# DROUGHT AND CLIMATE RESILIENT MIXED FARMING SYSTEMS

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## TAKE HOME MESSAGES

- For a systems trial at Kinnabulla, Victoria, where both 2024 and 2025 were Decile 2 growing seasons, plant available water at sowing (PAW) differed substantially across years (91mm in 2024 and 31mm in 2025). There was no difference in 2025 PAW due to 2024 crop type (wheat, barley, lentil or vetch).
- Wheat protein and screenings were higher after vetch than lentil due to higher soil nitrogen at sowing after vetch and overall limited crop water supply in 2025.
- Where lentil and vetch in 2025 followed barley, pulse crops' biomass at flowering were equivalent (2.8t/ha). Subsequently vetch was grazed and gross margin estimate was $566/ha, whereas for lentil, which yielded 0.9t/ha, corresponding gross margin was $525/ha.

## BACKGROUND

Total production and year-to-year stability can be highly variable for farming systems within semi-arid environments, such as the Wimmera and Mallee, where seasonal water availability has been long identified as a major constraint to production (French 1978). Moreover, water losses due to evaporation – particularly over the summer period, or where the soil water is not protected by adequate summer weed control, stubble, canopy cover or by being stored at depth – represent lost opportunity for production potential (O'Leary and Connor 1997; Hunt and Kirkegaard 2011). Farming system adaptations that improve drought resilience of broadacre grains, pasture and mixed farming systems by better harnessing annual rainfall and bridging dry periods are likely to increase the net production per millimetre of rainfall.

Currently research is being conducted at Kinnabulla, Victoria, assessing three different rotation systems: 1) continuous cropping, 2) cropping with a pasture phase and 3) a farmer-driven tactical rotation based on seasonal forecasting and markets to compare production stability and profitability. This work is part of a broader network of trials being conducted across southern Australia to determine what management strategies provide best adaptation opportunities for production and profitability into the future.

## AIM

To compare the production potential of intensive cropping and mixed farming systems, within the low rainfall zone of the Victorian southern Mallee, particularly under dry seasonal conditions. The longer-term objective is to evaluate the potential trade-offs between system resilience and profitability across different seasons.

## PADDOCK DETAILS

Location: Kinnabulla, Victoria (35°53’51”S 142°42’05”E)

Average annual rainfall*: 370mm

2024 Crop year rainfall (Nov–Oct): 275mm
2024 GSR (Apr–Oct): 149mm

2025 Crop year rainfall (Nov–Oct): 228mm
2025 GSR (Apr–Oct): 156mm

Soil type: Calcarosol

Paddock history: 2023 Wheat, 2024 trial established (various crops).

*Average rainfall figures: Beulah BOM weather station number 077004 – near Kinnabulla. Annual rainfall figures from SILO Kinnabulla 77020.

## TRIAL DETAILS

Crop type/s: Wheat (Scepter), barley (Maximus CL), lentil (Thunder XT), vetch (Morava) – grazed

Treatments: Crop rotation (R)
R1: wheat-barley-lentil
R2: wheat-barley-vetch
R3: lentil (2024)-wheat (2025) – TBD (responsive system)

Seeding equipment: 2024 tyne 30cm row spacing (researcher sown)
2025 disc 38cm row spacing (farmer sown)

Sowing date/rate: 2024: vetch, 24 April (54kg/ha); wheat, 08 May (62kg/ha); barley, 08 May (62kg/ha); lentil, 08 May (61kg/ha)
2025: vetch, 16 April (50kg/ha); barley, 30 April (45kg/ha); lentil, 10 May (40kg/ha); wheat, 15 May (50kg/ha)

Replicates: Three (R1 and R2 also phase replicated)

# TRIAL INPUTS

**Wheat**

| | |
|---|---|
| Fertiliser: | MAP @ 40kg/ha; Zinc Mang Copper Sulfate (ZMC+S) @ 2L/ha; UAN @ 50L/ha; ZMC+S @ 1.5L/ha ZMC; UAN @ 25L/ha (Fertiliser nitrogen = 36kg N/ha) |
| Herbicide: | Overwatch @ 1.5L/ha); post-emergent (metsulfuron @ 3g/ha, LVE 570 500ml/ha, Clopyralid 600 @ 20ml/ha, Rexade @ 100g/ha) |
| Fungicide: | Azoxystrobin @ 300ml/ha; Epoxiconazole @ 90ml/ha |

**Barley**

| | |
|---|---|
| Fertiliser: | MAP @ 40kg/ha; ZMC+S @ 2L/ha; UAN @ 50L/ha; ZMC+S @ 1.5L/ha ZMC; UAN @ 25L/ha (Fertiliser nitrogen = 36kg N/ha) |
| Herbicide: | Boxer Gold @ 2L/ha); post-emergent (Imaza combi @ 70ml/ha; MCPA LVE 570 @ 400ml/ha: Clopyralid 600 @ 25ml/ha) |
| Fungicide: | Epoxiconazole @ 90ml/ha |

**Lentil**

| | |
|---|---|
| Fertiliser: | MAP @ 40kg/ha; ZMC+S @ 2L/ha (Fertiliser nitrogen = 4kg N/ha) |
| Herbicide: | Diuron 900 WG @ 350g/ha; Diflufenican 500 SC @ 60ml/ha; Expedient @ 400ml/ha; Clethodim 360 @ 300ml/ha; Haloxyfop 520 @ 300ml/ha |
| Insecticide: | Gaucho @ 80ml/ha |
| Fungicide: | Epoxiconazole @ 90ml/ha |
| Seed treatment/inoculant: | Inoculated and Nutrien pulse seed coat applied |

**Vetch**

| | |
|---|---|
| Fertiliser: | MAP @ 40kg/ha (Fertiliser nitrogen = 4kg N/ha) |
| Herbicide: | Diuron @ 0.35kg/ha; Simazine @ 0.33kg/ha; Expedient @ 400ml/ha; Clethodim 360 @ 300ml/ha; Haloxyfop 520 @ 300ml/ha; Glyphosate 2L/ha – 4 October |
| Insecticide: | Trojan @ 60ml/ha |
| Fungicide: | Epoxiconazole @ 90ml/ha |
| Seed treatment/inoculant: | Loveland Pulse seed coating mix and inoculation with peat for vetch dry dusted, with lentil as peat slurry. Gaucho 350 on all seed vetch Pickle T. |

## METHOD

A multi-year randomised complete block design experiment was established in 2024 to compare three different rotation systems, continuous crop (R1), mixed farming (R2) and a seasonally responsive rotation (farmer driven) (R3) for productivity, resource use and ultimately economics. Rotation phases (treatments) were replicated three times and R1 and R2 systems were also phase replicated.
Large plots (37 x 100 metres) were farmer-sown and managed in-season during 2025. For soil and crop measurements, the plots were divided into four sub-plots to account for large-plot data variance. In-season measurements at the subplot level included soil water and nitrogen at sowing for six soil layers to 1 metre, crop establishment, crop biomass at flowering, yield components and grain quality. For the grazing/livestock component within R2, vetch biomass and sheep weight gain were recorded. Assessment of the R1, R2 and R3 systems is out of scope for this report as this analysis requires long-term data across the project's life. Interim analyses below constitute 2024 data being aggregated for crop type given this was the trial establishment year and for 2025, the effect of previous crop was compared.

## RESULTS AND INTERPRETATION

### Soil description

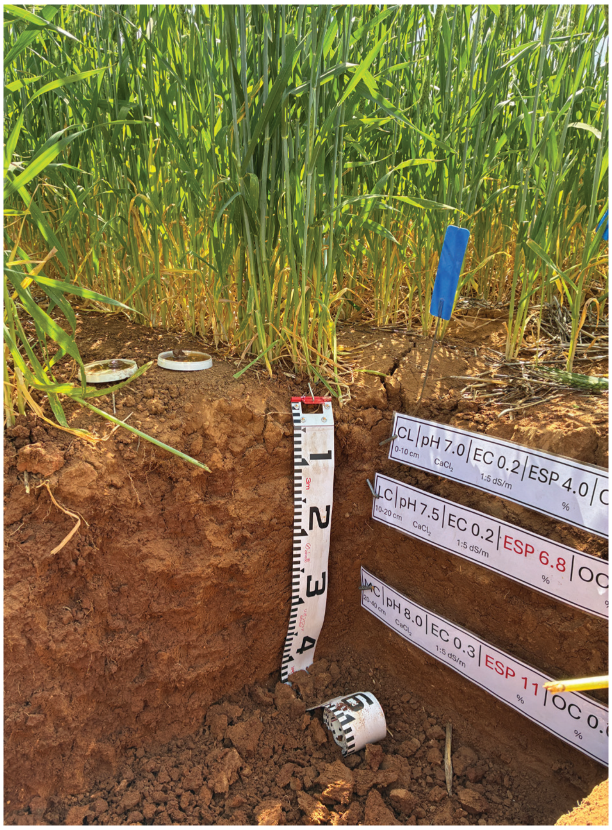

**Figure 1. Soil pit at Kinnabulla, Victoria. Soil type is a Calcarosol.**

The soil type across the site is a Calcarosol and has the following characteristics (Figure 1). The texture within the top-soil is a clay loam, grading into a light clay within the shallow sub-soil and becomes a medium clay texture within the deeper sub-soils, making it a gradational soil texture trend with depth (Table 1). Top-soil pH is neutral and becomes moderate to strongly alkaline within the sub-soil. Soil bulk density down the profile is non-limiting regarding soil strength effects on root penetration. Soil electrical conductivity (EC) is low to moderate and largely unlimiting to crops. Soil sodicity (ESP) is non-sodic in the top-soil (ESP<6%), however, becomes sodic at 10–20cm and highly sodic at 50cm. Sodic soils can have either inherently fragile structure or be poorly structured (hard set) thus limiting water and/or root penetration. Sodicity levels in the shallow sub-soil can be reduced with maintenance applications of gypsum.

**Table 1. Soil properties at the Kinnabulla trial site. EC, electrical conductivity; ESP, exchangeable sodium percentage (sodicity); B, boron. Mean values and standard deviation in parentheses are presented. For each soil layer n = 84, except for bulk density where n = 3.**

| Depth (cm) | Texture | Bulk density ($Mg/m^3$) | Organic carbon (%) | pH ($CaCl_2$) | EC (1:5) (dS/m) | ESP (%) | B (mg/kg) |
|---|---|---|---|---|---|---|---|
| 0–10 | Clay loam | 1.0 (0.06) | 1.0 (0.2) | 7.0 (0.6) | 0.2 (0.1) | 4.0 (2.0) | <3 |
| 10–20 | Light clay | 1.1 (0.07) | 0.7 (0.1) | 7.5 (0.4) | 0.2 (0.1) | 6.8 (2.7) | 3.4 (1.4) |
| 20–40 | Clay | 1.2 (0.04) | 0.6 (0.1) | 8.0 (0.3) | 0.3 (0.1) | 11 (2.7) | 6.0 (3.5) |
| 40–60 | Clay | 1.2 (0.12) | 0.5 (0.1) | 8.3 (0.2) | 0.4 (0.1) | 15 (3.0) | 10 (4.8) |
| 60–80 | Clay | 1.4 (0.08) | 0.4 (0.1) | 8.4 (0.2) | 0.5 (0.1) | 19 (3.4) | 16 (6.3) |
| 80–100 | Clay | 1.4 (0.05) | 0.3 (0.1) | 8.5 (0.2) | 0.8 (0.1) | 22 (3.4) | 19 (5.9) |

## Seasonal conditions

### 2024 season

For the 2024 season, in January there was about three times the average monthly rainfall which contributed to stored soil water deeper within the profile (Figure 2). Despite this, lower-than-average late summer and spring rainfall meant the trial was established under dry sowing conditions. Rainfall in late May enabled good establishment of all crop species, however, lower than average rainfall throughout most of the growing season translated to crops relying heavily on stored soil water. Low temperatures and frosts were frequent throughout the season.

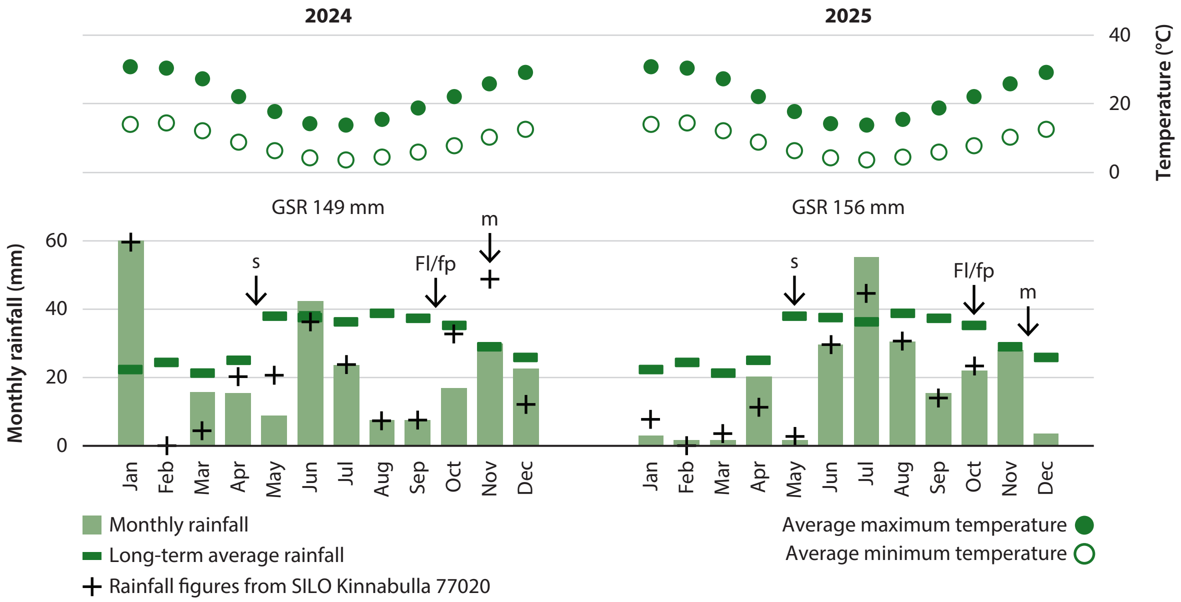

**Figure 2. Monthly rainfall and temperature at Beulah, Victoria, close to Kinnabulla, in 2024 and 2025. Bars are long term averages, solid circles average maximum temperatures and open circles average minimum temperatures. GSR, growing season rainfall; s sowing; Fl/fp flowering/flat pod; m maturity. Data from Bureau of Meteorology, Beulah station 077004. Black crosses are annual rainfall figures from SILO Kinnabulla 77020.**

For the 2025 season, very low summer/early autumn rainfall translated to crops being sown under dry conditions. Good rainfall during June, July and August supported late establishing crops and set up for reasonable yield potential. There was lower than average rainfall in September and October which induced progressive water stress to crops, particularly during onset of flowering.

### Soil water

At trial initialisation (sowing) in 2024, there was moderate plant available water (about 91mm) within the soil profile across the trial site, which was associated with significant summer rainfall in January 2024 (Figure 3). In contrast, a very dry summer and autumn in 2025 translated to low plant available water at sowing within the deeper sub-soil (about 31mm).

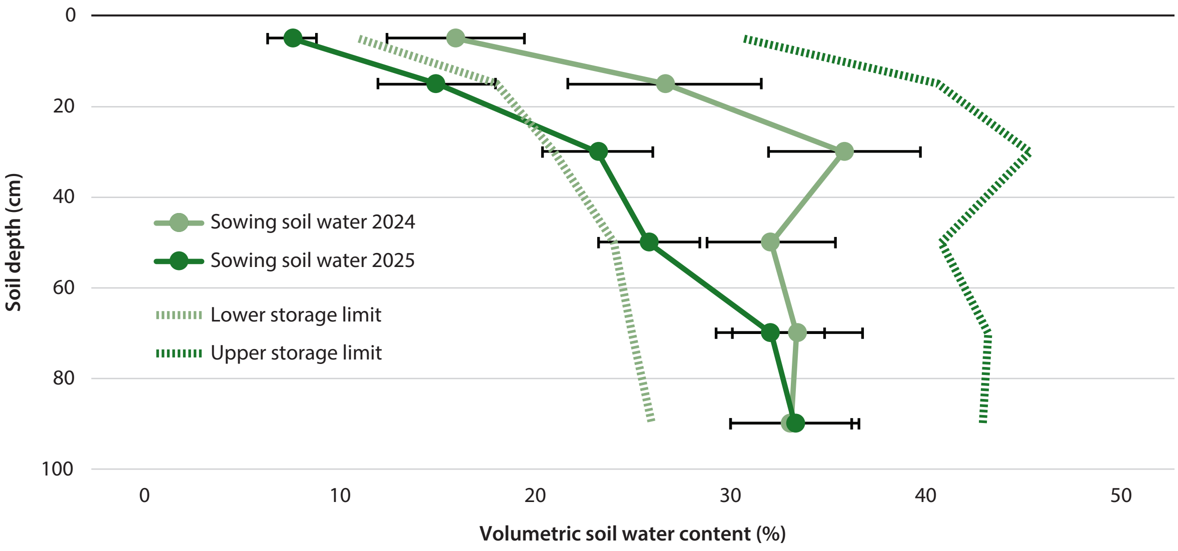

**Figure 3. Soil water at sowing, where amounts for 2024 and 2025 are compared. For 2024, this was the trial establishment year and values represents site means for each soil layer. For 2025, values are pooled for crop type treatments that occurred in 2024. Error bars are standard deviation of means. Soil lower storage limit estimate (15 bar) and upper storage limit (measured) are also presented.**

There was no effect of previous crop species on soil water at sowing in the following year (2025) (Table 2). The exception was in the 60–80cm soil layer where there was significantly greater soil water after vetch compared with barley and wheat, although this difference was small and unlikely to be relevant from an agronomic perspective. The limited differences in soil water given previous crop type are likely due to the very low growing season rainfall in 2024 forcing all crops to progressively draw down on soil water reserves being close to the lower storage limit of the soil (ie. sowing soil water levels in 2025).

**Table 2. Soil water (volumetric water content – %) at sowing in 2025 at Kinnabulla, Victoria. Values are for soil layers, where the effect of previous crop (2024) is compared. Max and min refer to replicate structure and are used when comparing LSD values.**

| 2024 crop | Soil depth (cm) | | | | | |
|---|---|---|---|---|---|---|
| | **0–10** | **10–20** | **20–40** | **40–60** | **60–80** | **80–100** |
| Barley$^{max}$ | 7.4 | 15.1 | 23.3 | 25.4 | 31.2 | 32.7 |
| Lentil$^{max}$ | 7.6 | 14.4 | 23.2 | 25.6 | 32.4 | 32.9 |
| Vetch$^{min}$ | 7.2 | 16.3 | 23.0 | 27.4 | 33.8 | 34.5 |
| Wheat$^{max}$ | 7.8 | 14.5 | 23.2 | 25.7 | 31.6 | 33.6 |
| **Sig. diff.** | - | - | - | - | **0.05** | - |
| **LSD (P=0.05)** | **NS** | **NS** | **NS** | **NS** | | **NS** |
| Max-min rep | | | | | **1.9** | |
| Max rep | | | | | **1.6** | |
| **CV%** | **14.5** | **19.5** | **12.6** | **10** | **8.4** | **9.7** |

### Soil nitrogen

At trial initialisation (sowing) in 2024, soil mineral nitrogen within the soil profile across the site was 62 (standard deviation 16) kg N/ha. Within the top-soil (0–10cm) there was 23 (11) kg N/ha. For the sub-soil layers, 10–20cm, 20–40cm, 40–60cm, 60–80cm and 80–100cm, there was 7 (2), 11 (3), 8 (2), 6 (1) and 7 (2) kg N/ha respectively. Note: Standard deviation, in parentheses, is a measure of the variability of the data from the average.

Interestingly, soil mineral nitrogen at sowing in 2025, top-soil (0–10cm) levels were significantly greater after wheat compared with other crops (Table 3). In contrast, least soil nitrogen in the topsoil occurred after lentil. For the subsoil, within the 10–20 cm layer there was no significant effect of previous crop on soil nitrogen, whereas for the 20–40cm and 40–60cm layers there was significantly greater soil nitrogen after vetch compared with other crops. Beyond 60cm there was no effect of previous crop on soil nitrogen status. For the total profile soil nitrogen to 60cm significantly higher levels occurred after wheat and vetch compared with where barley and lentil were grown.

**Table 3. Soil mineral nitrogen (kg N/ha) at sowing in 2025 at Kinnabulla, Victoria. Values are for soil layers, where the effect of previous crop (2024) is compared. Max and min refer to replicate structure and are used when comparing LSD values.**

| 2024 crop | Soil depth (cm) | | | | | | |
|---|---|---|---|---|---|---|---|
| | **0–10** | **10–20** | **20–40** | **40–60** | **60–80** | **80–100** | **0–60** |
| Barley$^{max}$ | 31 | 12 | 8 | 5 | 6 | 7 | 56 |
| Lentil$^{max}$ | 23 | 13 | 10 | 7 | 7 | 7 | 53 |
| Vetch$^{min}$ | 29 | 16 | 14 | 8 | 8 | 8 | 66 |
| Wheat$^{max}$ | 36 | 14 | 9 | 6 | 7 | 7 | 69 |
| **Sig. diff.** | **0.001** | - | **0.001** | **0.001** | - | - | **0.001** |
| **LSD (P=0.05)** | | **NS** | | | **NS** | **NS** | |
| Max-min rep | **5** | | **3** | **1** | | | **10** |
| Max rep | **4** | | **2** | **1** | | | **8** |
| **CV%** | **25** | **46** | **38** | **20** | **23** | **34** | **23** |

### Crop and livestock production

For trial set up in 2024, vetch was sown on 24 April and wheat, barley and lentil were sown on 8 May, with respective plant establishment numbers of 102/m$^2$, 84/m$^2$, 231/m$^2$ and 132/m$^2$. Flowering biomass was 4.2t/ha, 2.3t/ha and 1t/ha for barley, wheat and lentil respectively, and average grain yield was 0.9t/ha for both wheat and lentil and 1.8t/ha for barley (Table 4). Frost throughout the season impacted all crops and low grain numbers, particularly for wheat and lentil, were observed. Barley yield was least impacted, with both grain number and size maintained. Grain protein concentration (GPC) was 12.5 per cent, 13.3 per cent and 21.2 per cent for barley, wheat and lentil respectively.

For the livestock, vetch biomass prior to grazing was 1.7t/ha and dry merino ewes (3–4 years old) at 21 DSE/ha were grazed for 35 days between 17 September and 22 October. Average weight increased from 40 (3) kg to 48 (3) kg per head and corresponding rate of gain was 242 (84) grams per day.

**Table 4. Crop growth, yield components and quality for 2024. Means are pooled for replicate and rotation for the trial establishment year and standard deviation in parentheses. Harvest index, HI; grain protein concentration, GPC. Vetch was grazed.**

| 2024 crop | Flowering biomass (t/ha) | Yield (t/ha) | HI | Grain number (per m$^2$) | Grain size (mg) | GPC (%) | Screenings (%) |
|---|---|---|---|---|---|---|---|
| Barley | 4.2 (0.7) | 1.8 (0.3) | 0.46 (0.06) | 4081 (710) | 44.4 (2.4) | 12.5 (0.9) | 3.1 (1.2) |
| Lentil | 1.0 (0.5) | 0.9 (0.1) | 0.56 (0.08) | 1989 (295) | 45.2 (3.0) | 21.2 (0.7) | - |
| Wheat | 2.3 (0.4) | 0.9 (0.1) | 0.45 (0.45) | 2099 (312) | 40.8 (2.3) | 13.3 (0.8) | 3.7 (1.5) |
| Vetch | 1.7 (0.3) | - | - | - | - | - | - |

For 2025, crops were sown in April and May. Vetch was sown 16 April, barley 30 April, lentil 10 May and wheat 15 May. Plant establishment numbers were 163 plants per square metre (vetch), 179/m$^2$ (barley), 178/m$^2$ (lentil) and 180/m$^2$ (wheat).

Where wheat followed either lentil or vetch, there was no significant difference in growth or yield (yield components) of wheat (Table 5). In contrast, when wheat followed vetch, the GPC and screenings were significantly higher than where wheat followed lentil. This is likely linked to the significantly higher soil mineral nitrogen status at sowing where wheat followed vetch compared to lentil (Table 3).

Where lentil and vetch followed barley in 2024, biomass at flowering was equivalent (2.8t/ha) for these pulse crops (Table 5). At this point, vetch was grazed by composite cross lambs (6–12 months old) at 16 DSE/ha for 22 days between 8 and 30 October. Average weight increased from 45 (4) kg to 52 (5) kg per head and the corresponding rate of gain was 276g (118) per day. For lentil, average yield was 0.9t/ha where both grain number and size were low, and the GPC was 22.9 per cent. For barley following wheat, flowering biomass and yield were 4.5t/ha and 1.5t/ha respectively; yield components (grain number and size) were very low and screenings high.

Comparative gross margin estimates for vetch grazed and lentil grain in 2025 were $566/ha and $525/ha respectively. In 2024, the equivalent comparison was $598/ha and $786/ha respectively. This flip-flop trend demonstrates the large effect of grain price fluctuation.

**Table 5. Crop growth, yield components and quality for 2025 where crop response is context to previous crop type in 2024. For the barley/lentil, barley/vetch and wheat/barley rotations the 2025 yield components are replicate means and standard deviation in parentheses. For lentil/wheat* and vetch/wheat* rotations, the effect of previous crop is compared on wheat response in 2025. Grain protein concentration, GPC. Vetch was grazed.**

| Crop rotation 2024/2025 | 2025 crop | | | | | |
|---|---|---|---|---|---|---|
| | **Flowering biomass (t/ha)** | **Yield (t/ha)** | **Grain number (per m$^2$)** | **Grain size (mg)** | **GPC (%)** | **Screenings (%)** |
| Barley/lentil | 2.8 (0.5) | 0.9 (0.3) | 1040 (337) | 31.5 (3.1) | 22.9 (0.5) | - |
| Barley/vetch | 2.8 (0.6) | - | - | - | - | - |
| Wheat/barley | 4.5 (0.7) | 1.5 (0.2) | 1610 (298) | 33.0 (2.3) | 13.9 (1.4) | 33 (15) |
| Lentil/wheat* | 3.9 | 1.5 | 1654 | 32.5 | 12.9 | 3.0 |
| Vetch/wheat* | 2.8 | 1.4 | 1606 | 32.0 | 15.0 | 4.2 |
| **Sig. diff.** | - | - | - | - | **0.001** | **0.001** |
| **LSD (P=0.05)** | **NS** | **NS** | **NS** | **NS** | **0.66** | **0.66** |
| **CV%** | **13.3** | **9.1** | **12.4** | **4.7** | **6.6** | **26.5** |

## COMMERCIAL PRACTICE AND ON-FARM PROFITABILITY

Results from this systems comparison trial reinforce that while seasonal rainfall remains the dominant driver of productivity in the Victorian Mallee and Wimmera, crop rotation does influence soil water dynamics and how rainfall is captured, stored and used across years. Differences in plant available water at sowing between 2024 (91mm) and 2025 (31mm) largely reflected contrasting summer and autumn rainfall, yet rotational balancing of crop and pasture phases is likely important for maximising whole-system water use and production efficiency over time. Strategic inclusion of crops and forages with differing rooting depth, phenology and water extraction patterns can help balance temporal soil water drawdown, reduce non-productive losses, and improve the conversion of rainfall into grain and fodder.

In favourable seasons, when episodic summer rainfall occurs, this provides the opportunity to capitalise on soil water recharge through management practices that protect summer soil water. These include rigorous summer weed control, stubble retention and minimising unnecessary soil disturbance, thus improving overall kilograms of grain or livestock product per millimetre of annual rainfall. Conversely, in dry seasons, the value of rotation lies less in increasing absolute water supply and more in distributing risk. This ensures limited rainfall is converted into the most profitable mix of grain, livestock or forage production. This reinforces that resilient farming systems in semi-arid environments are not built around single crop sequences, but around flexible rotations that maximise production and profitability per millimetre of rainfall across both dry and favourable seasons.

Within this water-limited context, nitrogen dynamics and enterprise flexibility are factors likely to affect resilience and profitability. For example, where wheat followed vetch, higher soil mineral nitrogen at sowing translated into increased grain protein concentration, without a yield penalty relative to wheat following lentil. This outcome is consistent with crops being highly water-limited in 2025, where additional nitrogen was partitioned into grain quality rather than yield. For growers, this suggests legume choice can be strategically important in its impact on the following crop where in this study vetch preceding wheat improved grain protein in a dry season, whereas lentil was less effective at supplying mineral nitrogen under equivalent conditions. Higher grain protein in a low-yield year may partially offset reduced production through price premiums, thus improving gross margin stability.

The comparison between grazed vetch and grain lentil following barley further illustrates the value of mixed farming systems in managing climatic risk. Equivalent biomass at flowering (2.8t/ha) supported either a good grazing outcome for vetch, with strong liveweight gains of 7kg/head at 16 DSE/ha, or a moderate yielding lentil grain crop (0.9t/ha) combined with lower grain prices. In seasons where terminal drought limits grain fill, the capacity to tactically divert biomass into livestock production may represent one effective risk-management strategy – converting limited rainfall into meat/wool production. Taken together, these interim findings support farming systems that emphasise flexibility, integrating crops and livestock, matching inputs to realistic water-limited yield potential, and targeting profitability per millimetre of rainfall rather than maximising yield alone. Such approaches are likely to underpin more climate-resilient and profitable farming systems across the Mallee and Wimmera as seasonal variability increases.

Future years of trial results and economic analyses will provide greater insights into the performance of the cropping and mixed farming rotation systems for a range of seasonal conditions. Progressive findings will be published in 2026 and 2027.

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