Opportunities To Sow Soybeans in the Western Australian Winter-Spring for A Resilient Future

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Abstract
Western Australian cropping systems are facing the combined challenges of climate warming, maintaining soil fertility and managing weeds and diseases. Integrating new innovative break crops into cropping systems to address these challenges are urgently needed. This study explored the opportunity to sow the normally summer-grown legume soybean as a winter-spring sown break crop for cereals using a combined experimental and modelling approach. A 2-year experiment was conducted in Mingenew with first year trial sown in spring with two sowing dates and five soybean cultivars and second year experiment sown in winter. The APSIM model tested with the experimental data was used to explore the spatial-temporal characteristics of Genotype x Environment x Management for soybean grown in Western Australia. The results show that there is a potential to grow soybean in northern wheatbelt as a winter break crop for both now and in the future, while in the southern wheatbelt, it could be grown as a spring-sown summer crop now with a potential to grow as a winter crop in warmer future. Future climate warming is likely to continue to impact winter-based cropping systems in Western Australia. The findings of this study would help Western Australian grain growers to tackle climate challenge and provide them both a new break crop and increased diversity of cropping options to increase soil fertility and manage weeds and diseases.

Keywords
Soybean, Cropping system, Western Australia, Modelling

Introduction
Cropping systems in Western Australia are facing growing challenges from climate change (Fletcher et al., 2020), soil degradation (Spencer et al., 2021) and weeds (Llewellyn et al., 2016) and diseases (Murray and Brennan, 2010). The adoption of flexible and diverse cropping systems serves as an effective alternative solution to meet these challenges. Break crops add diversity and sustainability to cereal-based cropping systems. However current break crop options use autumn-sown winter crop types (canola/pulses/pastures), which are not able to well use the increased summer rainfall and to relieve the time pressure to manage winter weeds efficiently. New innovative break crops and management packages are urgently needed to address the challenges in Western Australian cropping systems. Soybean, economically the most important legume crop in the world, offers a number of unique opportunities to serve as a break crop for winter cereals to adapt to climate change, improve soil quality, help to manage weeds, and improve cereal crop yield, quality, and profitability. This study aims to determine the potential to introduce soybean as a new crop option for Western Australian growers to improve cropping systems for sustainability and resilience.

Methods
A combination of field experiment and simulation modelling was used to identify the responses of soybean development, growth and yield to climate conditions in the wheatbelt of Western Australia.

Field experiments
Field experiments were conducted during 2022 to 2023 at a paddock near Mingenew to evaluate the performance of summer soybean sown in a warm Western Australian area. The paddock has a heavy soil with high water holding capacity that soybean prefers. For the 2022 experiment, soybeans were sown on 25 Aug and 22 Sep in spring, with 5 cultivars (Burrinjuck, Gwydir, New Bunya, 0235-1, A6785) for each sowing date. For the 2023 experiment, two cultivars (Burrinjuck and Gwydir) were sown on 16 May in winter and 5 cultivars were sown on 8 Aug in spring. Each treatment had three replications. The plant establishment and growth characters were measured for each cultivar and each sowing date.

Simulation and analysis
The Agricultural Production Systems sIMulator (APSIM; Holzworth et al., 2014) was used to simulate the growth and yield of representative soybean cultivar and determine the potential to fit a soybean crop into current winter cereal -based (wheat is exampled here) cropping systems in Western Australia. APSIM Next

Generation (APSIM-NG) was tested with experimental data and then run with historical weather records (1900–2023) to assess the possibility of growing soybean in the wheatbelt of Western Australia. Considering the water availability and water requirement of soybean, simulations were performed in the high rainfall region with Geraldton and Albany representing warm and cool parts of the region, respectively. The cultivar of Burrinjuck was used for all the simulations as it was used in both winter and spring sowing in the experiments. For winter sowing, a soybean crop was sown when 15 mm of rainfall was accumulated in 7 days during 1 May─30 June, otherwise it was sown on 30 June. For spring sowing, a soybean crop was sown on 31 Aug. No fertilizer was applied for soybeans. For wheat simulations, the sowing rule was the same as soybean sown in winter. The common cultivar of Scepter was used, with 120 kg N/ha applied at sowing for both sites. A clay soil was used for all simulations.

To determine the potential to sow soybean in Western Australia, the breakeven yield of soybeans sown in the spring was calculated. Years in which the yields exceeded the breakeven yield were considered opportunities to sow soybeans. Yields and gross margins of soybeans sown in winter were compared with those of winter wheat. The gross margins of soybean, wheat and their rotations were calculated by using industry gross margin information (PIRSA, 2022), with simulated crop yields and amounts of N fertiliser applied. The price and variable cost of chickpea was used for soybean.

Results

Evidence from a field experiment

Soybeans sown in both spring and winter established well, with more than 38 plants/m^2 for each cultivar. For soybeans sown in spring, the above-ground biomass ranged from 0.38 to 2.35 t/ha among 5 cultivars across 2 years, with an average of 0.98 t/ha (Fig. 1). As the season of 2022 received little rainfall after Sep and the whole season of 2023 was a dry season, the soybean plants died before setting seeds for harvest.

For the soybean sown in winter, the above-ground biomass was 3.99 t/ha and 3.56 t/ha for the 2 experimented cultivars (Fig. 1). Considering the very dry season of 2023, this amount of above-ground biomass was decent. The early cultivar Burrinjuck podded well, yielding about 0.21 t/ha. While the yield was low, wheat yield in a nearby paddock was low as well (0.30 t/ha) as a result of the very dry season of 2023.

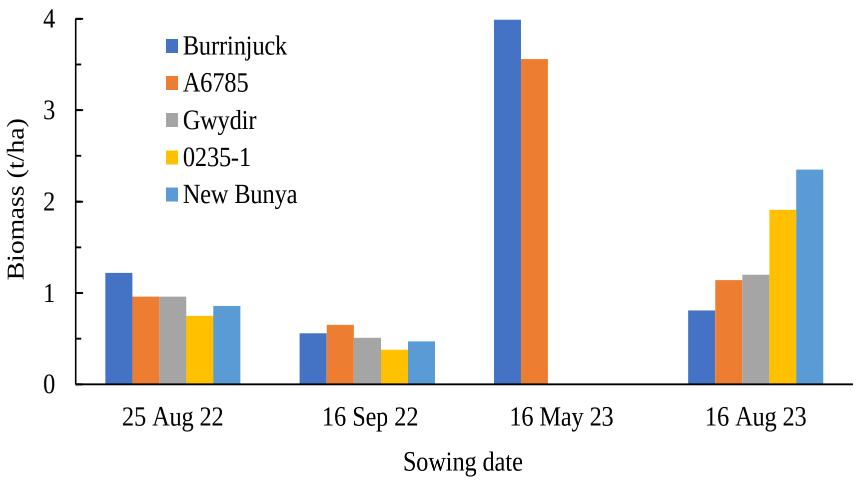

Figure 1. Above-ground biomass (t/ha) of each cultivar sampled on 21 Nov 2022 and 4 Oct 2023.

Evidence from model simulations

The performance of APSIM-NG in simulating the growth of soybean in Western Australia was tested with the above experimental data, which showed that the model was able to reflect the observed biomass of all 5 cultivars (Fig. 2).

When a soybean crop was sown in spring (on 31 Aug), it was simulated to achieve 0.10-1.70 t/ha with an average of 0.70 t/ha at Geraldton and 0.72-3.61 t/ha with an average of 1.89 t/ha at Albany (Fig. 3). Economic analysis showed that the breakeven yield of soybean was 0.94 t/ha (Data not shown), which needed about 250 mm of moisture, that is the sum of soil water at sowing and rainfall during growing season (Sep-Dec). There was limited chance to have more than 250 mm of moisture in Geraldton, whereas in

Albany, moisture levels exceeded 250 mm in most years. This indicates the potential to sow a summer soybean in spring in the cool, high rainfall region of Western Australia, but not in the warm region.

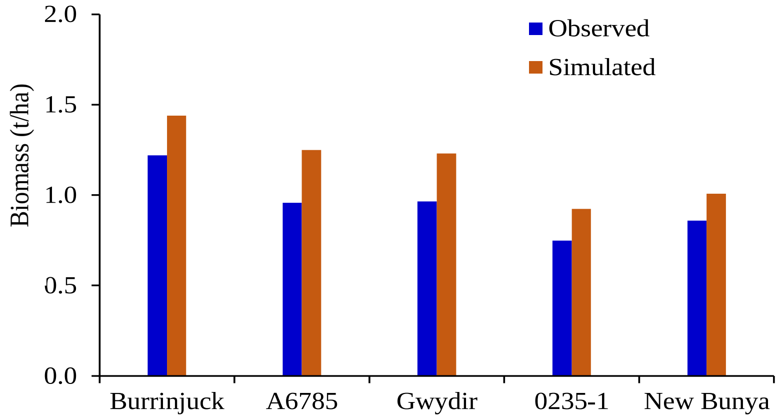

Figure 2. The comparison of observed and simulated above-ground biomass for five soybean cultivars.

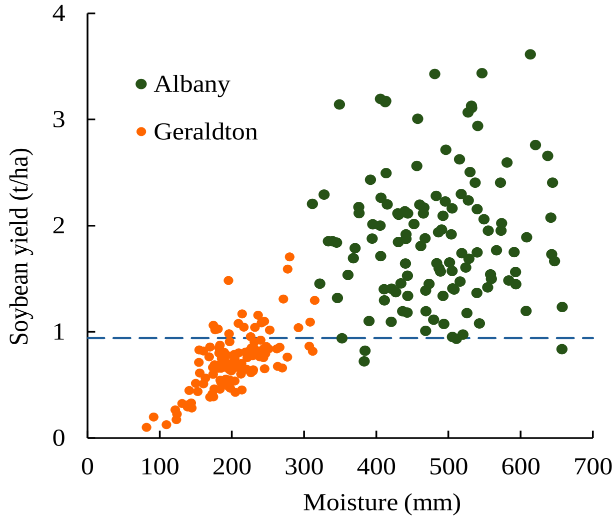

Figure 3. The relationship between moisture (sum of soil water at sowing and growing season (Sep-Dec) rainfall) and simulated soybean yields at the 2 study sites.

When a soybean crop was sown in winter, it was simulated to achieve good yield. The average yield was 2.10 t/ha in Geraldton with a range of 0.15-3.18 t/ha, and it was 2.51 t/ha in Albany with a range of 1.71-3.13 t/ha (Fig. 4a). Although soybean yield was lower than wheat yield at both sites in almost every year, the gross margin of soybean was higher than that of wheat, with an average of $901/ha in Geraldton and $1214/ha in Albany for soybean, compared with $589/ha and $537/ha for wheat at the corresponding location (Fig. 4b).

Mean temperatures in the wheatbelt of Western Australia have increased by about 1.1 °C since 1910 (CSIRO and BoM, 2015), which are projected to continue to rise. GCMs project the average annual temperature will increase about 2.6–4.2 °C by 2090 under a 'most-likely' case for RCP 8.5 (CSIRO and BoM, 2015). The greatest increase is projected for spring when winter crops are flowering and filling grain, with the frequency of hot days lasting longer. The current mean winter crop growing season temperatures are 16.6 ^{o}C for Geraldton and 13.4 ^{o}C for Albany. The changes in climate may threaten the feasibility of winter crops currently dominating the cropping system in Western Australia. Sowing an innovative summer crop (e.g. soybean) in winter may provide an opportunity to address climate change issue in a region like the high rainfall area of Western Australia.

Conclusion

Both experimental results and model simulations showed that there was a potential to adopt summer soybean as a break crop in Western Australia. In the warm high rainfall area, it was possible to grow soybean as a winter break crop for both now and in the future. In the cool high rainfall area, soybeans could be sown in both winter and spring now, while the results of the former should be interpreted with caution as frost was not considered in the study. With climate warming, there was a potential to grow soybean as a winter crop in

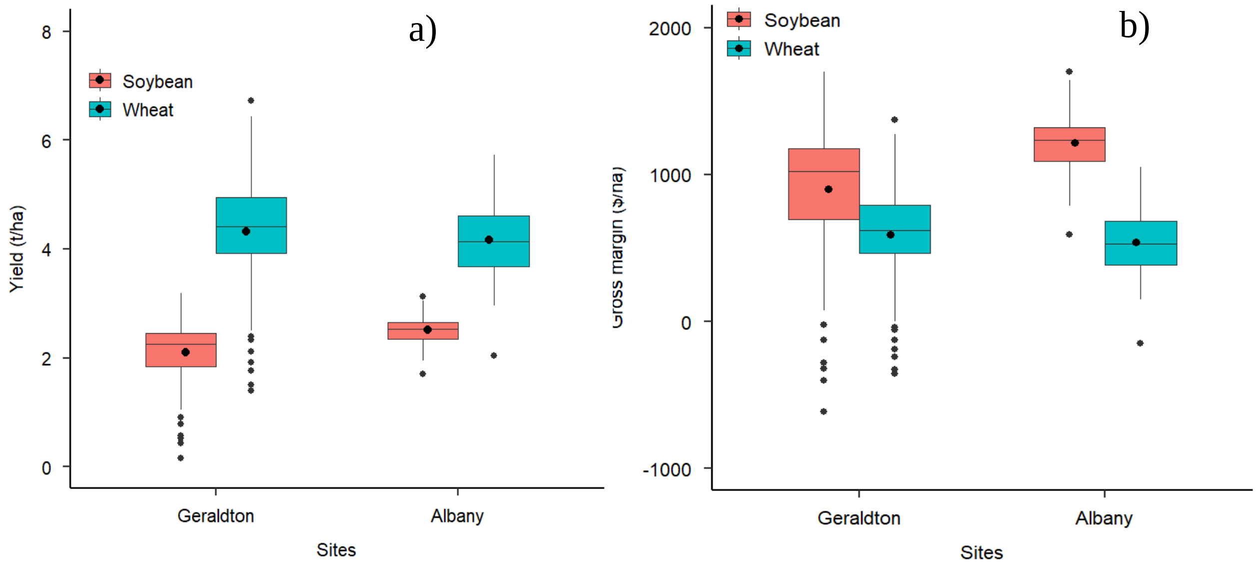

Figure 4. Simulated yields of soybean sown in winter and yield of winter wheat at the 2 study sites (a) and the corresponding gross margin (b).

that area in future. The results are inspiring. Sowing a species that has been traditionally considered a summer crop like soybean in winter might be a practical management option for growers to adapt their cropping systems to climate change. Integrating soybean into Western Australian cropping systems may also offer additional benefits, such as enhancing crop productivity and profitability, increasing crop diversity, reducing pests and diseases and decreasing fertilizer use. Further research is needed to quantify these potential advantages.

Acknowledgments

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