# Gross margin analysis of grain cropping at the Brigalow Catchment Study with APSIM simulations to evaluate the effect of nitrogen fertiliser application

## Technical report

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# Contents

# List of figures

## List of tables

# Summary

This report presents the methodology and findings from an economic investigation into the Brigalow Catchment Study (BCS) (The Study) grain cropping program. The project had three key outcomes which were:

- A historical gross margin analysis of grain cropping at the BCS.
- A calibrated Agricultural Production Systems sIMulator (APSIM) model of the BCS.
- A gross margin analysis on simulated nitrogen (N) fertiliser rate applications.

The BCS is a paired, calibrated catchment study conducted by the Department of Resources and is located in the Fitzroy Basin, Central Queensland. A cropping site was cleared, developed and cropped for 26 years (1984 to 2010). Crops grown included wheat and sorghum, as well as a barley and a chickpea crop. Crop selection was reflective of the commercially grown crops in the region at the time of planting. There was no fertiliser added to the site during this time. As such, all results should be interpreted only within the context of the crop sequences that were analysed.

## Historic gross margin analysis

The historic gross margin analysis included agronomic data from the study, extrapolated to a commercial scale. This was due to the small scale of the study (11.7ha). The analysis found that the cropping at the BCS produced positive gross margins for most crops grown. From the results, it appears that yield had the strongest effect on gross margin. The four crops that had a negative gross margin were the result of below average yields. Similarly, the highest gross margins for the study were the result of above average yields. Pricing applied to the crops did not prove to be consistently above or below average during the period, which suggested prices were not a major driver of gross margin. This was reinforced through statistical analysis that showed yields explained greater than 85% of the gross margin result.

One interesting insight was that yield, while expected to decline over time, and with an apparent visual decline over time, did not statistically decline over the 26 year period studied. However, this trend is still hypothesised to be statistically significant over a longer period (>40 years) due to soil available nutrients provided through mineralisation reducing over the longer-term (Cox & Strong, 2015).

## APSIM simulation of N fertiliser application scenarios

APSIM was successfully used to generate a ‘base’ APSIM file that mimicked the cropping program of the BCS. The simulation covered the period 1984 to 2009 and included 25 crops. Rundown in crop yield and protein appeared in both the observed and simulated results.

The base APSIM file was used to simulate the production outcomes if rates of fertiliser that were nominally, 30, 50, 70 and 150 kg/ha of N were applied. The 30N, 50N and 70N scenarios included a rule that avoided the N rate being applied when it was not necessary (i.e. total soil N was greater than 100 kg/ha of N). A tactical (‘top-up’ soil to 100kg/ha of N) scenario was also simulated. This scenario would appear to be very cost effective and this was examined in the economics section of the report.

The results show that the optimum ‘set’ rates per crop for yield would be slightly less than 50 kg/ha of N for wheat and slightly less than 70 kg/ha of N for sorghum. Only one barley crop was included in the rotation and it required a high N rate because the soil was N depleted at that point in the rotation.

Nine scenarios were also simulated constituting three minimum levels of soil water for which planting would occur and three N ‘top-up’ rates. The three soil water levels were refilling to 30%, 60% and 90% of plant available water capacity (PAWC). The three N strategies were topping-up to total soil N supply to 70, 100 or 130 kg/ha of N at planting. Similar scenario simulations for Central Queensland were conducted by Cox & Chudleigh (2001), and Cox, et al., (2004). The combined effect on production of soil water ‘triggers’ for planting and ‘top-up’ N rates differed between wheat and sorghum. For wheat, the soil water trigger level had only a small effect on total production. Low soil water triggers increased crop count, but reduced yields, and vice versa. Sorghum benefitted from lower soil water triggers because of increased crop counts and increased yields from earlier planting. Increasingly higher N fertiliser rates increased yield but the lowest N scenario (‘top-up’ to 70 kg/ha of N) limited yields.

## Gross margin analysis of simulated N fertiliser application scenarios

The gross margin analysis results for the simulated N rate applications found:

- Top-up N produced the highest gross margins for the entire cropping sequence but only marginally so above a 70N application rate.
- For individual crops, 70N produced the highest gross margin for wheat and top-up N for sorghum.
- The additional APSIM modelling to test seasonality showed the same result as the simulated N rate applications.

Whilst 70N had the highest gross margin result of the fixed N application rates, this result needs to be considered alongside other research, such as the APSIM simulation of the trial site ‘Moonggoo’ (Chudleigh, et al., 2001). In this study APSIM simulations suggested the optimal N rate would be 50-55 kg/ha of N, but the trial results found 30-40 kg/ha of N was more efficient. This was hypthosised to be a result of APSIM being unable to model weeds and other external pressures.

The soil water triggers to determine fertiliser top-up strategies found:

- 30% PAWC was the more profitable refill on average across each fertiliser top-up rate due to the additional number of crops able to be planted.
- 130N/90% scenario produced the highest gross margin for wheat.
- 130N/30% scenario produced the highest gross margin for sorghum.

These results however did not account for riskiness. Given the likelihood of crop failure of planting at lower stored soil water, further simulations would be needed to test the results.

Finally, all the results should be interpreted only within the context of the crop sequences that were simulated, as other cropping sequences may yield a different outcome with respect to both agronomic, input N rates and economic outcomes. Because the results of this project have findings similar to the CQ sustainable farming systems report, the recommendations for nutrient management are still applicable:

> Growers determine the water holding capacity of their paddocks. By using this information or seeking specialist consultancy for their own farm, growers may re-assess the viability of farming some paddocks.
>
> Growers determine the inherent soil N fertility of their paddocks. In conjunction with the strategies examined, growers will be able to choose a long-term N rate applicable to their paddocks. This may be achieved by strip trials and/or assessment of grain protein and yield results.
>
> In grain-only systems, N fertiliser can be expected to give large economic returns if applied at optimum rates to land that has declined in soil N but has high water-holding capacity.
>
> (Chudleigh, et al., 2001)

# Introduction

## Brigalow Catchment Study background

The BCS is a paired, calibrated catchment study located within the Fitzroy Basin, Central Queensland. The site was established in 1965 to quantify the impact of land development for agriculture on hydrology, productivity, and resource condition. From 1965 until 1982 the site was in a calibration phase to understand the hydrological relationship between three different catchment site locations identified for monitoring purposes (Cowie, et al., 2007). An 11.7 ha cropping site was cleared and developed between 1982 and 1983, after which it was utilised for dryland grain cropping from 1984 to 2010 (26 years). The site was under either sorghum (*Sorghum bicolor*), wheat (*Triticum spp.*), barley (*Hordeum vulgare*) or chickpea (*Cicer arietinum*) at different stages during this period.

The site was initially cultivated with tillage instruments, including conventional disc ploughs, for weed control and seed bed preparation. Zero tillage and reduced tillage farming systems were later introduced in 1990 and opportunity cropping in 1995. Opportunity cropping systems do not follow any pre-set crop rotation, but rather respond to the seasonal and available soil water conditions and plant accordingly. Suitable cropping opportunities are therefore taken as they arise. There was no fertiliser used since inception of the study and the site has been in a ley pasture phase since 2010.

## Project objectives

Overarchingly, the objective of this project is to provide support to the second deliverable of Action 2.4 of *The Reef 2050 Water Quality Improvement Plan* (WQIP) 2017-2022, which requires the Queensland Government to "conduct economic evaluations to validate the economics of management practices that improve water quality and provide information to landholders as part of the extension program.". The Grains Gap Analysis Report (Landsberg & Moravek, 2019) identified broad gaps in economic knowledge occurring for all risk categories listed under the Paddock to Reef (P2R) Grains Water Quality Risk Framework (The State of Queensland, 2020) for the Great Barrier Reef catchment areas. The P2R water quality risk framework outlines practices that can contribute to better water quality outcomes with respect to soil, nutrient and pesticide management. Much of the information reviewed in the report was dated and therefore not necessarily applicable under current market conditions. Soil and nutrient management practices had the lowest adoption rates and therefore were identified as areas for immediate priority.

The two practices of "determining N requirements" and "influence of stored soil water on yield and N fertiliser decisions" account for 80% of nutrient management practices under the framework (Appendix A). The minimum standard for determining N requirements is conducting regular soil analysis in conjunction with yield/protein information to make N management decisions. Minimum standard for the influence of stored soil water on yield and N fertiliser decisions is that stored soil water is monitored throughout the fallow and informs decisions on yield potential and appropriate fertiliser rates. The APSIM simulations undertaken for this project addresses both requirements.

Specifically, the purpose of the report was to:

- Update economic information in the grain industry and improve grower knowledge of the economic outcomes of adopting P2R Grains Water Quality Risk Framework Practices.

- Create a ‘base’ APSIM file of the BCS to be utilised by researchers.
- Help understand the economic impact of various N application rates for grain crops on brigalow soils (soils within the Brigalow Belt Bioregion) as simulated in APSIM.

This report has three parts. The first part assesses the gross margin outcomes of grain cropping at the BCS between 1984 and 2008, as no crops were planted after 2008. The second part details the bio-economic modelling of the BCS data that was conducted using APSIM (Holzworth et. al 2014). The APSIM modelling had two components; the first component was to create a ‘base’ BCS file, whilst the second component simulated various fertiliser application rates to represent a commercial grain enterprise using soil nitrate levels and soil PAWC. The third part of the report assessed the gross margin outcomes of the simulated applications rates from part two, as well as additional APSIM modelling to test seasonality of the simulated fertiliser application results.

Detail on the technical information underpinning the analyses can be located on the Brigalow Catchment Study Portal website (http://www.brigalowcatchmentstudy.com/). When interpreting the results of this report, it should be noted that several research projects were conducted at the BCS for which crop performance was analysed. The omission of fertiliser, particularly after the first decade of cropping means that comparisons of the financial results to commercial cropping outcomes for the same period should be carefully considered.

# Part One: Historical gross margin analysis

## Methodology

This analysis applies a gross margin approach to evaluate the economic outcomes from each year for the BCS grain cropping. A gross margin is gross revenue less all direct or variable growing costs, where other costs (capital and overheads) are unchanged and therefore not accounted for in the comparison. This method is useful in comparing the outcomes of alternative crops between years. A dollar per hectare gross margin was determined for each crop harvested, using an economic spreadsheet developed in Microsoft Excel. Some calculations were adopted from Financial Economic Analysis Tool (FEAT) version 3.1 developed by the Department of Agriculture and Fisheries (DAF).

Data from the 11.7ha BCS site was simulated using machinery and operational efficiencies applied as a 2,000ha dryland cropping enterprise located in the Dawson-Callide region (where the site is located). This was to ensure costs were not over-inflated due to the small-scale operations utilised on the BCS, including the use of expensive and outdated machinery and vehicles. It also allowed for a more commercially relevant comparison of economic results, despite the BCS having a research rather than commercial objective. A detailed list of the assumptions applied in the extrapolation can be found in Appendix A.

Crop data included the planting and harvest dates, variety, seed application rate, harvested yield, spray (chemical type and application rates) and tillage details (implement and date) as applied on the BCS site. Three different monitoring plots (64, 65, 66) had yield records used to determine the average yield across the site for each crop. For a better understanding of the layout of the site, full details can be found on the BCS website.

Machinery use and cost calculations were developed to accurately reflect the efficiency of paddock operations on a commercial scale. Expert advice was obtained from four commercial grain growers to develop assumptions applied to machinery operations. This included the typical size and capacity of machinery utilised in a 2,000 hectare commercial farming operation. Due to the longevity of the study, some of the tillage operations were no longer relevant for current practice and therefore most implements were consolidated and updated to include modern equipment (e.g. scarifier updated to speed tiller). These assumptions were made with input from a local grower and validated by an additional three commercial growers. The operational cost per hectare for each implement was determined by including costs of fuel, oil, repairs, and maintenance (FORM), and labour based on the work rate for each tractor and implement combination. Harvester and chaser bin cost assumptions were provided by the growers, but harvest speeds (kph) were adjusted to match $/ha costs recorded for each crop in the Dawson-Callide region from the AgMargins website (State of Queensland, 2020). More detail can be found in Appendix B.

Grain prices were sourced from the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES). Historical gross unit values of farm products were used for each crop. These are defined as the average gross unit value per tonne across all grades in principle markets. The average gross unit value relates to returns received from crops harvested in that year and the CPI index was used to convert the nominal pricing to real (2020) prices for each year. Figure 1 presents the real pricing for wheat and sorghum for each year of the analysis. The real gross unit value was applied to each crop for the year in which it was harvested. As the gross pricing included the cost of containers, commission and other expenses incurred in moving the commodities to principle markets (ABARES, 2019), these expenses were excluded as costs in the gross margin analysis to achieve a farm gate value. An insurance percentage rate of 1% was also included for each crop based on the total income ($) per hectare (State of Queensland, 2020).

Chemical prices were largely sourced from local farm chemical suppliers. Online chemical retailer websites were used for some products where prices were otherwise not available. Substitute products were used for missing data required for brand specific chemicals. These were matched by active ingredient and quantity.

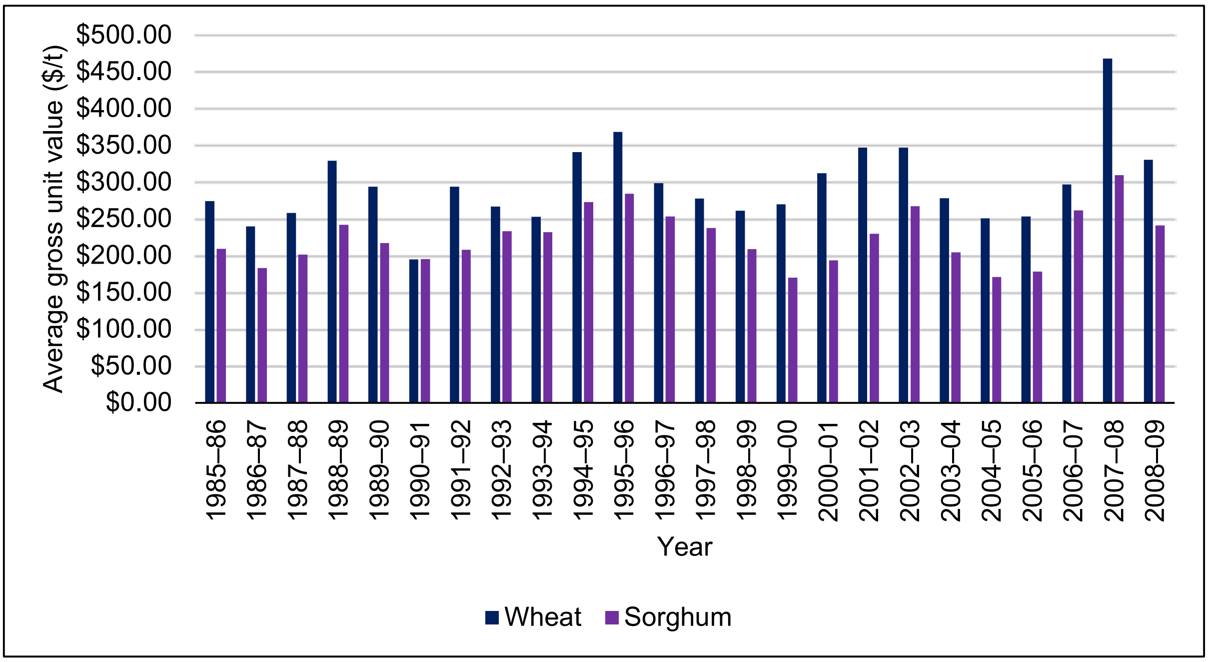


**Figure 1** Real (2020) wheat and sorghum prices per tonne (1985-86 to 2008-09)

## Analysis of the results

A post-hoc analysis of the gross margins and yields was conducted to provide insight into profitability drivers. Since the sample size over the period were both small and non-continuous, the results are not presented under the results section, but instead are referred to in the discussion. It is suggested that a more robust analysis be undertaken to confirm the discussion hypothesis. Regression analysis was used for temporal trend analysis and t-tests for testing site yields against state average yields (statistically significance set at *p* ≤0.05 for all analyses). The influence of rainfall on yields and gross margin was also investigated (see Appendix F for climate data).

## Results

The gross margin ($/ha) and yield (t/ha) results are presented in Table 1. Almost all crops produced a positive gross margin, except for three sorghum crops and the solitary barley crop. These crops are highlighted in red.

**Table 1** Gross margin results

| Crop Number | Crop type | Date Harvested | Gross margin | Yield |
|---|---|---|---|---|
| 01 | Sorghum | Jan-85 | $133 | 1.36 |
| 02 | Wheat | Sep-85 | $655 | 2.92 |
| 03 | Wheat | Sep-86 | $412 | 2.45 |
| 04 | Wheat | Oct-87 | $858 | 3.96 |
| 05 | Wheat | Sep-88 | $591 | 2.45 |
| 06 | Wheat | Nov-89 | $389 | 2.09 |
| 07 | Wheat | Oct-90 | $70 | 1.40 |
| 08 | Wheat | Oct-91 | $309 | 1.62 |
| 09 | Wheat | Oct-92 | $282 | 1.87 |
| 10 | Wheat | Sep-94 | $713 | 2.87 |
| 11 | Sorghum | Jul-95 | -$172 | 0.18 |
| 12 | Sorghum | Jan-96 | $347 | 1.46 |
| 13 | Wheat | Oct-96 | $123 | 0.83 |
| 14 | Sorghum | Jan-98 | $433 | 3.55 |
| 15 | Wheat | Oct-98 | $336 | 1.77 |
| 16 | Sorghum | Feb-99 | -$6 | 0.83 |
| 17 | Sorghum | Mar-01 | $136 | 2.33 |
| 18 | Sorghum | Apr-02 | -$139 | 0.18 |
| 19 | Wheat | Oct-02 | $93 | 0.66 |
| 20 | Wheat | Sep-03 | $517 | 2.59 |
| 21 | Sorghum | 26-May-04 | $211 | 2.05 |
| 22 | Sorghum | 23-Mar-05 | $221 | 2.07 |
| 23 | Barley | 27-Sep-05 | -$5 | 0.63 |
| 24 | Chickpea | 11-Oct-06 | $127 | 0.54 |
| 25 | Sorghum | 08-Jan-08 | $1,211 | 4.96 |
| 26 | Sorghum | 22-Jan-09 | $156 | 1.85 |

The gross margin results for the wheat and sorghum crops as well as the yield (t/ha) are presented below in Figure 2 and Figure 3, respectively.

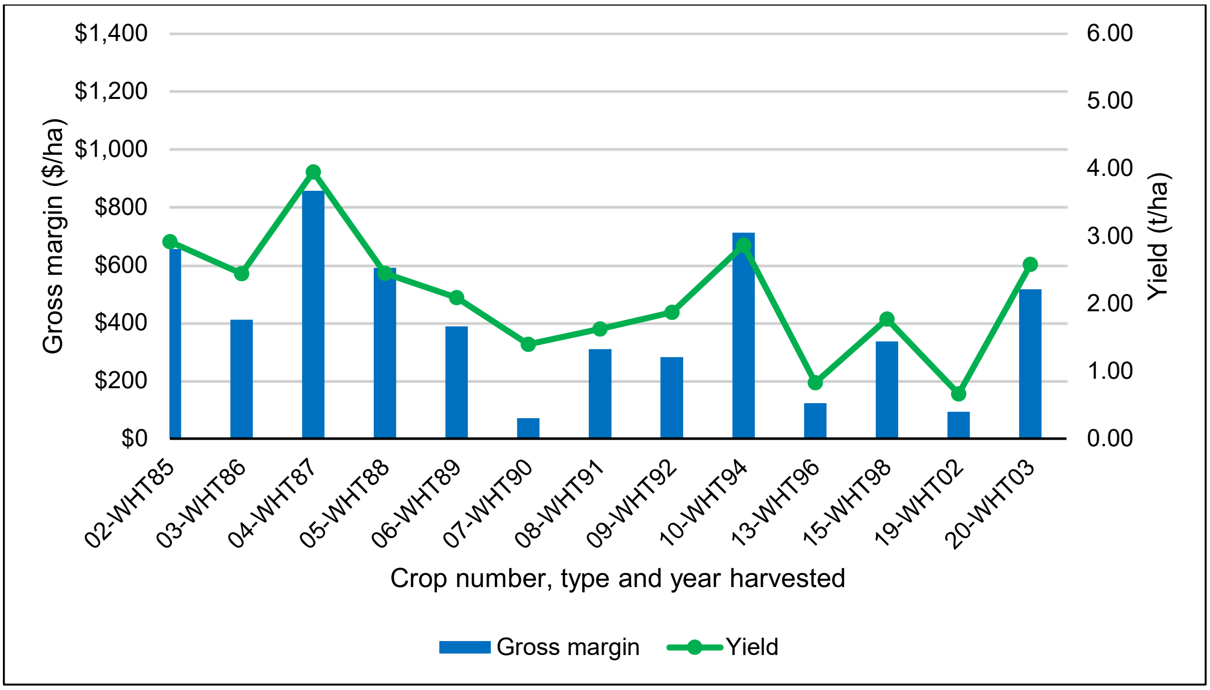


**Figure 2** Wheat gross margin and yield

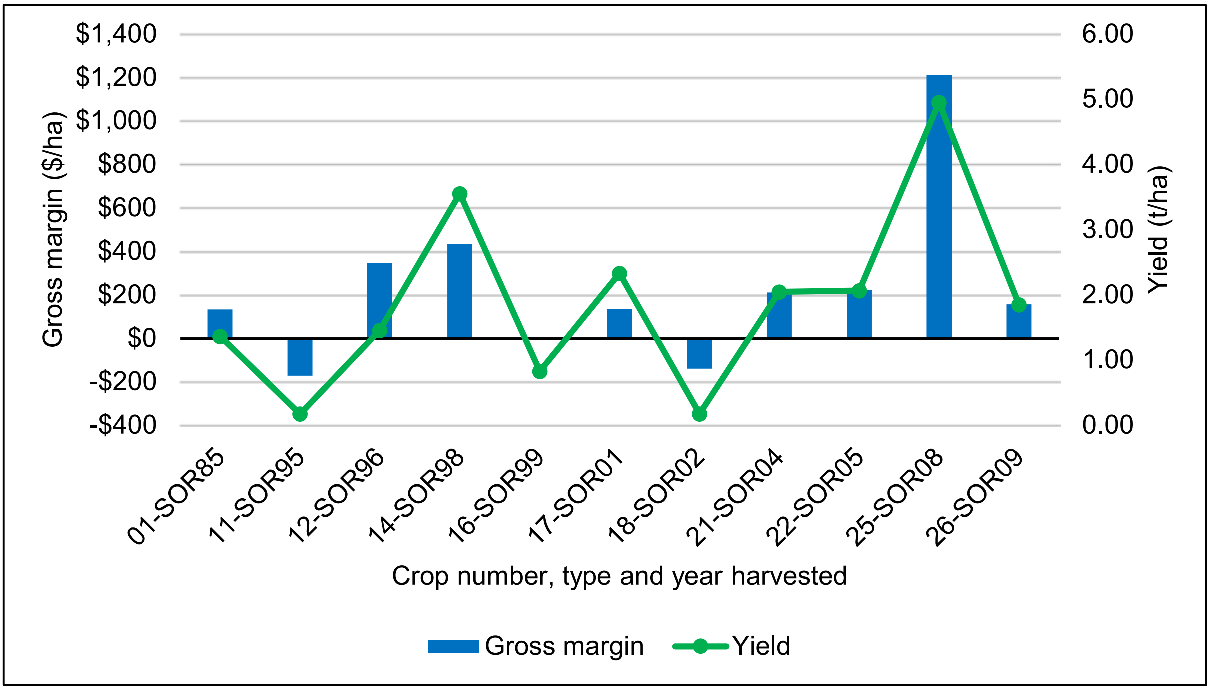


**Figure 3** Sorghum gross margin and yield

## Discussion

Yield was shown to be the primary driver of both wheat and sorghum revenue differences. There was a positive correlation between the two variables for wheat (*r* = 0.95, *p* = 0.030, $R^2$ = .911) and sorghum (*r* = 092, *p* = 0.015, $R^2$ = .857). In context, the average yield from the BCS for wheat and sorghum was 2.11t/ha and 1.89t/ha, respectively. This compared favourably for wheat but less favourably for sorghum when compared to average yields recorded for Queensland between 1989-90 and 2008-09 (1.4t/ha and 2.3t/ha). However, the analysis failed to reject the null hypothesis that the means were the same for wheat yields (*p* = <0.147) and therefore the difference of BCS yields compared to state yields were not statistically signficant. The data set to test wheat yield differences was limited and care should be taken in interpretation of the result. As the sorghum crop data set was even further restricted, a similar analysis was not undertaken. Although, there was no statistical analysis completed for the barley and chickpea yields as only one year of crop data was available. Interestingly, state yields from that year for barley and chickpea were higher at 1.5t/ha and 0.9t/ha respectively (ABARES, 2020) when compared to yields of 0.63t/ha and 0.54t/ha for the BCS.

It was observed that yields generally performed well in the earlier stages of the BCS site with an apparent decline in yields over time. This is assumed to be the result of initial soil disturbance due to land clearing and development activities which was followed by subsequent soil N mineralisation that declined over time. However, the analysis did not show a statistically significant decline in yields (*p* = 0.089). Given the well understood biophysical response from cultivation, it is likely the non-significant result was simply due to the limited data available, rather than there being no decline in yields. For detailed agronomic information regarding the BCS, refer to the original productivity paper of Radford et al. (2007).

Statistical analysis also suggested that over the period of analysis, there was no significant trend, positive or negative, in rainfall (*p* = 0.160*)*, yield *(p* = 0.089) or gross margin (*p* = 0.183*)* for wheat. This suggests that individual year results are being driven by data not available for the analysis.

Unprofitable crops (11,16, 18 and 23) were largely the result of low yields. Yields for the sorghum crops numbered 11 and 18 were 0.18t/ha, while crop 16 yielded 0.83t/ha. These were 90 percent and 56 percent respectively lower than average yields recorded from the BCS. As a result, the income from the poor yields did not cover variable costs. The barley crop also had a low yield and negative gross margin which was exacerbated by the lowest barley price recorded for the period analysed.

Grain protein was examined but not considered in the economic analysis. Only one of the varieties planted (Hartog) remains on the master wheat variety list. The remaining varieties used in the BCS therefore no longer meet requirements for current quality standards. It is acknowledged that there could be a slight over estimation in the gross margin for crops 10, 13, 15 and 19 due to their lower protein levels. The yield and grain protein for each crop can be viewed in Appendix D.

# Part Two: APSIM simulation of N fertiliser application scenarios

## Methodology

### Part A. APSIM parameterisation for the 'base' file

#### Soil file

As much as was possible, the APSIM soil file was created from data collected from the C2 site. Other required parameterisation data were sourced from written materials. Some data were used from other soil files or were known 'defaults' for soil files. Two main soil types (represented as sampling sites) had been identified on the C2 site. Sites 64 and 65 were black vertosol soils and soil factors were averaged prior to their use as parameterisation data (Table 2). Site 66 was a grey dermosol (sodic duplex) and had quite different characteristics (Table 3). These soils were present on the C2 site in a 70:30 area ratio (Cowie et. al 2007). When output was created for the C2 site, the results from sites 64/65 and 66 were weighted in the above ratio.

### Soil data

**Table 2** The general soil data for APSIM for Sites 64/65

| Depth (cm) | Bul density | Airdry (mm/mm) | LL15 (mm/mm) | Drained upper limit (mm/mm) | Saturation (mm/mm) | SWCON (0-1) | Soil OM | Fbiom | Finert | pH |
|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 1.22 | 0.048 | 0.17 | 0.346 | 0.541 | 0.2 | 2.25 | 0.05 | 0.4 | 6.56 |
| 10-20 | 1.43 | 0.068 | 0.17 | 0.357 | 0.462 | 0.2 | 1.349 | 0.02 | 0.5 | 7.54 |
| 20-40 | 1.56 | 0.07 | 0.17 | 0.364 | 0.412 | 0.2 | 0.738 | 0.015 | 0.5 | 8.14 |
| 40-60 | 1.61 | 0.071 | 0.204 | 0.367 | 0.391 | 0.2 | 0.355 | 0.01 | 0.6 | 5.7 |
| 60-80 | 1.65 | 0.069 | 0.212 | 0.348 | 0.376 | 0.2 | 0.284 | 0.01 | 0.6 | 5.7 |
| 80-100 | 1.68 | 0.067 | 0.237 | 0.334 | 0.366 | 0.2 | 0.227 | 0.01 | 0.7 | 4.76 |
| 100-120 | 1.67 | 0.065 | 0.249 | 0.327 | 0.372 | 0.2 | 0.213 | 0.01 | 0.9 | 4.7 |
| 120-140 | 1.64 | 0.067 | 0.26 | 0.333 | 0.381 | 0.2 | 0.213 | 0.05 | 0.9 | 4.5 |

**Table 3** The general soil data for APSIM for Site 66

| Depth (cm) | Bul density | Airdry (mm/mm) | LL15 (mm/mm) | Drained upper limit (mm/mm) | Saturation (mm/mm) | SWCON (0-1) | Soil OM | Fbiom | Finert | pH |
|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 1.28 | 0.031 | 0.122 | 0.264 | 0.517 | 0.2 | 2.16 | 0.05 | 0.45 | 6.56 |
| 10-20 | 1.51 | 0.053 | 0.122 | 0.304 | 0.432 | 0.2 | 1.2 | 0.02 | 0.6 | 7.54 |
| 20-40 | 1.68 | 0.056 | 0.122 | 0.309 | 0.365 | 0.2 | 0.7 | 0.01 | 0.75 | 8.14 |
| 40-60 | 1.73 | 0.055 | 0.154 | 0.305 | 0.348 | 0.2 | 0.3 | 0.01 | 0.9 | 5.7 |
| 60-80 | 1.72 | 0.059 | 0.178 | 0.297 | 0.349 | 0.2 | 0.25 | 0.01 | 0.9 | 5.7 |
| 80-100 | 1.72 | 0.061 | 0.174 | 0.287 | 0.349 | 0.2 | 0.2 | 0.01 | 0.9 | 4.76 |
| 100-120 | 1.72 | 0.06 | 0.169 | 0.267 | 0.351 | 0.2 | 0.2 | 0.01 | 0.9 | 4.7 |
| 120-140 | 1.75 | 0.06 | 0.158 | 0.258 | 0.34 | 0.2 | 0.2 | 0.05 | 0.9 | 4.5 |

Note: The soil depth of site 66 was 120cm rather than 140cm. The correct PAWC was enabled with the xf parameter (Table 5) which disabled water extraction from the 120-140 cm layer.

The derived soil (crop-related) data for APSIM is shown in Table 4 and Table 5 respectively.

**Table 4** The crop-related data for APSIM is for Sites 64/65

| Sorghum lower limit (mm/mm) | Sorghum PAWC (mm) | Sorghum KL mm/day | Sorghum XF | Wheat, barley and chickpea lower limit (mm/mm) | Wheat, barley and chickpea PAWC (mm) | Wheat, barley and chickpea KL mm/day | Wheat, barley and chickpea XF |
|---|---|---|---|---|---|---|---|
| 0.17 | 17.6 | 0.07 | 1 | 0.17 | 17.6 | 0.1 | 1 |
| 0.17 | 18.7 | 0.07 | 1 | 0.17 | 18.7 | 0.1 | 1 |
| 0.2 | 32.8 | 0.07 | 1 | 0.17 | 38.8 | 0.1 | 1 |
| 0.224 | 28.6 | 0.07 | 1 | 0.204 | 32.6 | 0.08 | 1 |
| 0.225 | 24.6 | 0.06 | 1 | 0.212 | 27.2 | 0.06 | 1 |
| 0.237 | 19.4 | 0.06 | 1 | 0.237 | 19.4 | 0.06 | 1 |
| 0.247 | 16 | 0.06 | 1 | 0.249 | 15.6 | 0.06 | 1 |
| 0.261 | 14.4 | 0.05 | 1 | 0.26 | 14.6 | 0.05 | 1 |
| **TOTAL** | **172.1** | | | **TOTAL** | **184.5** | | |

**Table 5** The crop-related data for APSIM is for Sites 66

| Depth (cm) | Sorghum lower limit (mm/mm) | Sorghum PAWC (mm) | Sorghum KL mm/day | Sorghum XF | Wheat, barley and chickpea lower limit (mm/mm) | Wheat, barley and chickpea PAWC (mm) | Wheat, barley and chickpea KL mm/day | Wheat, barley and chickpea XF |
|---|---|---|---|---|---|---|---|---|
| 0-10 | 0.122 | 14.2 | 0.07 | 1 | 0.122 | 14.2 | 0.1 | 1 |
| 10-20 | 0.122 | 18.2 | 0.07 | 1 | 0.122 | 18.2 | 0.1 | 1 |
| 20-40 | 0.133 | 35.2 | 0.07 | 1 | 0.122 | 37.4 | 0.1 | 1 |
| 40-60 | 0.182 | 24.6 | 0.07 | 1 | 0.154 | 30.2 | 0.08 | 1 |
| 60-80 | 0.19 | 21.4 | 0.06 | 1 | 0.178 | 23.8 | 0.06 | 1 |
| 80-100 | 0.167 | 24 | 0.06 | 1 | 0.174 | 22.6 | 0.06 | 1 |
| 100-120 | 0.155 | 22.4 | 0.06 | 1 | 0.169 | 19.6 | 0.06 | 1 |
| 120-140 | 0.157 | 0 | 0.05 | 0 | 0.158 | 0 | 0.05 | 0 |
| | **TOTAL** | **160** | | | **TOTAL** | **166** | | |

Notes: kl = potential crop water extraction (mm/day). From existing APSIM data
xf = root environment factor (1= no constraint, 0=full constraint)
f_inert – fraction of inert OM (high at depth)
f_biom – fraction of non-inert OM
Source: Soil and crop water data from Thornton C, unpublished.

**Table 6** Other soil parameters used in APSIM

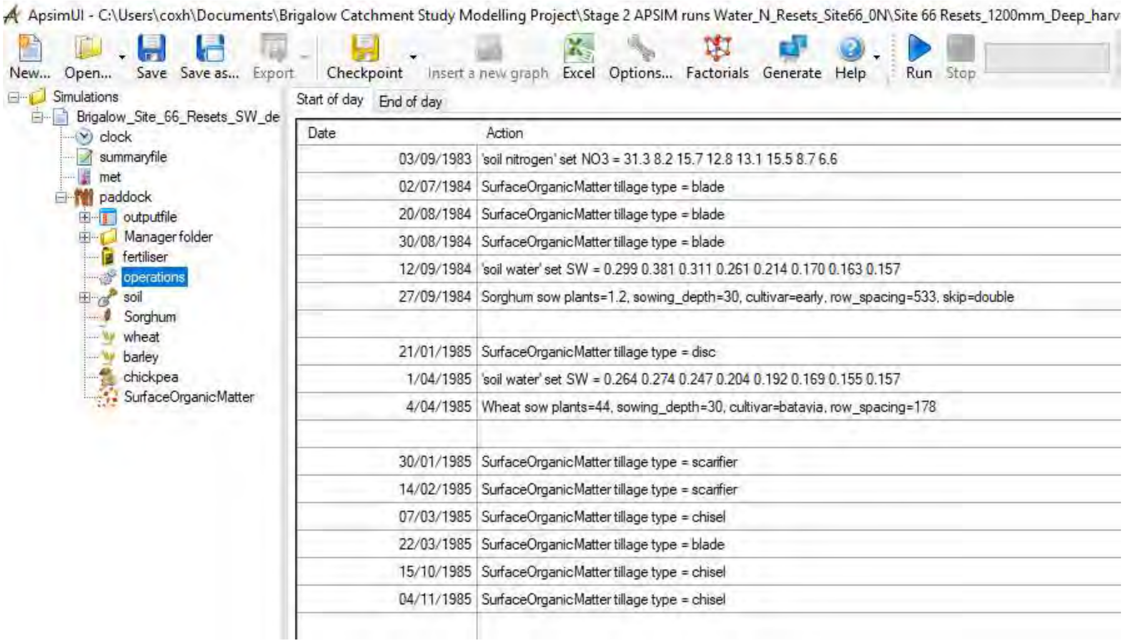
| **Parameter** | **Value** |
|---|---|
| Diffusivity Constant *(Unsaturated water flow – from water content gradient between adjacent layers):* | 40 |
| Diffusivity Slope: | 16 |
| Soil albedo *(Reflection for dark soils):* | 0.11 |
| Bare soil runoff curve number *(Based on rainfall on the day – moderately hard setting clay):* | 82 |
| Max. reduction in curve number due to cover: | 20 |
| Cover for max curve number reduction: | 0.8 |
| First stage evaporation - summer (U) | 5 [1] |
| Second stage evaporation - summer (cona) | 5 [1] |

| | |
|---|---|
| First stage evaporation - winter (U) | 2 [1] |
| Second stage evaporation - winter (cona) | 3 [1] |

[1]Source: Foley, J (pers. com)

## APSIM setup to mimic the site operations

An ‘operations’ node was used in APSIM so that actual values of planting date, plant population, cultivar etc., soil water, soil Nitrate ($NO_3$), and tillage operations could be used for each day on which it occurred on the site. A sample of the operations script is presented in Figure 4. Because no N fertiliser was added to the site, there was no fertiliser added in the APSIM simulations.



| Date | Action |
|---|---|
| 03/09/1983 | 'soil nitrogen' set NO3 = 31.3 8.2 15.7 12.8 13.1 15.5 8.7 6.6 |
| 02/07/1984 | SurfaceOrganicMatter tillage type = blade |
| 20/08/1984 | SurfaceOrganicMatter tillage type = blade |
| 30/08/1984 | SurfaceOrganicMatter tillage type = blade |
| 12/09/1984 | 'soil water' set SW = 0.299 0.381 0.311 0.261 0.214 0.170 0.163 0.157 |
| 27/09/1984 | Sorghum sow plants=1.2, sowing_depth=30, cultivar=early, row_spacing=533, skip=double |
| | |
| 21/01/1985 | SurfaceOrganicMatter tillage type = disc |
| 1/04/1985 | 'soil water' set SW = 0.264 0.274 0.247 0.204 0.192 0.169 0.155 0.157 |
| 4/04/1985 | Wheat sow plants=44, sowing_depth=30, cultivar=batavia, row_spacing=178 |
| | |
| 30/01/1985 | SurfaceOrganicMatter tillage type = scarifier |
| 14/02/1985 | SurfaceOrganicMatter tillage type = scarifier |
| 07/03/1985 | SurfaceOrganicMatter tillage type = chisel |
| 22/03/1985 | SurfaceOrganicMatter tillage type = blade |
| 15/10/1985 | SurfaceOrganicMatter tillage type = chisel |
| 04/11/1985 | SurfaceOrganicMatter tillage type = chisel |

**Figure 4** Sample screenshot of APSIM file showing soil and agronomic details

Source: Soil water and $NO_3$ data, agronomic and tillage data from Thornton C, unpublished.

## Resetting soil $NO_3$ and soil water from field sample values

Soil water content was sampled during the cropping period (1984 to 2008) using a neutron moisture metre (NMM). These values were used as forced resets within the APSIM runs at the equivalent dates. Data from 1989 to 1998 was excluded because it was reported that the NMM was set to incorrect depth values during that time. The progress of soil water and N was automatically simulated by APSIM during this period.

Similarly, soil $NO_3$ values were obtained for the same period and these were also used to reset the APSIM status for soil N.

## Meteorological data

A file is available for input into APSIM for the Brigalow Research Station. Actual rainfall data from the site for the study period was substituted into the file.

## Agronomic set-up data

For each year of the study, the supplied data on plant population, planting date, tillage operations and cultivar were used in the APSIM simulations. If the exact cultivar was not available in APSIM, a cultivar was substituted of a similar phenology (by cross checking time to anthesis of the planted cultivar).

## Crop Management

The crops were ‘planted’ in accordance with the rules in the ‘operations’ node. Crop growth was simulated by APSIM and ‘harvesting’ occurred on crop maturity as determined by APSIM.

A large number of outputs are available in APSIM, but the following were used to inform the economic study and to check the sensibility of the output: grain yield, crop biomass, grain protein, days to flowering, day of flowering, soil water status (ESW), rainfall, soil $NO_3$ status and fertiliser input (when applicable).

## Part B. APSIM parameterisation for the N fertiliser application strategies

The field site had no N fertiliser applied, but the project task was to simulate what yield and protein outcomes would have occurred if it had been applied (with all other conditions remaining the same). Both 'set' rates and tactical N application strategies were tested.

### Set rates

This strategy tested the N fertiliser application rates of; 0, 30, 50, and 70 kg/ha of N with the added rule that the total soil N (fertiliser plus inherent soil N) at planting did not exceed 100 kg/ha of N. This was to provide a more 'practical' situation in that fertiliser would not be applied if the soil already had a moderately high N status. The 100 kg/ha of N level was chosen because it can be shown using the CropARM (Cox, et al., 2004) calculator that 100kg/ha of N will be sufficient to fully supply crop needs in 75% of years as compared to a higher N rate. This was judged to be a balance between yield potential and minimising potential expenditure on inputs (Figure 5).

A set fertiliser annual rate of 150 kg/ha of N applied to every crop regardless of soil N status was tested to simulate a 'luxury' supply of N.

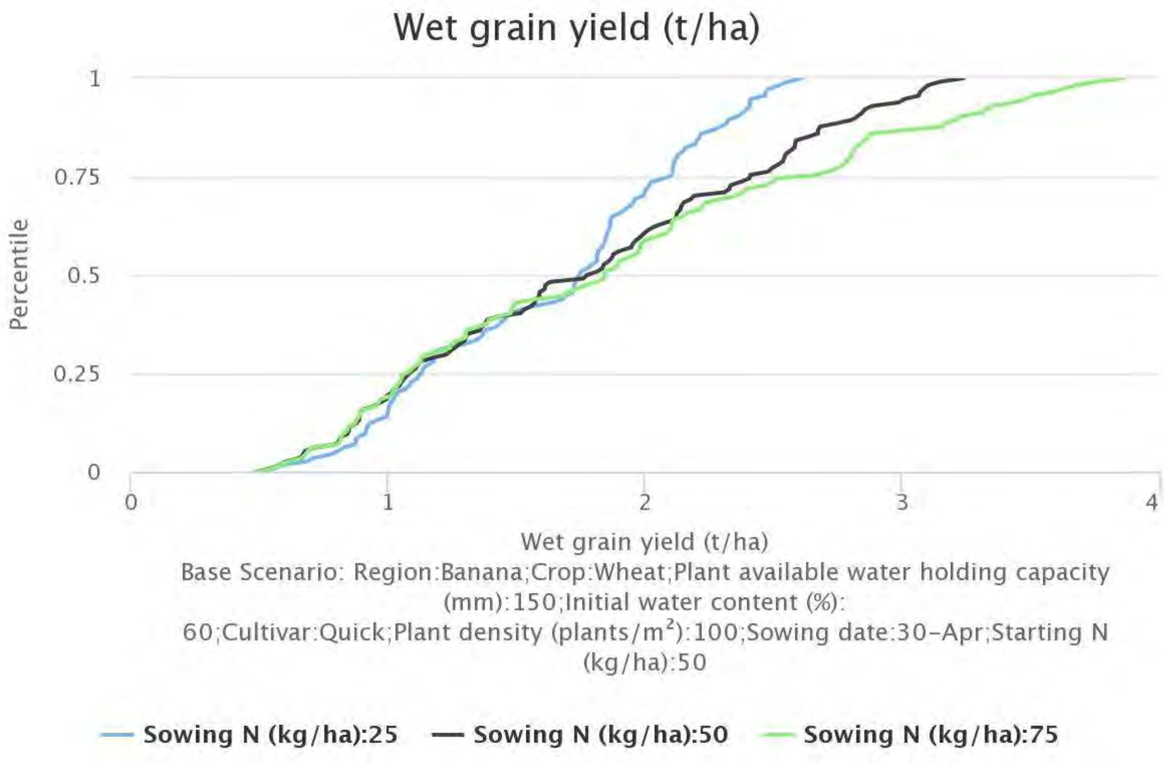


**Figure 5** Cumulative distribution from CropARM calculator showing the long-term yield outcomes in response to 75, 100 and 125 total soil N at planting.

Source: http://www.armonline.com.au/#/wc (CropARM). See also Cox et. al (2003) and Cox and Strong (2015), Nelson and Cox (2000).

### A 'top-up' strategy for N fertiliser not including soil water status at planting

A 'top-up' strategy of variable N fertiliser rates applied to each crop to give a total N supply of 100 kg/ha of N was simulated. This mimics a procedure of soil testing for N then applying a fertiliser rate needed to 'top-up' to 100kg/ha of N.

## Part C. N fertiliser ‘top-up’ strategies that incorporate a soil water trigger for planting

Nine strategies were simulated constituting three minimum levels of soil water for which planting would occur and three N fertiliser ‘top-up’ rates. The three soil water levels were refilling to 30%, 60% and 90% of PAWC. For the soil on Site 64 and 65 this corresponded to 55, 110 and 160mm of plant available water. The three N fertiliser strategies were topping-up total soil N supply to 70, 100 or 130 kg/ha of N at planting. Similar scenario simulations for central Queensland were conducted by Cox and Chudleigh (2000, 2001) and Cox et. al (2003).

Also included in these simulations was a requirement to receive a rainfall event before planting could occur. For wheat, this was 10mm of rainfall over 15 days and for sorghum it was 25mm of rainfall over 10 days. These values were chosen to better represent field decision-making. Many growers wait to receive a rainfall event to wet the surface and ensure there are no dry layers beneath the surface soil. Some growers are using zero-till and controlled-traffic techniques and some are sowing cereals, into deeper, wet soil layers if a ‘planting’ rainfall does not occur. However, this is not the most common practice at this time.

The APSIM rule was not very restrictive regarding planting, but made the simulations more appropriate, as it usually delayed planting beyond the first day in the planting ‘window’ for which planting was allowed. The rainfall requirement for sorghum was considered even more appropriate because growers rarely deep-plant sorghum because of its small seed size. In addition, in this environment, the surface soil can be very dry and hot if rainfall has not recently occurred. Waiting for a rainfall event simulates the more benign conditions that most growers would plant under. It also usually delayed planting beyond the first day in the planting ‘window’ for which planting was allowed creating more realistic scenarios.

A ‘trafficability’ rule was also added to better replicate field conditions required to enable planting. The soil must be sufficiently dry to allow traffic of a planter to occur. The extractable soil water of the surface soil (0 to 10cm) had to be less than 0.346 mm/mm before planting would occur. This value of 0.346 mm/mm was equivalent to the drained upper limit (DUL) of the surface soil. It was found to delay planting after a rainfall event by 5 to 10 days, which accurately reflected actual site management, compared to having no ‘trafficability’ rule.

# Results

## Part A. 'Base file' – mimicking the experimental design with no fertiliser application

Table 7 compares the APSIM yield outputs with the observed site yields. The simulated and observed yields for the wheat crops corresponded well. However, the observed sorghum yields were usually much lower than the simulated yields. This could have been due to APSIM overestimating yields or more likely, a problem with growing sorghum on this site. The APSIM model is well validated, used in over 50 countries and is constantly updated. However, some compromises had to be made when trying to match the site agronomic factors as closely as possible.

The initial simulated sorghum yield was forced to be lower than initially simulated in order not to affect the subsequent soil water and N conditions prior to the nine wheat crops that followed. It was suspected that the site yield was low due to the presence of weeds.

Summer weeds reduce yields and there were some records of this occurring at the BCS especially at the beginning of the study. APSIM yields are unconstrained by weeds, pests, and diseases. Water and N are the main driving factors for yield. The field study began over 35 years ago and there is limited information on factors that may have affected the site yields. Soil sampling can be subject to errors. In addition, there was an unusual situation in 1995 when a sorghum crop was partially sprayed out with 2,4 D herbicide, then allowed to ratoon. This crop was not included in the APSIM simulation. However, this crop may have subsequently affected the water relations in the study. These factors may explain some of the difference between the simulated and observed yields for sorghum. The positive results with the wheat yields, and other studies that have included sorghum, indicate that APSIM can be confidently used to produce results for crop rotations.

**Table 7** Comparison of simulated and observed yields for the C2 block of the BCS site. The yields are weighted on a 70:30 basis because two different soil types were present in the C2 site on a 70:30 proportion of area. Grain yields and proteins are all at field soil water contents. Wheat grain was corrected to 12.5% moisture, sorghum to 13.5 %, barley yield at 13.5%, barley protein remained at 0% moisture. Chickpea at 14%.

| Planting Date | Crop | APSIM yields 70:30 ratio | Observed Yields 70:30 ratio | Absolute yield difference % | APSIM simulated proteins | Observed protein 70:30 ratio |
|---|---|---|---|---|---|---|
| 27/09/1984 | Sorghum [1] | 1762 | 1209 | 21 | 8.6 | 11.4 |
| 4/04/1985 | Wheat | 3179 | 2611 | 6 | 13.2 | 13.9 |
| 6/05/1986 | Wheat | 2037 | 2162 | 21 | 12.4 | 12.9 |
| 11/05/1987 | Wheat | 2793 | 3512 | 44 | 8.7 | 13.7 |
| 12/04/1988 | Wheat | 3158 | 2160 | 22 | 10.7 | 13.6 |
| 14/06/1989 | Wheat | 2487 | 1855 | 15 | 10.9 | 12.8 |
| 10/05/1990 | Wheat | 1734 | 1246 | 18 | 6.8 | 11.3 |
| 13/06/1991 | Wheat | 1980 | 1431 | 17 | 14.0 | 13.8 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 7/05/1992 | Wheat | 2866 | 1633 | 35 | 7.3 | 14.7 |
| 20/04/1994 | Wheat | 2506 | 2535 | 16 | 13.3 | 10.6 |
| 1/11/1995 | Sorghum [2] | 2772 | 1331 | Ratoon crop | 8.3 | 13.4 |
| 23/05/1996 | Wheat | 2761 | 741 | 69 | 12.1 | 10.5 |
| 15/10/1997 | Sorghum | 4786 | 3125 | 25 | 10.8 | 10.6 |
| 30/05/1998 | Wheat | 1570 | 1569 | 14 | 11.0 | 9.6 |
| 4/11/1998 | Sorghum | 2555 | 728 | 67 | 4.9 | 9.0 |
| 6/12/2000 | Sorghum | 5045 | 2085 | 52 | 8.5 | 10.4 |
| 4/12/2001 | Sorghum | 2073 | 162 | 91 | 4.6 | 10.8 |
| 29/06/2002 | Wheat | 831 | 597 | 18 | 7.1 | 10.0 |
| 14/05/2003 | Wheat | 2693 | 2304 | 2 | 7.3 | 13.0 |
| 28/01/2004 | Sorghum | 3099 | 1813 | 32 | 4.6 | 12.8 |
| 25/11/2004 | Sorghum | 1467 | 1832 | 44 | 5.8 | 8.3 |
| 26/04/2005 | Barley | 781 | 571 | 16 | 8.0 | 7.3 |
| 15/05/2006 | Chickpea | 2283 | 482 | 75 | 17.7 | 17.9 |
| 31/08/2007 | Sorghum | 4492 | 4358 | 12 | 9.3 | 9.8 |
| 17/09/2008 | Sorghum | 5086 | 1654 | 62 | 7.6 | 6.1 |

[1] Note: The first simulated yield of sorghum was forced to a low level to minimise the impact on the soil water and N conditions for subsequent crops. Field notes indicated that a high weed population was present. This would have reduced the crop yield to a much lower level than would be have been expected given the high rainfall and newly-cultivated soil on the block.

[2] This crop was ratooned from a semi-failed plant crop. APSIM does not simulate ratoon sorghum. For the simulation, the crop was considered as planted at time of the semi-knockdown 2,4 D spray on the site.

## Grain protein

Variation in observed grain protein over the study period was a result of season type, crop removal of N and previous fallow length. Short fallows between crops depleted N levels whereas long fallows allowed rebuilding of soil N. The overall trend in grain protein was down by approximately four percentage points from the beginning to the end of the study (Figure 6).

The simulated grain protein decreased over time as would be expected in a rotation of crops without added N fertiliser (Figure 7). APSIM values (Figure 7) were sometimes lower than the observed values (Figure 6). This could partially be explained by the higher grain yields that occurred in the simulated crops of sorghum which would have resulted in lower grain protein values.

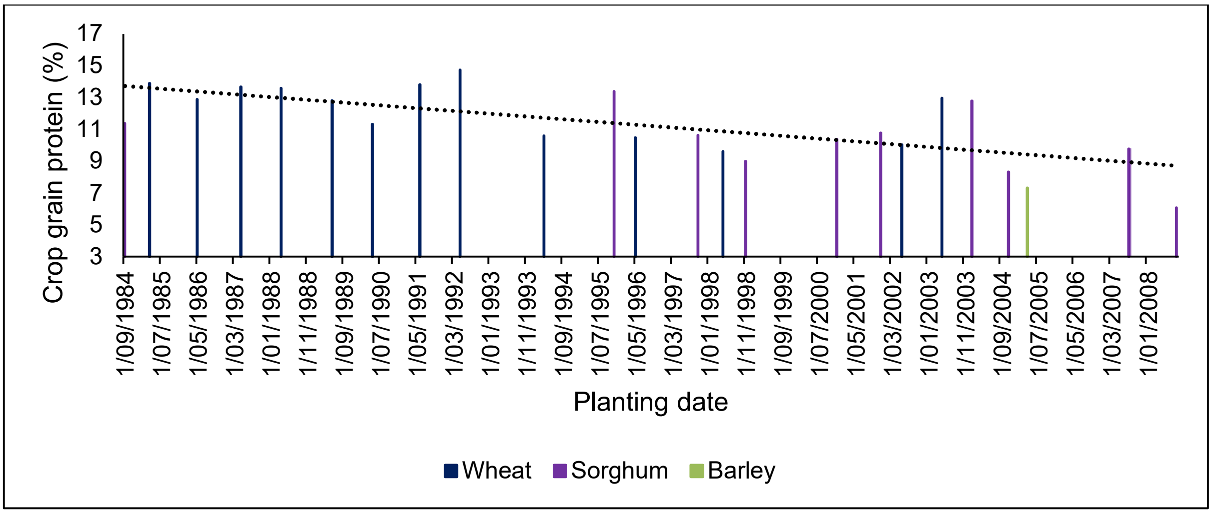


**Figure 6** Observed crop grain protein over time on the C2 site

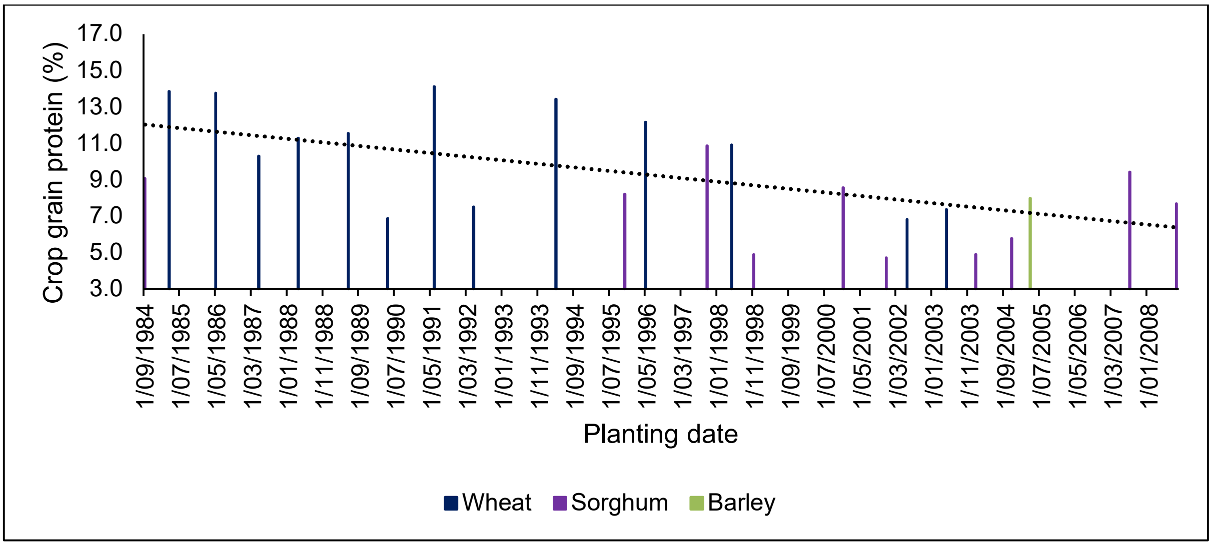


**Figure 7** Simulated grain proteins 1984 to 2008. Proteins were weighted using data from sites 64/65 and 66 on a 70:30 basis. Wheat grain protein was corrected to 12.5% grain moisture, sorghum to 13.5 % and barley remained at 0% grain moisture.

## Comparing results resetting water and $NO_3$ using soil sample data vs without resetting

The 'With resets' APSIM runs used the site data to reset the soil water and $NO_3$ values at the sampling dates (except 1984 to 1998 because the soil water field data was incorrect). The 'No resets' runs used only the first soil water reset prior to planting the first crop.

The resultant grain yields (Table 8) are all at 0% grain moisture. The correlation was better (0.736) using the 'No-resets' process than using resets (0.557). However, early in the project it was decided to use the resets with the aim to utilise as much sampling data as possible. Usually, this improves confidence in a simulation study. However, in this case, the correlation was lower. Either way, the result reinforces the conclusion that APSIM alone can effectively simulate a crop rotation system.

**Table 8** Comparison of simulated (with and without resets) and observed yields for the Sites 64/65 of the BCS site

| Planting Date | Crop | With resets APSIM yields (kg/ha) | No resets APSIM yields (kg/ha) | Observed yields (kg/ha) |
|---|---|---|---|---|
| 27/09/1984 | Sorghum[1] | 1571 | 1550 | 1289 |
| 4/04/1985 | Wheat | 2931 | 2931 | 2989 |
| 6/05/1986 | Wheat | 1695 | 1982 | 2244 |
| 11/05/1987 | Wheat | 3261 | 3499 | 3786 |
| 12/04/1988 | Wheat | 2923 | 3244 | 2204 |
| 14/06/1989 | Wheat | 2212 | 2021 | 1972 |
| 10/05/1990 | Wheat | 1673 | 1321 | 1385 |
| 13/06/1991 | Wheat | 1725 | 1735 | 1439 |
| 7/05/1992 | Wheat | 2747 | 1824 | 1492 |
| 20/04/1994 | Wheat | 1908 | 3110 | 2618 |
| 23/05/1996 | Wheat | 2791 | 2018 | 850 |
| 15/10/1997 | Sorghum | 4265 | 3752 | 3102 |
| 30/05/1998 | Wheat | 1958 | 290 | 1655 |
| 4/11/1998 | Sorghum | 2636 | 1184 | 686 |
| 6/12/2000 | Sorghum | 4319 | 4740 | 2376 |
| 4/12/2001 | Sorghum | 2163 | 801 | 213 |
| 29/06/2002 | Wheat | 792 | 790 | 708 |
| 14/05/2003 | Wheat | 2386 | 2611 | 2565 |
| 28/01/2004 | Sorghum | 2732 | 2322 | 1925 |
| 25/11/2004 | Sorghum | 1426 | 1122 | 1967 |
| 26/04/2005 | Barley | 911 | 623 | 737 |
| 15/05/2006 | Chickpea | 2122 | 2122 | 548 |
| 31/08/2007 | Sorghum | 3997 | 3470 | 4331 |
| 17/09/2008 | Sorghum | 4494 | 2091 | 1866 |

Note: Correlation Observed vs Resets = 0.557, Correlation Observed vs No Resets = 0.736

1. Forced lower yield

## Part B. Simulating the effect of N fertiliser application on the BCS

The simulated application of N fertiliser usually increased the grain yields and protein of the individual crops (Table 9). Some exceptions occurred with the 150 kg/ha of N fertiliser rate on grain yield. The most likely reason for this was excess biomass production that depleted the plant available water and reduced the amount of water available for grain filling. Grain protein was almost always increased with increasing N fertiliser rate.

The ‘top-up’ N scenario was designed to replicate a farm-based decision more closely in only applying the fertiliser rate needed to obtain a soil N supply at planting of 100 kg/ha. This value is based on experience and the output from a long-term simulation of the distribution of yields in response to N fertiliser application (Figure 5). The total N supply of 100kg/ha addresses the trade-off between maximising yields with the minimum N fertiliser application.

**Table 9** Individual yearly APSIM outputs from simulated N fertiliser treatments for the C2 site corrected for field grain moisture (12.5% for wheat and barley, 13.5% for sorghum and 14% for chickpea)

| | Planting date | 27/09/1984 | 4/04/1985 | 6/05/1986 | 11/05/1987 | 12/04/1988 | 14/06/1989 | 10/05/1990 | 13/06/1991 | 7/05/1992 | 20/04/1994 | 1/11/1995 | 23/05/1996 | 15/10/1997 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fertiliser rate or scenario | Crop | Sorghum | Wheat | Wheat | Wheat | Wheat | Wheat | Wheat | Wheat | Wheat | Wheat | Sorghum | Wheat | Sorghum |
| ON | Yield (kg/ha) | 1762 | 3179 | 2037 | 2793 | 3158 | 2487 | 1734 | 1980 | 2866 | 2506 | 2772 | 2761 | 4786 |
| | Protein (%) | 8.6 | 13.2 | 12.4 | 8.7 | 10.7 | 10.9 | 6.8 | 14.0 | 7.3 | 13.3 | 8.3 | 12.1 | 10.8 |
| | Fertiliser applied (kg/ha) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Sum N at planting (kg/ha) | 122 | 117 | 79 | 50 | 66 | 61 | 23 | 73 | 38 | 97 | 100 | 66 | 100 |
| | | | | | | | | | | | | | | |
| 30N | Yield (kg/ha) | 1745 | 3499 | 2455 | 2781 | 3559 | 2513 | 1816 | 1983 | 3235 | 1721 | 2726 | 3283 | 4853 |
| | Protein (%) | 8.4 | 12.7 | 13.0 | 8.8 | 11.5 | 12.4 | 7.2 | 14.5 | 8.3 | 14.5 | 8.3 | 14.5 | 10.9 |
| | Fertiliser applied (kg/ha) | 0 # | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 0 | 0 | 30 | 30 |
| | Sum N at planting (kg/ha) | 113 | 128 | 97 | 68 | 88 | 85 | 49 | 89 | 67 | 121 | 124 | 99 | 122 |
| | | | | | | | | | | | | | | |
| 50N | Yield (kg/ha) | 1740 | 3621 | 2489 | 3306 | 3878 | 2508 | 2162 | 1965 | 3446 | 1545 | 2789 | 3283 | 4768 |
| | Protein (%) | 8.4 | 13.4 | 13.4 | 10.5 | 12.6 | 14.4 | 8.2 | 14.5 | 11.0 | 14.5 | 8.3 | 14.5 | 9.1 |
| | Fertiliser applied (kg/ha) | 0 # | 50 # | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 0 | 0 | 50 | 0 |
| | Sum N at planting (kg/ha) | 119 | 137 | 115 | 97 | 113 | 109 | 70 | 105 | 102 | 127 | 142 | 128 | 104 |
| | | | | | | | | | | | | | | |
| 70N | Yield (kg/ha) | 1757 | 3621 | 2639 | 3860 | 3937 | 2541 | 2278 | 1872 | 3528 | 1427 | 2880 | 3284 | 4734 |
| | Protein (%) | 9.9 | 14.4 | 13.7 | 11.9 | 14.2 | 14.5 | 11.4 | 14.5 | 14.5 | 14.5 | 9.6 | 14.5 | 12.6 |
| | Fertiliser applied (kg/ha) | 0 # | 70 # | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 0 | 0 | 70 | 49 |
| | Sum N at planting (kg/ha) | 125 | 155 | 140 | 132 | 138 | 128 | 93 | 132 | 147 | 131 | 154 | 153 | 146 |
| | | | | | | | | | | | | | | |
| 150N | Yield (kg/ha) | 1840 | 3620 | 2682 | 3999 | 3930 | 2542 | 1902 | 1061 | 2179 | 1192 | 2965 | 3274 | 4997 |
| | Protein (%) | 9.2 | 14.4 | 14.5 | 14.4 | 14.4 | 14.5 | 14.6 | 14.5 | 14.6 | 14.6 | 9.1 | 14.5 | 10.8 |
| | Fertiliser applied (kg/ha) | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| | Sum N after fert. (kg/ha) | 254 | 358 | 260 | 280 | 253 | 248 | 232 | 291 | 409 | 288 | 394 | 373 | 257 |
| | | | | | | | | | | | | | | |
| Top-up N | Yield (kg/ha) | 1733 | 3298 | 2431 | 3325 | 3712 | 2492 | 2289 | 1962 | 3442 | 1535 | 2790 | 3283 | 4758 |
| | Protein (%) | 8.4 | 12.2 | 13.1 | 10.7 | 12.1 | 14.3 | 11.1 | 14.5 | 10.9 | 14.5 | 8.3 | 14.5 | 10.7 |
| | Fertiliser applied (kg/ha) | 2 | 7 | 41 | 61 | 37 | 41 | 80 | 52 | 48 | 0 | 0 | 22 | 1 |
| | Sum N at planting (kg/ha) | 106 | 100 | 100 | 100 | 100 | 99 | 100 | 100 | 100 | 127 | 143 | 100 | 99 |

# The fertiliser rate shown is for the Site 64/65 only, which occupies the larger area of the C2 block.

**Table 9 (continued)** Summary of APSIM output from simulated N fertiliser treatments for the C2 site corrected for field grain moisture (12.5% for wheat and barley, 13.5% for sorghum and 14% for chickpea)

| | Planting date | 30/05/1998 | 4/11/1998 | 6/12/2000 | 4/12/2001 | 29/06/2002 | 14/05/2003 | 28/01/2004 | 25/11/2004 | 26/04/2005 | 15/05/2006 | 31/08/2007 | 17/09/2008 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fertiliser rate or scenario | Crop | Wheat | Sorghum | Sorghum | Sorghum | Wheat | Wheat | Sorghum | Sorghum | Barley | chickpea | sorghum | Sorghum |
| ON | Yield (kg/ha) | 1570 | 2555 | 5045 | 2073 | 831 | 2693 | 3099 | 1467 | 211 | 2423 | 4492 | 5086 |
| | Protein (%) | 11.0 | 4.9 | 8.5 | 4.6 | 7.1 | 7.3 | 4.6 | 5.8 | 8.0 | 17.7 | 9.3 | 7.6 |
| | Fertiliser applied (kg/ha) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 chickpea | 0 | 0 |
| | Sum N at planting (kg/ha) | 14 | 8 | 89 | 13 | 10 | 45 | 26 | 5 | 15 | 80 | 99 | 48 |
| | | | | | | | | | | | | | |
| 30N | Yield (kg/ha) | 2644 | 4594 | 5008 | 2636 | 1143 | 2357 | 3414 | 2343 | 1397 | 2423 | 4691 | 5198 |
| | Protein (%) | 8.2 | 4.5 | 9.0 | 6.2 | 8.3 | 7.6 | 5.6 | 4.3 | 10.1 | 17.7 | 9.9 | 8.2 |
| | Fertiliser applied (kg/ha) | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 0 chickpea | 9 | 30 |
| | Sum N at planting (kg/ha) | 45 | 35 | 118 | 45 | 41 | 51 | 55 | 34 | 51 | 54 | 112 | 79 |
| | | | | | | | | | | | | | |
| 50N | Yield (kg/ha) | 3013 | 5422 | 4973 | 2741 | 1258 | 2948 | 3410 | 3309 | 1885 | 2423 | 4846 | 5256 |
| | Protein (%) | 8.2 | 4.3 | 9.5 | 10.4 | 12.8 | 9.4 | 8.3 | 5.3 | 10.8 | 17.7 | 9.7 | 8.3 |
| | Fertiliser applied (kg/ha) | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 0 chickpea | 0 | 50 |
| | Sum N at planting (kg/ha) | 62 | 54 | 141 | 74 | 69 | 81 | 81 | 57 | 69 | 48 | 113 | 100 |
| | | | | | | | | | | | | | |
| 70N | Yield (kg/ha) | 3407 | 6522 | 4889 | 2738 | 1302 | 3615 | 3431 | 3721 | 2901 | 2423 | 4775 | 5071 |
| | Protein (%) | 9.6 | 6.5 | 11.5 | 13.8 | 13.9 | 11.6 | 11.6 | 9.9 | 11.6 | 17.7 | 11.1 | 9.6 |
| | Fertiliser applied (kg/ha) | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 0 chickpea | 0 | 0 |
| | Sum N at planting (kg/ha) | 83 | 78 | 161 | 106 | 107 | 114 | 109 | 87 | 96 | 52 | 119 | 50 |
| | | | | | | | | | | | | | |
| 150N | Yield (kg/ha) | 3640 | 8462 | 4734 | 2813 | 1356 | 3698 | 3051 | 3646 | 3187 | 2423 | 5415 | 4441 |
| | Protein (%) | 14.4 | 8.4 | 10.4 | 16.0 | 14.6 | 14.4 | 18.3 | 11.7 | 17.3 | 17.7 | 9.5 | 9.3 |
| | Fertiliser applied (kg/ha) | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 0 chickpea | 150 | 150 |
| | Sum N after fert. (kg/ha) | 223 | 235 | 234 | 266 | 280 | 357 | 377 | 368 | 378 | 239 | 383 | 206 |
| | | | | | | | | | | | | | |
| Top-up N | Yield (kg/ha) | 3514 | 7258 | 4845 | 2821 | 1299 | 3491 | 3376 | 3820 | 2988 | 2423 | 4962 | 5281 |
| | Protein (%) | 10.1 | 6.5 | 8.6 | 10.7 | 14.1 | 10.3 | 9.6 | 9.1 | 10.2 | 17.7 | 9.6 | 8.3 |
| | Fertiliser applied (kg/ha) | 88 | 91 | 8 | 87 | 78 | 62 | 61 | 88 | 71 | chickpea | 0 | 49 |
| | Sum N at planting (kg/ha) | 100 | 99 | 100 | 100 | 100 | 100 | 98 | 99 | 98 | 62 | 118 | 99 |

## N Fertiliser application rates

### Mean N fertiliser rate

The mean N rates for the 30N, 50N and 70N scenarios were less than the labelled scenario value. For wheat they were 28, 46 and 65 kg/ha of N respectively (Figure 8). For sorghum they were 23, 33 and 44 kg/ha of N respectively. This occurred because a rule was applied so fertiliser was not applied if the soil N at planting exceeded 100 kg/ha of N. This rule was applied to make the scenarios more like a field situation in which fertiliser rates are minimised rather than applied at a consistent rate regardless of the soil N levels. This was a similar concept to that of the 'top-up' rate described previously. The mean 'top-up' rate was 47 kg/ha of N (wheat) and 43 kg/ha of N (sorghum), but individual rates varied widely.

The 150 kg/ha of N rate was applied every year to simulate a luxury N supply.

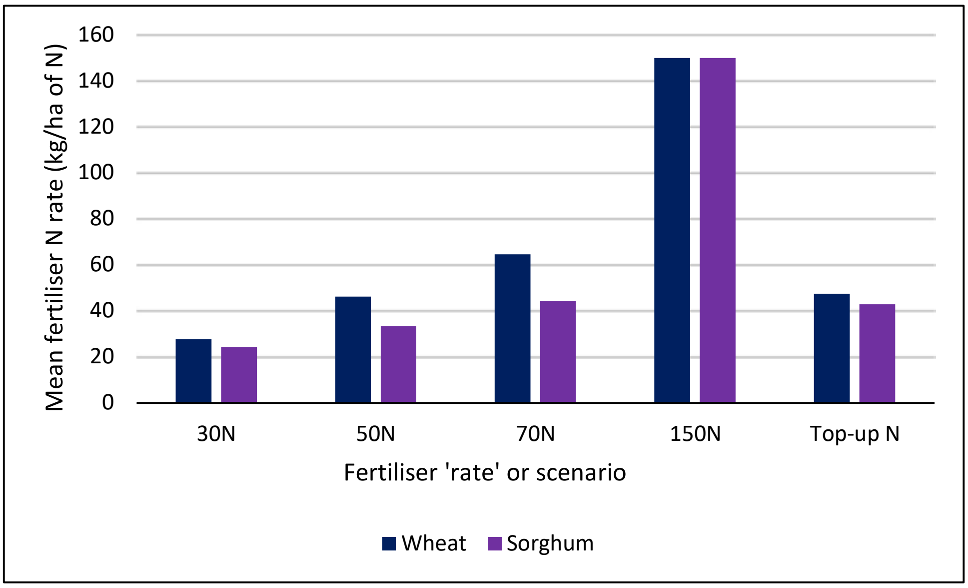


**Figure 8** Mean simulated fertiliser N applied for the fertiliser scenario

### Total N fertiliser application

The total quantity of fertiliser applied increased linearly from the 30N to 70N scenarios (Figure 9). The 150N scenario applied a large quantity because the application was made every year regardless of the soil N level. This contrasts to the 30N, 50N and 70N scenarios, which had the rule applied that fertiliser was not applied if the soil N level was greater than 100kg/ha of N.

The 'top-up' N rate varied widely (2 to 91 kg/ha of N) in response to the rule requiring the soil N level to be increased to 100kg/ha of N at planting. The total quantity was like that of the 50N scenario.

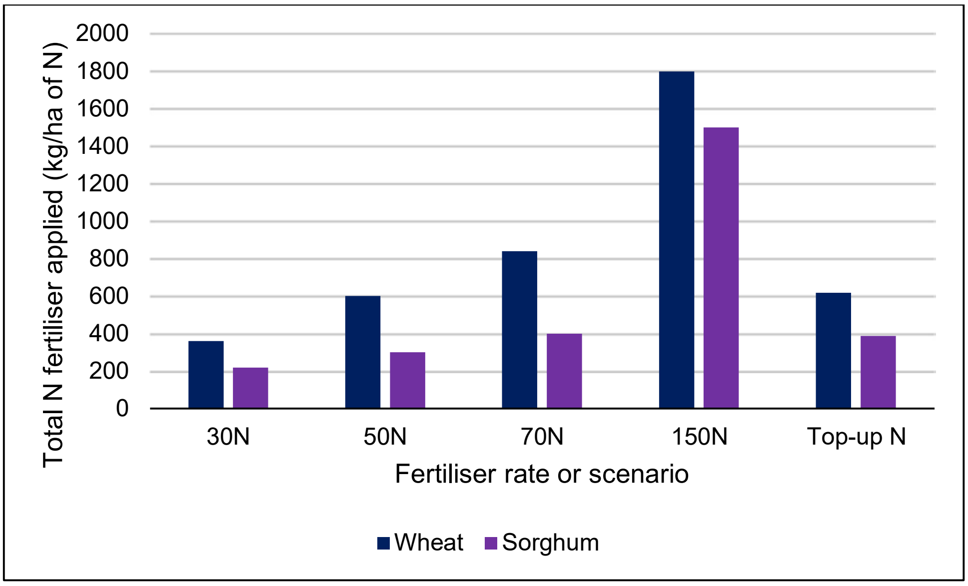


**Figure 9** Total simulated quantity of N fertiliser applied for the C2 site over the cropping period

### Total grain production

The total grain production from the crop rotation (1984 to 2008) increased with N fertiliser rate up to the 70kg/ha of N scenario (Figure 10). Applying a luxury amount of 150kg/ha of N annually did not further increase production. The 'top-up' N rate (average 43 kg/ha of N across all crops) resulted in greater total production than the 50N rate scenario (average 38kg/ha of N) and very similar to that of the 70N scenario (average 52 kg/ha of N across all crops).

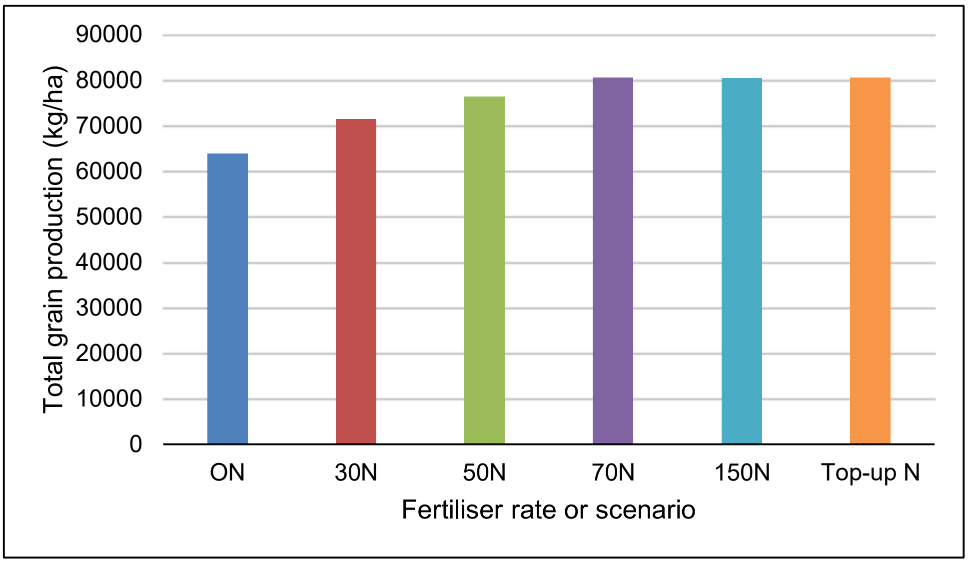


**Figure 10** Simulated total grain production of wheat, barley and sorghum in response to N fertiliser strategies for the C2 site. Yields were weighted using data from sites 64/65 and 66 on a 70:30 area basis. Yields were corrected to delivery grain moisture (12.5% for wheat and barley and 13.5% for sorghum). There were 13 wheat crops, 10 sorghum crops and one barley crop.

## Mean grain yields

### Winter crops

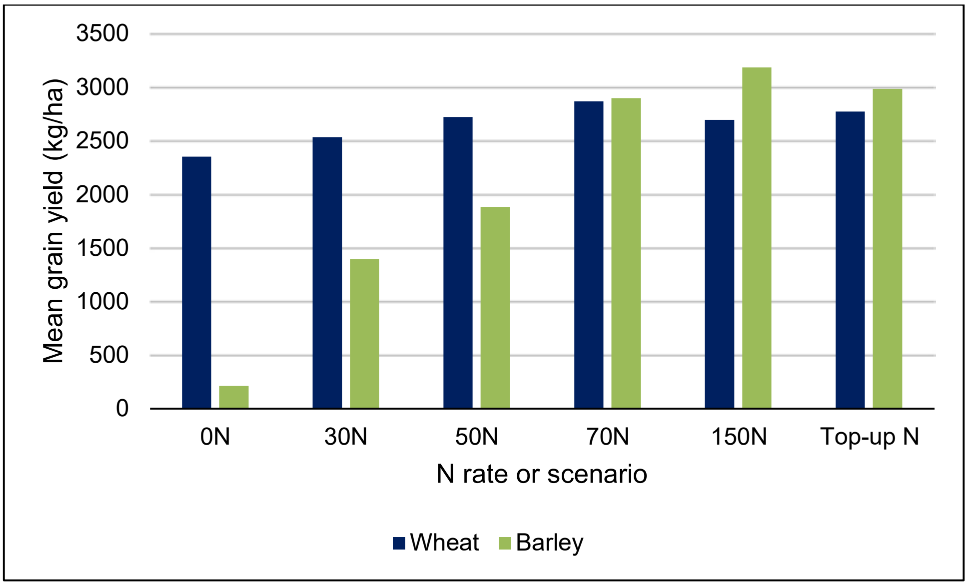
The simulated increase in mean wheat yields (n=13) were almost linear up to the 70N scenario (Figure 11).

The single crop of barley responded to the 150N rate because the crop occurred very late (2005) in the crop rotation (1984 to 2008) that had no N fertiliser applied to any crop. Hence the simulated soil N supply was significantly depleted by 2005. Thus, a large amount of applied N was required to maximise grain yield.

The mean 'top-up' N rate of 47 kg/ha of N produced a similar mean wheat yield as the set rate scenario of 50kg/ha of N (mean 46 kg/ha of N). The simulated 'top-up' rates varied from 2 to 91 kg/ha of N. As described previously, all the fertiliser scenarios except the 150N scenario, included the rule that N fertiliser was not applied if the total soil N exceeded 100kg/ha of N. For example, one wheat crop and four sorghum crops did not receive an application of 50N (see Table 9).

The 'top-up' N rate for the barley crop was 88 kg/ha of N.

The reduction in mean simulated wheat yield with 150 kg/ha of N was caused by the occasional yield reduction with the very high N rate. The 150 N rate was applied annually, and soil N accumulated to high levels.



Note: the single crop of barley was late in the cropping program (2005), hence with rundown of soil N, the potential response to applied N was high.

**Figure 11** Winter crop yield response to N fertiliser strategies for the C2 site. Yields were weighted using data from sites 64/65 and 66 on a 70:30 basis. Yields were corrected to delivery grain moisture (12.5% for wheat and barley and 13.5% for sorghum).

## Sorghum

The simulated mean grain yield response of sorghum to applied N was curvilinear peaking at 150 kg/ha of N (Figure 12). The yield response to N was less than the winter cereals which is also observed in field situations (Wylie 2014). Grain yield response to high N rates is also less common in practice but in this simulation, the majority of the sorghum crops occurred in the latter half of the rotation when soil N fertility could be low if N fertiliser supply had been less than crop demand. Similarly, the grain yield from the mean 'top-up' N rate (43 kg/ha of N) resulted in a mean grain yield similar to that of the 150N set rate applied annually. The 'top-up' rate varied from 0 to 88 kg/ha of N. The mean yield was also greater than that of the 70kg/ha of N scenario. The cost of the 'top-up' rate

(43 kg/ha of N) would be significantly less than the 150 N (150 kg/ha of N) rates but similar to the 70N (44kg/ha of N) scenario.

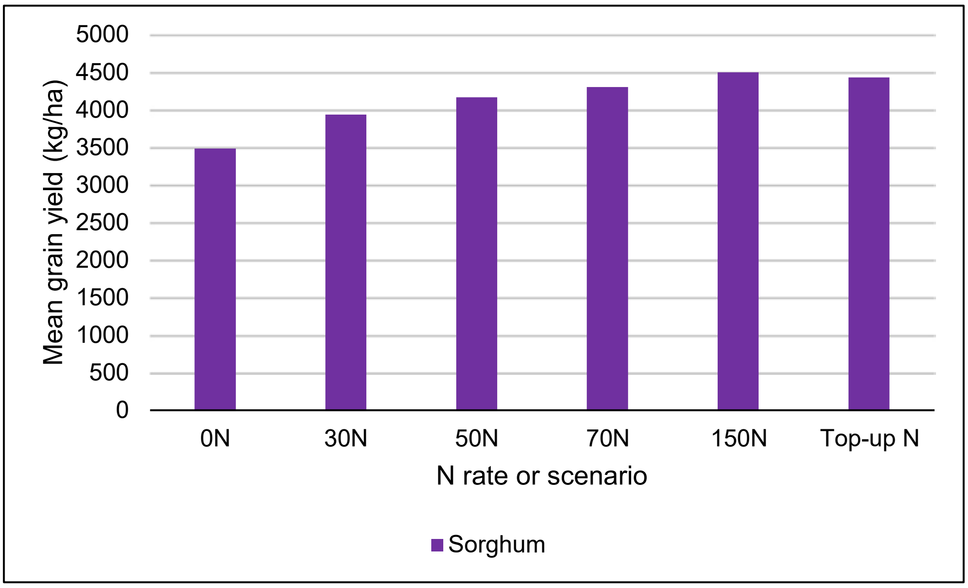


**Figure 12** Sorghum crop yield response to N fertiliser strategies for the C2 site. Yields were weighted using data from sites 64/65 and 66 on a 70:30 basis. Yields were corrected to delivery grain moisture (13.5% for sorghum).

### Simulated grain protein

Grain protein was simulated to calculate the economic returns more accurately for the crops in the ‘base’ simulation (mimicking the field site) with no N applied.

It was also simulated for the scenarios in which fertiliser N was applied to wheat and barley (Figure 13) and sorghum (Figure 14). The mean grain proteins increased with increased N rate. The ‘top-up’ N rate (range 2 to 91 kg/ha of N, mean 47 kg/ha of N) resulted in very similar proteins to that of the 50N set rate. Grain proteins for which grain yield has not been sacrificed, 11.5% for wheat and 10.5% for barley (Cox and Strong 2015) were indicated with N rates of 50kg/ha of N or greater. N rates of 30 kg/ha of N or nil resulted in low grain proteins.

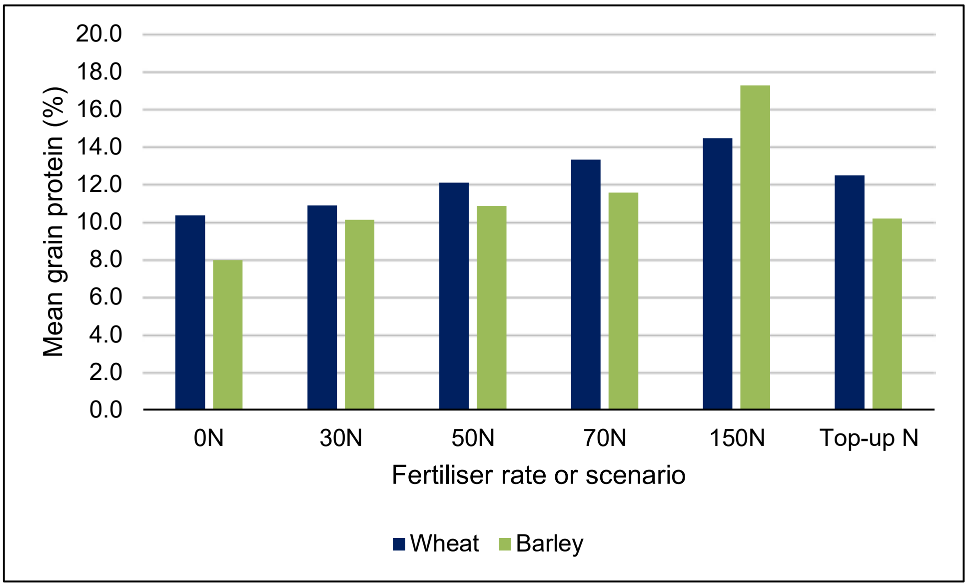


**Figure 13** Winter crop grain protein response to N fertiliser strategies for the C2 site. Yields were weighted using data from sites 64/65 and 66 on a 70:30 basis. Wheat grain protein was corrected to 12.5% moisture, barley 0% moisture.

Grain protein is not usually a determinant of price in grain sorghum, but values of less than 9.5% are considered to have reduced yield potential (Cox and Strong 2015). In this instance, the 50N rate resulted in a mean grain protein of less than 9.5% which would be considered yield-limiting. The 'top-up' rate (range 0 to 88 kg/ha of N, mean of 43 kg/ha of N) produced a satisfactory grain protein. Satisfactory grain protein levels were indicated from 'set' rates of 70 kg/ha of N or more.

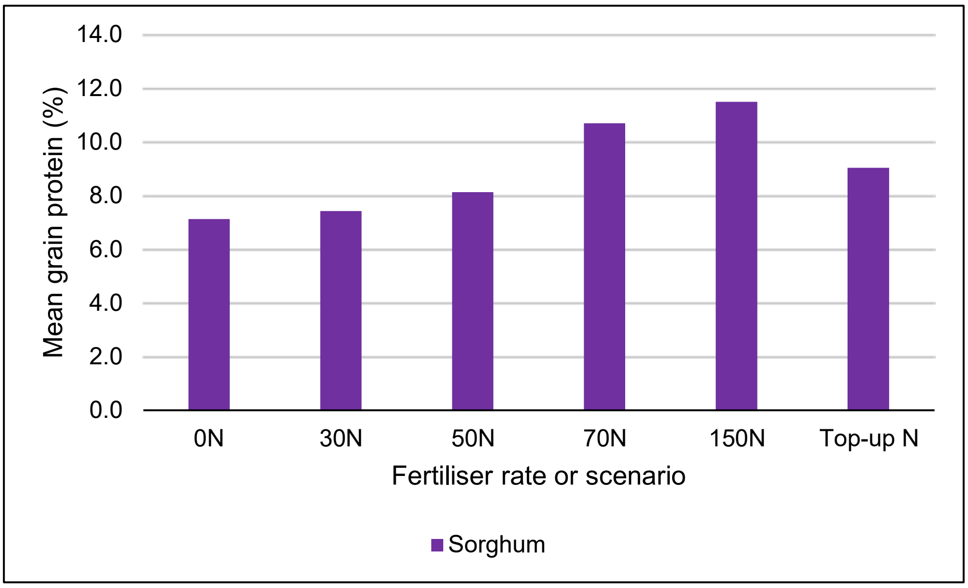


**Figure 14** Sorghum crop grain protein response to N fertiliser strategies for the C2 site. Yields were weighted using data from sites 64/65 and 66 on a 70:30 basis. Sorghum grain protein was corrected to 13.5% moisture.

## Part C. Simulating the production effects of a planting with a pre-determined plant-available soil water ('soil water trigger') together with various N fertiliser rates.

### Crop count

Waiting for the soil profile to refill (higher plant available water capacity) generally reduced the simulated number of crops that would have been planted over the period 1984 to 2008 (Figure 15).

Increased soil N status, through greater N fertiliser application, did not change the number of crops planted except for sorghum in which the 70N rate increased the crop count by one at 90% PAWC.

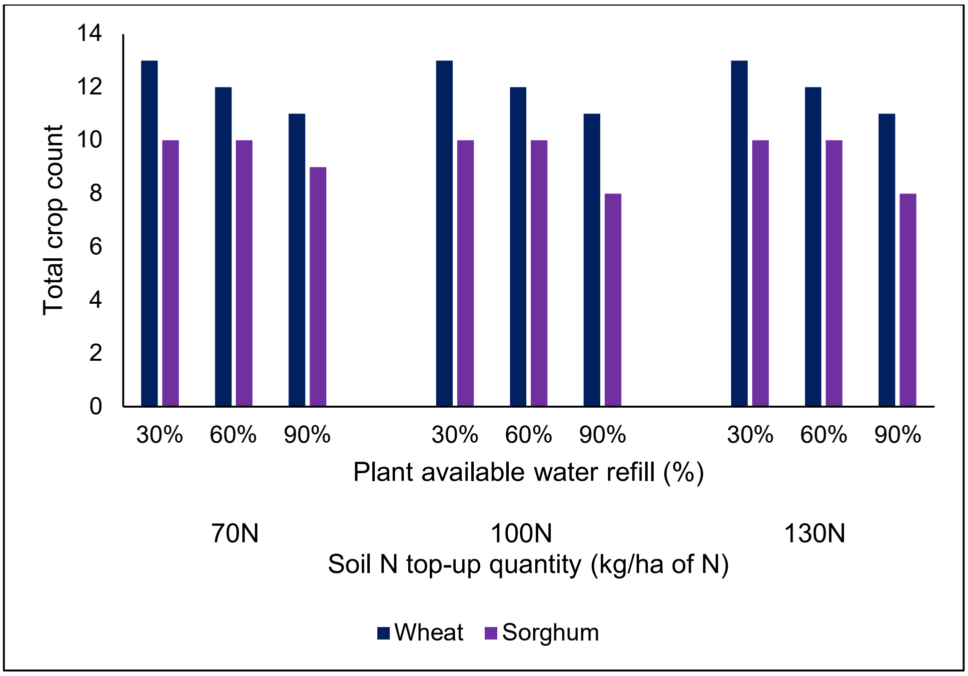


**Figure 15** Effect of plant available water (PAWC) and soil N level on the number of wheat and sorghum crops in the 1984 to 2008 rotation

## Total grain production

Waiting for the soil profile to refill reduced the total grain production from the wheat and sorghum in the rotation (Figure 16). This occurred because of the effect of soil PAWC refill on the crop count (Figure 15).

Increasing soil N status for wheat progressively increased total grain production. There was a similar trend for sorghum except for the 100N/90% scenario. With the 100N rate, there was slightly greater soil drying from previous crops. This resulted in one less crop than the 70N/90% scenario. The 130N rate also had one less crop than the 70N rate, but the total grain production was slightly increased compared to the 100N rate.

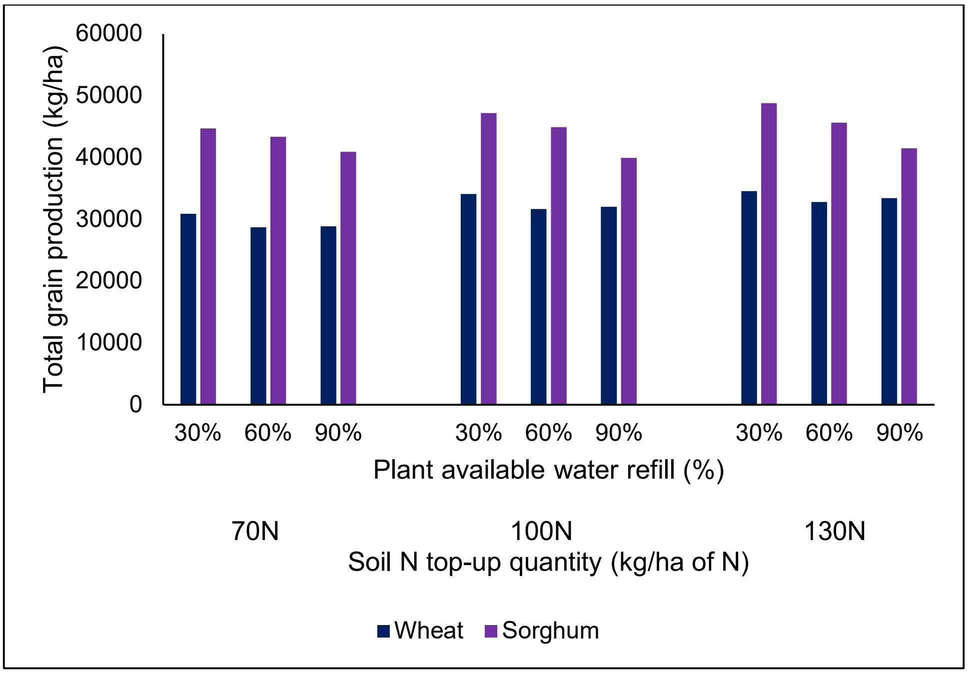


**Figure 16** Effect of plant available water (PAWC) and soil N level on total grain production for wheat and sorghum in the 1984 to 2008 rotation. Site 64/65 data used.

## Mean grain yield

It would generally be expected that the mean grain yield would increase with both N rate and greater PAWC at planting. This trend was evident for wheat with a mean increase of approximately 300 kg grain/ha/crop between the 70N and 100N rates (Figure 17). The mean grain yield increases from the 100N to 130N rates was much less. The yields from refilling to 30% and 60% of PAWC resulted in similar yields across the N levels but 90% PAWC produced greater mean yields on fewer crops.

For sorghum, the mean yields from the 30% PAWC were greater than that of the 60% PAWC because the simulated crops were planted significantly earlier as result of the lower refill required. Higher yields were usually achieved because of more favourable environmental conditions, despite the lower accumulated quantity of soil water. The crop counts were the same (Figure 15).

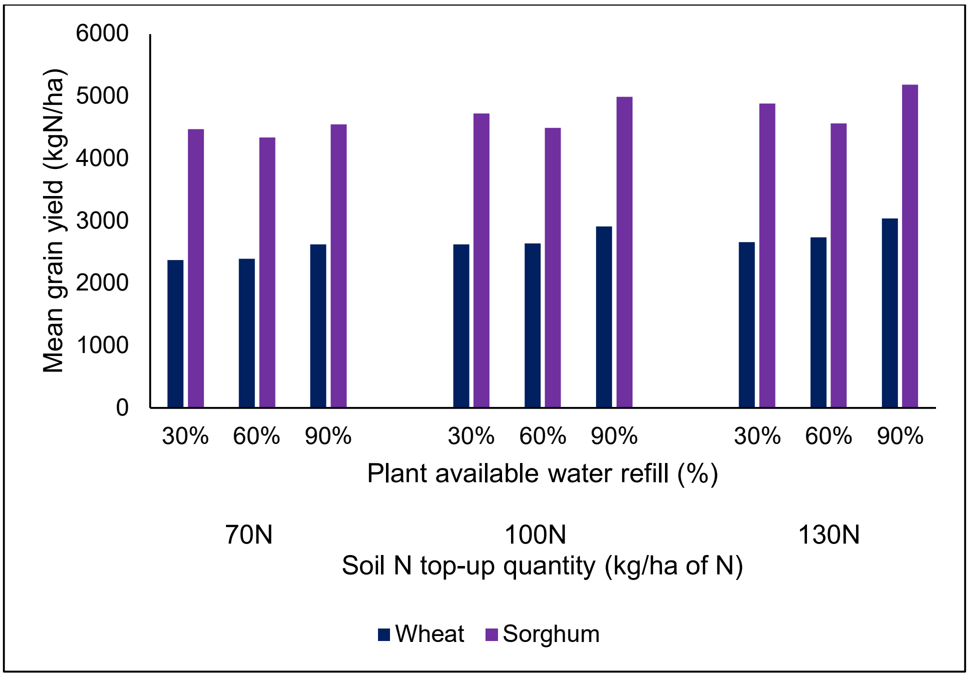


**Figure 17** Effect of plant available water (PAWC) and soil N level on mean grain yield for each crop of wheat and sorghum in the 1984 to 2008 rotation

### Total (simulated) N fertiliser applied during the cropping period 1984 until 2008

With increasing N 'top-up' rate, the total quantity of N fertiliser applied increased (Figure 18). However, with waiting to refill to greater PAWC amounts, the total N application trended down. This was mainly a result of the reduced crop count (Figure 15).

### Mean (simulated) N fertiliser applied per crop, during the cropping period 1984 until 2008

With increasing N scenario rate, the mean quantity of N fertiliser applied increased (Figure 19). For the 70N, 100N and 130N scenarios these were approximately 28, 50 and 68 kg/ha of N respectively. Within the PAWC soil water trigger scenarios, there a slight variation because of differing crop counts and total quantities applied.

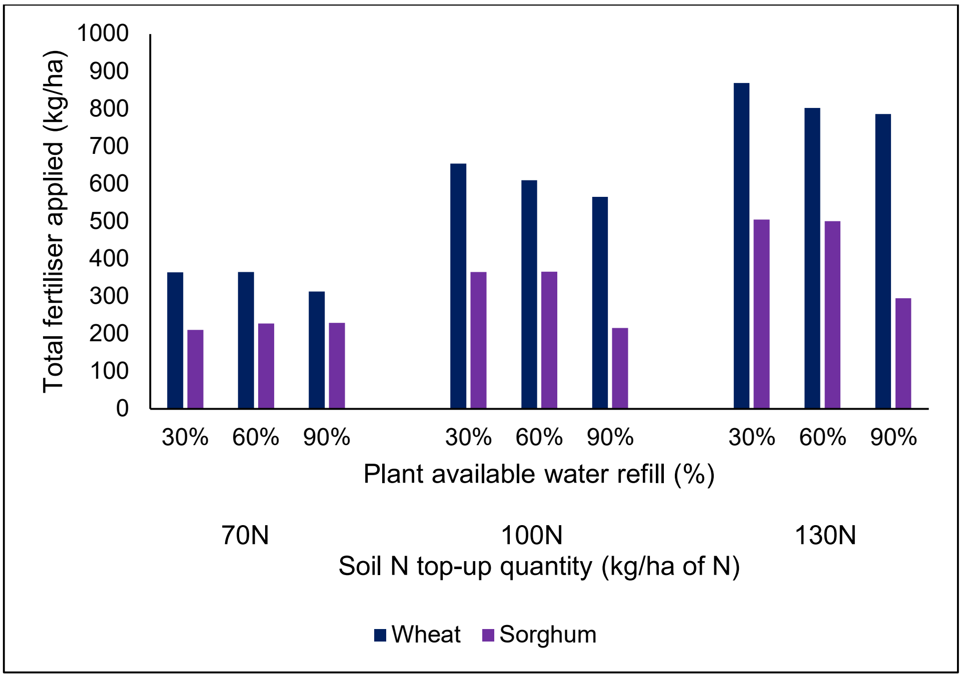


**Figure 18** Effect of plant available water (PAWC) and soil N level on the total quantity of fertiliser applied to wheat and sorghum in the 1984 to 2008 rotation

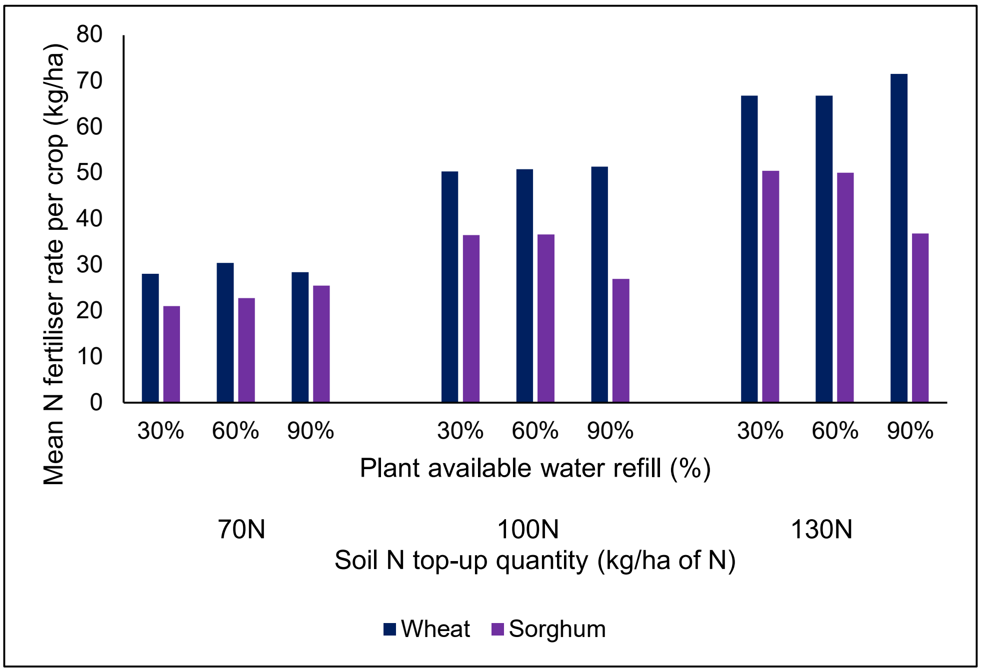


**Figure 19** Effect of plant available water (PAWC) and soil N level on mean N fertiliser rate for each crop of wheat and sorghum in the 1984 to 2008 rotation

# Discussion

## Part A. ‘Base file’ – mimicking the experimental design with no fertiliser application

APSIM was able to simulate wheat yields generally within ±25% of those of the site (Table 2Table 2). We consider this was satisfactory considering the site commenced 36 years ago and was not designed for use in crop simulation. However, the field measurements of soil properties, planting data and soil water and N were useful for calibrating the APSIM soil parameters. Unfortunately, there was not a lot of information available on the agronomic conditions that may have affected the crop growth. Hence, there may have been other factors that affected the observed results.

For sorghum, the correlation of APSIM output with field yields was much more variable. It was known that there were weeds on the site at the time of the first sorghum crop in 1984. A ratoon crop of sorghum occurred in 1995. This made it more difficult to model the soil water, soil N and crop yields after this time. The site yields were consistently lower than the simulated yields, indicating a possible ongoing issue with sorghum production at this site.

The trendline in Figure 6 shows a decline in grain protein results over time from the site. However, it could be more correctly stated that the years 1984 to 1992 returned consistently high grain proteins followed by a decline to 2008. This would be expected on soil on which had been recently converted from native vegetation to cultivation then crops grown without added N fertiliser. With no fertiliser application and continuing crop removal, the grain proteins (and grain yields) would be expected to decline.

Figure 7 is simulated grain protein data for the same time period. A similar pattern of decline as for yield is evident, though with more variability. In general, simulated results were approximately two percentage points lower than the observed data. This is likely because of the greater yields simulated by APSIM and hence greater N demand.

The comparison of using ‘resets’ and ‘no resets’ of soil water and $NO_3$ data showed that APSIM could better model the site rotation with no resets than with resets at various dates during the rotation (correlation 0.736 vs 0.557) (Table 8). However, early in the project activity it was decided to use the runs with resets from the site data for the N fertiliser application scenarios, to mimic the site situation as closely as possible.

Considering the uncertainty involved in the site data, we consider that APSIM provided a satisfactory set of yield outcomes. This is regardless of resetting (or not) soil water and $NO_3$ values at the times that occurred on the site.

## Part B. Simulating the effect of N fertiliser application on the BCS

The fertiliser rate simulations showed that applying N fertiliser would have significantly increased grain production over the crop rotation from 1984 to 2008 (Figure 10).

The total simulated grain production from the 24 cereal crops increased from 65,000 kg to a maximum of 80,000 kg by applying N fertiliser (a 23% increase). A rate of 70 kg/ha of N maximised yield but the most economic N rate will be calculated in another section of this report.

The ‘top-up’ N rate could be a very suitable alternative to the (modified) set rates, because it precisely matches the N fertiliser rate to the designated requirement, in this instance a ‘top-up’ to 100 kg/ha of total soil N. The ‘top-up’ rate produced as much total production as both the 70N and 150N scenarios. With an average rate of 43 kg/ha of N compared to 52 kg/ha of N for the 70N scenario, the cost/benefit should be much greater.

Of course, other total soil N targets could be chosen. The application rates varied from 2 to 91 kg/ha. It is unlikely that rates less than 20 kg/ha of N would be applied in practice except if it was a ‘starter’ fertiliser applied with the seed. The economic results of this strategy will be detailed in another section of the report.

The amounts indicated in the fertiliser rate scenarios of 30N, 50N and 70N were applied in most years, but not every year. A rule was included that avoided fertiliser application if the total soil N was greater than 100kg/ha of N. This was done to better replicate field situations where soil testing was used and there was a desire to avoid applying N fertiliser if it was not required. Thus, the mean N rates across all cereal crops, from these scenarios were 25, 38 and 52 kg/ha of N respectively.

The 150N annual rate was included as a test of a luxury supply of N and was not intended to represent a practical treatment. As with real-world situations, the excessive rate sometimes reduced yields compared to lower N rates (Brill, et al., 2012).

The mean yield of wheat responded up to a maximum yield with the 70N (average 44kg/ha of N) scenario value (Figure 11). Alternatively, the ‘top-up’ scenario (mean rate of 43kg/ha of N) maximised grain yield with only a minor cost increase than for the 50N (mean 38kg/ha of N) scenario.

The yield response of the barley crop indicated the magnitude of the potential crop response when the soil N levels have decreased. It also showed that the cost of N application would be high at that time because the N rate required was around 70 to 90 kg/ha of N.

The simulated sorghum yields were greater under conditions of lower N input than for wheat or barley (Figure 12). This is similar to field experience. However, the rate required to optimise the economic return was greater than that of wheat and barley, being at least 70 kg/ha of N or a ‘top-up’ rate averaging 43 kg/ha of N.

Obtaining prime hard protein in wheat has been of economic benefit only when there was a premium price for the product. However, as reported by Cox and Strong (2015), the main indicator of grain protein level is whether the available N was sufficient to maximise yield. For wheat and barley this is greater than 11.5% and 10.5% respectively. Because of the unpredictable nature of the premium prices, it is usually recommended to be more economical to apply N rates to achieve the maximum yields as frequently as possible (Cox and Strong, 2015). Applying excessive N rates was unlikely to be economical, but conversely, low N supply could significantly reduce yields, especially in high rainfall years. In low-rainfall years that result in low grain yields, the wheat protein is automatically increased unless N is acutely limiting. If this coincides with a high premium price, then some of the losses from low yields are recouped.

The simulations indicated a N rate between 30 and 50 kg/ha of N could give sufficient grain protein to optimise yield for wheat and barley (Figure 13). For sorghum applying between 50 and 70 kg/ha of N could give sufficient grain protein to optimise yield (Figure 14).

Importantly, for both wheat, barley, and sorghum, the ‘top-up’ N rate resulted in mean grain protein similar to the set rate of 50kg/ha of N (Figure 13 and Figure 14). However, the mean grain yields and total grain production for the ‘top-up’ rate was most similar to the 70N set rate (Figure 8 and Figure 9).

The mean ‘top-up’ N rate was most similar to the 50N set rate scenario for wheat and the 70N scenario for sorghum (approximately 42 kg/ha of N) (Figure 14). As stated previously these rates were at the upper end of those which would optimise grain yield. The total N application rate was also most similar to the 50N scenario for wheat and the 70N scenario for sorghum (Figure 9).

Thus, the ‘top-up’ N rate would appear to maximise the production but minimise the N application and hence costs as well as possible off-site effects.

## Part C. Simulating the production effects of a planting with three levels of plant available soil water (‘soil water trigger’) at planting together with three N fertiliser rates.

Waiting for the soil to refill with water to a greater quantity is sometimes considered a risk-minimisation strategy (Cox and Strong 2015, Wylie 2014). Conversely, planting with lower soil water levels will increase cropping frequency but may increase the risk of crop failure. This study examined three water levels at which planting was allowed. Waiting for 90% PAWC reduced the crop number by up to two crops over the 25-crop rotation and decreased total production. Planting with a minimum of 30% PAWC produced the greatest crop count and total crop production (Figure 15).

The strategy of refilling the soil to different levels to ‘trigger’ planting has slightly different effects on wheat than sorghum. The effect of percentage refill is much greater for sorghum than wheat, largely because of the wide sorghum planting ‘window’. This was because delaying planting to allow soil water refill reduced the crop count and/or reduced yield by planting into hotter conditions. Wheat production was largely unaffected by the quantity of soil water refill because any loss of crop number, by planting later, was compensated by increased grain yields from stored soil water.

For wheat, the choice of soil water trigger will largely depend on the growers’ attitude to risk and machinery capability. Some growers may prefer to await a greater soil water profile to help guarantee grain yield because in-crop rainfall is less reliable in this summer-dominant rainfall environment. Conversely, growers that will accept more risk may decide to plant with lower refill amounts and obtain a greater number of crops. The difficulty of the decision of soil water trigger level has been reduced somewhat by the uptake of zero till, controlled-traffic farming (CTF) and deep planting. Zero till and CTF increase water storage over fallow and hence increase the quantity of soil water at planting and possibly facilitate earlier planting. Deep planting can allow planting based on optimum date rather than waiting for the surface soil to be fully re-wet, but there is still the question of the total amount of water that is in the soil. This analysis included a requirement for some rainfall at planting to make it more widely applicable.

For sorghum, there appears to be benefits from planting with a lower soil water ‘trigger’ level. A sorghum crop was more likely to receive in-crop rainfall in this summer-dominant rainfall environment. This may compensate for a lower starting soil water. Not waiting for a higher refill amount allows earlier plantings which can result in a greater crop number in a rotation. Earlier planting can also result in higher yields from cooler growing conditions. Conversely, rainfall in spring in this environment is variable and can increase the risk of crop failure. Some growers also avoid planting late in spring or early summer because the crop will be flowering in the hottest time in summer. This has been reported to increase pollen abortion and/or exacerbate the effect of water stress if soil water reserves are depleted. APSIM does not account for heat stress on pollen but soil water stress is well accounted for.

Mean grain yields (Figure 17) were maximised by the highest starting soil water and N rate, but this is less important than the total crop count (Figure 15).

The total quantity of N fertiliser applied increased with the greater N ‘top-up’ scenarios (Figure 18). However, as previously shown, the lowest rate (70N ‘top-up’) decreased total production. Hence, the intermediate rate scenario (100N) would be considered optimum from this study. In Part B it was shown that a 30 to 50 N ‘annual set’ rate for wheat and a 50 to 70N ‘annual set’ rate for sorghum would have similar production outcome as the ‘‘top-up’ to 100N scenario. Note that the ‘annual set’ rate was modified to not apply N fertiliser if the soil N exceeded 100 kg/ha of N. Thus, some annual applications did not occur.

The mean fertiliser rate for wheat was most influenced by the target N scenario with only a minor effect from refill percentage (Figure 19). The effect on sorghum from target N was of a lesser magnitude. The higher soil water refill trigger points affected the mean fertiliser rates of sorghum more than wheat, because of the greater yields exceeding the effect of a generally lower crop count.

# Part Three: Gross margin analysis of simulated N fertiliser application scenarios

## Methodology

### Part A. Simulated N fertiliser applications

The methodology for the simulated N rate scenarios used the same approach as the historical gross margin analysis outlined in Part One: Historical gross margin analysis. The main difference being the simulated APSIM yields were used in place of the observed BCS yields. This was necessary as the BCS did not investigate different N rates. Additionally, the cost of the fertiliser application varied with the rate applied. The product cost of urea as well as the operation cost of a broadcast spreader was sourced from the AgMargins website (State of Queensland, 2020).

As mentioned in the APSIM Results (Table 7), the ratooned sorghum crop from the historical BCS site was not simulated. Therefore, this crop was removed from the gross margin analysis.

### Part B. Soil water triggers to determine N fertiliser top-up scenarios

The APSIM simulation for the soil water trigger scenarios (30%, 60% and 90%) (Part Part C. N fertiliser 'top-up' strategies that incorporate a soil water trigger for planting) provided average yields for each of the following total soil N supply (70,100 and 130). Variable costs for each crop were averaged from the historical BCS data. Gross margin analysis was then conducted using the average yield from the scenario and the averaged historical costs. These gross margins were then multiplied by the number of crops under each scenario to determine cumulative gross margins for the scenarios.

The pricing used for the strategies was an average of the 2020 September and October cash prices sourced from GrainCorp Moura site for wheat (all grades average, except FED1) and sorghum (SOR1). Insurance premiums were applied to the average income for each crop.

### Part C. Additional simulated years to test seasonality

Additional APSIM simulations was conducted to determine if the results of the various fertiliser application rates, except for 0N and 150N, were specific to the climatic conditions during the BCS period or if the trends would continue under different conditions. The BCS equivalent rotation (same crop sequence over 25 years) was simulated for 26 different starting points. The 1st rotation started in 1957 for 25 years, the 2nd started in 1958 for 25 years etc., with the 26th and final rotation beginning in 1982. This ensured that each set of the rotation received different climate sequences and fallow periods.

The same economic methodology for the simulated N fertiliser applications (as above) was applied to the additional runs, except for pricing. The pricing for the additional simulated years was the same methodology as the soil water trigger strategies (Part B of Part 3). Pricing for chickpea was based on GrainCorp Moura and pricing for barley (BAR1) was based on GrainCorp Miles.

# Results

## Part A. Simulated N fertiliser applications

The gross margin (GM) results are presented in Table 10. All crops produced a positive gross margin, except for the barley crop in the base scenario.

**Table 10** Gross margin results

| **Crop code** | **0 N** | | **30 N** | | **50 N** | | **70 N** | | **150 N** | | **Top-up N** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | GM | Yield | GM | Yield | GM | Yield | GM | Yield | GM | Yield | GM | Yield |
| **01-SOR85** | $215 | 1.8 | $214 | 1.8 | $211 | 1.7 | $213 | 1.8 | $148 | 1.8 | $207 | 1.7 |
| **02-WHT85** | $726 | 3.2 | $795 | 3.5 | $817 | 3.6 | $806 | 3.6 | $762 | 3.6 | $753 | 3.3 |
| **03-WHT86** | $315 | 2.0 | $397 | 2.5 | $394 | 2.5 | $418 | 2.6 | $384 | 2.7 | $384 | 2.4 |
| **04-WHT87** | $561 | 2.8 | $540 | 2.8 | $663 | 3.3 | $794 | 3.9 | $785 | 4.0 | $661 | 3.3 |
| **05-WHT88** | $821 | 3.2 | $934 | 3.6 | $1,027 | 3.9 | $1,036 | 3.9 | $989 | 3.9 | $980 | 3.7 |
| **06-WHT89** | $504 | 2.5 | $493 | 2.5 | $481 | 2.5 | $480 | 2.5 | $436 | 2.5 | $481 | 2.5 |
| **07-WHT90** | $135 | 1.7 | $133 | 1.8 | $189 | 2.2 | $200 | 2.3 | $84 | 1.9 | $197 | 2.3 |
| **08-WHT91** | $413 | 2.0 | $396 | 2.0 | $380 | 2.0 | $342 | 1.9 | $62 | 1.1 | $377 | 2.0 |
| **09-WHT92** | $544 | 2.9 | $624 | 3.2 | $669 | 3.4 | $680 | 3.5 | $279 | 2.2 | $669 | 3.4 |
| **10-WHT94** | $590 | 2.5 | $325 | 1.7 | $266 | 1.5 | $225 | 1.4 | $63 | 1.2 | $261 | 1.5 |
| **11-SOR96** | $558 | 2.8 | $545 | 2.7 | $563 | 2.8 | $587 | 2.9 | $528 | 3.0 | $561 | 2.8 |
| **12-WHT96** | $695 | 2.8 | $832 | 3.3 | $821 | 3.3 | $810 | 3.3 | $764 | 3.3 | $836 | 3.3 |
| **13-SOR98** | $723 | 4.8 | $721 | 4.9 | $719 | 4.8 | $683 | 4.7 | $689 | 5.0 | $715 | 4.8 |
| **14-WHT98** | $284 | 1.6 | $544 | 2.6 | $628 | 3.0 | $719 | 3.4 | $735 | 3.6 | $736 | 3.5 |
| **15-SOR99** | $351 | 2.6 | $755 | 4.6 | $915 | 5.4 | $1,132 | 6.5 | $1,489 | 8.5 | $1,272 | 7.3 |
| **16-SOR01** | $657 | 5.0 | $632 | 5.0 | $614 | 5.0 | $587 | 4.9 | $513 | 4.7 | $612 | 4.8 |
| **17-SOR02** | $291 | 2.1 | $401 | 2.6 | $414 | 2.7 | $402 | 2.7 | $375 | 2.8 | $411 | 2.8 |
| **18-WHT02** | $150 | 0.8 | $240 | 1.1 | $268 | 1.3 | $269 | 1.3 | $232 | 1.4 | $252 | 1.3 |
| **19-WHT03** | $546 | 2.7 | $436 | 2.4 | $588 | 2.9 | $760 | 3.6 | $739 | 3.7 | $730 | 3.5 |
| **20-SOR04** | $424 | 3.1 | $470 | 3.4 | $458 | 3.4 | $451 | 3.4 | $331 | 3.1 | $445 | 3.4 |
| **21-SOR05** | $120 | 1.5 | $251 | 2.3 | $403 | 3.3 | $462 | 3.7 | $405 | 3.6 | $469 | 3.8 |
| **22-BAR05** | -$82 | 0.2 | $120 | 1.4 | $199 | 1.9 | $376 | 2.9 | $385 | 3.2 | $391 | 3.0 |
| **23-CHKP06** | $1,493 | 2.4 | $1,493 | 2.4 | $1,493 | 2.4 | $1,492 | 2.4 | $1,493 | 2.4 | $1,493 | 2.4 |
| **24-SOR08** | $1,069 | 4.5 | $1,130 | 4.7 | $1,177 | 4.8 | $1,154 | 4.8 | $1,268 | 5.4 | $1,211 | 5.0 |
| **25-SOR09** | $928 | 5.1 | $937 | 5.2 | $940 | 5.3 | $923 | 5.1 | $690 | 4.4 | $946 | 5.3 |

The average gross margin per hectare and the accumulative gross margin for each N rate or scenario are presented in

Figure 20 and Figure 21 respectively. Top-up N produced the highest gross margin at $642/ha and $16,050 total. 70N was only marginally less at $640/ha and $16,001 total. Yield results per hectare are presented in Figure 22.

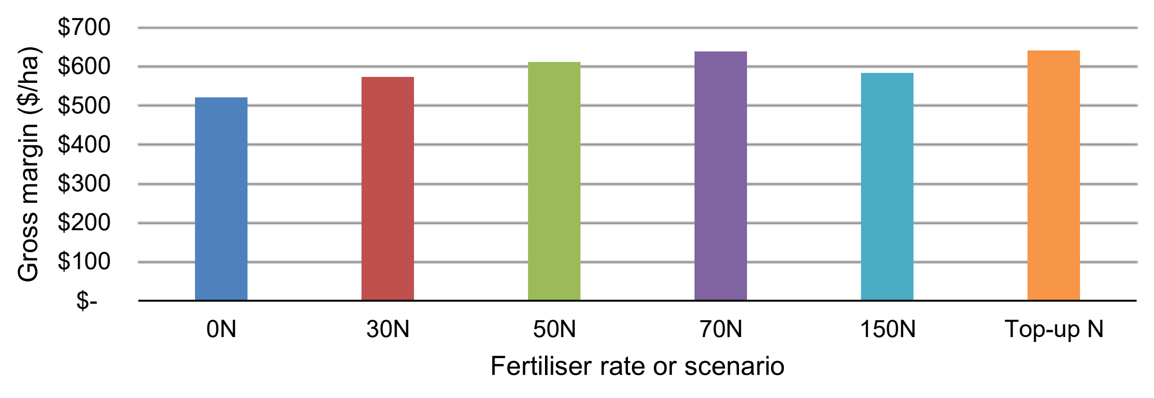


**Figure 20** Average gross margin for each fertiliser rate or scenario

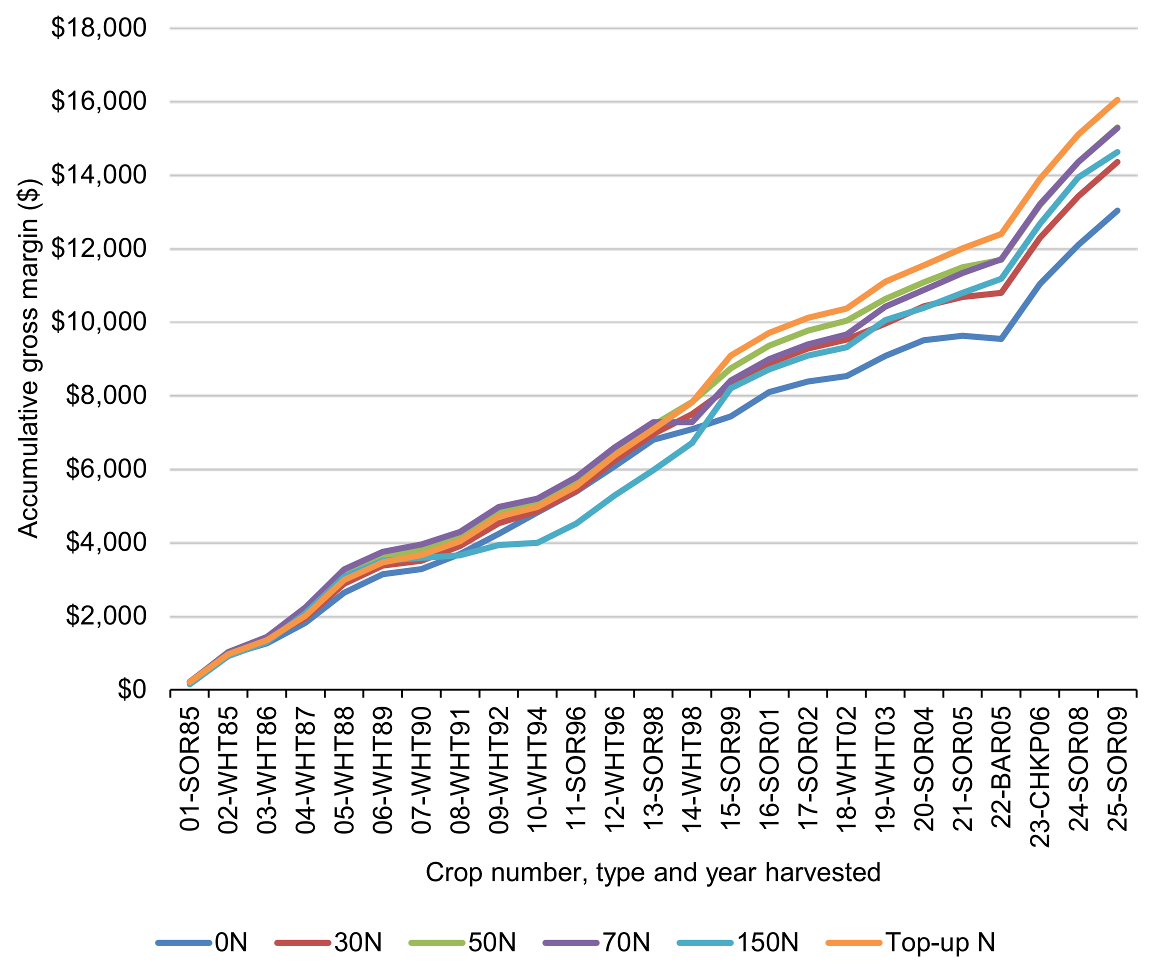


**Figure 21** Accumulative gross margin for each fertiliser rate or scenario

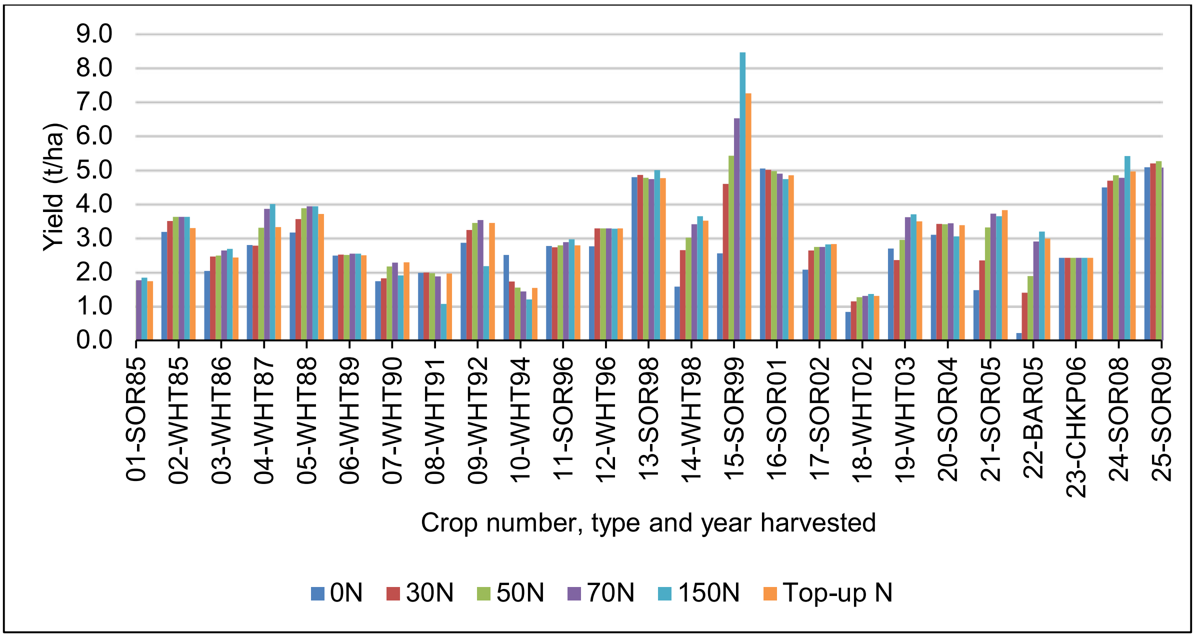


**Figure 22** Yield result for each fertiliser rate or scenario

Individual crop results for wheat and sorghum can be viewed in Appendix E. The average gross margin of the wheat and sorghum crops for each fertiliser rate or scenario are presented in Figure 23.

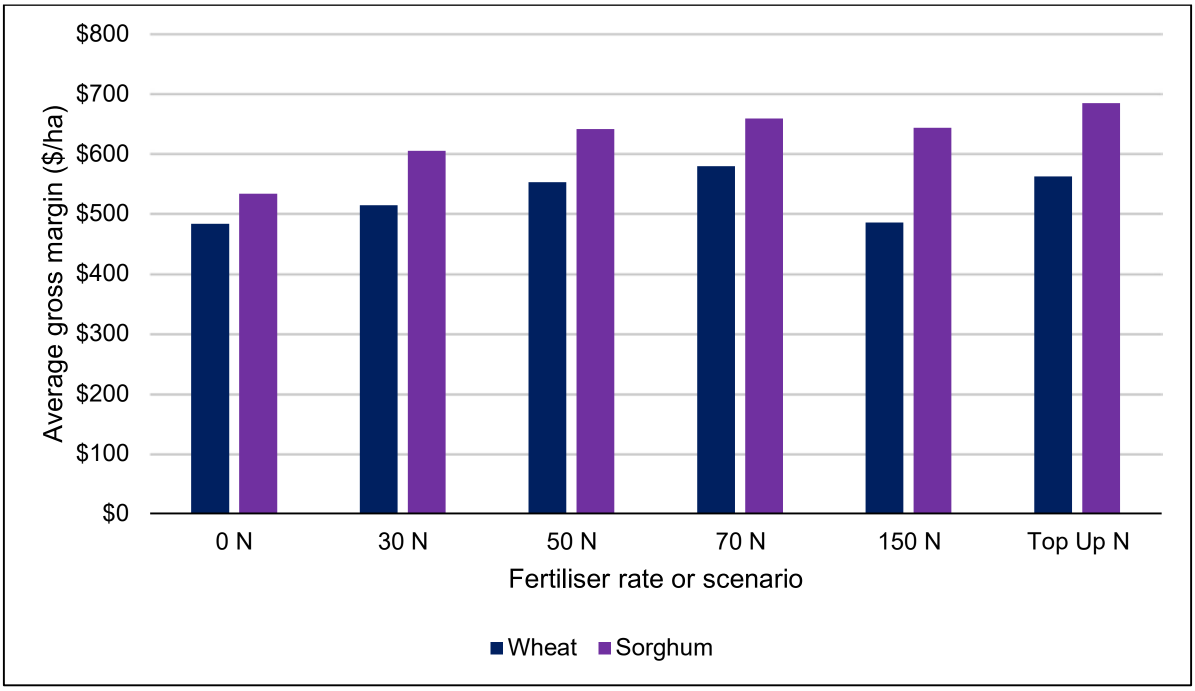


**Figure 23** Average gross margin of the wheat and sorghum crops for each fertiliser rate or scenario

## Part B. Soil water triggers to determine N fertiliser top-up scenarios

Figure 24 presents the gross margin results for the different soil water triggers and N top-up scenarios. On average across each fertiliser top-up rate, it was more profitable to plant at 30% PAWC. The exception was for wheat as the 130N/90% scenario produced the highest gross margin. The 130N/30% scenario produced the highest gross margin for sorghum.

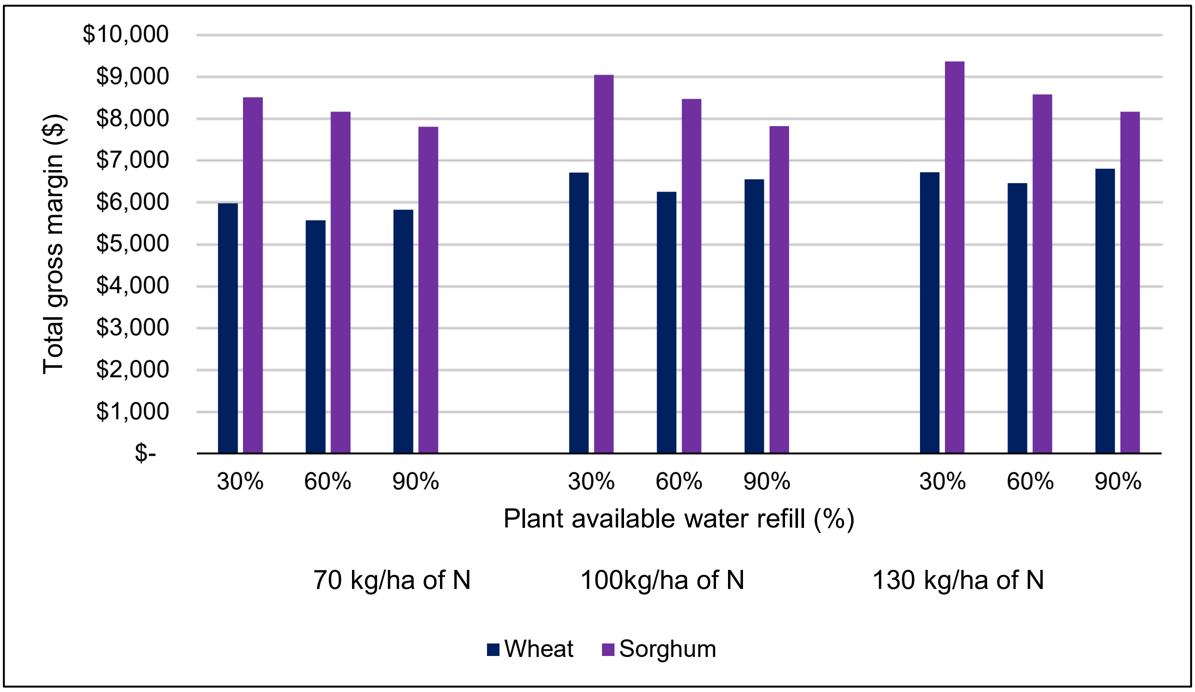


**Figure 24** Total gross margin for different soil water triggers and N fertiliser top-up rates

## Part C. Additional simulated years to test seasonality

The average ($/ha) and total gross margin ($) per application rate each year of the 26 crop sequence was calculated, and the results are presented in Table 11. The overall average of the crop sequence as well as the cumulative total gross margin per application rate was also calculated. There was only a $1/ha difference between Top-Up N ($524) and 70N ($523). Top-up N produced the highest gross margin at $524/ha and $340,844 total. The 70N was only marginally less at $523/ha and $340,095 total. The next most profitable rate was 50N at $488/ha with $316,965 total, with 30N being the least profitable at $425/ha with $276,518 total.

**Table 11** Average and total gross margin for each 26 crop sequence

| **Crop sequence set number and starting year** | **30N** | | **50N** | | **70N** | | **Top-up N** | |
|---|---|---|---|---|---|---|---|---|
| | **Average** | **Total** | **Average** | **Total** | **Average** | **Total** | **Average** | **Total** |
| **1 – 1957** | $471 | $11,779 | $512 | $12,805 | $541 | $13,522 | $550 | $13,754 |
| **2 – 1958** | $451 | $11,287 | $496 | $12,391 | $514 | $12,845 | $526 | $13,145 |
| **3 – 1959** | $501 | $12,523 | $530 | $13,261 | $555 | $13,865 | $555 | $13,868 |
| **4 – 1960** | $497 | $12,414 | $561 | $14,024 | $586 | $14,658 | $601 | $15,035 |
| **5 – 1961** | $488 | $12,196 | $524 | $13,105 | $575 | $14,372 | $575 | $14,370 |
| **6 – 1962** | $473 | $11,819 | $520 | $12,996 | $557 | $13,925 | $554 | $13,850 |
| **7 – 1963** | $491 | $12,281 | $542 | $13,554 | $542 | $13,541 | $563 | $14,065 |
| **8 – 1964** | $493 | $12,319 | $519 | $12,984 | $543 | $13,582 | $547 | $13,686 |
| **9 – 1965** | $432 | $10,789 | $482 | $12,058 | $514 | $12,862 | $503 | $12,580 |
| **10 – 1966** | $474 | $11,858 | $531 | $13,270 | $566 | $14,138 | $566 | $14,161 |
| **11 – 1967** | $408 | $10,200 | $437 | $10,914 | $470 | $11,751 | $475 | $11,881 |
| **12 – 1968** | $387 | $9,666 | $436 | $10,900 | $466 | $11,639 | $454 | $11,340 |
| **13 – 1969** | $366 | $9,156 | $418 | $10,449 | $455 | $11,364 | $448 | $11,194 |
| **14 – 1970** | $455 | $11,376 | $520 | $13,002 | $556 | $13,905 | $564 | $14,108 |
| **15 – 1971** | $441 | $11,030 | $501 | $12,517 | $543 | $13,568 | $534 | $13,339 |
| **16 – 1972** | $415 | $10,369 | $480 | $11,991 | $509 | $12,736 | $500 | $12,496 |
| **17 – 1973** | $372 | $9,298 | $424 | $10,612 | $451 | $11,274 | $453 | $11,334 |
| **18 – 1974** | $404 | $10,102 | $474 | $11,850 | $514 | $12,856 | $520 | $12,997 |
| **19 – 1975** | $404 | $10,098 | $493 | $12,325 | $529 | $13,224 | $527 | $13,187 |
| **20 – 1976** | $376 | $9,406 | $458 | $11,451 | $507 | $12,669 | $513 | $12,813 |
| **21 – 1977** | $418 | $10,459 | $514 | $12,838 | $569 | $14,213 | $564 | $14,090 |
| **22 – 1978** | $379 | $9,480 | $452 | $11,309 | $483 | $12,078 | $482 | $12,061 |
| **23 – 1979** | $313 | $7,825 | $379 | $9,474 | $425 | $10,616 | $435 | $10,883 |
| **24 – 1980** | $406 | $10,154 | $512 | $12,807 | $559 | $13,974 | $565 | $14,137 |
| **25 – 1981** | $413 | $10,313 | $514 | $12,839 | $561 | $14,020 | $560 | $13,995 |
| **26 – 1982** | $333 | $8,321 | $450 | $11,240 | $516 | $12,897 | $499 | $12,477 |

# Discussion

## Part A. Simulated N fertiliser applications

The results show that overall, no fertiliser rate or scenario resulted in a negative return, with the exception of the barley crop from the ‘base’ 0N scenario; however, there was variation in the levels of profitability for each fertiliser rate or scenario. Overall, there was minimal difference between the two most profitable gross margin results of top-up N scenario and the 70N rate.

It is noted with the 150N application rate that PAWC was probably the limiting factor, not N, as post-clearing of brigalow already had ‘luxury’ levels of N and therefore no immediate response from the higher N application. This is demonstrated with the high yield response of Crop15-SOR99 with the 150N application rate in Figure 22, as it was an exceptionally wet year (Figure F1 in Appendix F).

As mentioned in Part Two of the report, there was some variation in the observed yields versus the simulated yields due to environmental factors as well as the ratoon sorghum crop causing difficulties in the simulation. It is noted that the APSIM simulations potentially overstated the likelihood of achievable yields. The APSIM simulation of the trial site “Moonggoo“ (Chudleigh, et al., 2001) suggested 50-55 kg/ha of N outperformed both unfertilised and highly fertilised farm businesses however the trial results suggested that 30-40kg N/ha was more efficient. This was due to environmental factors that APSIM does not account for. Therefore, the simulated N rate applications of the BCS should be carefully considered as a lower N rate could be more efficient as in the case of ‘Moonggoo’.

## Part B. Soil water triggers to determine N fertiliser top-up scenarios

The economic results showed that on average across each fertiliser top-up rate, it was more profitable to plant at 30% PAWC. Even though higher stored soil water resulted in higher yields, it was not enough of a difference to cover the loss of income from a lowered crop count. As mentioned in Part Part C. N fertiliser ‘top-up’ strategies that incorporate a soil water trigger for planting of the report, planting with lower soil water may also increase the risk of crop failure. The riskiness of the system was not considered in the analysis and therefore further risk analysis should be conducted to validate the findings. Additionally, the results are restricted to the climatic conditions of the BCS and further study is recommended to rigorously test the results.

It should be noted that for wheat, the mean applied N for the 130N top-up rate was 67 kg/ha of N for 30% and 60% PAWC and 72 kg/ha of N for 90% PAWC. For sorghum, the mean applied N for the 130 top-up rate was 50 kg/ha of N at 30% and 60% PAWC and 37 kg/ha of N at 90% PAWC. Assuming APSIM overstated the achievable yields as per the Moonggoo trial, then 40 – 50 kg/ha of N could be the more efficient rate for wheat and ~30 kg/ha of N for sorghum.

## Part C. Additional simulated years to test seasonality

The additional APSIM simulations to test seasonality showed the same result as the simulated N rate applications with the BCS climate data. There was minimal difference between the top-up N scenario and the 70N fertiliser rate, with top-up N being slightly more profitable, despite the different climatic conditions.

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# Appendix A Paddock to Reef grains water quality risk framework (nutrient management)

<table>
<tr><th rowspan="3"><b>Nutrient management</b> (weighting)</th><th colspan="5">Relative water quality risk</th></tr>
<tr><th>Lowest risk (A)</th><th>Moderate – Low risk (B)</th><th>Moderate risk (C)</th><th>High risk (D)</th><th rowspan="2">Not applicable</th></tr>
<tr><td>Innovative</td><td>Best practice</td><td>Minimum standard</td><td><b>Superseded</b></td></tr>
<tr><td><b>Determining nitrogen requirements (40%)</b></td><td>Yield mapping data informs precise variable fertiliser rate control for specific management zones.<br>Pulse crops are regularly included in the crop rotation to reduce need for N fertiliser.</td><td>Yield and protein data is matched to crop performance zones to formulate soil sampling strategies and N management decisions for individual zones.<br>Pulse crops are regularly included in the crop rotation to reduce need for N fertiliser.</td><td>Regular soil analysis, in conjunction with yield/protein information, is used to make N management decisions.</td><td>Fertiliser N rates are based on historical rates or rules of thumb for particular crops.</td><td>Do not use nitrogen fertiliser.</td></tr>
<tr><td><b>Influence of stored soil moisture on yield and N fertiliser decisions (40%)</b></td><td>Stored soil moisture is monitored throughout the fallow and decision support tools are used to indicate yield potential when selecting fertiliser application rates.</td><td colspan="2">Stored soil moisture is monitored throughout the fallow and informs decisions on yield potential and appropriate fertiliser rates.</td><td>Stored soil moisture is not considered when selecting fertiliser application rates.</td><td>Do not use nitrogen fertiliser.</td></tr>
<tr><td><b>Application timing to minimise potential losses and maximise uptake of N fertiliser (20%)</b></td><td>N fertiliser is applied early in a fallow to minimise probability of losses. Fertiliser may be applied as split applications (e.g. during the fallow, at planting and/or in crop).</td><td>N fertiliser is applied early in a fallow to minimise probability of losses.</td><td colspan="2">Normal practice is that N fertiliser is only applied late in the fallow and/or when there is a full soil moisture profile.</td><td></td></tr>
</table>

(The State of Queensland, 2020)

# Appendix B Model assumptions

## Chemicals

Where the brand and active ingredient were known but the application rate was missing, the assumptions were as follows:

- Crop 16 – missing data for LI-700 application. Assumed the label rate application for the situation “addition to herbicides to improve spreading and penetration” of 500ml per 100L which is 0.5L per ha.

- Crop 17 – missing data for Wet Spray 1000 application. Assumed the label rate application for the situation “general herbicide sprays with a high volume power spray” of 10ml per 100 L which is 0.01L per ha.

- Crop 18 – missing data for Companion application. Assumed the label rate application for the situation “Glyphosate, Paraquat and 2,4-D to improve penetration” of 500mL per 100L which is 0.5L per ha.

- Crop 24 – missing data for ammonium sulphate application. Assumed label rate application for Spray Grade Ammonium Sulphate of 800g per 100L per ha which is 0.8L per ha.

- Crop 24 – missing data for “wetting agent unknown” application. Assumed Spreadwet 1000 as the wetting agent and assumed the label rate application for the situation “general weedkilling sprays with a high volume power spray” of 10 ml per 100 L which is 0.01L per ha.

Where the application rate was known but the quantity of active ingredient was missing (labelled as “unknown”), the assumptions were as follows:

- 2,4-D unknown assumed to be Amine 625.

- Lorsban unknown – sourced from Zull (2020) Cheminfo Mastersheet. Does not state quantity of active ingredient.

- Wetting agent unknown assumed to be Spreadwet 1000 which was the most recent wetting agent used in BCS. Sourced from Zull (2020) Cheminfo Mastersheet

- Atrazine unknown assumed to be Atrazine 900.

- Lannate unknown - sourced from Zull (2020) Cheminfo Mastersheet. Does not state quantity of active ingredient.

- Glyphosate unknown assumed to be Glyphosate 450.

- Glyphosate 450 (brand unknown) assumed to be Glyphosate 450

- 2,4-D 300 (brand unknown) assumed to be Amine 300

## Machinery

- Replaced the small BCS tractors with typical sized tractors used in commercial operations.
- The following machinery/implements were added:
    - Boomsprayer (conventional) – for crops prior to 1990
    - Boomsprayer (zero till) – for crops after 1990
    - 350hp Harvester
    - 400hp tractor for tillage operations
    - 300hp tractor for planting/spraying operations
    - Chaser bin / or assumed to be flat $10/ha cost.
- Consolidated the following implement based on advice from commercial grower:
    - One-way disc, scarifier, wideline (light scarifier) and buster points were replaced with a speed tiller.
    - Chisel plough replaced with trashworker (sweeps).
    - Discs unknown were assumed to be an offset disc.

# Appendix C Pricing

**Table C1** Per tonne price applied to each crop

| Crop Number | Crop type | Date Harvested | Price ($/t) | Crop Number | Crop type | Date Harvested | Price ($/t) |
|---|---|---|---|---|---|---|---|
| 01 | Sorghum | Jan-85 | $209.00 | 14 | Sorghum | Jan-98 | $238.00 |
| 02 | Wheat | Sep-85 | $274.00 | 15 | Wheat | Oct-98 | $261.00 |
| 03 | Wheat | Sep-86 | $239.00 | 16 | Sorghum | Feb-99 | $209.00 |
| 04 | Wheat | Oct-87 | $258.00 | 17 | Sorghum | Mar-01 | $194.00 |
| 05 | Wheat | Sep-88 | $329.00 | 18 | Sorghum | Apr-02 | $229.00 |
| 06 | Wheat | Nov-89 | $294.00 | 19 | Wheat | Oct-02 | $347.00 |
| 07 | Wheat | Oct-90 | $195.00 | 20 | Wheat | Sep-03 | $278.00 |
| 08 | Wheat | Oct-91 | $294.00 | 21 | Sorghum | May-04 | $204.00 |
| 09 | Wheat | Oct-92 | $267.00 | 22 | Sorghum | Mar-05 | $171.00 |
| 10 | Wheat | Sep-94 | $341.00 | 23 | Barley | Sep-05 | $187.00 |
| 11 | Sorghum | Jul-95 | $284.00 | 24 | Chickpea | Oct-06 | $733.00 |
| 12 | Sorghum | Jan-96 | $284.00 | 25 | Sorghum | Jan-08 | $309.00 |
| 13 | Wheat | Oct-96 | $299.00 | 26 | Sorghum | Jan-09 | $241.00 |

**Table C2** Per unit (L or kg) price applied to each chemical

| Trade name | Price ($/unit) | Trade name | Price ($/unit) | Trade name | Price ($/unit) |
|---|---|---|---|---|---|
| Gramoxone 250 | $9.68 | Roundup CT XTRA | $6.45 | Glyphosate 450 (brand not known) | $5.78 |
| Reglone | $21.18 | Atradex WG | $8.60 | Surpass 300 | $7.02 |
| Glean | $0.18 | Flow Right | $11.60 | Balance 750 WG | $146.06 |
| 2,4-D Unknown | $16.20 | Glyphosate Unknown | $5.78 | Simazine 900 DF | $9.73 |
| Roundup | $6.45 | Wet Spray 1000 | $7.54 | 2,4-D 300 (brand unknown) | $7.02 |
| Lorsban Unknown | $9.27 | Wetter 1000 | $5.98 | Liase | $1.64 |
| Roundup CT | $6.45 | Wipeout 450 | $5.78 | Chemwet | $5.98 |
| Ally | $55.00 | GlyphosateCT (NuFarm) | $6.45 | Amsul 417 | $1.64 |
| Wetting Agent Unknown | $7.70 | Hasten | $7.25 | Farmozine 500 | $8.60 |
| Glyphosate CT | $9.08 | Companion | $9.08 | Amicide 625 | $7.55 |
| NuFarm Wetter | $16.20 | Activoil | $7.25 | Comet 400 | $28.93 |
| LI-700 | $9.08 | Hot-Up Spray Adjuvant | $4.97 | Allout 450 | $5.78 |
| Sherweed | $16.20 | Trigger | $5.78 | Spreadwet 1000 | $7.70 |
| Tordon 50D | $36.72 | Lynx | $55.00 | Deluge 1000 | $7.54 |
| Atrazine Unknown | $8.60 | Glyphosate (Summit) | $5.78 | Spraymate Activator | $7.54 |
| Surpass | $7.02 | Amicide | $6.75 | Uptake spraying oil | $7.98 |
| Sprayseed 250 | $13.75 | Amine 625 | $16.20 | Verdict 520 | $37.50 |
| Goal CT | $25.00 | Glyphosate 450 (Sipcam) | $5.78 | Convict | $37.50 |
| Touchdown | $9.60 | Flagship 200 | $14.68 | Amicide Advance 700 | $7.43 |

| | | | | | |
|---|---|---|---|---|---|
| Nu-Trazine | $7.67 | MAIZINA 900 WDG HERBICIDE | $8.60 | Spray Grade Ammonium Sulphate | $11.60 |
| Starane 200 | $14.68 | Gesaprim granules (900g/Kg) | $8.60 | Weedmaster DST 470 | $9.75 |
| Lannate Unknown | $16.40 | Ammonium Sulphate | $11.60 | | |

**Table C3** Tractors and harvester specification and pricing

| **Name** | **Horsepower (hp)** | **Total hours (hrs/yr.)** | **Life (yrs.)** | **Life (hrs)** | **R&M ($/total life)** | **R&M ($/hr)** | **PTO (kW)** | **Fuel Use (L/hr)** | **Fuel and oil ($/hr)** |
|---|---|---|---|---|---|---|---|---|---|
| Tractor - tillage | 400 | 500 | 20 | 10000 | $65,000 | $6.50 | 298 | 74.5 | $78.97 |
| Tractor - planter | 300 | 500 | 20 | 10000 | $50,000 | $5.00 | 224 | 56 | $59.36 |
| Harvester | 350 | 300 | 15 | 4500 | $67,500 | $15.00 | 261 | 65.25 | $69.17 |

**Table C4** Implement specification and pricing

| NAME | Tractor | R&M ($/Total Life) | Width of pass (m) | Speed (kph) | Field Efficiency | Work Rate (ha/hr) | % of full load | Ha per year | Hrs per year | Life (years) | Life (hours) | R&M ($/hr) | FORM incl. Tractor ($/hr) | Labour Cost ($/hr) | Total Cost ($/ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Trashworker (sweeps) | Tractor - tillage | $7,000 | 10 | 8 | 85% | 6.80 | 85% | 800 | 118 | 25 | 2941 | $2.38 | $76.00 | $30.00 | $15.59 |
| Speed tiller | Tractor - tillage | $10,000 | 7 | 15 | 80% | 8.40 | 95% | 800 | 95 | 25 | 2381 | $4.20 | $85.72 | $30.00 | $13.78 |
| Air seeder | Tractor - planter | $5,000 | 12 | 8 | 65% | 6.24 | 85% | 2000 | 321 | 25 | 8013 | $0.62 | $56.08 | $30.00 | $13.79 |
| Offset disc | Tractor - tillage | $8,000 | 8 | 6 | 90% | 4.32 | 90% | 800 | 185 | 25 | 4630 | $1.73 | $79.30 | $30.00 | $25.30 |
| Boomsprayer (conventional) | Tractor - planter | $25,000 | 36 | 20 | 55% | 39.60 | 50% | 4000 | 101 | 10 | 1010 | $24.75 | $59.43 | $30.00 | $2.26 |
| Boomsprayer (zero till) | Tractor - planter | $35,000 | 36 | 20 | 55% | 39.60 | 50% | 8000 | 202 | 10 | 2020 | $17.33 | $52.01 | $30.00 | $2.07 |
| Harvester - wheat | Harvester | $0.01 | 12 | 7.69 | 80% | 7.38 | 95% | 2000 | 271 | 15 | 4065 | $0.00 | $80.71 | $30.00 | $15.00 |
| Harvester - sorghum | Harvester | $0.01 | 12 | 4.61 | 80% | 4.43 | 95% | 2000 | 452 | 15 | 6775 | $0.00 | $80.71 | $30.00 | $25.00 |
| Harvester - barley | Harvester | $0.01 | 12 | 6.07 | 80% | 5.83 | 95% | 2000 | 343 | 15 | 5149 | $0.00 | $80.71 | $30.00 | $19.00 |
| Harvester - chickpea | Harvester | $0.01 | 12 | 5.24 | 80% | 5.03 | 95% | 2000 | 397 | 15 | 5962 | $0.00 | $80.71 | $30.00 | $22.00 |
| Chaser bin - wheat | Tractor - planter | $6,500 | 12 | 7.69 | 80% | 7.38 | 60% | 2000 | 271 | 30 | 8130 | $0.80 | $41.42 | $30.00 | $9.68 |
| Chaser bin - sorghum | Tractor - planter | $6,500 | 12 | 4.61 | 80% | 4.43 | 60% | 2000 | 452 | 30 | 13550 | $0.48 | $41.10 | $30.00 | $16.06 |
| Chaser bin - barley | Tractor - planter | $6,500 | 12 | 6.07 | 80% | 5.83 | 60% | 2000 | 343 | 30 | 10298 | $0.63 | $41.25 | $30.00 | $12.23 |
| Chaser bin - chickpea | Tractor - planter | $6,500 | 12 | 5.24 | 80% | 5.03 | 60% | 2000 | 397 | 30 | 11924 | $0.55 | $41.16 | $30.00 | $14.14 |

# Appendix D Yield and protein data

**Table D1** Yield and grain protein per crop

| Crop Number | Crop type | Date Harvested | Yield (t/ha) | Grain protein (%) |
|---|---|---|---|---|
| **01** | Sorghum | Jan-85 | 1.36 | 11.37 |
| **02** | Wheat | Sep-85 | 2.92 | 13.93 |
| **03** | Wheat | Sep-86 | 2.45 | 12.87 |
| **04** | Wheat | Oct-87 | 3.96 | 13.67 |
| **05** | Wheat | Sep-88 | 2.45 | 13.60 |
| **06** | Wheat | Nov-89 | 2.09 | 12.80 |
| **07** | Wheat | Oct-90 | 1.40 | 12.03 |
| **08** | Wheat | Oct-91 | 1.62 | 13.77 |
| **09** | Wheat | Oct-92 | 1.87 | 14.70 |
| **10** | Wheat | Sep-94 | 2.87 | 10.57 |
| **11** | Sorghum | Jul-95 | 0.18 | 13.23 |
| **12** | Sorghum | Jan-96 | 1.46 | 13.50 |
| **13** | Wheat | Oct-96 | 0.83 | 10.45 |
| 14 | Sorghum | Jan-98 | 3.55 | 10.63 |
| 15 | Wheat | Oct-98 | 1.77 | 9.60 |
| 16 | Sorghum | Feb-99 | 0.83 | 9.00 |
| 17 | Sorghum | Mar-01 | 2.33 | 10.37 |
| 18 | Sorghum | Apr-02 | 0.18 | 10.77 |
| 19 | Wheat | Oct-02 | 0.66 | 10.00 |
| 20 | Wheat | Sep-03 | 2.59 | 12.53 |
| 21 | Sorghum | May-04 | 2.05 | 12.77 |
| 22 | Sorghum | Mar-05 | 2.07 | 8.33 |
| 23 | Barley | Sep-05 | 0.63 | 7.37 |
| 24 | Chickpea | Oct-06 | 0.54 | 17.90 |
| 25 | Sorghum | Jan-08 | 4.96 | 9.73 |
| 26 | Sorghum | Jan-09 | 1.85 | 6.07 |

# Appendix E Sorghum and wheat gross margins and yield results from simulated N rate applications

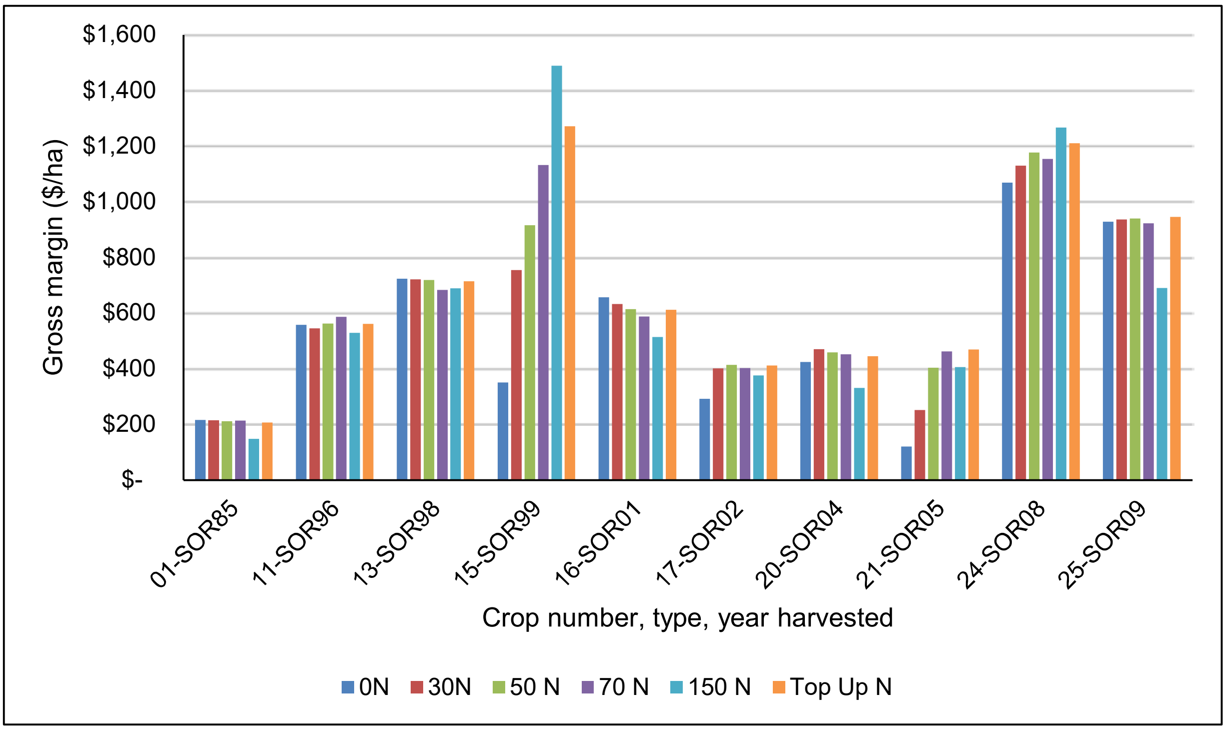

**Figure E1** Sorghum gross margin results

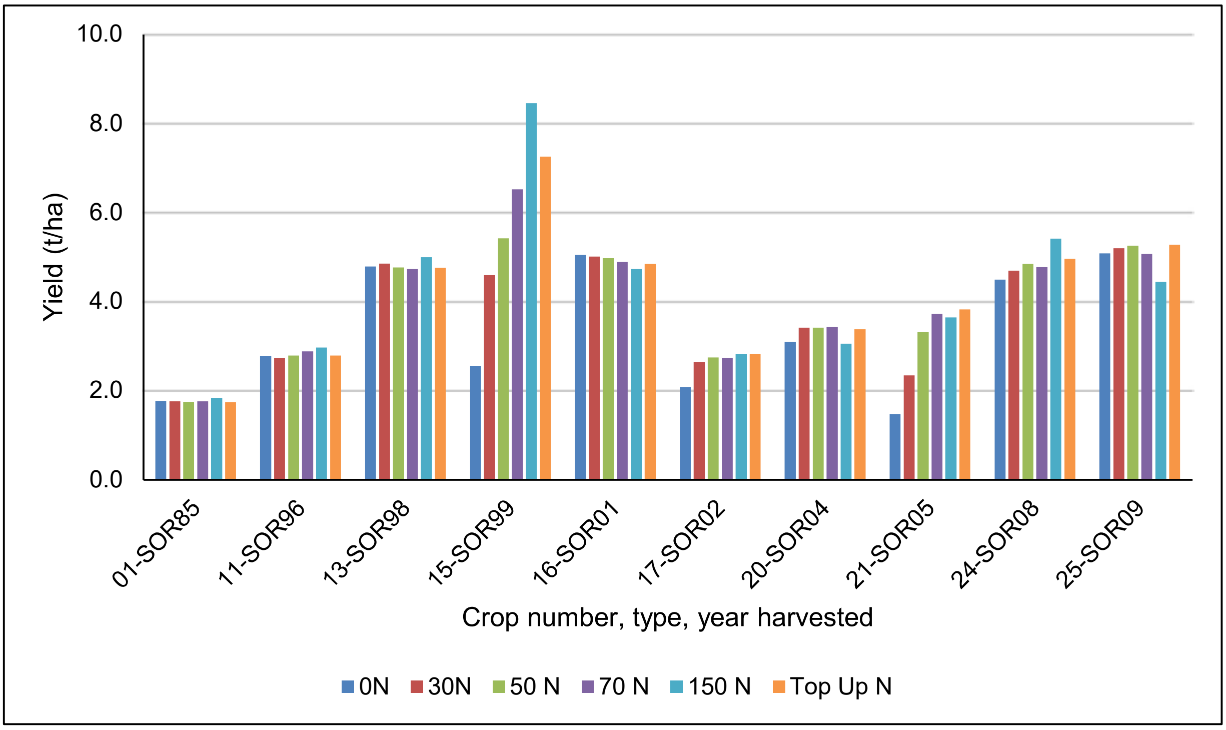

**Figure E2** Sorghum yield results

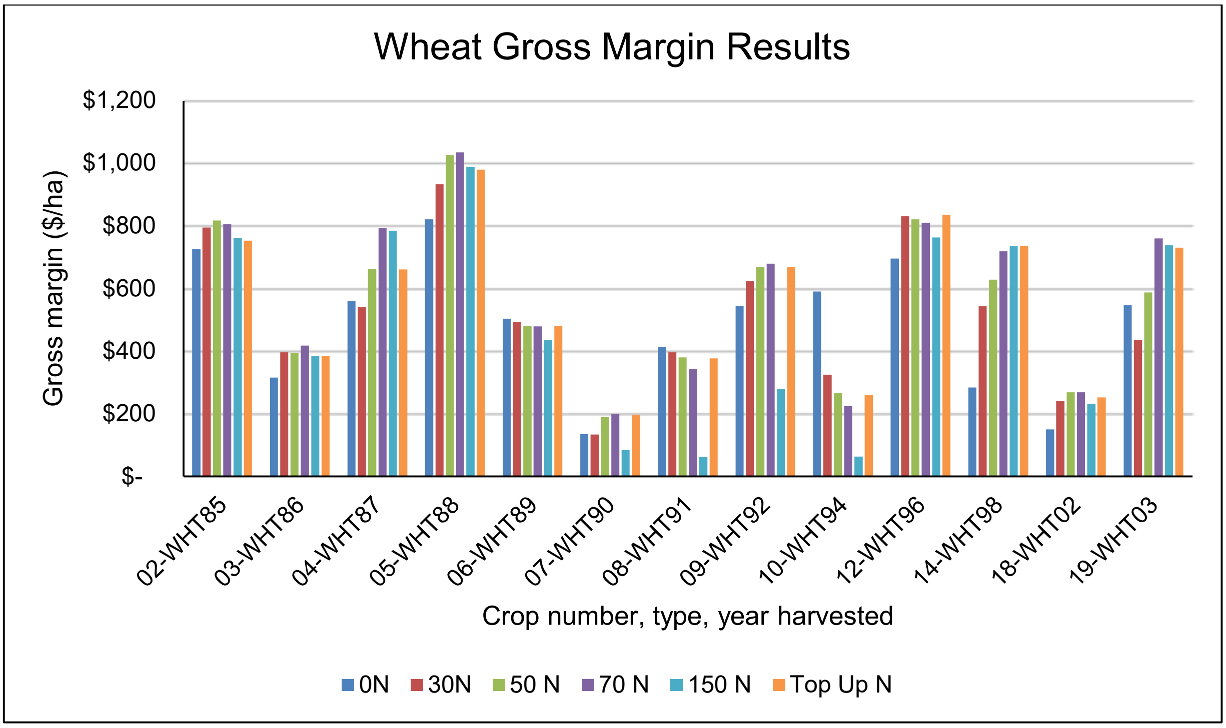

**Figure E3** Wheat gross margin results

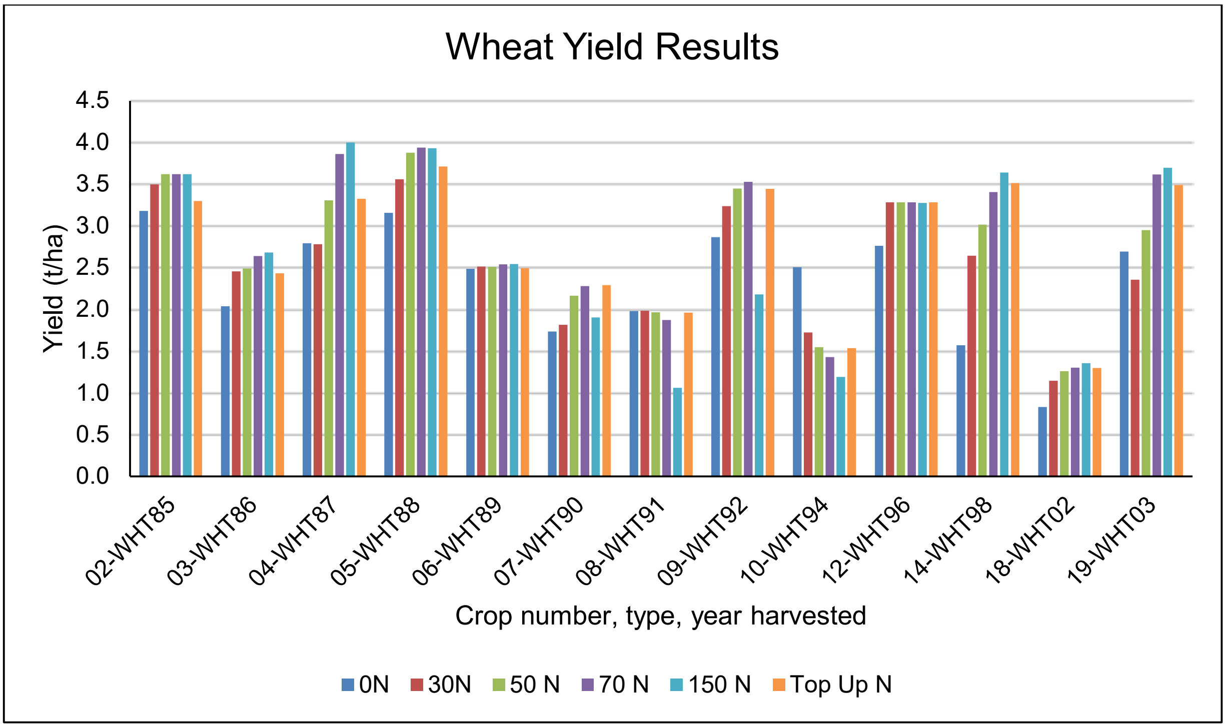

**Figure E4** Wheat yield results

# Appendix F Climate data

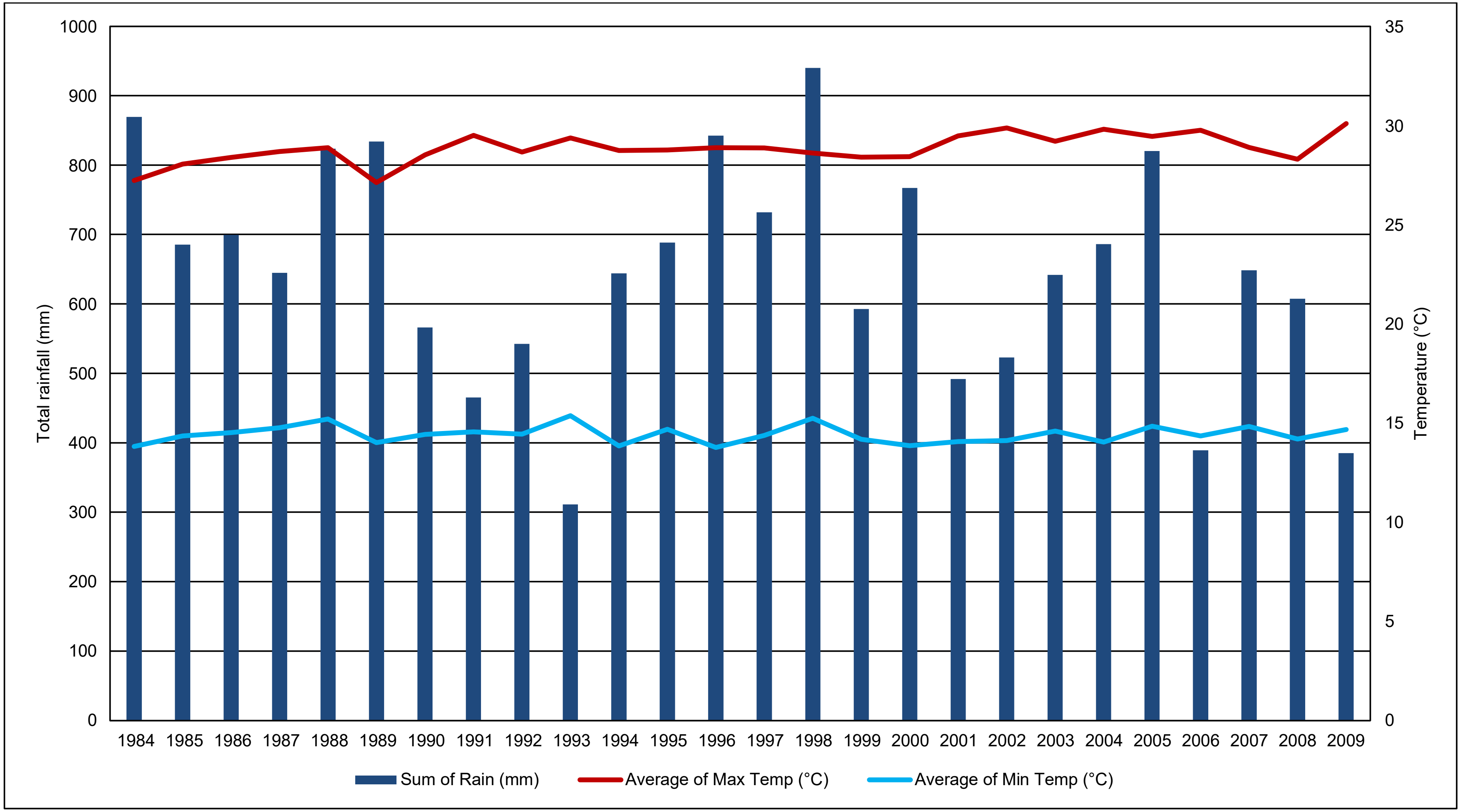

**Figure F1** Yearly climate data for the grain cropping period at the BCS

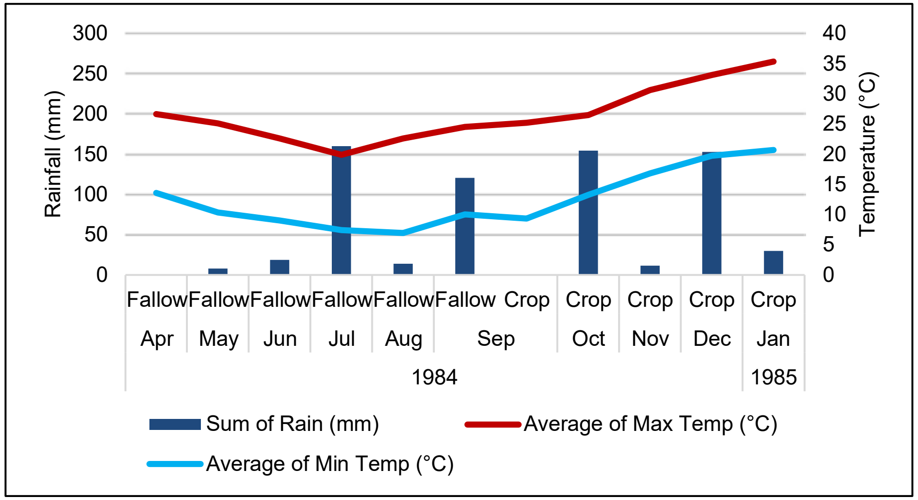

**Figure F2** Climate data during fallow and in crop for 01-SOR85

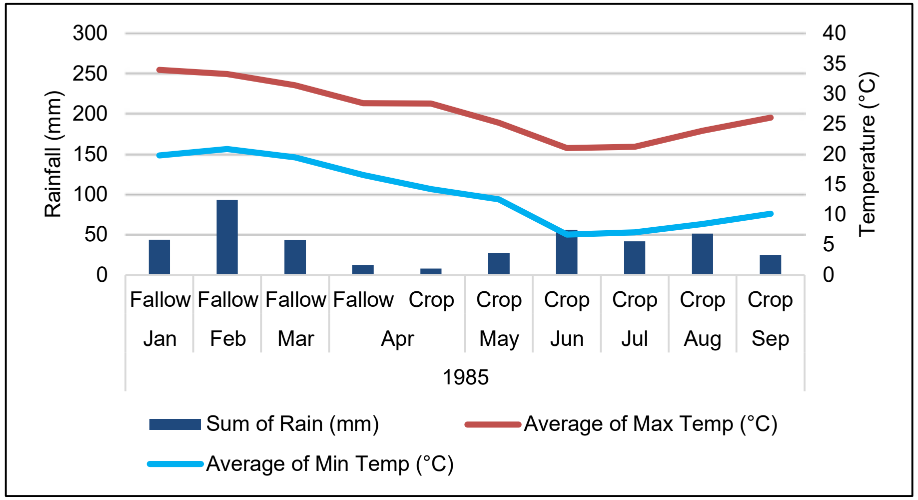

**Figure F3** Climate data during fallow and in crop for 02-WHT85

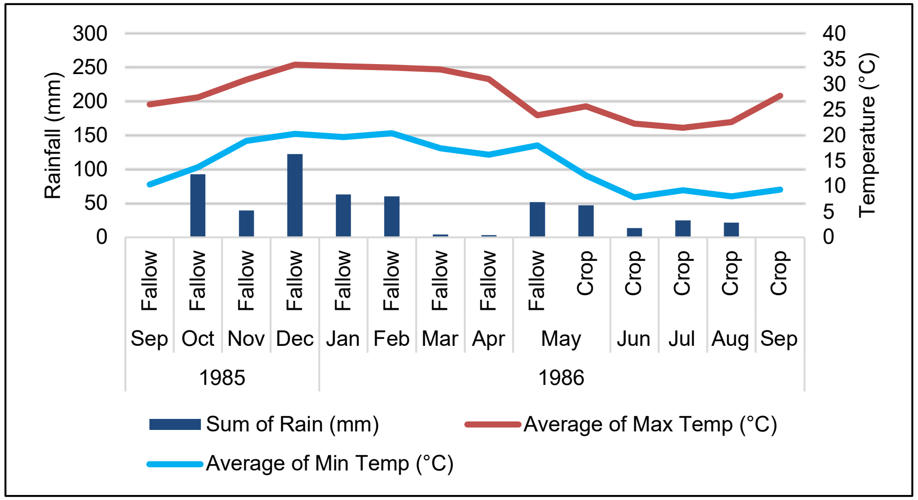

**Figure F4** Climate data during fallow and in crop for 03-WHT86

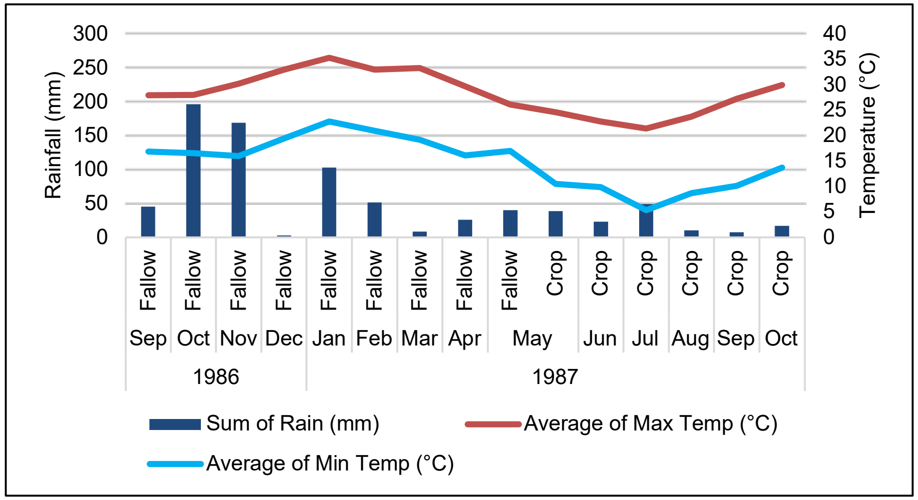

**Figure F5** Climate data during fallow and in crop for 04-WHT87

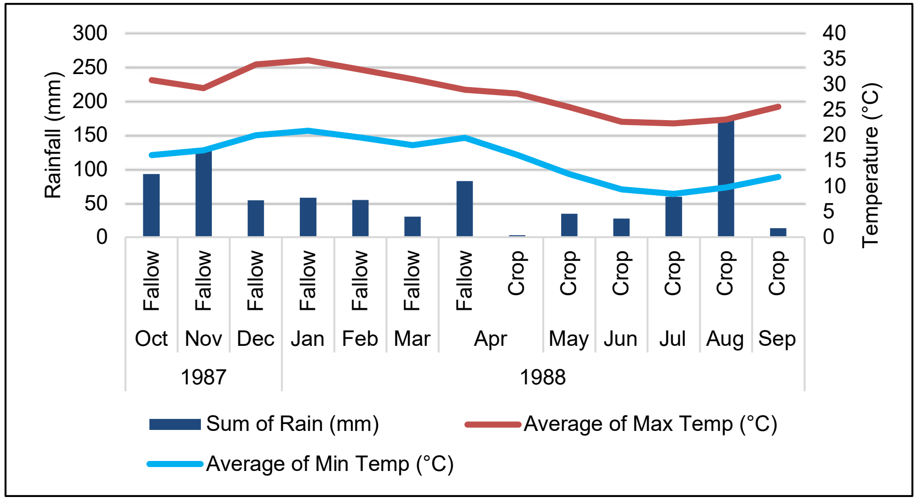

**Figure F6** Climate data during fallow and in crop for 05-WHT88

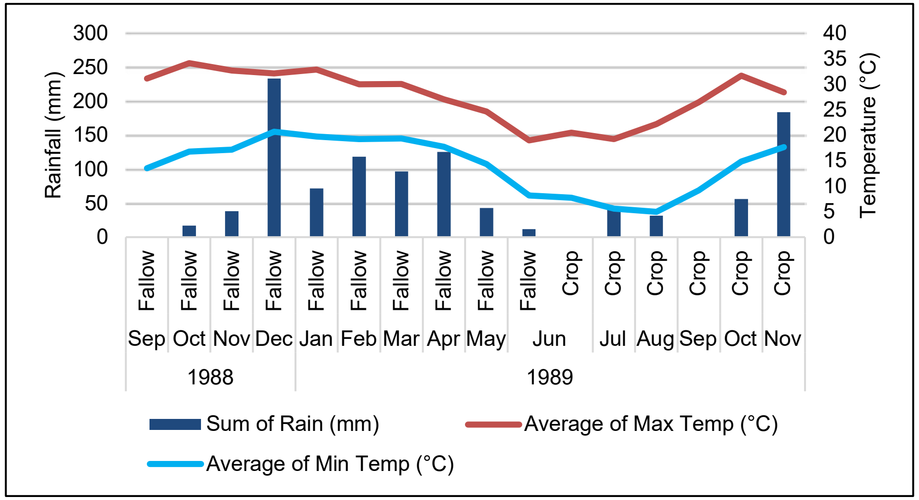

**Figure F7** Climate data during fallow and in crop for 06-WHT89

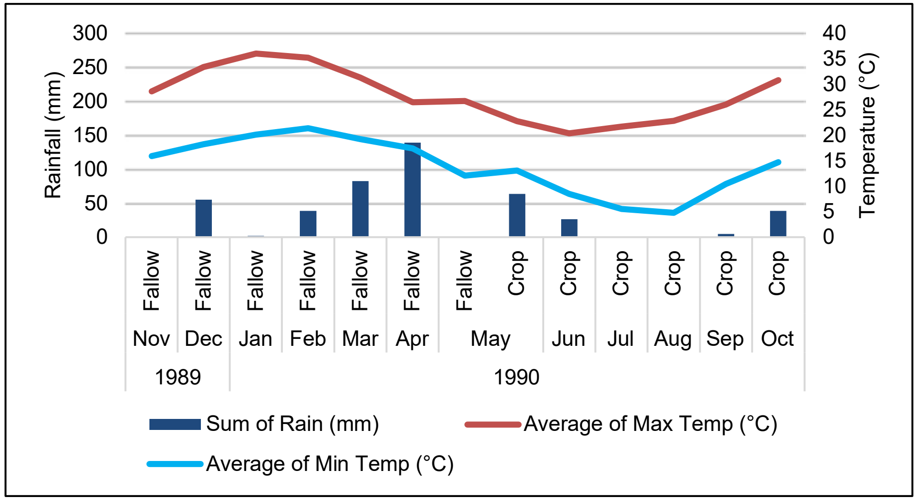

**Figure F8** Climate data during fallow and in crop for 07-WHT90

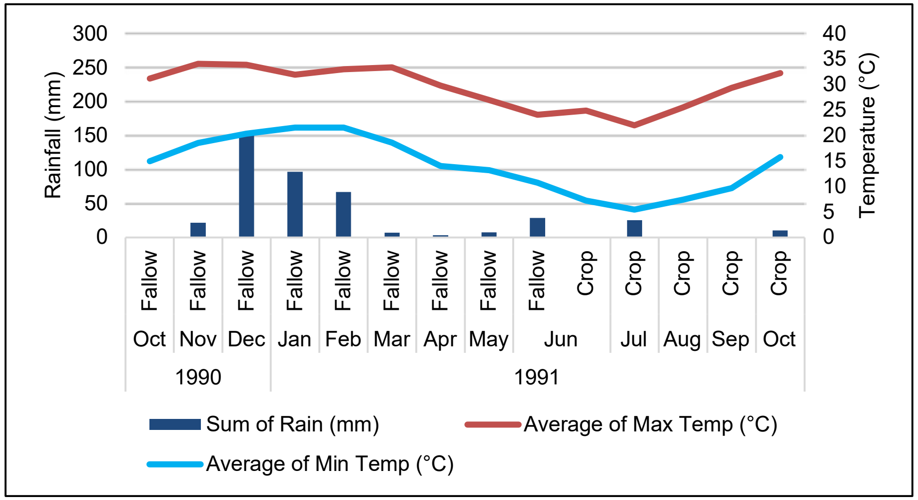

**Figure F9** Climate data during fallow and in crop for 08-WHT91

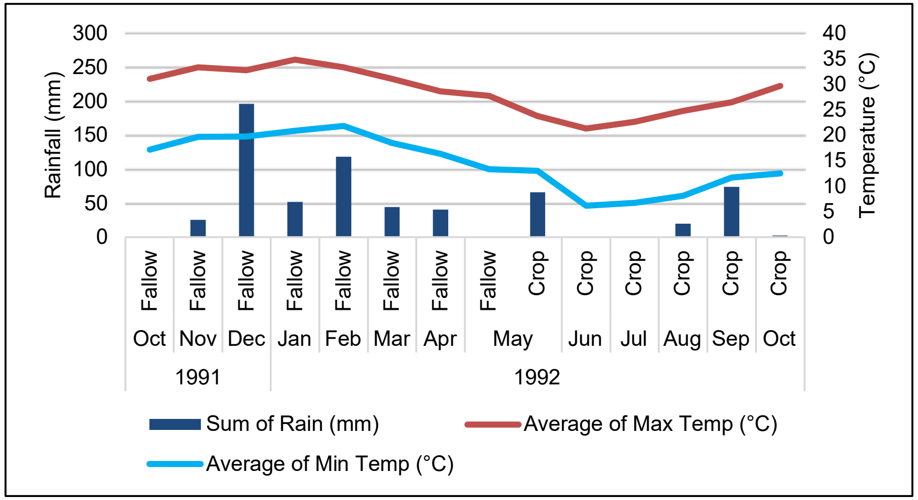

**Figure F10** Climate data during fallow and in crop for 09-WHT92

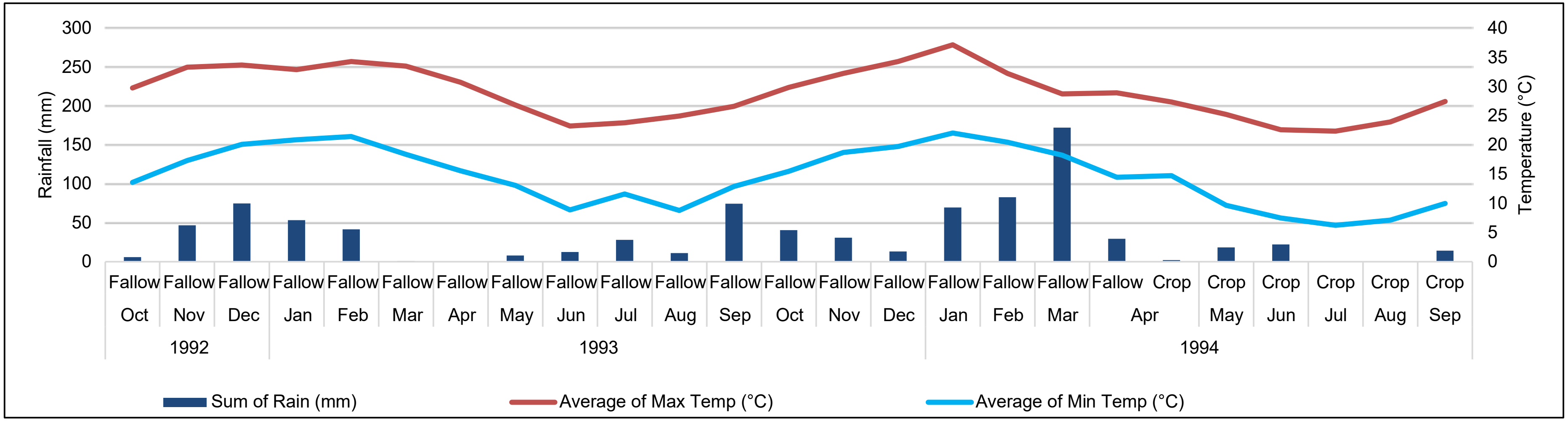

**Figure F11** Climate data during fallow and in crop for 10-WHT94

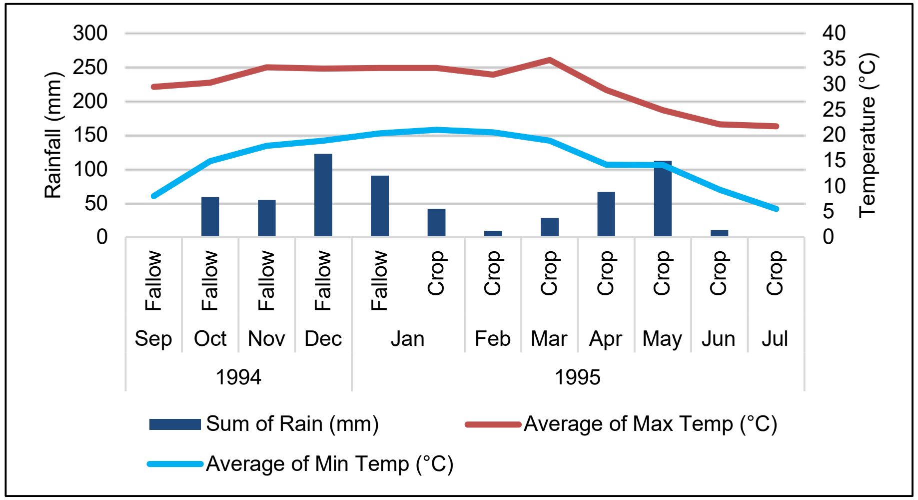

**Figure F12** Climate data during fallow and in crop for 11-SOR95

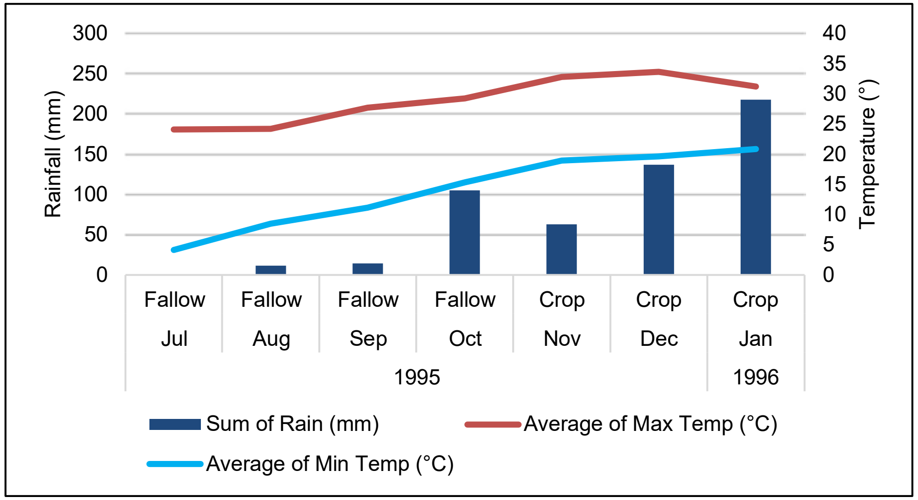

**Figure F13** Climate data during fallow and in crop for 12-SOR96

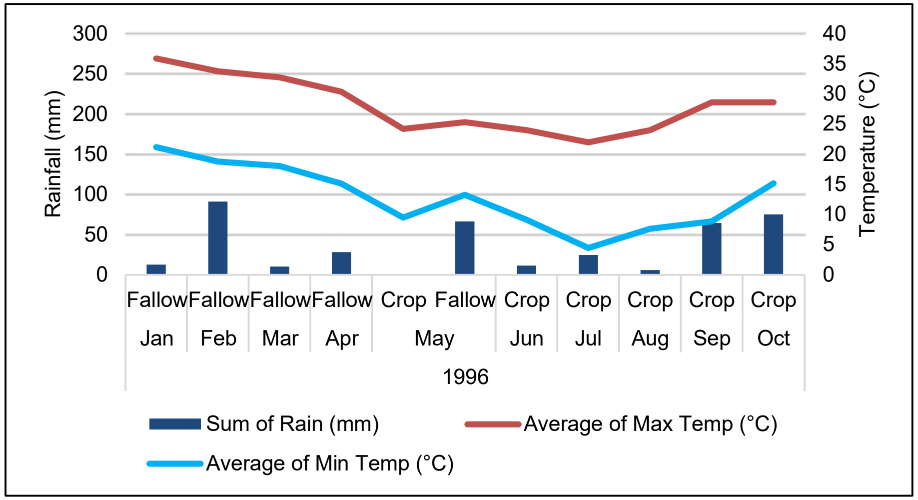

**Figure F14** Climate data during fallow and in crop for 13-WHT96

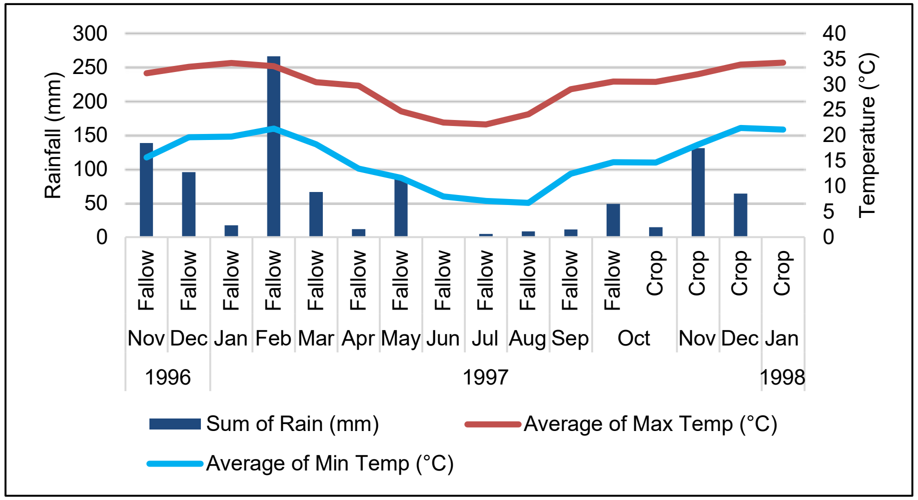

**Figure F15** Climate data during fallow and in crop for 14-SOR98

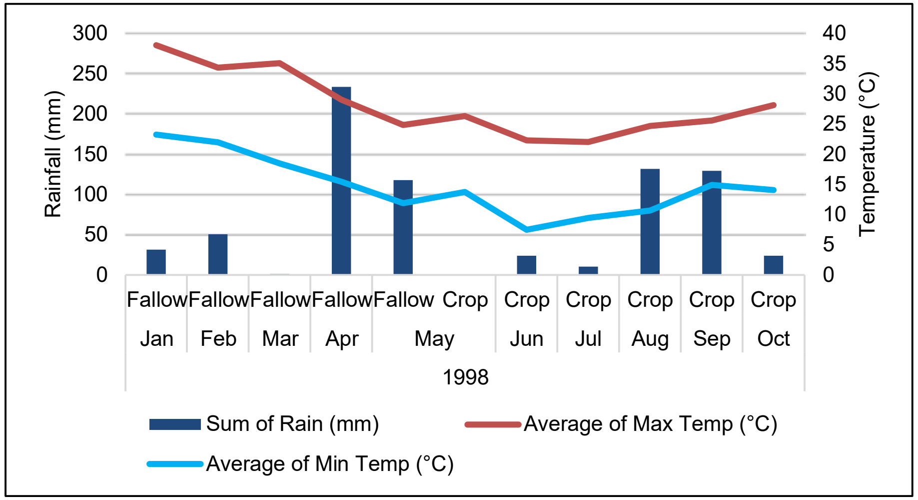

**Figure F16** Climate data during fallow and in crop for 15-WHT98

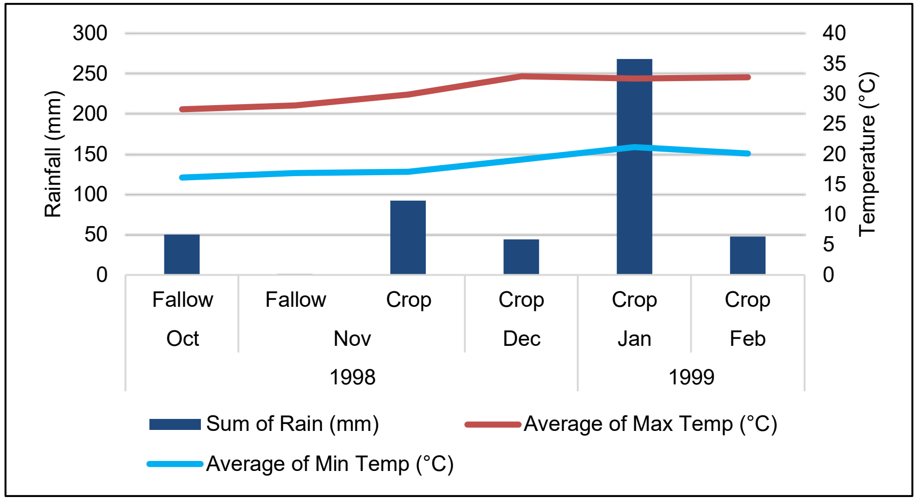

**Figure F17** Climate data during fallow and in crop for 16-SOR99

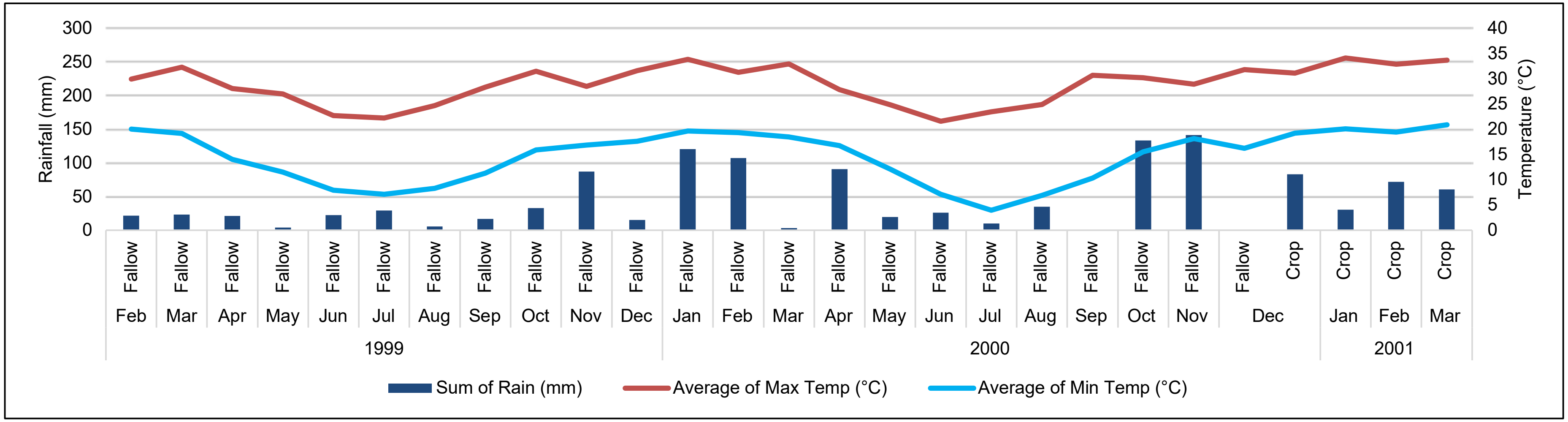

**Figure F18** Climate data during fallow and in crop for 17-SOR01

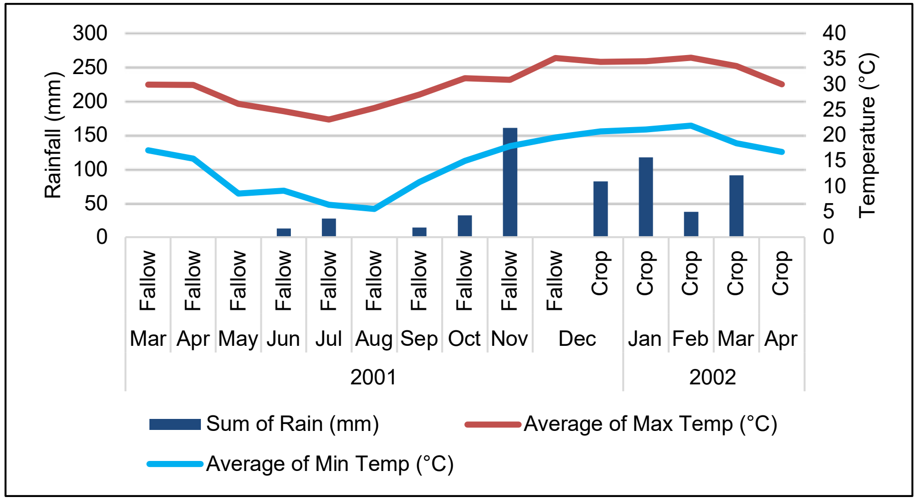

**Figure F19** Climate data during fallow and in crop for 18-SOR02

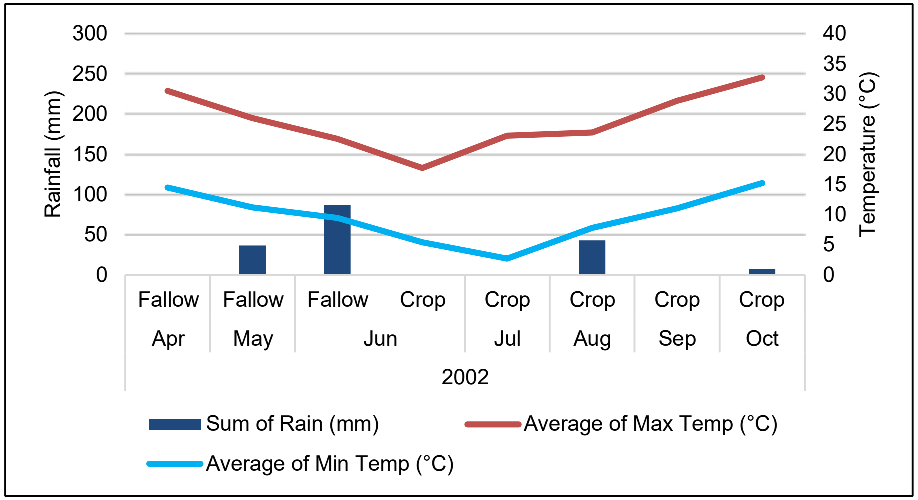

**Figure F20** Climate data during fallow and in crop for 19-WHT02

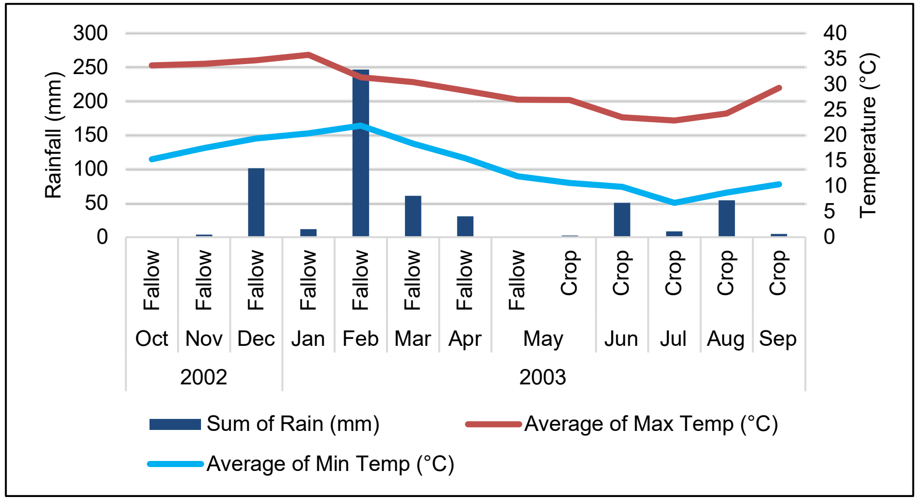

**Figure F21** Climate data during fallow and in crop for 20-WHT03

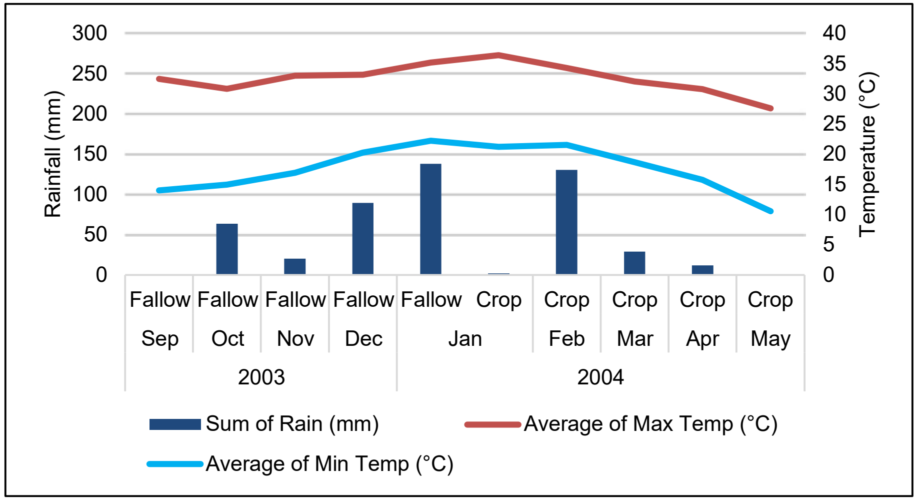

**Figure F22** Climate data during fallow and in crop for 21-SOR94

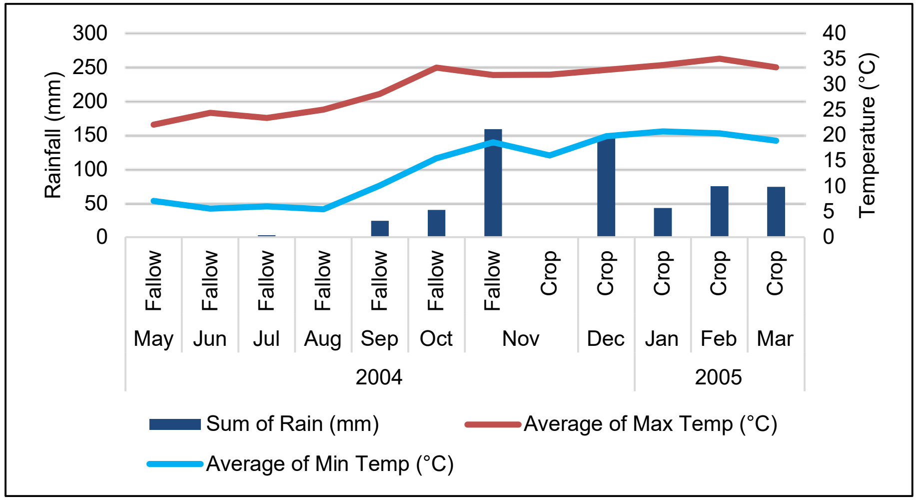

**Figure F23** Climate data during fallow and in crop for 22-SOR05

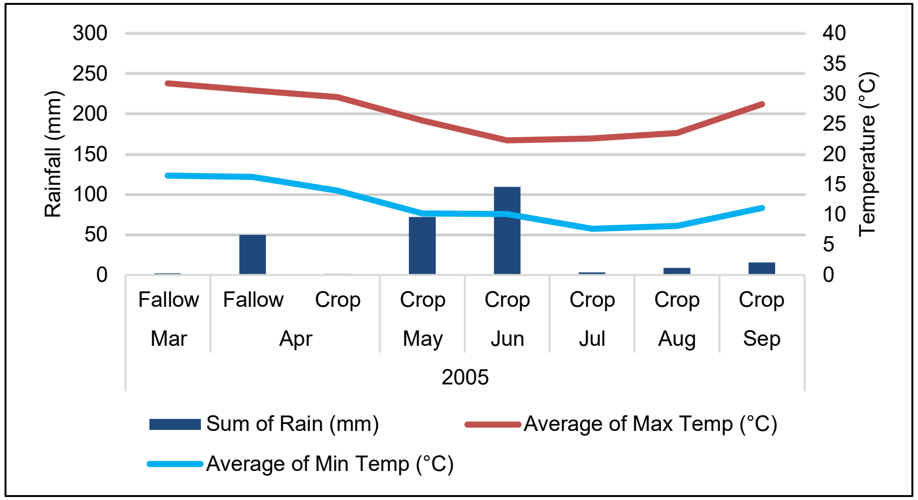

**Figure F24** Climate data during fallow and in crop for 23-BAR05

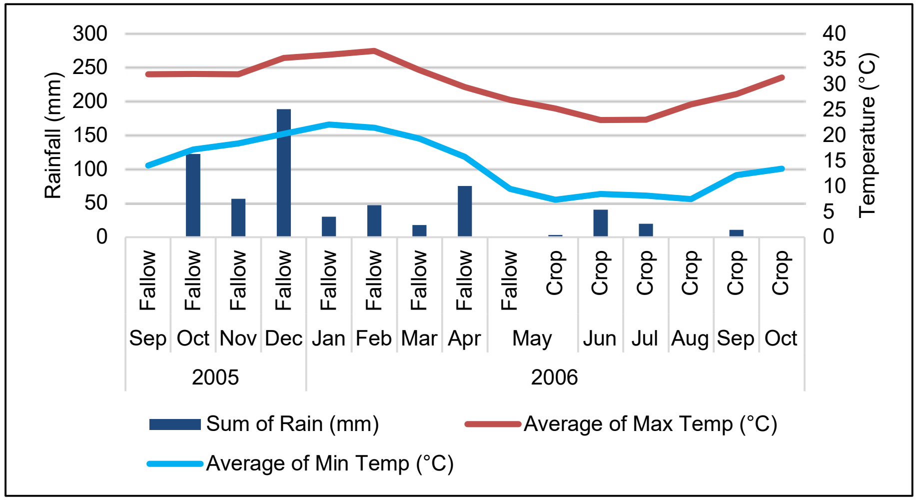

**Figure F25** Climate data during fallow and in crop for 24-CHK06

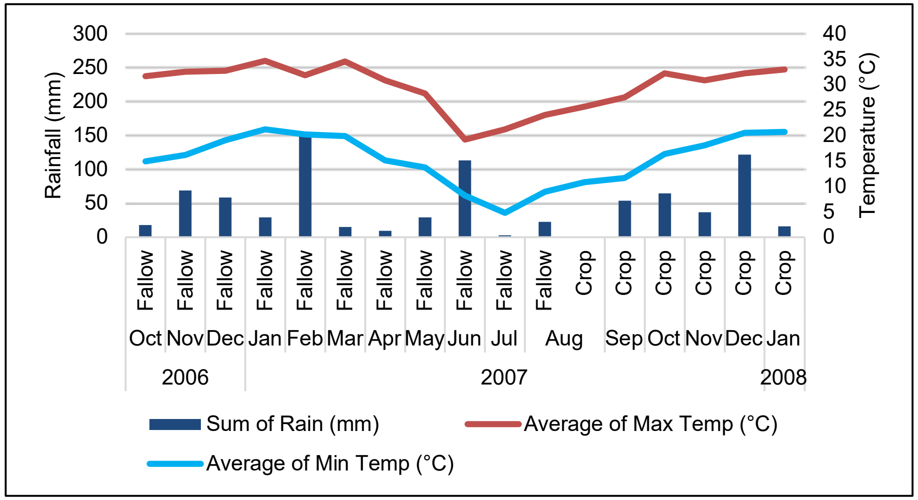

**Figure F26** Climate data during fallow and in crop for 25-SOR08

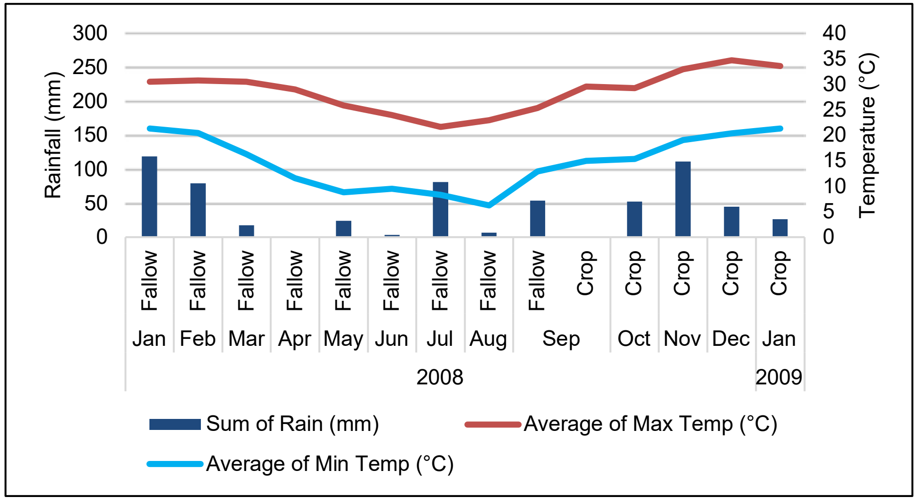

**Figure F27** Climate data during fallow and in crop for 26-SOR09