New directions in BMR silage research: Brown midrib (BMR) maize hybrids are valued for improved fibre digestibility and animal performance but limited by lower yield and lodging. This study evaluated new short duration BMR (P07003) and conventional (CON; P0937) hybrids across three planting densities (80,000, 95,000, 110,000 plants/ha) over two years at Camden, NSW, under non-limiting nitrogen and irrigation. Biomass, grain yield, harvest index, phenology, and nutritive value were measured, and drone-based remote sensing data were taken at the flowering stage. Both hybrids achieved high yields (25-28 t DM/ha), with no lodging observed in the BMR hybrid, indicating improved resilience. The CON hybrid produced higher yields (by ~2 t DM/ha), but nutritive value was similar between the hybrids (11.8 MJ ME/kg DM). Planting density affected yield optimisation but not nutritive value- BMR performed best at 95,000 plants/ha, while CON achieved maximum yield at 110,000 plants/ha. These results indicate that modern BMR hybrid can match CON yields while maintaining quality, enabling better hybrid × density decisions in intensive dairy systems.

Together, results based on all four components, modelling and remote sensing provided the basis of real-time biomass and nutritive value proxy for quality. It also provided a new direction for BMR hybrid maize for commercial farms and proposed a two compartment model to evaluate maize silage nutritive value accurately.

2. Project Overview

Item	Description
Project Title	Feedbase for Intensive Systems
Funding Body	Dairy UP
Dairy UP Project	P4
Project Duration	2022-2026
Lead Organisation	The University of Sydney
Project Lead	Professor Sergio Garcia
Key Collaborators	University of Southern Queensland, Universidad Nacional de La Pampa, Argentina, NSW Department of Primary Industries and Regional Development, Scibus, Charles Sturt University, Pioneer Seeds, Australian Plant Phenomics Network

3. Abbreviations

- ADF— Acid detergent fiber**
- ADFD— Acid detergent fiber digestibility**
- ADSA — American Dairy Science Association**
- APPN — Australian Plant Phenomics Network**
- APSIM — Agricultural Production Systems Simulator**
- BMR — Brown midrib**
- CCC— Concordance Correlation Coefficient**
- CON — Conventional**
- CSU— Charles Sturt University**
- DM — Dry matter**
- FPS — Frontiers in Plant Science**
- FAPAR — Fraction of absorbed photosynthetically active radiation**
- HI — Harvest index**
- JDS — Journal of Dairy Science**
- ME — Metabolisable energy**
- NDVI — Normalised difference vegetation index**
- NDF— Neutral detergent fiber**
- NDFD— Neutral detergent fiber digestibility**
- NSW DPIRD — NSW Department of Primary Industries and Regional Development**
- OMD — Organic matter digestibility**
- RMSE — Root Mean Square Error**
- RMSPE — Root Mean Square Percentage Error**
- TMR — Total mixed ration**
- USYD — The University of Sydney**
- WCMS— Whole crop maize silage**

4. Project Background and Rationale

Australian dairy herd sizes have increased by approximately by 5% over the past decades, reflecting a shift towards more intensive systems in near future and greater reliance on TMR. This transition is evident in regions such as inland New South Wales, the Riverina, northern Victoria, and south-east Queensland. In these systems, maize silage is a key dietary component, often comprising around 50% of the total ingredients of TMR. As feed accounts for more than 50% of the total production costs, achieving high biomass yield with superior silage quality is critical for improving productivity and farm resilience. Although the Future Dairy project consistently produced maize silage yields exceeding 25 t DM/ha, silage quality did not improve with varying grain proportions.

Maize silage is highly valued by intensive farmers as it contains ~30% starch (Dairy Australia). Grain in maize silage is the primary source of starch and is one of the main factors driving energy density. Therefore, improved approaches such as Agricultural Production Systems Simulator (APSIM), remote sensing and more precise evaluation of nutritive value are needed to monitor and predict both biomass and grain yield including nutritive value of maize silage to reduce feed costs and enhance profitability in intensive dairy farming.

Therefore, the P4 “Feedbase for Intensive Systems” was undertaken to explore four areas of research: improve the accuracy of prediction of maize silage yield through calibration and real-time monitoring and modelling of crops, its validation in commercial farms, improving quality, and new directions in bmr maize research in order to support informed decision-making for both yield and nutritive value by intensively managed Australian dairy farmers.

5. Project Objectives

The overall objectives of this project were to improve the prediction of maize silage yield and nutritive value, and to develop practical tools to support farmers in optimising silage for diet formulation, thereby enhancing productivity and efficiency of intensive dairy farming. The specific objectives were to:

- **Calibrate and validate maize growth and development** using APSIM and remote sensing with a focus on biomass and grain yield, and harvest index (HI) variability relevant to silage nutritive value.
- **Predict biomass and silage nutritive value** using either by APSIM, remote sensing, or their integration to enable farm scale monitoring across NSW.
- **Redefining silage quality and determine more precise nutritive value** to explore real nutritive value of maize silage through on-farm monitoring and synthesis of published literature.
- **Evaluate next generation maize hybrids for silage** including BMR types to value to enhance both yield and nutritive quality for dairy production systems.

6. Subproject P4a — Calibration and Validation of APSIM and Remote Sensing for Maize Silage Yield and Quality

Research team: Rafiq Islam (The University of Sydney - USYD), Jonathan Ojeda (University of Southern Queensland), Diego Rotili (Universidad de Buenos Aires,) Martin Correa Luna (USYD), Juan Gargiulo (NSW Department of Primary Industries & Rural Development), Yani Garcia (USYD)

6.1 Background

The APSIM (Holzworth et al., 2014) crop model widely used to simulate crop growth, and yield responses to environmental and management conditions. Previous applications of APSIM have primarily focused on grain maize. Therefore, the APSIM cultivar library includes 90 calibrated grain type genotypes, but the model does not include any silage-specific genotypes. Silage maize differs fundamentally from grain maize in both harvest timing and biomass partitioning. Silage crops are typically harvested at ~65% grain maturity (i.e., DM% of grain at harvest; milk to dent stage), whereas grain maize is harvested closer to physiological maturity (~80% grain maturity). As a result, HI and biomass allocation patterns in silage maize are expected to differ substantially from those of grain genotypes. Therefore, parameterisation of maize silage cultivars and its validation with field data are essential to investigate model's ability to simulate silage crop growth, phenology, and biomass partitioning including nutritive value across contrasting environments to have confidence in practice.

The main goal of this study was to calibrate and validate APSIM by creating maize silage library using detailed plot and paddock level maize silage based data to simulate crop growth, development, and biomass partitioning across a wide range of genotype, management, and environmental conditions. Another approach was to investigate APSIMs ability to predict maize silage quality directly or developing an index to use as a proxy for silage quality.

6.2 Objectives

Calibrate and validate APSIM using detailed field experimental data and paddock level studies to simulate maize silage crop growth, development, and biomass partitioning.

Identify the key drivers of grain yield and HI variability and their potential to predict nutritive value of silage.

Quantify the primary sources of HI variability in silage maize across a wide range of genotype, management, and environmental conditions.

6.3 Materials & Methods

- **Data sources for calibration:** The data used for calibration were from four maize silage experiments of the Future Dairy project, the University of Sydney. These research were conducted in small plots and in commercial farms from 2009 to 2014 (Islam et al., 2011; Islam et al., 2012; Islam and Garcia, 2012, 2014). A total of five silage type maize hybrids were included for parameterisation and calibration. The experiments encompassed a wide range of management conditions, non-limiting N and water, planting densities, maturity stages, and sowing and harvesting windows.
- **Data sources for validation:** The data used for model in this study was obtained from five paddocks Silvermere Holstein and MVD Dairy of NSW (longitude 148.45-152.35; latitude 31.91-33.73). Two maize silage genotypes were grown in these farms during 2021-22 growing

seasons in paddocks (7-35 ha). Plants/ha was 7.4-8.5, N fertiliser application was 232-300 kg/ha. Crops were harvested after 112-142 days after sowing.

- **Statistical analysis:** Model was assessed by regression (R^2) and significance ($P < 0.05$), Concordance Correlation Coefficient (CCC), model error was assessed by Root Mean Square Error (RMSE) and the Root Mean Square Percentage Error (RMSPE) and models' efficiency was assessed by Nash–Sutcliffe model efficiency coefficient (NSE).

6.4 Key Findings

- **Calibrated APSIM accurately predicted maize silage crop growth.** APSIM predicted total biomass, grain, cob, leaf, and stover weight (CCC=0.86-0.94) accurately (RMSPE=13%) suggesting calibration was successful (Figure 1).
- **APSIM was able to predict maize silage crop phenology:** The model accurately predicted leaf number and canopy green cover (CCC=0.79-0.97) accurately (RMSPE=23-39%).
- **APSIM also accurately predicted HI of maize silage.** APSIM accurately predicted HI of maize for silage and canopy green cover (CCC=0.78) accurately (RMSPE=12%) indicating calibrated APSIM can simulate crop growth, phenology and HI of maize silage (Figure 1).
- **APSIM validated biomass and grain yield.** APSIM validated biomass (CCC=0.75) and grain yield (CCC=0.88) but prediction error was high (RMSPE=45-57%) (Figure 2).
- **Remote sensing was able to predict APSIM simulated biomass.** However, remote sensing consistently underpredicted APSIM simulated biomass (Figure 3).

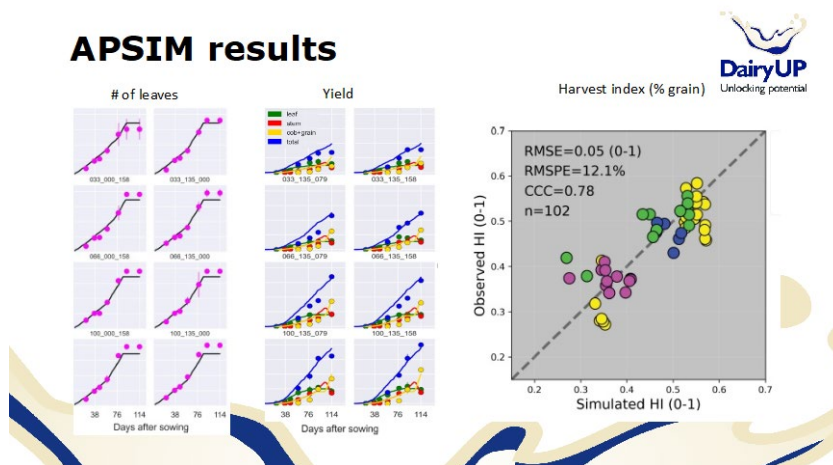


Figure 1. Parameterised and calibrated APSIM simulated biomass, leaf no. and harvest index

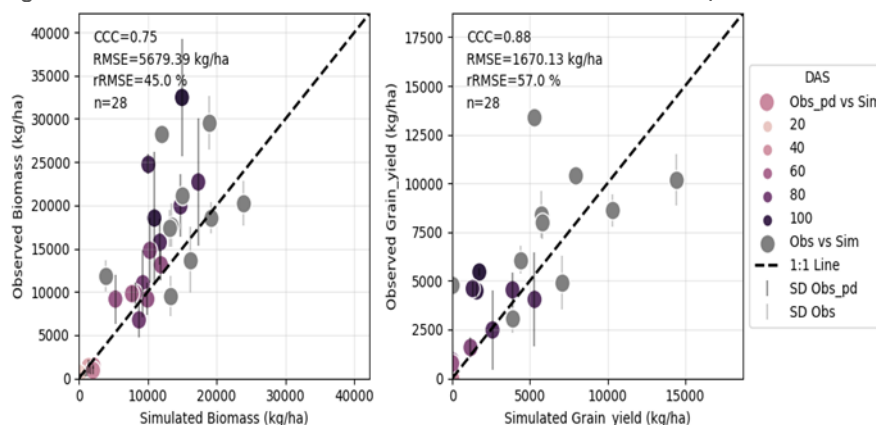


Figure 2. Observed vs. simulated biomass (left panel) and grain yield (right panel) by days after sowing (colour palette). Grey dots indicate observed data at harvest (square 5 m²) and coloured dots indicate observed data collected from 3 plant sampling during the growing seasons. Vertical bars indicate standard deviations

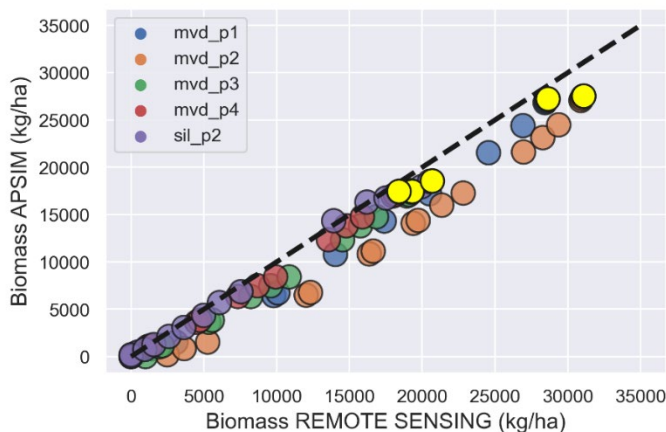


Figure 3. Simulated biomass by APSIM vs biomass estimated by remote sensing (NDVI) for each paddock across the season. Yellow circles indicate the final biomass harvested. Dashed black line represents the 1:1 line ($y=x$).

6.5 Applications & Impacts

The findings have direct relevance across multiple levels of the dairy farm and industry.

Improved feed planning and cost efficiency, APSIM parametrisation and calibration enables more accurate prediction of maize silage biomass and HI, which is one of the key determinants of feed quality. It also enables forecasting silage yield and quality for farmers before harvest which help farmers in decision making and improved farm-feed planning and to reduce risk.

Precision crop management for higher productivity, the model identifies key drivers of yield and HI variability across genotype, management and environment combinations. The system enables to adjust management in-season using remote sensing and supports transition towards data driven precision dairy farming system for intensive farms.

At the sustainability and environmental level, accurate prediction of biomass, grain yield, and HI improves understanding of resource use efficiency and crop performance, which supports sustainable intensification and helps meet environmental and emissions targets in dairy systems.

6.6 Key Outputs

- A robust parameterisation of APSIM was developed for silage-specific maize genotypes, enabling accurate simulation of crop growth, phenology, biomass accumulation, and partitioning. The calibrated parameters were then used to validate maize silage rather than grain maize, grown at paddock level.
- Quantified and predicted variability in HI, a key proxy for silage nutritive value. Harvest index has the potential to be used as a reliable tool to estimate nutritive value of maize silage.
- Identified key drivers of yield and HI variability e.g., genotype, N and water and a clear understanding of genotype, environment and management effects on silage productivity.

- The research established a framework to combine APSIM simulations with remote sensing for dynamic, in-season monitoring of maize growth and yield.
- Peer-reviewed publication in the *Frontiers in Plant Sciences* demonstrating HI variability in maize silage and its use as a proxy of silage nutritive value.

6.7 Future Research Opportunities

The dataset used for model calibration was based on maize silage genotypes grown at a single site (Camden) and validated at two sites (Silvermere Holstein and VMD farms) using four and two genotypes respectively, resulting in limited spatial representation. Future research should focus on validation across a wider range of commercial farms and regions, and on integrating crop models with real-time sensing and silage-specific genotype characterisation to enable precise, climate-resilient, and economically efficient intensive dairy production in Australia.

Priority areas for future research include:

- **Validation of the model across more commercial farms:** Testing the model performance across environments (genotype, N, water, plant density, large sowing and harvesting windows, heat stress) to test sensitivity and robustness of the model.
- **Integrate APSIM with remote sensing data:** Integrate APSIM with satellite platforms (e.g., Sentinel-2) through data to provide real-time decision support for farmers.
- **Development of silage-specific genotype modules:** Silage module in APSIM is not available. Further research is needed to parameterise and calibration for next generation BMR and stay-green hybrids to accurately predict yield–quality trade-offs.
- **Uncertainty and error decomposition:** High errors in some scenarios indicates structural and scale-related uncertainties. To adopt by the industry, it is necessary to improve model credibility. Thus, it is important to initiate research to identify whether the errors are related to field variability or measurement errors, or partitioning of fractions assimilation, or due to the regions or years associated with climate.

7. Subproject P4b — Integration of APSIM with Remote Sensing Data

Research team: Rafiq Islam (The University of Sydney - USYD), Jonathan Ojeda (University of Southern Queensland), Diego Rotili (Universidad de Buenos Aires), Martin Correa Luna (USYD), Juan Gargiulo (NSW Department of Primary Industries & Rural Development), Fernando Masia (USYD), Cameron Clark (Charles Sturt University), Yani Garcia (USYD)

7.1 Background

P4a demonstrated that APSIM can be used to assess interannual variability of maize silage yield and its HI, and remote sensed biomass can moderately predict APSIM simulated biomass. However, both APSIM and remote sensed biomass has limitations. While APSIM cannot easily capture field variability or reflect real time crop status, remote sensing provides spatial and temporal coverage of a paddock, able to detect real time canopy conditions and biomass using various indices under good weather conditions. However, remote sensing does not simulate physiological processes e.g., soil N status, grain filling. Therefore, it was hypothesised that integrating APSIM with remote sensing data may enable dynamic yield forecasts and quality predictions. Using field scale data from commercial maize silage systems, it was assessed whether integration improves prediction accuracy compared with standalone modelling approaches and identify key sources of uncertainty influencing model performance. The goal was to integrate APSIM with satellite data to improve yield and quality predictions and enhance dairy farmers' ability to monitor and manage crop growth in real time.

7.2 Objectives

- To evaluate APSIMs performance in predicting of biomass, grain yield and HI using data collected from commercial maize growing farms across NSW.
- Evaluate the performance of biomass and yield prediction using an integrated APSIM-remote sensing framework.
- Identify key sources of uncertainty influencing model performance.

7.3 Materials & Methods

To address these objectives, the project undertook a series of coordinated studies:

- **Data sources and crop management:** Biomass, grain yield and HI of maize data were generated from field studies conducted in commercial dairy farms growing maize for silages across NSW, covering areas from North Coast, Middle Coast, Camden and South Coast by taking 3 farms from each area and grown over two years (2022-23; y1 in 12 farms, total 145 ha, and 2023-24; y2 in 6 farms, 84 ha). Farm soil in the study areas were loam, silty loam, silty clay loam, loamy sand and silty clay. Maize hybrids sown were C29A1, hsr brutus and different hybrids of Pacific and Pioneer. Sowing dates ranged from 9 October to 20 January with 53,228-85,000 plants/ha and harvest after 99-147 days of sowing. Nitrogen fertiliser applied was 125-369 kg N/ha and irrigation water was 0-480 mm/ha. Biomass yield was recorded at 4 growth stages: V6, flowering, grain filling and at final harvest stage. At each stage, 2 random plants were harvested, dried and weight recorded. Average weight of plant was multiplied by plant density to estimate biomass at each stage. However, biomass yield at final harvest was also calculated by harvesting two 5 linear m maize rows and fresh weight was taken. Plants were chopped and dried in an oven DM biomass was calculated on DM basis. Grain yield was calculated from the proportion of grain in total biomass. Harvest index was calculated by dividing the grain yield by total biomass yield.

- **APSIM parameterisation:** Cultivar parameter sets developed for the silage hybrid '*PacificX*' by Ojeda et al. (2023) were adopted for simulations. However, *tt_emerg_to_endjuv* was changed to 260 instead of 350 and *tt_flower_to_maturity* was changed to 800 instead of 600, which provided values relatively close to the real time observations for each hybrid as the hybrids evaluated by Ojeda et al. (2023) exhibited lower HI than those grown in the current experiments.
- **Remote sensing data:** Remote sensing data were obtained from Sentinel2 satellite mission which derived NDVI, and NDVI was used to derive fAPAR.
- **Integration of APSIM and sentinel2 data:** APSIM and sentinel data were combined to investigate if integrated approach could predict biomass more accurately than APSIM. In this process, NDVI data were used to calculate potential and actual real time fAPAR. Intercepted solar radiation was calculated by multiplying fAPAR (NDVI)*intercepted radiation by APSIM. Biomass accumulation was calculated by summing the intercepted radiation (fAPAR plus RUE of APSIM). Calculations used to determine biomass using sentinel2 and APSIM were as follows:

i) fAPAR calculation from sentinel2

fAPAR was calculated using Zhang et al. (2015) and Gitelson et al. (2014)

equations:

$$fAPAR_z = 1.242 \times EO - 0.204 \text{ (Zhang et al., 2015)}$$

$$fAPAR_G = 1.35 \times NDVI - 0.32 \text{ for vegetative stage (Gitelson et al., 2014)}$$

$$fAPAR_G = 1.89 \times NDVI - 0.7827 \text{ for reproductive stage (Gitelson et al., 2014)}$$

ii) potential RUE calculation from APSIM:

$$intRad = fAPAR_APSIM \times Rad_APSIM$$

$$APSIM_RUE = biomass_APSIM / cum_intRad$$

intRad, intercepted radiation; cum, cumulative; RUE, radiation use efficiency

iii) biomass calculation from fAPAR and APSIM

$$intRad_NDVI_z \text{ or } intRad_NDVI_G = fAPAR_z \text{ or } fAPAR_G \times Rad_silo$$

$$biomass_accumulated = intRad_NDVI_z \text{ or } intRad_NDVI_G \times APSIM_RUE$$

- **Data analysis and model evaluation:** Observed biomass and grain including HI were evaluated against these yields obtained by 1) APSIM alone, and 2) a combination of APSIM and sentinel2 data based biomass derived using fAPAR_z or fAPAR_G. Model output was assessed by R² at P<0.05 including CCC, RMSE, RMSPE and NSE.

7.4 Key Findings

- **APSIM and integrated APSIM-remote sensing predicted maize biomass across years in commercial farms.** APSIM simulated biomass accurately (Figure 1; R² = 0.86) across regions, farms and years, which improved with outlier correction (Figure 1; R² = 0.88). Prediction error also improved with outlier correction (RMSPE, 32%), which improved efficiency (NSE, 0.76) and agreement (CCC, 0.86). APSIM-remote sensing also predicted biomass with similar accuracy (Figure 2; R² = 0.80).
- **APSIM also simulated real-time biomass yield for most farms across years.** The model generally captured the shape of growth curves well across sites. Simulated biomass closely tracked observed temporal dynamics where simulated and observed biomass were closely aligned in mostly in farms under irrigated conditions (Figure 3)
- **APSIM predicted grain yield and HI with moderate to good capacity across.** Agreement between simulated and observed grain yield was moderate (R² = 0.61-0.72, p<0.001). Model performance was better in y2 than in y1.

- Uncertainties in model prediction.** The primary limitation lies not in biomass accumulation processes using either APSIM or integrated APSIM-remote sensing but in accurately representing partitioning dynamics under varying stress conditions which lead to measurement uncertainties in observed data. Paddock level variations also increased data deviations. In addition, phenological mismatch and discrepancies between simulated and observed data particularly at flowering and grain filling impact grain yield and HI. There is also a mismatch in observed data and sentinel2 data collection dates. These uncertainties propagate into model evaluation metrics, inflating RMSPE and potentially underestimating model performance. Improving model performance will require enhanced representation of stress interactions, phenological alignment, and better integration of high quality observational data.

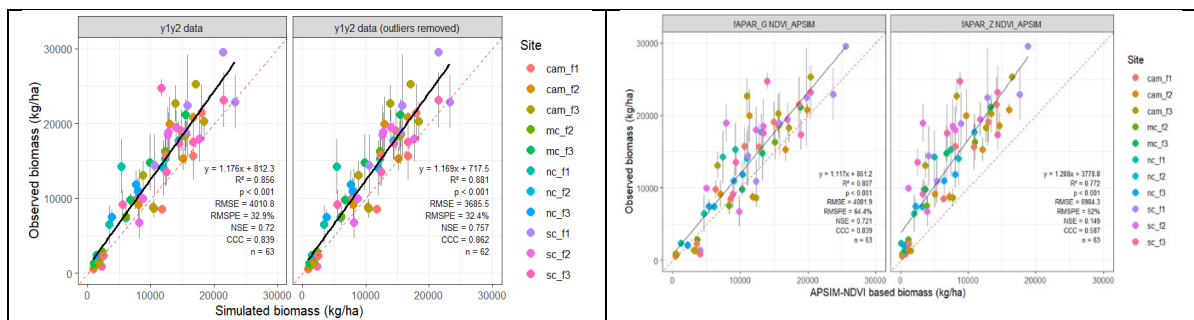


Figure 1. Simulated vs observed biomass with (left) or without outlier correction (right)

Figure 2. Integrated APSIM-NDVI derived vs observed biomass using two different fAPAR methods

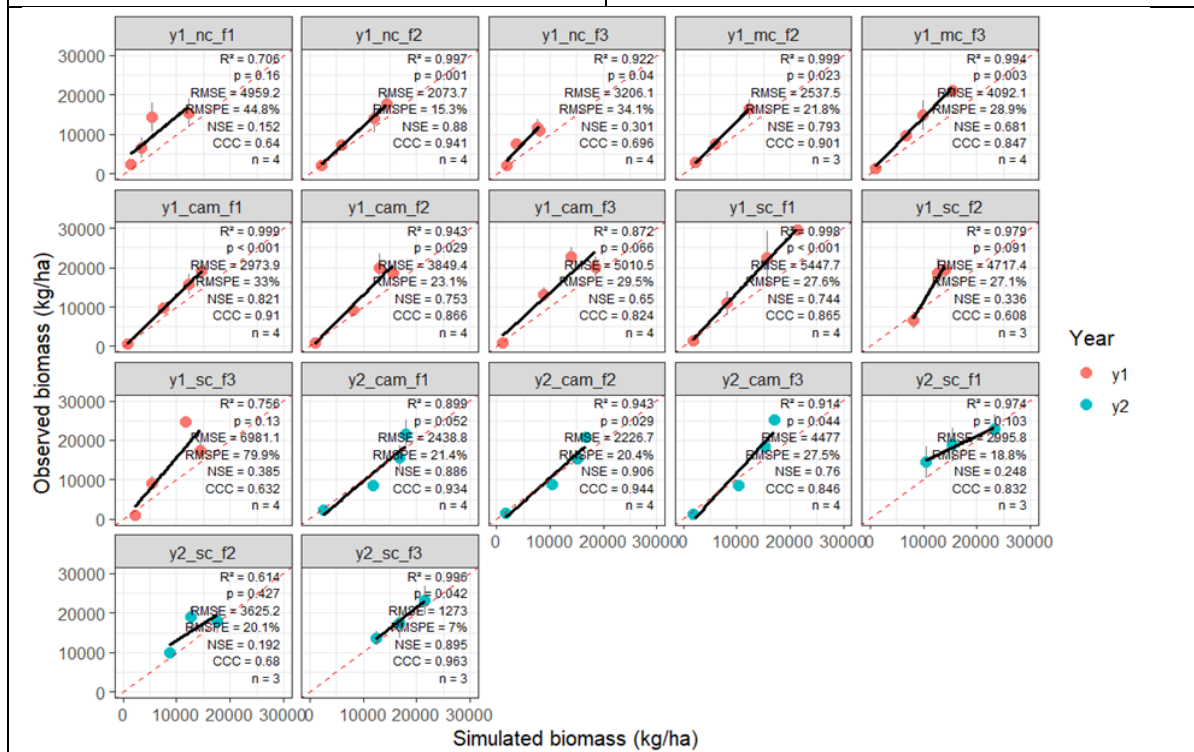


Figure 3. Simulated vs observed biomass by farms across sites, regions and year

7.5 Applications & Impacts

- **Real-time decision support for maize silage management:** APSIM alone and integration of APSIM-remote sensing enables dynamic, near real-time monitoring of crop growth and biomass accumulation, allowing farmers to adjust irrigation, nitrogen, and harvest timing more precisely. This improves management efficiency and reduces uncertainty compared to relying on either modelling or integration with satellite data.
- **Improved feed planning:** Accurate prediction of yield and HI allows better estimation of silage quantity and nutritive value, which is critical for intensive, in-housed TMR based dairy systems where maize silage constitutes a major feed component. This supports optimised diet formulation, reduced feed costs and improved farm profitability.
- **Model applicable to farm or paddock levels:** The model's strong performance across most regions, farms, and years demonstrates its ability to support decision making under diverse climatic and management conditions. By identifying key uncertainties (e.g., stress effects, phenology mismatches), the framework helps improve future modelling and supports climate resilient, data-driven intensive dairy production systems.

7.6 Outputs

- Validated APSIM model for maize silage across diverse environments, farms, and years confirming its suitability as a robust tool for silage production systems.
- Integrated APSIM-remote sensing using sentinel2 NDVI through fAPAR was developed, which enable spatial and temporal monitoring of crop growth and offering a foundation for real-time yield prediction tools.
- A comprehensive dataset was generated across 18 commercial farms across multiple regions over two years, capturing variability in management such as N, irrigation, plant density and environments, which is valuable for future model calibration and validation.
- This study identified key drivers and uncertainties in model performance such as biomass partitioning at grain filling stage, phenological mismatch, paddock variability and measurement uncertainties, observed and satellite data collection date mismatch including resolution and weather situation during satellite data collection.
- Presentations at major national and international scientific conferences, including the American Dairy Science Association Annual Meeting (USA, 2025) and International Precision Dairy Farming Conference (Christchurch, 2025).

7.7 Future Research Opportunities

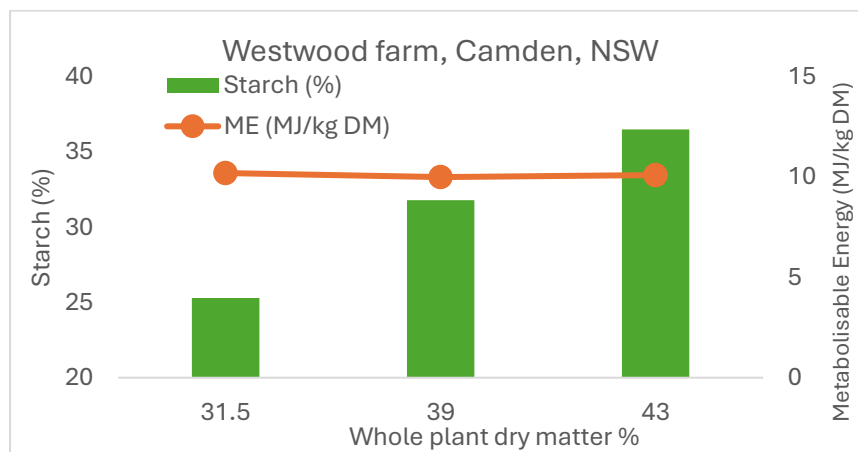
- Future studies should focus on advanced data acquisition using high-resolution remote sensing to improve real time predictions and reduce errors caused by temporal mismatch between observed and satellite data.
- Future work should also focus on stage specific biomass partitioning and stress interactions (water, N, temperature), particularly during grain filling stage to enhance prediction of grain yield and HI.
- Further works needed to develop silage specific genotype modules. Parameterisation of silage-specific maize genotypes harvested around 60-70% grain maturity to better capture variability in HI and nutritive value across environments.

8. Subproject P4c — Redefining nutritive value of maize silage

Research team: Rafiq Islam (The University of Sydney - USYD), Ian Lean (Scibus), Cameron Clark (Charles Sturt University), Martin Correa Luna (USYD), Yani Garcia (USYD)

8.1 Background

A key challenge in evaluating whole crop maize silage (WCMS) evaluation is that silages differing widely in grain proportion or starch content often exhibit remarkably similar energy values (see figure below). Future Dairy research consistently showed that WCMS containing contrasting starch (or DM) had similar energy content. This discrepancy occurs even though grain and stover ratio in silages is approximately 50:50 and grains metabolisable energy (ME) content is 14-16 MJ/kg DM but stover's ME content is 7-9 MJ/kg DM. Again, maize grain in silage is almost 100% digestible in ruminants whereas stovers digestibility is 50-60%.



We hypothesise this discrepancy stems from the fact that WCMS is defined as a forage although it is a heterogenous feed containing both forage (stover) and grain. In traditional feed analysis methods, WCMS containing both grain (starch) and stover (fibre) digested together to derive energy of maize silage. Thus, it is possible that digestion of these contrasting starch and fibre of WCMS suppresses the effect of starch and its digestibility does not reflect in the contribution of energy content of WCMS. Thus, a review of literature was taken to understand why WCMS with contrasting starch remains similar in digestibility or energy content.

This review aimed at) addressing why WCMS with contrasting starch contents consistently demonstrate similar energy values, b) identify biological mechanisms underpinning this phenomenon, and c) propose an alternative approach for evaluating WCMS that more accurately reflects its energy that defines its nutritional value. In addition, a meta-analysis on the impact of DM content at harvest on yield and nutritive value of WCMS was investigated.

8.2 Objectives

- Address why WCMS with contrasting starch contents consistently demonstrate similar digestibility and energy values
- Identify biological mechanisms underpinning this phenomenon
- Propose an alternative approach for evaluating WCMS that more accurately reflects its digestibility and energy contents in order to define its potential nutritional value
- To investigate the impact of DM content at harvest on yield and nutritive value of maize silage

8.3 Materials & Methods

- **Literature review:** Literature published from 2000-20025 on *in vivo* digestibility of WCMS using dairy cows, steers and sheep were collected.
- **Literature sorting and data analysis:** Experiments that evaluated WCMS fed at maintenance levels of feeding, with or without small amounts of concentrate supplementation were included to avoid interactions that might occur when maize silage was digested with other feeds such as concentrates, forages or TMR. Regression analysis was conducted to investigate relationships between fibre and starch content on their digestibility.
- Meta-analysis data was collected from the literature published from 2000 to 20025.

8.4 Key Findings

- **Increased starch in WCMS reduces fibre digestibility.** Contrary to our hypothesis, increased starch does not reduce its digestibility, but starch reduces fibre digestibility (Figure 1).
- **Mechanism of fibre digestibility reduction.** Greater amounts of starch of WCMS degrades rapidly in the rumen, produce volatiles and lactic acid (Nocek and Tamminga (1991). Accumulation of these acids lowers ruminal pH (Lean et al., 2013), which suppresses cellulolytic microbes and reduces fiber digestion. However, amylolytic bacteria that degrades starch are more tolerant of acidic conditions (Mackie et al., 1978). Consequently, NDFD decreases as ruminal pH decreases, whereas starch digestibility remains largely unaffected.
- **Proposed two compartment digestion models for stover and grain, and to redefine WCMS.** To explore the full energy potential of WCMS, a two-compartment digestion model proposed that separately digests the forage (stover) and grain of WCMS in contrast to the conventional approach that treats WCMS as a single, homogenous feed.
- **Meta-analysis on the impact of DM on yield and nutritive value:** The meta-analysis demonstrates that increasing DM content of maize silage enhances DM yield, harvest index, starch and energy content of maize silage.

8.5 Applications & Impacts

- **More precise evaluation and ration formulation based on WCMS:** Redefining WCMS using a two-compartment model (grain and stover) enables more precise estimation of energy supply. This allows intensive farmers to better balance starch and fibre in rations, improving diet formulation accuracy, and dairy performance.
- **Improved rumen health and feeding strategies:** Understanding that higher starch reduces fibre digestibility via rumen pH suppression, provides a mechanistic basis to design diets, that avoid suboptimal rumen conditions, thereby improving feed efficiency, milk production, and animal health.
- **Reduced feed costs and improved dairy system efficiency:** Understanding the concept that starch of high grain silage WCMS can meet a significant amount of starch in the diet, farmers can add less grain in the diet of cows, optimise diet accordingly leading to cost-effective intensive dairy production and better profitability.

8.6 Outputs

- The review demonstrated that increasing starch in WCMS does not reduce starch or overall digestibility, but instead reduces fibre digestibility, explaining why WCMS with contrasting starch contents show similar energy values.

- Review also provided biological mechanism explaining constant energy content of maize silage. WCMS starch rapidly degraded in the rumen, accumulating acids, lowers rumen pH, which ultimately reduces fibre digestibility but does affect starch digestibility. Consequently, WCMS digestibility or energy remains constant.
- Accordingly, a novel two-compartment digestion model framework to digest grain and stover separately was proposed to evaluate WCMS, providing a more realistic representation of its nutritive value than traditional single-WCMS evaluation.
- Presented orally at the ADSA at Louisville, Kentucky, USA in 2025.

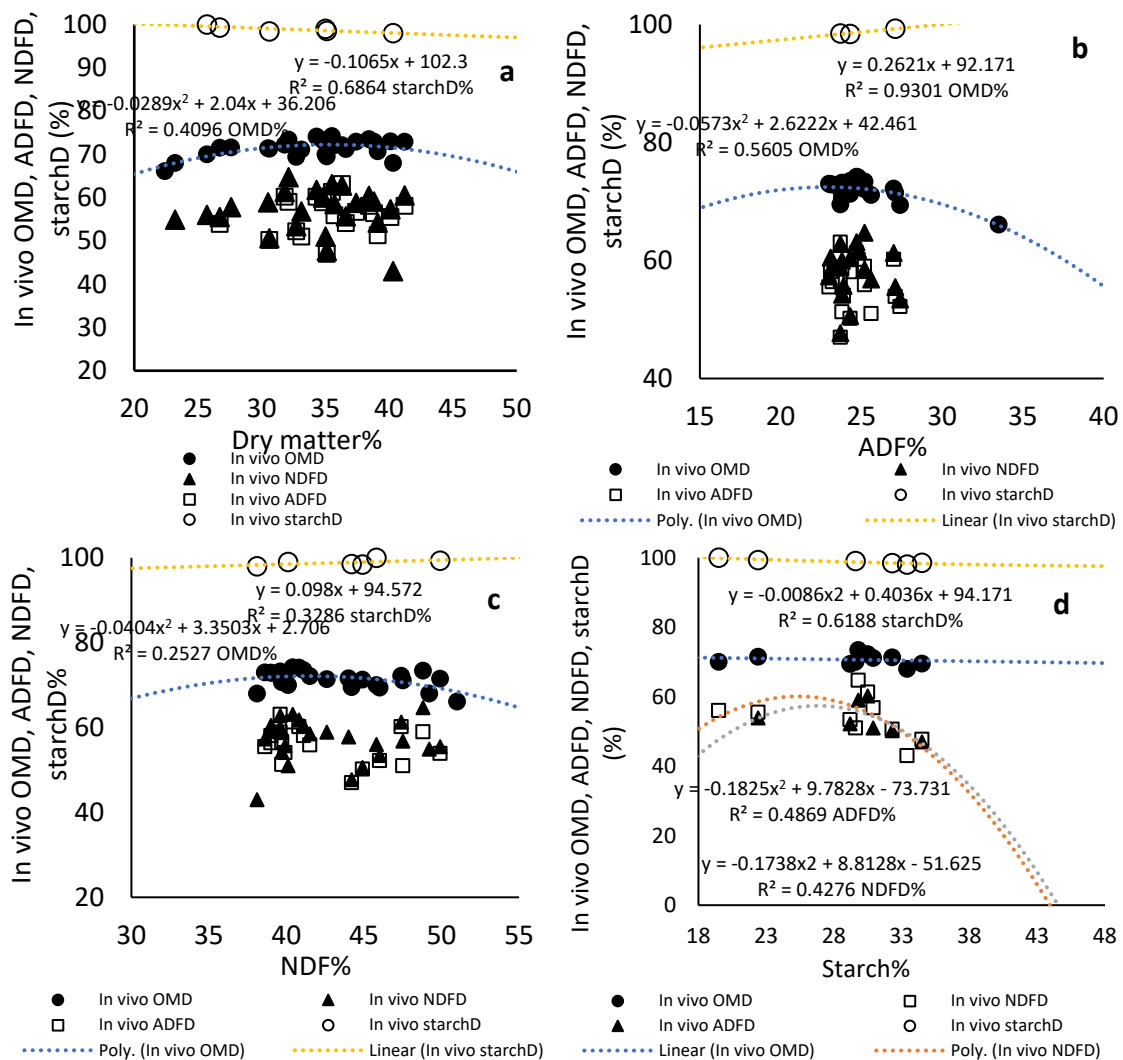


Figure 1. In vivo organic matter digestibility (OMD%), acid detergent fiber digestibility (ADFD%), neutral detergent fiber digestibility (NDFD%), and starch digestibility (starchD%) affected by dry matter, ADF, NDF and starch contents of WCMS

8.7 Future Research Opportunities

This review provided a foundation concept to re-evaluate and re-define WCMS, or other grain silages used in TMR industry for intensive dairy systems. However, the concept needs to be validated and established through further research.

Priority areas for future research include:

- **Validation of the two-compartment model:** Testing the proposed model by digesting stover and grain separately using in vitro, in situ and vivo dairy trials and compare with single-WCMS evaluation.
- **Integration with nutrition and ration formulation models:** Incorporate the two-compartment approach into feeding systems (e.g., NRC/ARC models) to investigate how much grain in the diet can be replaced by WCMS grain in the diet of cows in intensive system and its impact on cost reduction by farmers.
- **Investigating the impact of grain to stover ratio or starch of WCMS on rumen dynamics and microbiome:** Investigate how varying grain-to-stover ratios influence rumen microbiology, pH dynamics, and fibre degradation kinetics, enabling development of precision feeding strategies.

9. Subproject P4d — New Directions in BMR Silage Research

Research team: Rafiq Islam (The University of Sydney - USYD), William Salter (USYD), Anna Chlingaryan (USYD), Ben Vercoe (Pioneer Seeds), Raewyn Densley (Pioneer Seeds), Ian Lean (Scibus), Yani Garcia (USYD)

9.1 Background

During the last decades, BMR maize hybrids have gained considerable attention because of their reduced lignin content, higher fibre digestibility, increased DM intake and milk production (Tebbe and Weiss, 2018). However, it is characterised by its lodging habit, and its yield is relatively low compared to the conventional (CON) hybrids. Recently developed maize hybrids are claimed to be overcome lodging and yield gaps. Thus, in collaboration with Pioneer seeds and APPN, research was conducted to investigate trade-offs between yield and quality of maize hybrids (BMR vs CON) under different sowing density across years. Such evaluations provide the basis for recommendations of hybrid types that balance productivity, nutritive value, and crop resilience for intensive dairy farmers.

9.2 Objectives

- To evaluate the effects of maize hybrid type and planting density on yield and nutrient partitioning trade off at different stages of growth affecting nutritive value
- To investigate how hybrid type and planting density influence plant phenology, lodging and canopy characteristics
- To compare the nutritive value of BMR and CON maize hybrids, and fibre digestibility in determining silage quality
- To assess yield, phenology and nutritive value of BMR and CON maize hybrids using remote sensing

9.3 Materials & Methods

- **Crop management:** The experiment was conducted over two growing seasons (2024-25 and 2025-26) at the USYDs Lansdowne farm, Camden. A factorial design was used with two maize BMR (P07003) and CON (P0937), sown at three planting densities (80,000, 95,000 and 110,000 plants/ha) with three replicates arranged in a randomised complete block design with non-limiting N and irrigation. Data on biomass, grain yield and HI including phenology was collected at four growth stages (V6, flowering, grain filling and at final harvest). Nutritive value including NDF, ADF, starch, and ME and NDFD at 24 were determined. Data were analysed using a REML mixed model in R, with hybrid, density, and year as fixed effects and block nested within year as a random effect to evaluate main effects and interactions.
- **Remote sensing data:** Remote sensing data were obtained at flowering stage using a drone in collaboration with APPN.

9.4 Key Findings

- **Both hybrids maintained high yield under non-liming N and water.** No lodging was apparent in BMR hybrid. Both hybrids yielded 25-28 t DM/ha on average across years. Hybrid had no effect on nutritive value (11.8 MJ ME/kg DM).
- **Plant density influences yield but had no effect on nutritive value.** Plant density had no impact on yield and nutritive value. However, optimal density management was crucial in general as BMR performed best at 95,000 plants/ha (26-27 t DM/ha) in both years, but CON

hybrid performed best at 110,000 plants/ha (27-28 t DM/ha) indicating more plasticity of this hybrid (Figure 1).

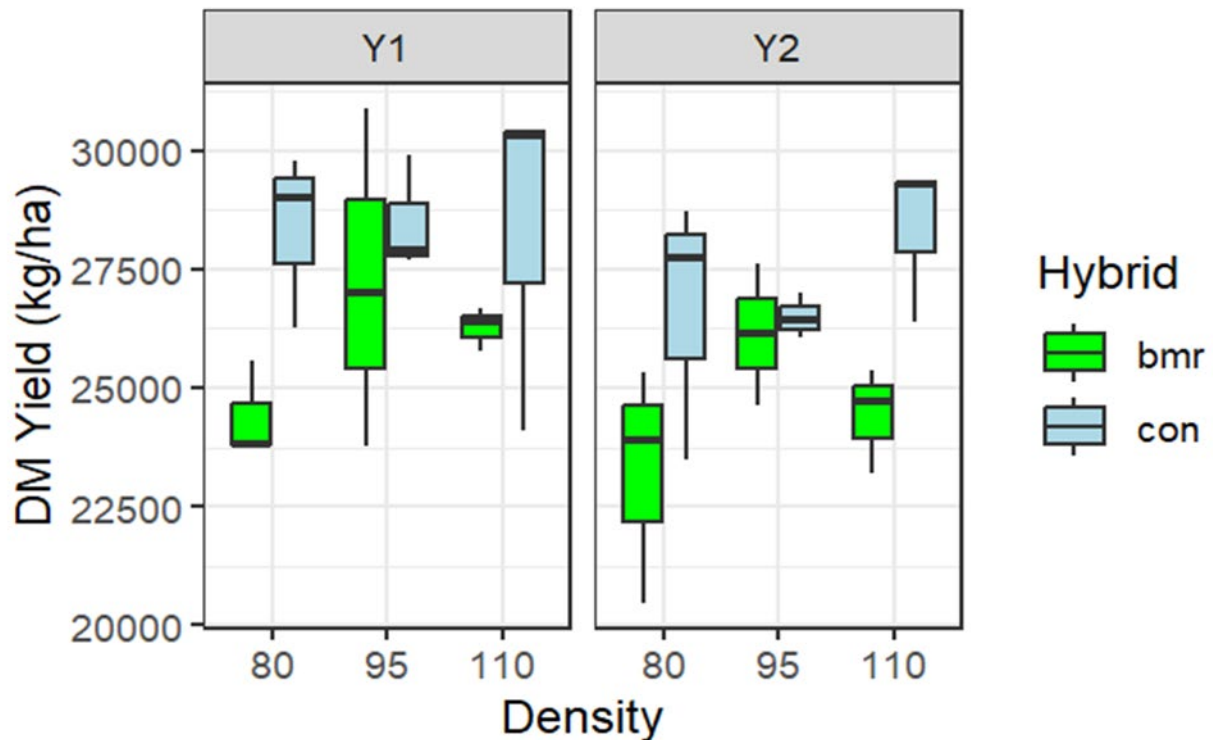


Figure 1. Yield of BMR and conventional hybrid affected by hybrid and plant density

9.5 Applications & Impacts

- **Improved hybrid selection for specific production goals:** Farmers can select hybrids based on system priorities. CON hybrid had higher yield and grain, but BMR had improved fibre digestibility. This enables more targeted decision making for TMR systems in intensive dairy farming.
- **Starch-fibre trade-off between hybrids:** Starch-fibre trade-off between CON and BMR hybrids allows farmers to better balance diets, and improving rumen function, feed efficiency and milk production.

9.6 Outputs

- The study generated robust field data on biomass, grain yield, HI, and digestibility, providing a practical benchmark for silage production in Australian dairy systems.
- This study also provided a better understanding of yield-quality trade off of CON and BMR hybrids offering Australian intensive dairy farmers a refined framework to interpret this trade-off for diet formulation and decision in feeding system based on the farm need.

9.7 Future Research Opportunities

Priority areas for future research include:

- **Multi-environment validation trial:** Hybrid effects and yield-quality relationships under real farm conditions required across climates and management system under variable input levels. System modelling also required to validate data.
- **Animal feeding trial:** Future research should investigate performance of CON and BMR hybrids in order to enable better prediction of animal performance from silage.

10. Project-wide Dissemination

One manuscript published in a high-impact international journals (FPS), which has an impact factor of 4.8 and is ranked Q1 in its field. In addition, two significant works presented orally in two significant forums. One in the American Dairy Science Association (ADSA) Annual Meeting at Kentucky in the USA, and another one present in the Precision Dairy Farming Conference in NZ, Christchurch (Table 1). These presentations collectively reached an estimated audience of over 3,700 people, spanning industry professionals, researchers and policymakers.

Table 1. Peer review publication, conference presentations, abstracts and other communications

Authors	Title	Journal/Prese ntation Type	Conference/ Event	Location	Year	Audienc e
Ojeda et al	Field and in silico analysis of harvest index variability in maize silage.	Front. Plant Sci 14:1206535 (2023)				
Islam et al.	Revealing the real nutritional value for maize silage	J. Dairy Sci. Vol. 108, Suppl. 1, pp 174-175 (2025)				
Islam et al.	Integrating APSIM and remote sensing to predict maize silage biomass	Proc Precision Dairy Farming Conf, pp 171-172 (2025)				
Islam et al.	Revealing the real nutritional value for maize silage	Oral presentation	ADSA Annual Meeting, 22-25 June 2025	Louisville, USA	2025	1,000
Islam et al.	Integrating APSIM and remote sensing to predict maize silage biomass	Oral presentation	4 th Int Precision Dairy Farming Conference , 3-5 Dec, 2025	Christchurch, NZ	2025	200
Garcia and Islam	Maize for silage	Dairy UP Website			2025	
Ojeda et al	Digitising forage options for intensive dairy systems	Dairy Up report			2024	

II. Conclusions and Recommendations

The P4 Feedbase for Intensive System project has delivered new insights on real-time monitoring of maize for intensive dairy farming and TMR industry and identified HI as a tool to monitor feed quality. It also investigated ways to explore its nutritive value accurately which may play a significant role to reduce feed cost and improving efficiency of farming. In addition, information help farmers in decision making and improved farm-feed planning to reduce risk in intensive dairy farms.

P4a successfully calibrated to simulate maize silage biomass using APSIM modelling across diverse environments, demonstrating strong predictive capacity for biomass yield. APSIM also provided a robust framework for analysing genotype, management an environment interaction and provides a strong foundation for further refinement of silage-specific modelling. It identified HI to use as a key determinant of feed quality.

P4b demonstrated that APSIM alone or integration of APSIM with remote sensing can be used for biomass, grain yield and HI prediction by combining mechanistic understanding with real-time observations. This hybrid approach showed strong potential for dynamic yield forecasting. However, limitations were evident in predicting grain yield and HI, particularly under variable water and nitrogen conditions, due to challenges in representing phenology, biomass partitioning, and stress responses. Integration methods require further refinement, especially in linking canopy signals (NDVI/fAPAR) with biomass partitioning during flowering and grain filling stages.

P4c demonstrated that energy content remains relatively constant despite large variation in starch concentration is driven by a biological trade-off mechanism: increased starch reduces fibre digestibility via rumen pH effects. The proposed two-compartment model (grain and stover) provides a more accurate framework for evaluating silage quality than traditional single-feed approaches, which can be used to redefine the nutritive value of WCMS.

P4d demonstrated that farmers can select hybrids based on system priorities. Conventional hybrid had higher yield and grain, but BMR had improved fibre digestibility. This enables more targeted decision making for TMR systems in intensive dairy farming.

Recommendations for future investment should prioritise:

- Research on parameterisation and calibration of silage specific hybrids including BMR enable more accurate prediction of yield and nutritive value
- Integrating APSIM with high frequency remote sensing with modelling to capture variation both at early and late growth stages particularly at flowering and grain filling stage
- Validation of the two-compartment digestibility model in dairy systems and its integration in NRC/ARC framework to improve precision feeding, productivity and sustainability in TMR based dairy systems
- Multi-environment validation trial of BMR maize and its performance in TMR and dairy industry

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