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Northern NSW research results 2020

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Foreword

The Northern Cropping Systems Unit of NSW Department of Primary Industries (NSW DPI) is pleased to be able to offer you the most recent snap shot of results from their research and development work undertaken in the Northern Grains Region of NSW. This book aims to compile and extend the findings and outcomes of this research which can then be implemented to inform key decisions and practice change throughout the region. Our audience includes agribusiness, consultants, other research bodies and, most importantly the growers themselves.

The majority of this work is conducted in partnership with the Grains Research and Development Corporation (GRDC), using grower's funds to address key production constraints and opportunities facing growers, covering both summer and winter cropping.

The NSW DPI Northern Cropping Systems Unit is based across the Northern Grains Region of NSW with the key research hubs at Trangie, Tamworth, Narrabri and Grafton and satellite sites at Breeza and numerous on-farm locations. This geographical spread allows work to be replicated throughout differing rainfall and climatic scenarios creating greater rigour of the findings and recommendation.

These short papers have been compiled to improve the awareness and accessibility of the results from the NSW DPI trials in the region. The papers are based on scientifically sound and independent research but need to take into account the situation, location and season in which the work has been conducted. It is hoped that this research will prompt more questions and we encourage you to contact the authors to discuss these queries. These experiments cover disciplines from agronomy to plant breeding, crop protection, along with phenology, soils and nutrition research. This is the 10th Edition and in many cases provides updates on research that has been conducted over several years and locations.

The research reported on in this book is only possible through the cooperation of the many growers, advisors and consultants who actively work with our research teams throughout the year. These collaborators are individually acknowledged at the end of each paper. NSW DPI is fortunate to partner with other organisations such as universities, CSIRO, grower groups and other state-based agricultural departments providing greater breadth and width to our trial portfolio.

A special thanks to all the authors and editorial staff for their willingness to contribute to this publication and their efforts in reviewing the diverse range of papers in this year's book.

2020 presented some unique challenges but thankfully we saw a significantly better winter cropping season and a promising start to the summer crop especially compared to the very poor 2019 year. We hope you find the papers to have some value to your business and appreciate any feedback that will help improve future editions of the Northern NSW Research Results book.

Guy McMullen
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On behalf of the Northern Cropping Systems Unit
NSW Department of Primary Industries

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Influence of sowing date on phenology, grain yield and quality of wheat – Edgeroi, 2017

Rick Graham, Stephen Morphett, Jim Perfrement, Michael Dal Santo, and Peter Formann

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Key findings

- High grain yields can be achieved from a range of variety × sowing date (SD) combinations. This enables growers to exploit differences in wheat phenology types for various SDs.

- Optimum yields were achieved by targeting flowering in the early part of the optimal window (defined by the risk of frost and heat and moisture stress).

- Yield response curves showed that slow developing, spring types (e.g. Sunmax[Φ] and DS Pascal[Φ]) achieved optimal yields when sown early. In contrast, very fast spring varieties (e.g. LongReach Mustang[Φ]) suffered significant yield penalties of up to 49% from SD1 due to frost damage, performing better with a delayed sowing date.

- Delayed sowings of later maturing varieties (e.g. EGA Eaglehawk[Φ] and Sunmax[Φ]), increased the potential for down graded grain quality due to increased screenings (>5%) associated with heat and moisture stress at flowering.

- Improved understanding of phenology responses of different varieties to various SDs will help to optimise yield potential and assist with variety selection and uptake.

Introduction

Phenology refers to the timing of the plant lifecycle or development phases such as flowering. Wheat development and maturity is primarily controlled by varied responses to vernalisation (Vrn) and photoperiod (Pdp) genes (Harris, Graham et al. 2018). The combination of variety and SD can influence the timing of environmental stresses during key developmental phases, such as flowering and grain formation. The range of developmental patterns due to Vrn and Ppd responses in Australian wheat varieties provides growers with flexibility in SD, which can be used to manage the risk of frost, heat, and moisture stress at flowering. Genotypes that respond to vernalisation require a period of cold temperatures (i.e. 3–10 °C) to progress from vegetative to reproductive development, with 'winter' wheats having the strongest vernalisation requirements (e.g. EGA Wedgetail[Φ]). Photoperiod sensitive genotypes require long day conditions to progress to the reproductive phase, with short day conditions prolonging the vegetative phase and delaying the transition to reproduction (e.g. Sunmax[Φ]). Varieties that are insensitive to photoperiod and vernalisation, mature predominantly in response to accumulated thermal time or day degrees (e.g. LongReach Mustang[Φ]).

When selecting a variety × SD combination, the aim is to match plant phenology with seasonal conditions so that crops flower during an optimal period. In the northern grains region (NGR) the optimum flowering window is considered an agronomic compromise between avoiding excessive yield loss due to frost and ensuring that flowering occurs early enough to enable a long grain-fill period, before heat and moisture stress restrict yield potential.

In 2017, field experiments were conducted across eight environments in the NGR from Wagga Wagga in southern NSW and north to Emerald in central Queensland, to determine the influence of different maturity groupings on crop development and yield potential for a core set of genotypes. This paper reports specifically on the results from Edgeroi in north-western NSW.

Site details	Location	Lockslea, Edgeroi, NSW.
	Soil type	Grey–black vertosol.
	Previous crop	Chickpea.
	Sowing	• Direct-drilled with Boss parallelogram tyne.
		• Spacings 330 mm × 5 rows.
		• Plots 12 m long on 2 m centres.
	Starting soil nitrogen (N)	~ 227 kg N/ha (0–120 cm).
	Starting soil phosphorus	• Colwell: 16 mg/kg (0–10 cm), 3 mg/kg (10–30 cm).
		• BSES: 45.6 mg/kg (0–10 cm), 27.3 mg/kg (10–30 cm).
	Starting water	~68 mm plant available water capacity (PAWC) to 120 cm.
	Fertiliser	60 kg/ha Granulock Z.
	Weed control	• Knockdown: Glyphosphate (450 g/L) 1.2 L/ha.
		• In-crop: 900 mL/ha Starane® Advanced + Uptake® 500 mL/100 L water (7 July).
	Disease management	• Seed treatment: Vibrance® + Emerge®.
		• Flutriafol-treated fertiliser (200 ml/ha).
	Rainfall	• In-crop (April–October): 177 mm, decile 2
		• In-crop long-term average: 310 mm
		• In-crop long-term median: 292 mm

Treatments

- Thirty-two wheat varieties, varying in maturity (Table 1).
- Split-plot design, three replicates.
- Treatments: sowing date (blocked), genotype (randomised within blocks).
- Sowing dates: 20 April (SD1), 8 May (SD2) and 30 May 2017 (SD3).

Table 1   Variety maturity grouping

Maturity grouping	Genotype
Winter (W)	EGA Wedgetail[ɸ], Longsword[ɸ], LongReach Kittyhawk[ɸ], RGT Accroc, Manning[ɸ]
Very slow (VS)	EGA Eaglehawk[ɸ], Sunlamb[ɸ]
Slow (S)	DS Pascal[ɸ], Cutlass[ɸ], Kiora[ɸ], Mitch[ɸ], Suntime[ɸ], Sunmax[ɸ]
Mid-slow (MS)	Coolah[ɸ], DS Faraday[ɸ], EGA Gregory[ɸ], LongReach Lancer[ɸ]
Mid (M)	Beckom[ɸ], Janz, Sunvale
Mid-fast (MF)	DS Darwin[ɸ], LongReach Reliant[ɸ], LongReach Trojan[ɸ], Suntop[ɸ]
Fast (F)	Corack[ɸ], Mace[ɸ], Scepter[ɸ], LongReach Spitfire[ɸ]
Very fast (VF)	Condo[ɸ], LongReach Dart[ɸ], H45, LongReach Mustang[ɸ]

Temperature and flowering time — Edgeroi 2017.

Based on the probability of a 1:10-year event of temperatures <0 °C and >30 °C, the period from late August to mid–late September is considered the preferred flowering window for this location. The flowering window for this experiment spanned 106 days (10 July to 24 October), a reflection of the range of genotype × SD combinations and phenology responses (Figure 1).
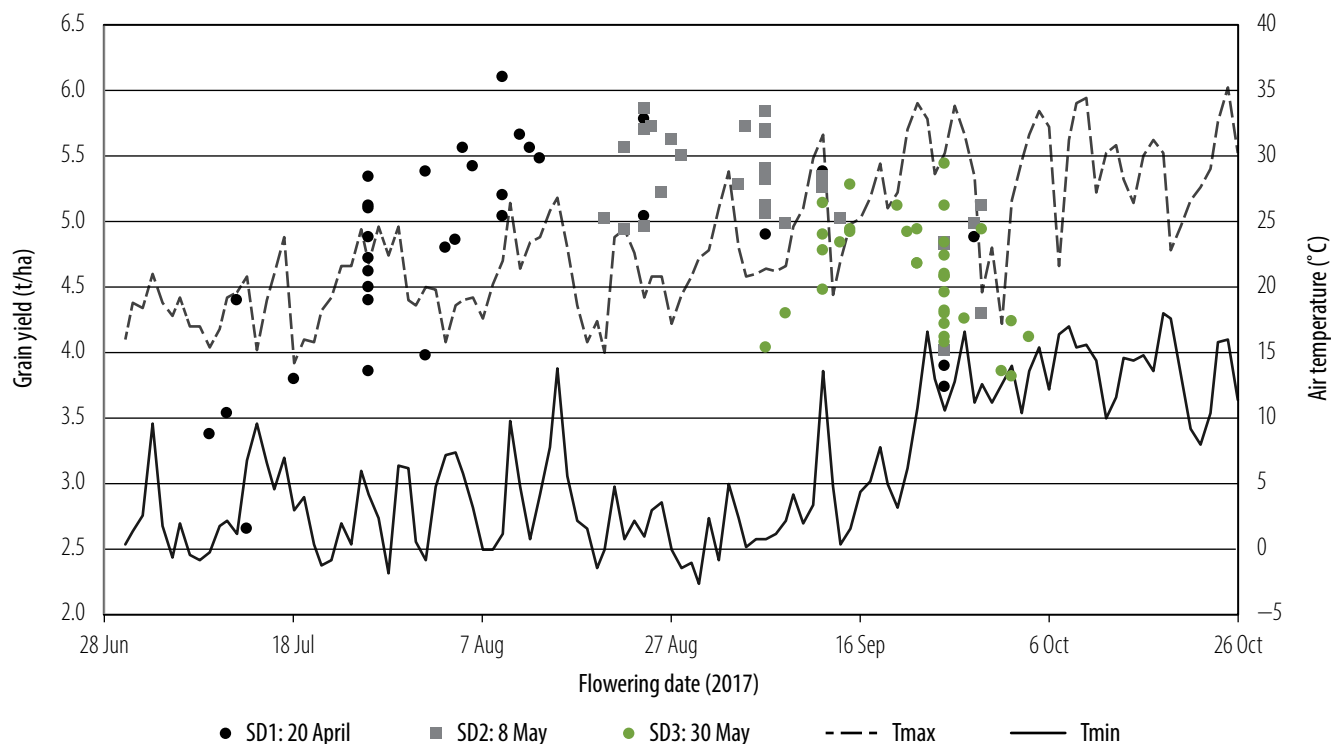
Figure 1   Relationship between temperature, flowering date and yield of wheat genotypes at Edgeroi, 2017.

Grain yield

There were distinct differences in different variety's yield potential to SD. Slow developing spring types (e.g. Sunmax[Φ] and DS Pascal[Φ]) achieved optimal yields when sown early. Later sowings resulted in a negative yield response (Figure 2). This is further illustrated when looking at the effect of SD on phasic development: Sunmax[Φ] for example from SD1 reached GS30 (stem elongation) on 20 June, and flowered in the optimal window on 7 September, while delayed SDs pushed flowering outside the optimum flowering window (Figure 3). In terms of effect on potential yield, DS Pascal[Φ] suffered a 1.7 t/ha or 29% decrease in yield. Delayed flowering caused a 5.79 t/ha yield for SD1 (flowering on 25 August) vs 4.09 t/ha for SD3 (flowering on 29 September) (Table 2).

In contrast, the faster developing spring types achieved higher yields relative to the mean from the later sowing date, as seen by a positive yield response curve (e.g. LBP Mustang[Φ]) in Figure 2. Very fast varieties, with minimal vernalisation and photoperiod requirements, sown early (SD1) into warm temperatures, progressed rapidly and reached GS30 on 30 May–4 June (Figure 3). The rapid development of these VF varieties meant that they were exposed to an increased risk of frost, flowering from 10 July to 19 July (Figure 1). The VF varieties suffered significant yield penalties ranging from 28% to 49% from SD1 versus SD2 due to frost damage.
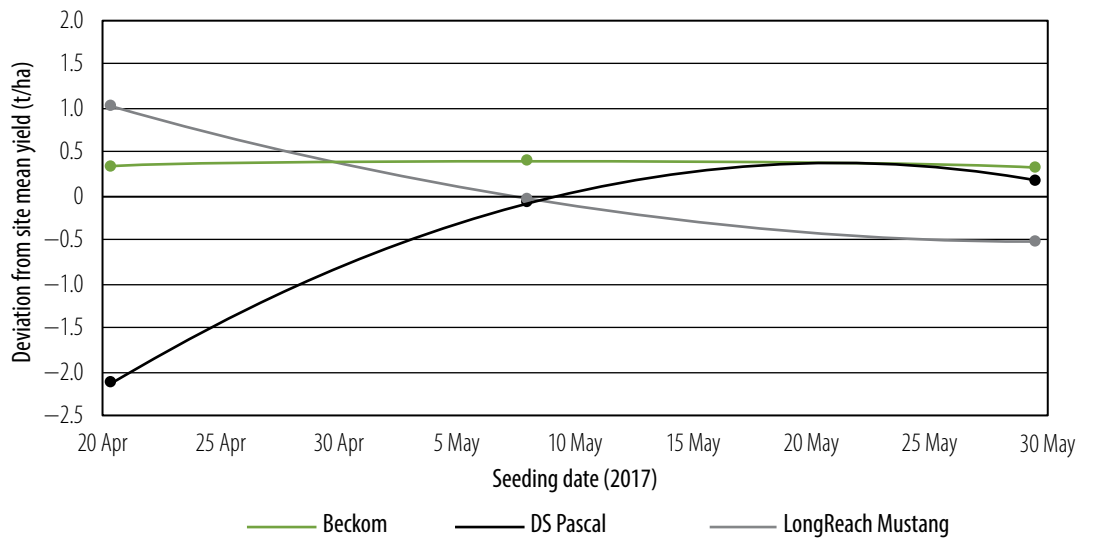
Figure 2   Genotype × sowing date yield response in 2017. Response is the deviation from the SD mean across three sowing dates. Sowing date mean: SD1 4.78t/ha; SD2 5.30t/ha; SD3 4.61t/ha.
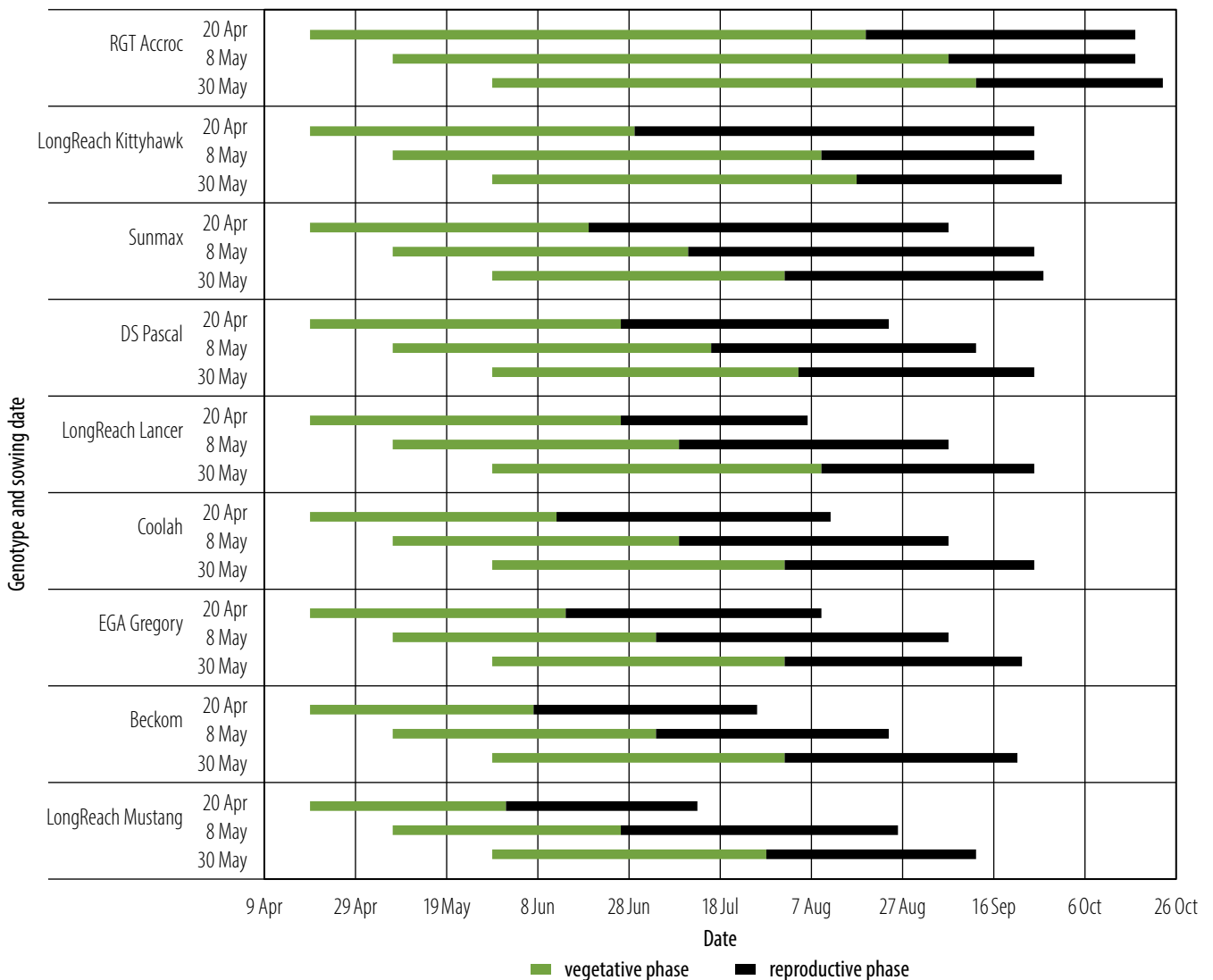
Figure 3   Influence of sowing date on development of selected genotypes sown SD1: 20 April, SD2: 8 May and SD3: 30 May. Vegetative phase (sowing to GS30); Reproductive phase (GS30 to GS65).

At the other extreme, winter varieties, with strong vernalisation requirements such as Manning[⌀] and RGT Accroc, flowered too late in this environment, even from SD1, and did not achieve grain fill. RGT Accroc did not reach GS30 from SD1 until 27 July and did not flower until 18 October (Figure 3). Both EGA Wedgetail[⌀] and LongReach Kittyhawk[⌀], with mid-vernalisation requirements, were able to achieve yields across all SDs. These yields were, however, significantly lower (by~20%) than the mean for any given SD, a reflection of the difference in vernalisation requirement and hence maturity. The faster winter variety Longsword[⌀], with less vernalisation requirement on the other hand, was able to achieve comparable yields to the mean for the range of SDs (Table 2).

Despite the increased risk of frost, some M and MF genotypes were able to maintain relatively stable grain yields, (indicated by a flatter slope), across all sowing dates e.g. Beckom[⌀] (Figure 2).

Grain quality

Grain quality parameters were significantly affected by genotype, sowing date and the interaction between the two (Table 3). The VF varieties Condo[⌀] and H45, both exceeded 5% screenings for SD1, indicative of frost damage most likely occurring during grain fill. In contrast, LongReach Dart[⌀], LongReach Mustang[⌀] and LongReach Spitfire[⌀] had significant yield penalties from SD1 versus SD2 (Table 2), as did Condo[⌀] and H45. Screenings for these varieties was >5%, indicative of frost damage occurring before grain filling, most likely during the post head emergence period. Delayed sowings, particularly for VS and winter varieties, increased the potential for down grading due to high screenings (Table 3), from increased heat and moisture stress and delayed flowering affecting the varieties' ability to fill grain.

All genotype × sowing date combinations achieved a test weight of >76 kg/hL. Frost-affected genotypes, e.g. LongReach Dart[⌀], LongReach Mustang[⌀] and H45 in SD1, or heat and moisture stress (e.g. EGA Eaglehawk[⌀] and DS Pascal[⌀] in SD3), were lower yielding and had higher grain protein concentration (GPC), underlining the inverse relationship between yield and GPC.

Table 2 Grain yield of genotypes across three sowing dates; percentage of SD mean in parentheses.

Genotype	Grain yield (t/ha)					
	SD1I		SD2		SD3	
Beckom	5.11	(107)	5.70	(108)	4.93	(107)
Condo	3.79	(79)	5.73	(108)	4.91	(107)
Coolah	5.66	(118)	5.10	(96)	4.13	(90)
Corack	4.50	(94)	5.86	(111)	4.93	(107)
Cutlass	5.48	(115)	5.12	(97)	4.58	(99)
DS Darwin	4.40	(92)	5.63	(106)	4.74	(103)
DS Faraday	5.56	(116)	5.35	(101)	4.84	(105)
DS Pascal	5.79	(121)	5.26	(99)	4.09	(89)
EGA Eaglehawk	5.39	(113)	4.98	(94)	4.23	(92)
EGA Gregory	5.05	(105)	5.08	(96)	4.68	(102)
EGA Wedgetail	3.91	(82)	4.30	(81)	3.81	(83)
H45	3.54	(74)	4.95	(93)	4.30	(93)
Janz	4.71	(99)	5.28	(99)	4.47	(97)
Kiora	4.81	(100)	5.02	(95)	4.23	(92)
LongReach Dart	3.38	(71)	5.02	(95)	4.04	(88)
LongReach Kittyhawk	3.73	(78)	4.01	(76)	3.86	(84)
LongReach Lancer	5.43	(113)	5.06	(95)	4.33	(94)
LongReach Mustang	2.66	(56)	5.22	(98)	4.78	(104)
LongReach Reliant	5.56	(116)	5.84	(110)	5.13	(111)
LongReach Spitfire	3.87	(81)	4.96	(94)	4.61	(100)
LongReach Trojan	6.12	(128)	5.68	(107)	4.94	(107)
Longsword	4.88	(102)	4.84	(91)	4.94	(107)
Mace	4.89	(102)	5.51	(104)	5.28	(115)
Mitch	4.86	(102)	5.33	(101)	4.67	(101)
Scepter	5.38	(113)	5.74	(108)	5.12	(111)
Sunlamb	5.05	(106)	5.12	(97)	4.12	(89)
Sunmax	4.91	(103)	4.82	(91)	4.27	(93)
Suntime	5.21	(109)	5.33	(101)	4.57	(99)
Suntop	5.13	(107)	5.40	(102)	4.84	(105)
Sunvale	3.98	(83)	4.99	(94)	4.30	(93)
Mean	4.78	(100)	5.30	(100)	4.61	(100)
l.s.d. (SD)	0.20					
l.s.d. (Genotype)	0.45					
l.s.d. (SD×Genotype)	0.79					

*Manning[b] and RGT Accroc did not achieve a harvestable yield for any SD.

Table 3   Grain protein concentration (GPC), test weight (TWT) and screenings (SCRN) of genotypes across three SDs.

Genotype	SD1: 20 April			SD2: 8 May			SD3: 30 May		
	Protein (%)	TWT (kg/hL)	SCRN (%)	Protein (%)	TWT (kg/hL)	SCRN (%)	Protein (%)	TWT (kg/hL)	SCRN (%)
Beckom	12.3	82.1	2.2	12.4	83.0	1.7	13.1	84.8	4.4
Condo	13.6	82.2	7.0	12.6	84.2	3.0	12.8	85.7	2.9
Coolah	11.2	83.4	1.9	11.4	84.2	1.1	11.6	86.1	3.0
Corack	12.8	82.1	2.0	11.6	84.1	2.7	12.3	83.2	2.7
Cutlass	11.7	84.0	3.0	12.6	84.5	1.4	12.9	85.2	3.6
DS Darwin	13.0	81.8	2.8	12.2	83.6	2.6	12.5	85.3	3.5
DS Faraday	12.2	83.7	2.5	12.7	84.3	2.0	12.7	85.8	3.4
DS Pascal	11.7	81.4	2.3	12.6	80.6	2.8	13.0	83.3	6.5
EGA Eaglehawk	13.4	83.9	3.4	13.7	84.5	6.2	14.0	85.3	7.1
EGA Gregory	12.1	82.7	3.3	12.8	83.7	1.8	12.9	85.3	4.5
EGA Wedgetail	16.3	81.0	1.5	15.7	80.7	2.2	15.4	81.9	2.1
H45	13.0	82.0	6.0	11.3	83.4	1.6	12.0	85.4	2.5
Janz	13.2	83.5	1.4	12.4	82.7	1.1	13.6	84.6	4.7
Kiora	12.2	84.4	1.7	13.1	83.6	2.2	14.2	86.2	6.2
Longsword	15.2	84.5	1.1	13.8	84.9	2.0	13.2	85.4	4.2
LongReach Dart	14.4	81.5	2.7	12.6	83.1	3.0	13.7	83.8	5.8
LongReach Kittyhawk	14.7	85.8	1.5	14.3	85.9	2.0	14.0	84.5	5.2
LongReach Lancer	13.0	82.7	1.7	13.7	83.2	1.3	13.7	85.5	3.0
LongReach Mustang	14.4	80.8	2.9	11.3	83.7	5.1	12.2	85.7	3.1
LongReach Reliant	11.8	84.6	4.8	11.8	84.7	2.3	12.5	85.4	4.8
LongReach Spitfire	15.2	84.3	2.2	13.2	85.0	3.3	14.8	85.6	3.4
LongReach Trojan	11.6	85.6	1.8	12.4	85.5	1.1	12.3	86.5	2.9
Mace	12.3	83.2	1.9	11.4	83.4	1.8	12.3	84.5	4.0
Mitch	12.1	81.4	3.2	12.2	81.3	1.9	12.9	82.2	6.3
Scepter	11.8	83.3	2.5	11.5	84.1	1.8	12.5	84.3	5.5
Sunlamb	14.6	84.4	3.4	14.3	84.3	5.0	14.9	86.1	4.8
Sunmax	13.5	81.9	2.7	13.7	82.8	4.8	14.2	84.5	8.3
Suntime	13.0	83.8	3.2	12.9	84.8	2.1	13.6	85.6	4.4
Suntop	12.4	83.8	2.7	12.1	84.3	3.1	12.5	84.8	6.1
Sunvale	13.3	83.2	2.2	13.9	84.0	1.3	14.3	85.0	3.4
Mean			2.7			2.5			4.4
l.s.d. (Genotype)	0.4	0.7	1.0						
l.s.d. (SD)	0.3	0.4	0.7						
l.s.d. (Genotype×SD)	0.7	1.3	1.7						

Winter crops

Summary

High yields can be achieved from a range of genotype × sowing date combinations, due to differences in phenology (i.e. phasic development and flowering time). In 2017, at Edgeroi, slow maturing varieties (e.g. DS Pascal[b]) achieved optimum yields from SD1, with yields declining with delayed SDs (5.79 t/ha SD1 vs. 4.09 SD3). In contrast, VF varieties (e.g. LongReach Mustang[b]) suffered significant yield penalties of up to 49% from SD1 due to frost damage (Table 2), and performed better from the delayed sowing dates (2.66 t/ha SD1 vs. 5.22 t/ha SD2). Mid maturing (e.g. Beckom[b]) and MF varieties (e.g. LongReach Reliant[b]), were able to maintain yield potential across the SDs, despite frost risk. At the other extreme, winter types (e.g. Manning[b] and RGT Accroc) with strong vernalisation requirements, flowered too late even from SD1 and were unable to achieve grain fill.

The results highlight both the effect of frost and heat/moisture stress on wheat's yield potential in the NGR. Encouragingly, the findings show the potential to minimise exposure to stresses by targeting the correct SD and flowering windows. Grain quality parameters, in particular high screenings, were also affected by variety and sowing date, through exposure to frost or heat/moisture stress at flowering. Delayed sowing of winter types and slow spring varieties, and early sowing of VF varieties significantly increased the potential for quality downgrading.

Improved understanding by growers of genotype and phenology responses to various SD opportunities will maximise yield potential of wheat in varying environments across the NGR.

Reference

Harris F, Graham R, Brooke G and Aisthorpe D (2018). Understanding drivers of phenology to increase grain yield of wheat. *Proceedings of GRDC Update*, 27–8 February, 2018, Dubbo, Australia https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2018/02/understanding-drivers-of-phenology-to-increase-grain-yield-of-wheat

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Crop response to deep placement of phosphorus – Gilgandra 2019

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Key findings

- Drought conditions limited production at Gilgandra in 2019. In-crop rainfall was 10% of the long-term average (LTA).

- The application of starter fertilisers containing phosphorus (P) resulted in a large (90%) increases in grain yield, averaged across all treatments.

- Significant increases in yield were recorded where deep P was applied at 80 kg P/ha as triple superphosphate (TSP) plus starter P, compared to the control treatment where only starter P was applied as well as the treatment that was deep-ripped and no deep-P was applied.

- Results demonstrated that responses to residual phosphorus (as TSP) were still being recorded four years after application.

- Phosphorus appeared to be more readily available when applied as monoammonium phosphate (MAP) compared to TSP.

Introduction

Research has been conducted in recent years to investigate the potential benefits of deep-placement of P. This research has been conducted due to the growing awareness of P stratification in cropping soils, particularly with the adoption of no-till farming and cropping intensification. The area of nutrient rundown has typically been in the 10–30 cm soil layer, beneath where starter fertiliser (starter P) is placed at sowing and residual plant matter is returned. Phosphorus is often more readily available in surface layers of soils (0–10 cm) and less available further down the profile. Crops will often rely on subsoil moisture and nutrients for extended periods in the growing season, particularly when the topsoil is dry. Unless immobile nutrients such as P are present in the subsoil, crop roots are unable to access nutrients required to meet seasonal yield potential. In dry seasons, when crops are reliant on stored water for growth, P is almost entirely obtained from the sub-surface layers (10–30 cm) for most of the growing season (Bell et al. 2018).

Experiments investigating the potential benefits of deep-placement of P (deep-P) initially focussed on the vertosols of northern New South Wales (NSW) and south/central Queensland (QLD). However, there has been growing interest in the potential benefits of deep-P on chromosol/dermosol soils such as those found in central west NSW. In contrast to the northern vertosols, soils in the central west tend to be of moderate fertility, have lower soil water holding capacity and are more reliant on in-crop rainfall.

The aim of this experiment was to test whether placing immobile nutrients such as P deeper in the soil profile of chromosol soils would result in increased grain yields. This is in contrast to the traditional approach of placing starter P in or near the seeding row and close to the soil surface. The results presented are a summary of data collected over the 2019 winter growing season from the ongoing residual P-response experiment at Gilgandra, NSW.

Site details	Location	Chippendale, Gilgandra, NSW 2827 (31°59'18.18"S, 148º68'77.77"E).
	Paddock history	2018, Wheat (SpitfireA)
	Co-operator	Kevin Kilby
	Soil type and nutrition	• Red/brown chromosol
		• Background P (Colwell): 14 mg/kg (0–10 cm), 5 mg/kg (10–30 cm)
		• Background N (Nitrate): 42 mg/kg (0–10 cm), 14 mg/kg (10–30 cm)
	Rainfall	Annual rainfall at Gilgandra in 2019 was 97 mm, compared to the LTA of 560 mm (Bureau of Meteorology, BOM). Starting soil moisture was measured as 42.4 mm with the site receiving 17 mm of in-crop rainfall in 2019, compared to the LTA of approximately 170 mm for the same period. (BOM).
	Sowing date	8 May 2019
	2019 crop	Barley (Commander[b])
	2019 sowing rate	Target, 120 plants/m^2
	Weed management	Velocity® (700 ml/ha) and Axial® (250 ml/ha) applied on 5 July 2019
	Harvest date	17 October 2019

Treatments

Experimental design

Treatments were established in April 2015 (Table 1)

- Six treatments with and without starter P, four replicates.
- A control treatment. No deep-ripping or deep-P application.
- Deep-P was applied as TSP (monocalcium phosphate [Ca(H2PO4)2.H2O]) to a depth of ~ 20 cm, parallel to the sowing direction.

A new deep-P treatment was established in February 2019 (Table 1).

- Deep-P applied as MAP [(NH4)H2PO4] at 40 kg P/ha where the TSP had previously been applied at 10 kg P/ha in 2015 (the lowest TSP rate was replaced). The new deep-P treatment was established based on results obtained from Gilgandra between 2016 and 2018 that indicated that TSP may not be an effective P source when deep-banded.
- At sowing, starter P (MAP) was applied with the seed to treatments where required. Other treatments were balanced for nitrogen and sulphur using urea and gypsum.
- Means were compared by analysis of variance (ANOVA) assessments using least significant difference.

Table 1 Deep P treatments

Treatment	Deep-P applied in 2015	Deep-P applied in early 2019	Starter P applied at sowing in 2019	Nitrogen applied at sowing in 2019
1 (Control)	0 kg P/ha.	0 kg P/ha.	–	40 kg N/ha as urea
1 (Control)	0 kg P/ha.	0 kg P/ha.	60 kg/ha Granulock®Z	40 kg N/ha as urea
2	0 kg P/ha.	0 kg P/ha. Deep-ripped and 50 kg N/ha applied as urea.	–	40 kg N/ha as urea
2	0 kg P/ha.	0 kg P/ha. Deep-ripped and 50 kg N/ha applied as urea.	60 kg/ha Granulock®Z	40 kg N/ha as urea
3	10 kg P/ha TSP	40 kg P/ha as MAP. 50 kg N/ha applied as urea.	–	40 kg N/ha as urea
3	10 kg P/ha TSP	40 kg P/ha as MAP. 50 kg N/ha applied as urea.	60 kg/ha Granulock®Z	40 kg N/ha as urea
4	20 kg P/ha TSP	0 kg P/ha. Deep-ripped and 50 kg N/ha applied as urea.	–	40 kg N/ha as urea
4	20 kg P/ha TSP	0 kg P/ha. Deep-ripped and 50 kg N/ha applied as urea.	60 kg/ha Granulock®Z	40 kg N/ha as urea
5	40 kg P/ha TSP	0 kg P/ha. Deep-ripped and 50 kg N/ha applied as urea.	–	40 kg N/ha as urea
5	40 kg P/ha TSP	0 kg P/ha. Deep-ripped and 50 kg N/ha applied as urea.	60 kg/ha Granulock®Z	40 kg N/ha as urea
6	80 kg P/ha TSP	0 kg P/ha. Deep-ripped and 50 kg N/ha applied as urea.	–	40 kg N/ha as urea
6	80 kg P/ha TSP	0 kg P/ha. Deep-ripped and 50 kg N/ha applied as urea.	60 kg/ha Granulock®Z	40 kg N/ha as urea

Results

The use of starter P resulted in a significant increase in yield (90 %) increasing from 0.44 t/ha to 0.85 t/ha, averaged across all treatments.

For the treatments where starter P was applied, the highest yield was recorded from the 80 kg P/ha deep TSP treatment, followed by the 40 kg P/ha deep MAP treatment (Figure 1). These yields were not significantly different. The yield from the 80 kg P/ha deep TSP treatment was significantly higher than yields from the control and the 0 kg P/ha deep TSP (deep-ripped) treatment. Yields from the control and 0 kg P/ha deep TSP treatments were not significantly different.

For the treatments where starter P was not applied, the highest yield was recorded from 40 kg P/ha deep MAP treatment (Figure 1). This yield was significantly higher than the control treatment, but not significantly higher than the 0 kg P/ha deep TSP treatment. Yields from the control and 0 kg P/ha deep TSP treatments were not significantly different.
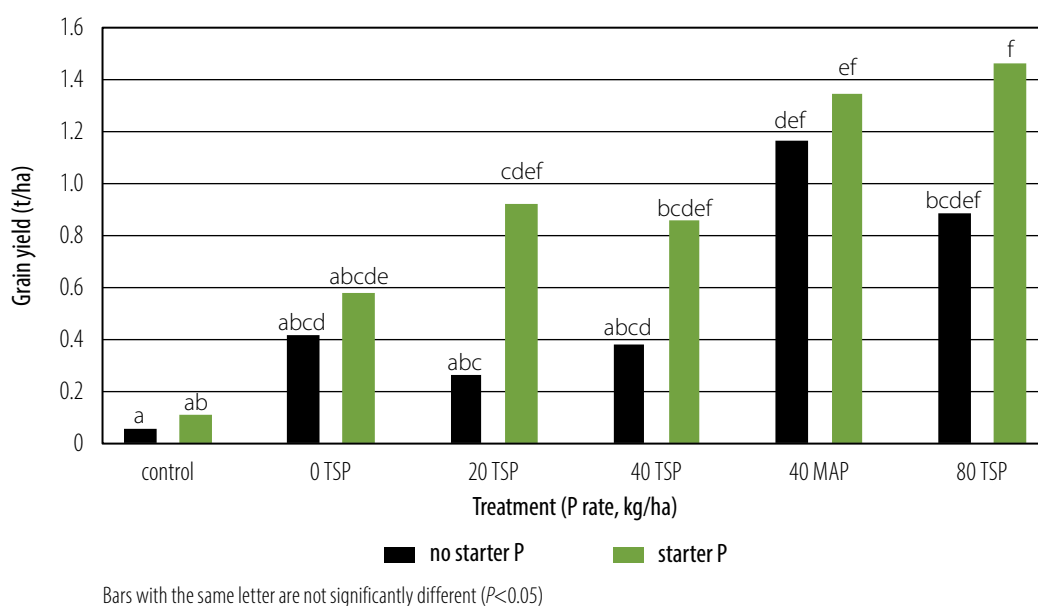
Bars with the same letter are not significantly different (*P*<0.05)

Figure 1   Yield response to deep-P/tillage treatments, with and without starter fertiliser.

Summary

The aim of this experiment was to test whether placing P deeper in the profile of a chromosol soil could result in increased yields compared to the more traditional shallow P placement.

- Crop yields were significantly limited by the drought conditions experienced at Gilgandra in 2019. Across all treatments, the average yield recorded was less than 1 t/ha. However, even with limited yields, a positive yield response to starter P was recorded in every treatment (Figure 1). The consistent response to starter P indicated that the crop relied heavily on shallow placed P.

- Where starter P was applied, there was a general yield increase with increasing rates of deep-P (Figure 1). The highest yield where starter P was applied (as well as highest yield recorded overall), was from where deep-P was applied as TSP at 80 kg P/ha (1.5 t/ha). This yield was significantly higher than the control and 0 kg P/ha TSP treatments plus starter P.

- A significant yield increase was measured where 40 kg P/ha MAP was applied deep compared to the control (Figure 1). This yield was not significantly different from the 80 kg P/ha deep TSP treatment.

- Grain yields did not appear to be limited by N as indicated by an average grain protein concentration (GPC) of ~13 %, averaged across all treatments (data not shown). The average GPC was higher than the suggested 2019–2020 industry maximum GPC of 12 % for Malt 1 grade (GrainCorp barley standards).

- Grain P analysis was limited to the control, 0, 40 and 80 kg P/ha deep TSP and 40 kg P/ha deep MAP treatments. Grain P uptake was low across all treatments. A typical 3 t/ha crop will generally take up ~15 kg P/ha, with 1–2 kg taken up from P fertiliser applied at planting (GRDC Grownotes, 2016). Where starter P was applied with deep-P, the highest grain P uptake (2.08 kg P/ha) was recorded from the 40 kg P/ha deep MAP treatment at 1.3 t/ha . This was significantly higher than the grain P uptake recorded from the control treatment (0.06 kg P/ha), which was the lowest grain P content recorded, but still very low. Grain P uptake did not significantly differ between the control plus/minus starter (data not shown). Results suggest the majority of P uptake occurred early in the season before the fertilised soil layers dried out and moisture became limited. This P was then most likely redistributed to produce biomass.

Conclusions

Yields were significantly limited by drought conditions at Gilgandra in 2019 with in-crop rainfall only 10 % of the LTA. A significant response to starter P was still recorded. Where starter P was applied, a significant yield increase occurred for the 80 kg P/ha deep TSP treatment compared to the control

and 0 kg P/ha deep TSP treatments (Figure 1). Results demonstrated that yield increases could still be recorded from deep TSP treatments being applied in 2015.

The significant response to starter P suggests that the crop may have relied heavily on this source of P. The crop may have also struggled to access sources of P deeper in the soil profile due to the drought conditions. This result might also indicate that MAP as a source of P may have been more readily available to the plant roots. Studies involving deep-P application in various soils of northern NSW and south/central QLD have highlighted the potential limitations of using TSP as a source of deep-banded P due to its acidic nature. When soil pH is reduced (including by TSP application), more P can potentially precipitate into unavailable forms (Meyer et al., 2020).

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Dryland safflower response to plant population in northern NSW – 2015

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Key findings

- Low temperatures immediately after sowing did not inhibit crop germination or establishment.

- Increasing plant population resulted in significant increases in overall plant height and the height of the lowest flower.

- In the late May sown safflower, canopy closure and maximum normalised difference vegetation index (NDVI) levels occurred in all populations 25 days before the start of flowering. In comparison, the crop canopy of the July sown safflower was smaller and less developed. Maximum NDVI was delayed in the lowest populations – just 13 days before flowering compared with higher populations reaching a maximum 27 days before flowering.

- Plant population had no effect on leaf area index and sunlight interception at flowering.

- Crop canopy leaf area (at flowering) of the late May sown crop was almost double the leaf area of the July sown crop.

- Average crop canopy light interception was 36% higher in the late May sown crop compared with the July sown crop.

- Delaying sowing decreased the overall length of the crop cycle.

- Increasing plant population increased overall plant height and the height above ground of the lowest flower.

- Higher plant populations were the first to start flowering.

- In the late May sown safflower, yields plateaued at populations greater than 30 plants/m^2. Yield was 20% lower at 17 plants/m^2 population. Seed size was maximised at lower populations.

- In the July sown safflower, there was no yield or seed size response to plant population.

Introduction

The 'Tactical agronomy of minor crops (safflower, linseed, sunflower)' (DAN00197) was a co-funded project between NSW DPI and the Grains Research and Development Corporation (GRDC). A major objective was to determine the agronomic constraints to yield potential in oilseed crops, other than canola, in northern NSW.

Irregular safflower research activity and commercial safflower production in northern NSW for many decades has resulted in limited progress of sound industry knowledge and experience. Industry consultation in 2014–15 revealed wide-ranging views on foundational agronomic practices such as appropriate plant populations, seeding rates and suitable row spacing for optimal production under

dryland and irrigation production systems. The effects of management practices on crop yield and other agronomic attributes were not known.

This paper reports on the cultivar Sironaria's response to being grown under dryland conditions at four target plant populations at Tulloona in northern NSW and Breeza on the Liverpool Plains in 2015. This information will be used to develop agronomic recommendations for safflower agriculture in northern NSW.

Treatments	**Plant population** 10, 20, 30, 40 plants /m²

Site details

Details of experiment locations are summarised in Table 1.

Table 1   Experiment site details in 2015.

Site	Tulloona	Breeza
Location	Myling (S 28°52′39.0″; E 150°05′10.9″)	Nullabean (S 31°10′53″; E 150°20′34″)
Co-operator	Jack Gooderham	Alan Riordan
Soil type	Grey vertosol	Black vertosol
Previous crop	Long fallow following sorghum	2014 – wheat
Variety	Sironaria	Sironaria
Sowing date	29 May 2015	10 July 2015
Row spacing	33 cm	33 cm
Fertiliser	70 kg/ha Granulock® Z at sowing	50 kg/ha Granulock® Z at sowing
Starting soil N (0–120 cm)	137 kg N/ha	97 kg N/ha
Starting soil water (0–120 cm)	153 mm	107 mm
In-crop rainfall	150 mm	213 mm
Harvest date–days after sowing (DAS)	30 November (185 DAS)	21 December (163 DAS)

Experiment design	Randomised complete block; six replications.

Seed quality

The seed used in the experiment was tested before sowing. The seed size and germination percentage of Sironaria was 3.5 g/100 seeds and 86% respectively. Seeding rates were calculated assuming an 80% establishment rate. Equivalent seeding rates for target populations of 10, 20, 30 and 40 plants/m² were 5, 10, 15 and 20 kg/ha respectively.

Sowing

Tulloona – The experiment was sown into soil moisture suitable for germination with 36 mm of rain falling 20 days after sowing. Seeding depth averaged 50 mm.
Breeza – Seedbed moisture was ideal after approximately 40 mm rain the previous month and a further 20 mm in the four days after sowing. Seeding depth averaged 20 mm.

Site climate details

Tulloona – Temperatures throughout the growing season varied between −1 °C and 42.1 °C (Figure 1). Average minimum and maximum temperatures were 9.5 °C and 24.9 °C respectively.
Breeza – Temperatures throughout the growing season varied between −4 °C and 40.7 °C (Figure 2). Average minimum and maximum temperatures were 9.9 °C and 25.5 °C respectively.
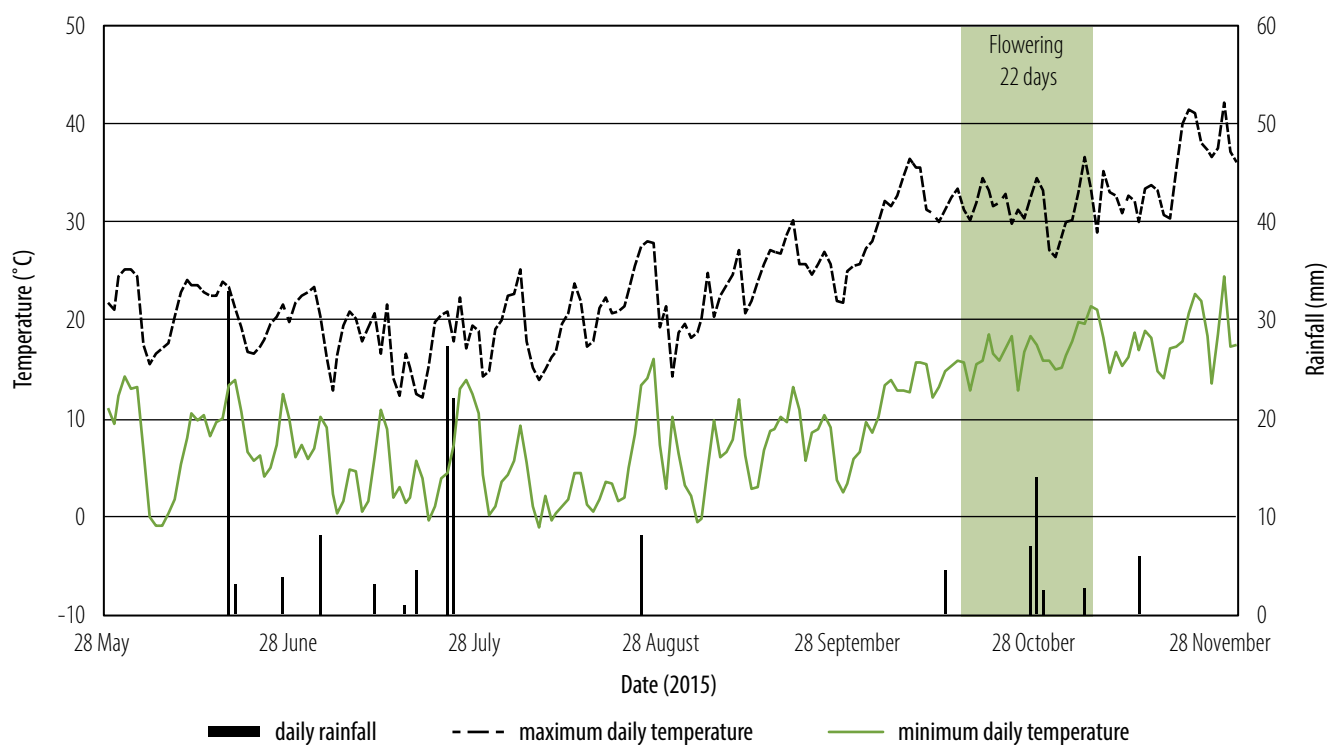
Figure 1   Experiment site climate data at Tulloona in 2015.
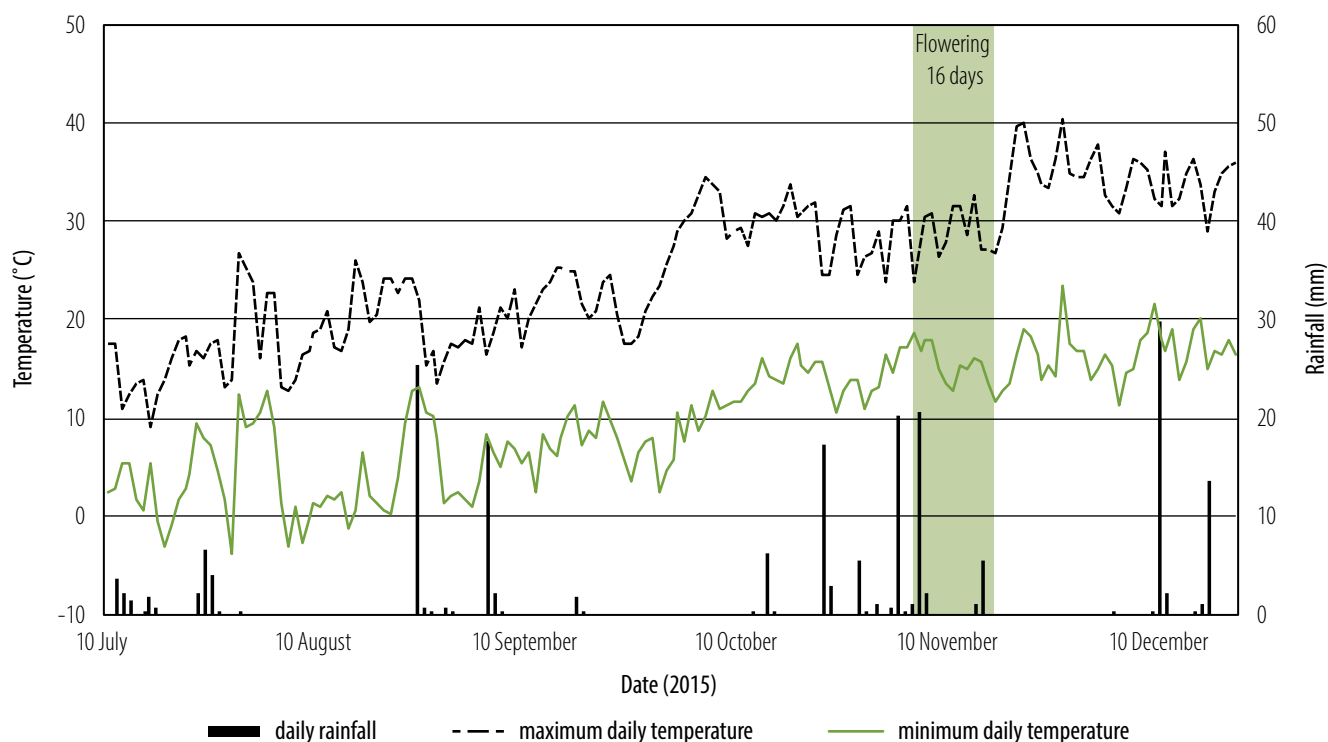
Figure 2   Experiment site climate data at Breeza in 2015.

Results

Crop establishment

Crop establishment exceeded the target populations in all instances at both locations, resulting in very similar corresponding populations at both sites (Table 2). Seed was sown into suitable seedbed moisture for germination: average seeding depth at Tulloona was 51 mm, and 20 mm at Breeza. Daily air temperatures in the 10 days following sowing at Tulloona ranged between −1 °C and 15.5 °C mm;

and −3.1 °C to 9.2 °C at Breeza. In the same 10-day period, the Breeza site also recorded five wet days totalling 10.8 mm rainfall.

Table 2   Safflower establishment at Tulloona and Breeza in 2015.

Target population(plants/m²)	Achieved plant population (plants/m²)	
	Tulloona	Breeza
10	17 [d]	16 [d]
20	30 [c]	30 [c]
30	44 [b]	43 [b]
40	56 [a]	56 [a]
Site mean	36.6	36.2
l.s.d.	9.6**	6.3**

** Values with the same letter are not significantly different at $P<0.001$.

Plant structure

Plant height and the height above ground of the lowest flower was measured during early flowering at both locations. The average plant height at Tulloona was 118 cm, slightly taller than the average height of 109 cm at Breeza.

Figure 3 shows the plant structural response to increasing plant population at Tulloona and Breeza. Each bar shows the overall plant height, with flowers located in the upper canopy. The 'stem' indicates the position of the lowest flower on the plant. As population increased, there were significant increases in overall plant height and the height to the lowest flower at both locations.

Talloona: plant height − l.s.d. ($P<0.05$) = 6 cm
             lowest flower − l.s.d. ($P<0.001$) = 7 cm

Breeza: plant height − l.s.d. ($P<0.001$) = 2 cm
           lowest flower − l.s.d. ($P<0.001$) = 7 cm
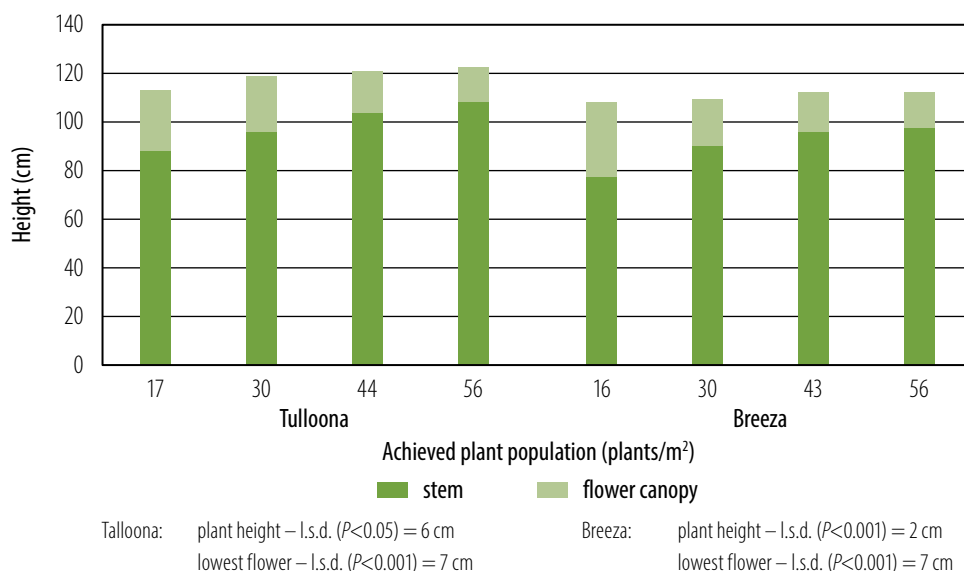
Figure 3   Effect of safflower population on plant structure in 2015.

Canopy development

The normalised difference vegetation index (NDVI) is a measure that indicates the amount of green plant material and canopy development. Changes in NDVI show the comparative early canopy development of safflower at the four plant populations at Tulloona (Figure 4) and Breeza (Figure 5).

At Tulloona, differences in canopy development of the four populations progressively decreased until all populations showed maximum green canopy 25 days before the start of flowering (Figure 4). In populations of 30 plants/m² and higher, maximum green canopy was reached 43 days after the beginning of stem elongation (90 days after sowing (DAS)) and 51 days before flowering.

At Breeza, there was no significant difference at any time in plant populations of 43 plants/m² or 56 plants/m² (Figure 5b). The first reading (21 August) was taken 42 DAS when the crop was at the 6-leaf rosette growth stage (GS16). At this early growth stage there were significant differences between the lower populations 16 plants/m² and 30 plants/m². The differences between these two populations increased after elongation (4 September – 55 DAS).

Maximum green canopy levels at Breeza were reached 91 DAS, the lowest population delayed until 105 DAS. There was no significant difference in green canopy levels between populations at 23 October (105 DAS and 13 days before flowering).

Canopy development was measured when each crop reached 50% flowering (F50) at each site. Measuring leaf area index (LAI) and the percentage of light interception gave an indication of plant growth and canopy development.

LAI is a measure of the total leaf area per unit of ground area and is directly related to the amount of light that plants intercept. There was no significant LAI response to population difference at either Tulloona or Breeza (Table 3). The average LAI was greater at the earlier sown Tulloona site, i.e. 5.12 m² compared with 2.67 m² at the July sown Breeza experiment.

Table 3   Safflower variety canopy response to plant population at flowering at Tulloona and Breeza in 2015.

Site	Tulloona		Breeza	
Target population (plants/m²)	Leaf area index (/m²)	Light interception (%)	Leaf area index (/m²)	Light interception (%)
10	4.93 [a]	90.2 [a]	2.93 [a]	68.4 [a]
20	5.25 [a]	90.3 [a]	2.45 [a]	61.4 [b]
30	5.14 [a]	89.0 [a]	2.81 [a]	66.9 [ab]
40	5.23 [a]	90.1 [a]	2.48 [a]	59.9 [b]
Site mean	5.14	89.9	2.67	64.1
l.s.d.	ns	ns	ns	6.9*

* Values with the same letter are not significantly different at 95% ($P<0.05$).

At Tulloona, there were no significant differences in light interception of the crop canopy at F50 between any population. The site average was 90%.

At Breeza there were significant differences between populations. Populations targeting 10 and 30 plants per square metre measured the maximum amount of light interception. However, the overall range across all populations was less than 10%, with the site averaging 64%.

3 Aug   l.s.d. (*P*<0.05) = 0.155   27 Aug   l.s.d. (*P*<0.001) = 0.038   30 Sep   l.s.d. (*P*<0.001) = n.s.
11 Aug   l.s.d. (*P*<0.001) = 0.054   31 Aug   l.s.d. (*P*<0.001) = 0.042   7 Oct   l.s.d. (*P*<0.05) = n.s.
17 Aug   l.s.d. (*P*<0.001) = 0.064   23 Sep   l.s.d. (*P*<0.001) = 0.027   22 Oct   l.s.d. (*P*<0.05) = n.s.
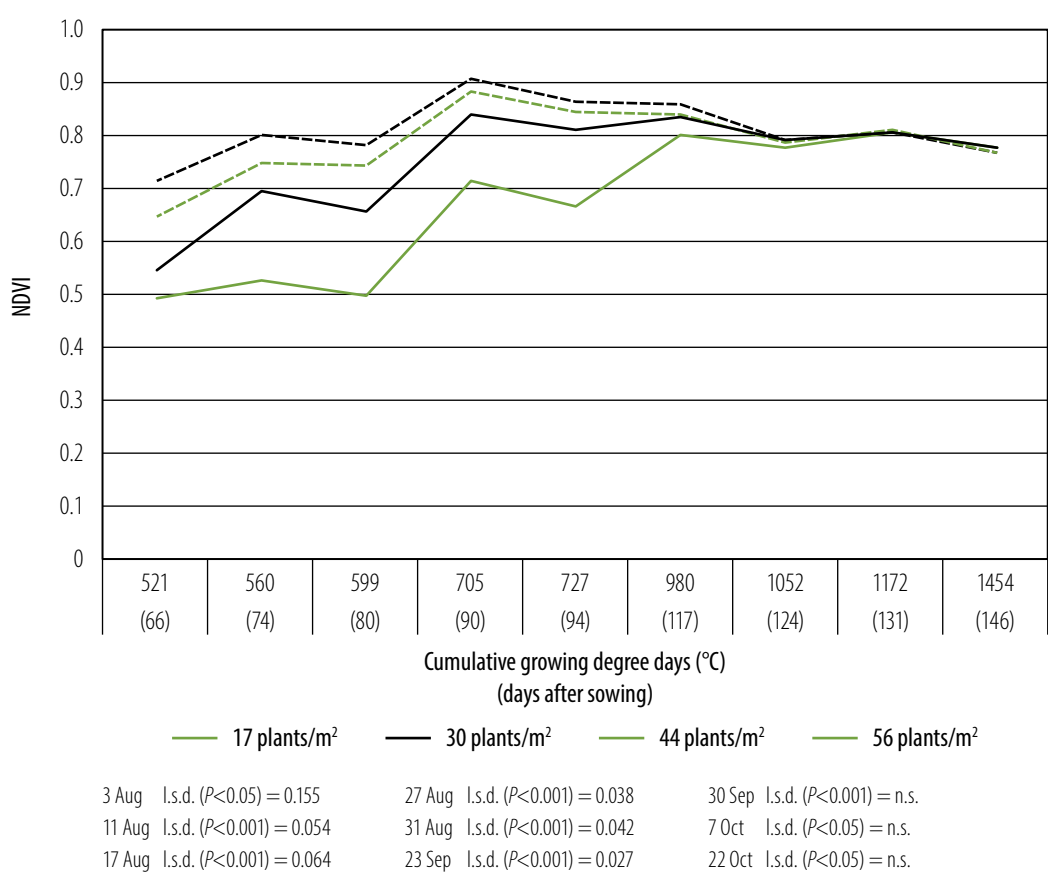
Figure 4   Changes in safflower canopy development and crop maturation at Tulloona in 2015.

21 Aug   l.s.d. (*P*<0.001) = 0.009   25 Sep   l.s.d. (*P*<0.001) = 0.029   15 Oct   l.s.d. (*P*<0.05) = 0.035
28 Aug   l.s.d. (*P*<0.001) = 0.030   1 Oct   l.s.d. (*P*<0.001) = 0.031   23 Oct   l.s.d. (*P*<0.05) = n.s.
3 Sep   l.s.d. (*P*<0.001) = 0.034   9 Oct   l.s.d. (*P*<0.001) = 0.037   29 Oct   l.s.d. (*P*<0.05) = n.s.
17 Sep   l.s.d. (*P*<0.001) = 0.036
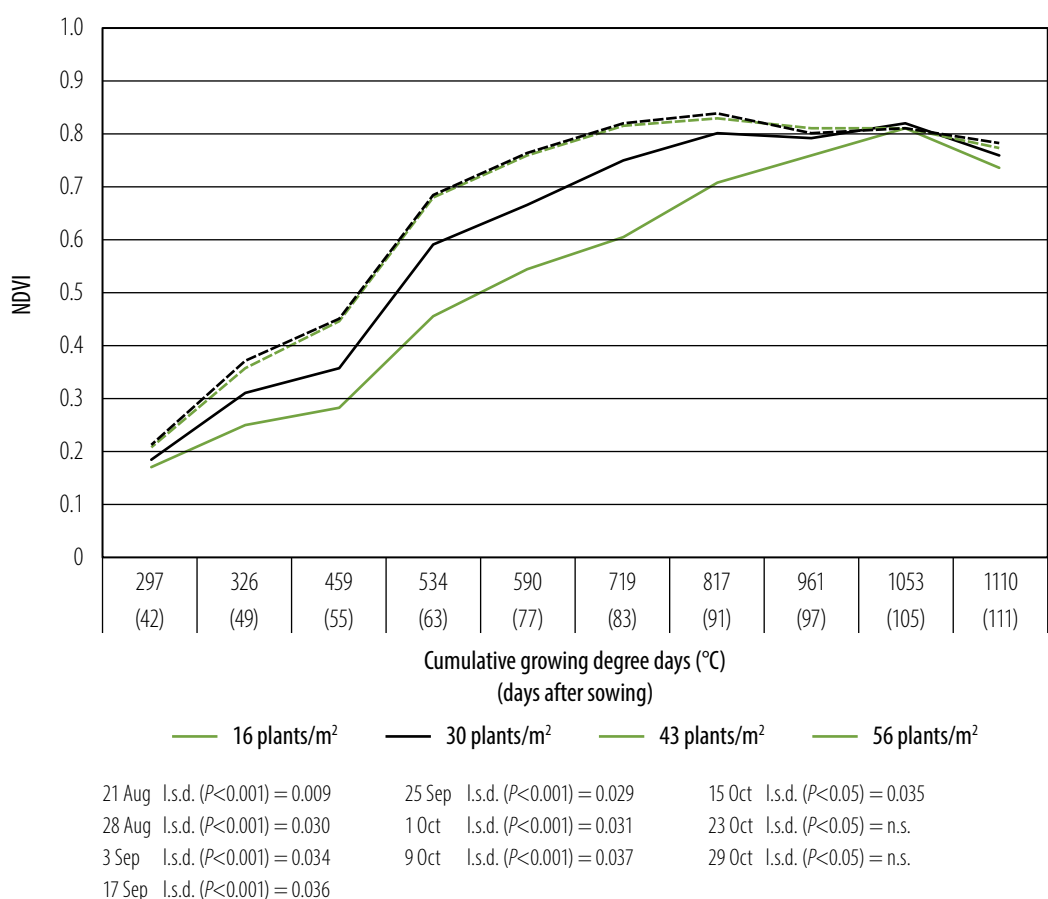
Figure 5   Changes in safflower canopy development and crop maturation at Breeza in 2015.

Crop phases

Crop cycle

The overall length of the crop cycle was reduced by 12% when sown in July compared with sowing in late May (Figure 6). The duration of flowering was 22 days at Tulloona compared with 16 days at Breeza, however the time taken from the end of flowering to physiological maturity was similar at both locations.
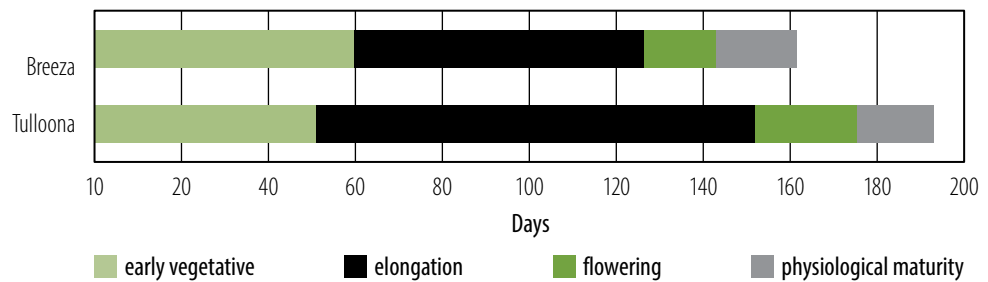
Figure 6   Comparison of safflower crop cycles at Tulloona and Breeza in 2015.

Flowering

The response of population to the start of flowering was significant at Breeza (Figure 7). Lower populations delayed flowering compared with higher populations.

l.s.d. (P<0.001) = 10.1 %
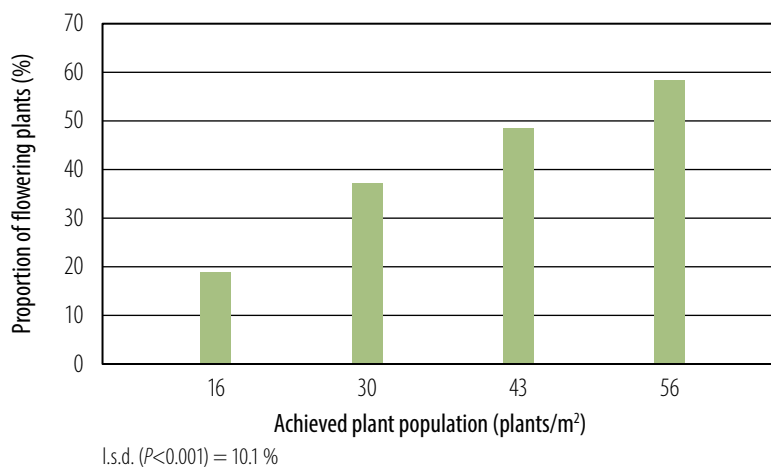
Figure 7   Effect of plant population on the commencement of flowering at Breeza in 2015.

Temperature response

Growth and development are largely temperature driven. Photoperiod sensitivity in Sironaria safflower has not been determined.

At each experiment site, the thermal sum of growing day degree (GDD) was calculated from the average daily air temperature, using a lower base temperature of 5 °C (Table 4). No upper base temperature was applied. The calculation has assumed that the crop's development was constant throughout all growth and development phases. The maximum and minimum temperatures recorded at location during various crop phases are shown in brackets.

Table 4   Response of safflower phenological development to temperature at Tulloona and Breeza in 2015.

Site	Tulloona			Breeza		
Growth phase	Days	Average temperature (range) (°C)	Cumulative day degrees (base 5 °C)	Days	Average temperature (range) (°C)	Cumulative day degrees (base 5 °C)
Sowing to elongation	47	12.1 (−1−24.9)	397	55	11.4 (−4−26.8)	327
Sowing to start of flowering	141	17.7 (−1.1−36.5)	1356	118	15.2 (−4−34.5)	1171
Flowering duration	22	24.7 (12.9−36.6)	407	16	18.1 (−4−40.2)	264
Sowing to physiological maturity	178	20.2 (−1.1−41.4)	2096	149	18.3 (−4−40.7)	1766
Sowing to harvest	185	20.2 (−1.1−41.5)	2260	163	18.3 (−4−40.7)	2056

Note: Calculation of daily growing day degree (GDD) used the formula: (daily minimum temperature + daily maximum temperature)/2 minus base temperature.

Cumulative GDD was less for each major crop phase at Breeza compared with Tulloona. The largest difference in the range of temperatures during crop phases occurred during flowering. For example, at Breeza, temperatures varied between −4 °C and 40.2 °C during flowering, whereas the range at Tulloona was 12.9 °C to 36.6 °C.

Yield

At Tulloona, plant populations of 17 plants/m^2 yielded 2.15 t/ha, significantly lower than yields from populations of 30 or more plants/m^2 (Figure 8a) (P<0.001. l.s.d. 0.26 t/ha). There were no significant differences in yield at populations of 30, 44 or 56 plants/m^2 (average 2.7 t/ha). The average site yield expressed at 8% moisture content was 2.56 t/ha at Tulloona.

There was no significant difference (P<0.05) in yield response to plant population in the later sown Breeza experiment where the average site yield was 1.79 t/ha (Figure 8b).

a) $y = -0.1103x^2 + 0.7253x + 1.5728$
$R^2 = 0.8748$

b) $y = -0.0157x^2 + 0.1508x + 1.5318$
$R^2 = 0.9291$

l.s.d. (P<0.001) = 0.26 t/ha

l.s.d. (P<0.05) = n.s.
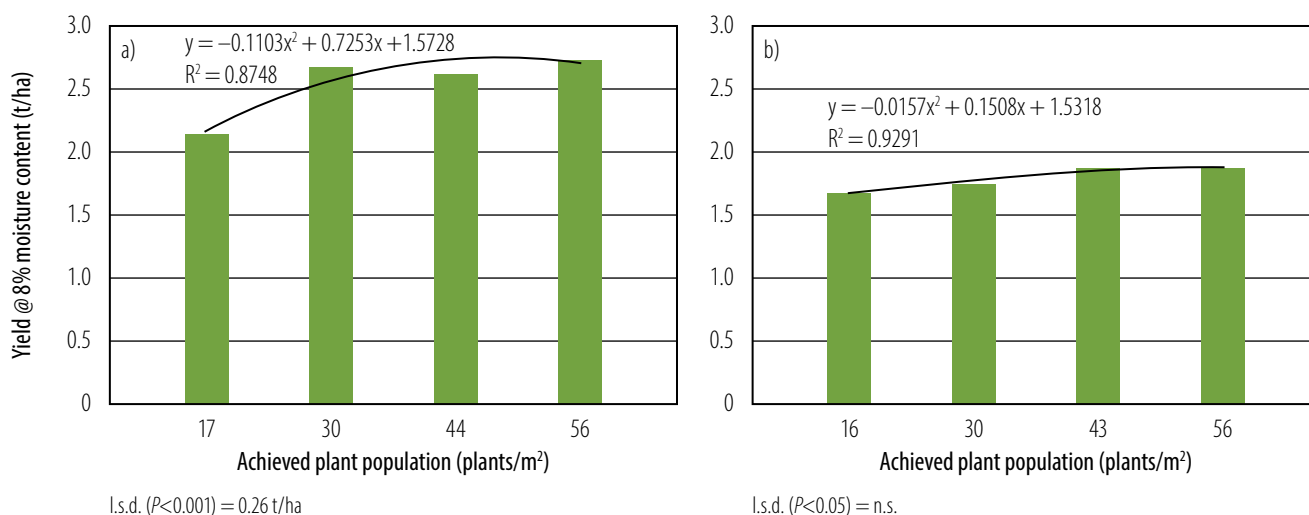
Figure 8   Effect of population on safflower yield at a) Tulloona and b) Breeza in 2015.

Harvest index

Harvest index (HI) is the ratio of harvested grain to above-ground total dry matter. It gives an indication of crop reproductive efficiency. There was no significant difference (P<0.05) in HI between both sites. The average HI at Tulloona was 0.21 and 0.24 at Breeza.
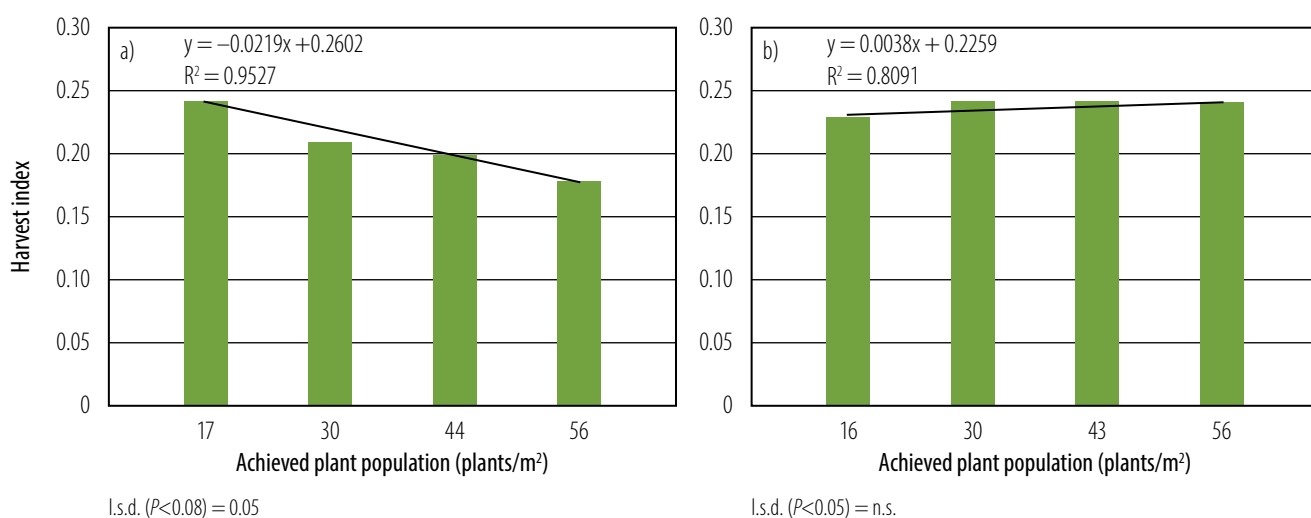
a) $y = -0.0219x + 0.2602$
$R^2 = 0.9527$

b) $y = 0.0038x + 0.2259$
$R^2 = 0.8091$

l.s.d. ($P<0.08$) = 0.05

l.s.d. ($P<0.05$) = n.s.

Figure 9   Effect of population on safflower harvest index at a) Tulloona and b) Breeza in 2015.

Seed size

Seed size is expressed as the weight of 100 seeds. The average seed size, expressed at 8% moisture content in both experiments was 3.39 g, however, there were only significant differences in the response of seed size to plant population at Tulloona (Table 5). Seed size was significantly smaller at populations of 44 and 56 plants/m^2 compared with lower populations (l.s.d. ($P<0.05$) = 0.09 g). There was no significant difference in seed size at populations of 17 and 30 plants/m^2.

Table 5   Effect of population on safflower seed size in 2015.

Target population (plants/m^2)	Seed size (g/100 seeds)	
	Tulloona	**Breeza**
10	3.46 [a]	3.40 [a]
20	3.41 [ab]	3.37 [a]
30	3.36 [b]	3.44 [a]
40	3.33 [b]	3.33 [a]
Site mean	3.39	3.39
l.s.d.	0.09*	*ns

*Values with the same letter are not significantly different at 95% ($P<0.05$).

Conclusions

These experiments demonstrated the response of safflower to population differences under dryland conditions.

Population affected the start of flowering, however, small differences would not make an important difference in the broader crop situation. The timing of flowering had a greater effect on crop performance, specifically the risk of heat and drought stress during the flowering and grain fill periods, as was shown in the Breeza experiment. Flowering ceased at Breeza when temperatures reached 40 °C, and we suggest this to be a maximum threshold temperature. We suspect that the maximum threshold temperature is most likely much lower, but is yet to be determined.

Safflower adapted to variable plant populations in these experiments, however sowing date affected the extent of this compensatory ability. Sowing early increased the early vegetative development and crop canopy, essential to building plant reserves through assimilates produced by photosynthesis. Then these reserves were used for grain development and seed fill. Later sowing shortened this

vegetative phase, thereby limiting leaf area and canopy development. This effectively placed a limit on the potential grain yield.

Plant population had no significant effect on leaf area at Breeza with only small differences in sunlight interception of the canopy. Therefore, we assumed that the photosynthetic capacity was the same across all populations and set a similar limit to yield potential – the result was no difference in yield across all populations.

Our data shows that increasing population at later sowing dates did not increase yield or seed size.

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Safflower: Response to row configuration and population under different irrigation regimes in 2014

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Key findings

- The current commercial safflower varieties, Sironaria and S317, have similar agronomic characteristics including plant structure, flowering time and yield potential.

- Flowering duration was consistently 10 days, irrespective of irrigation regime or row spacing. Increasing plant population progressively shortened the flowering phase.

- Safflower sown at 34 cm row spacing in a four-plant row configuration yielded 25% more than when sown at 60 cm row spacing in a three-plant row configuration.

- Safflower has considerable compensatory ability to maintain yield at various plant populations. Yield was maximised at plant population thresholds of between 20 and 40 plants/m^2. Yield declined at populations of 10 and 60 plants/m^2.

- Under a dryland regime (full soil water profile at sowing), yield progressively declined as populations increased above 20 plants/m^2.

- The dryland regime significantly out-yielded the two in-crop irrigation treatments at target populations of 10 and 20 plants/m^2.

- A single irrigation applied at early elongation consistently out-yielded the dryland and two in-crop irrigation treatments.

- Compared with other treatments, two in-crop irrigations reduced yield. Two in-crop irrigations had no significant effect on yield at populations of 20 plants/m^2 and greater.

- Increasing populations from 10 plants/m^2 to 40 and 60 plants/m^2, decreased seed size by 9%. Seed size was not affected by irrigation regime or row configuration.

- Plant height and the height above ground of the lowest flower increased as population increased. Effects on plant structure would not present harvest difficulties.

Introduction

Historically, safflower (*Carthamus tinctorius*) production has been regarded as a secondary crop. Grown intermittently in northern NSW, its inclusion in farming systems has been limited. Safflower is generally regarded as an opportunity crop and/or crop diversification option, grown under area contracts and/or where seasonal breaks are too late for main season winter crop production. Safflower can be grown as a biological means to manage soil compaction in cotton production systems.

Usually, two public varieties were grown, each suited to one of two main markets. Sironaria is suitable for birdseed and small animal feed mixes; S317 is an oleic oil variety that is exported as either oil or as seed, depending on the costs of crushing and oil extraction at the time. Oleic oil is used in the food industry, supplying manufacturers, wholesalers and food service operators.

Safflower 'Tactical agronomy of minor crops (safflower, linseed, sunflower)' (DAN00197) was a co-funded project between NSW DPI and the Grains Research and Development Corporation (GRDC). A major objective was to determine the agronomic constraints to yield potential in safflower in northern NSW.

Industry consultation at the start of the project revealed that the few growers in northern NSW held wide-ranging views about safflower agronomy. There were diverse views regarding optimal plant populations, general seeding rates and suitable row spacing for optimal production under dryland and irrigation production systems. Knowledge of the effects of management on crop yield and other agronomic attributes was not known.

This paper reports on the response of safflower grown in different row configurations comprising four target plant populations under three irrigation regimes at Narrabri in 2014. This information will be used to develop agronomic recommendations for safflower in northern NSW.

Site details		
Location	Australian Cotton Research Institute (ACRI), Narrabri.	
Soil type	Grey vertosol.	
Configuration	• Three plant rows at 60 cm row spacing on 2-metre-wide raised beds. • Four-plant rows at 34 cm row spacing on 2-metre-wide raised beds.	
Sowing date	21 July 2014.	
Fertiliser	50 kg/ha Granulock® Z applied at sowing.	
Herbicide	• Pre-emergent: 2.25 L/ha Stomp® (pendimethalin). • Post emergent: 75 mL/ha Verdict® (haloxyfop).	
Starting soil water	380 mm.	
Harvest date	20 December 2014 (150 Days after sowing - DAS).	
Irrigation dates:	1. 11 July (11 days pre-sow) 2. 16 September – early elongation (56 DAP). 3. 29 October – late vegetative phase (89 DAP, 7 days before flowering).	
Soil test results	Table 1	

Table 1   Soil chemical characteristics in June 2014.

Soil depth (cm)	pH$_{Ca}$	Nitrate nitrogen (mg/kg)	Ammonium nitrogen (mg/kg)	Colwell phosphorus (mg/kg)	Colwell potassium (mg/kg)	Sulfur (mg/kg)	Zinc (mg/kg)	Salinity (dS/m)	Organic carbon (%)
0–10	7.7	11	4	55	507	28.3	32.65	0.214	1.89
10–20	8.1	13	3	37	354	46.7	17.81	0.273	0.69
30–60	8.4	5	3	41	336	23.4	-	0.164	0.51
60–90	8.6	3	2	51	381	21.8	-	0.196	0.54
90–120	8.7	3	2	58	399	32.8	-	0.214	0.49

Seed quality

Seed used in the experiment was tested for quality before sowing. The seed size and germination percentage of Sironaria and S317 were 3.5 g/100 seeds and 3.6 g/100 seeds and 81% and 68% respectively. Seeding rates were calculated based on the assumption of 80% establishment.

Equivalent seeding rates are shown in Table 2. These were calculated according to seed size; germination and establishment percentage.

Table 2   Experiment plant populations and equivalent seeding rates in 2014.

Population (plants/m²)	Sironaria (kg/ha)	S317 (kg/ha)
10	5	7
20	10	13
40	20	27
60	30	40

Sowing

The experiment was sown into soil moisture suitable for germination 11 days after irrigation. Seeding depth averaged 68 mm. Soil temperatures at 10 cm deep at 9:00 am AEST during the week immediately following sowing varied between 8.9 °C and 16.8 °C, averaging 11.9 °C.

Site climate details

Temperatures throughout the growing season varied between −4.2 °C and 44.1 °C (Figure 1). Average minimum and maximum temperatures were 10.8 °C and 28 °C respectively. Total in-crop rainfall was 168 mm.
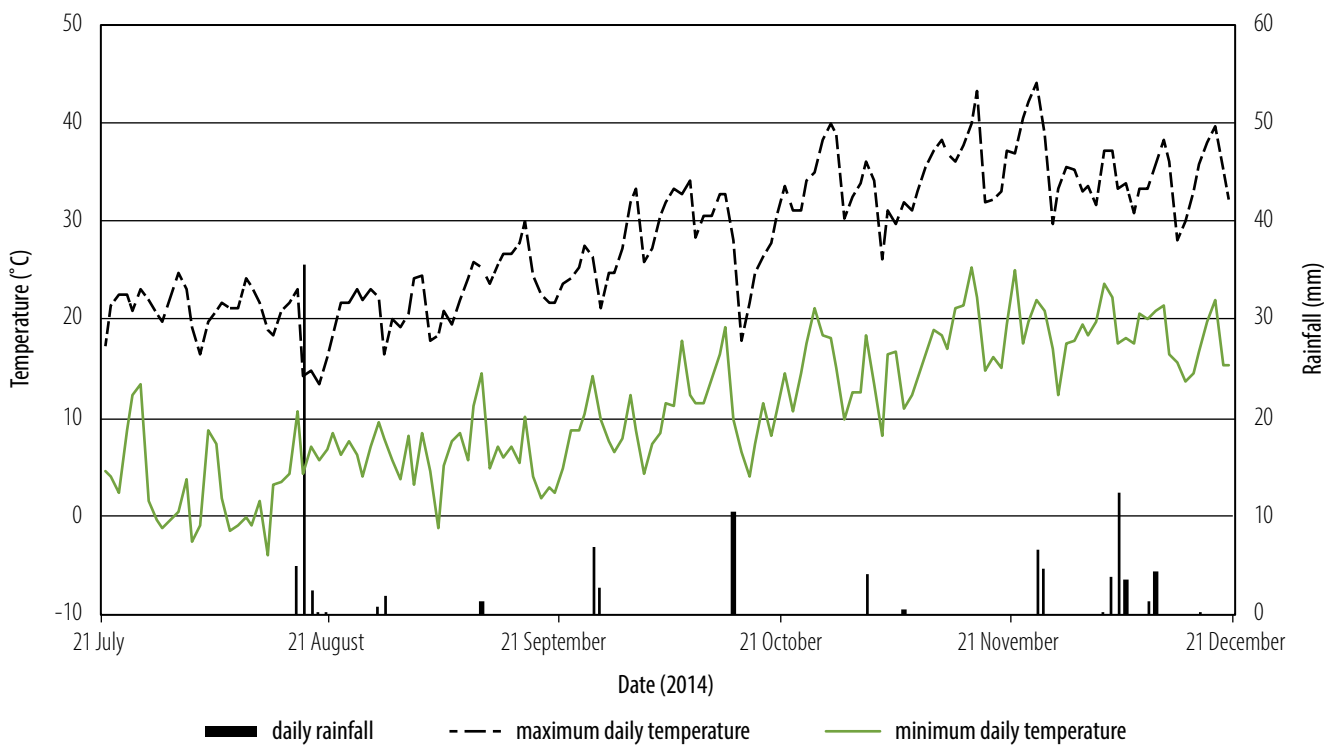

Figure 1   Experiment climate information in 2014.

Experiment design	A split-plot design with irrigation treatment as the main block, and row spacing as sub-plots with plant populations randomised within sub-plots; three replications was used.

Treatments

Irrigation	1. Dryland
	2. One irrigation at early elongation
	3. Two irrigations: at early elongation and at late vegetative phase

Varieties	Sironaria, S317

Row spacing (cm)	34, 60

Population (plants /m^2)	10, 20, 40, 60

Results

Effects of irrigation treatment

Plant structure

The height of safflower at 50% flowering (F50) averaged 92 cm across the site. Where one irrigation was applied at early crop elongation, plant height was significantly shorter at 89.9 cm ($P<0.05$; l.s.d. 2.7 cm). There was no significant difference between the crop height in the dryland and two irrigation treatments, measuring 93 cm and 94 cm respectively. The height of the lowest flower averaged 61 cm with no significant difference between irrigation treatments. These measurements indicate grain capture during harvest as this height is above the minimum harvester setting.

Flowering timing and duration

Safflower development was significantly affected by irrigation management ($P<0.001$; l.s.d. 1 day), even though effects were small. Safflower receiving one in-crop irrigation reached F50 105 DAS. Flowering in the dryland and two irrigation treatments was delayed by two days, both reaching F50 at 107 DAS.

These differences carried through to the end of flowering when 95% of plants had ceased flowering (F95). The dryland and two irrigation treatments ceased flowering 117 DAS. This was two days later than the one irrigation treatment at 115 DAS ($P<0.05$; l.s.d.1 day).

Regardless of irrigation treatment, the flowering period was 10 days.

Yield and seed size

Irrigation treatment had no significant effect ($P<0.05$) on yield or seed size. The average site yield was 1.29 t/ha and seed size 2.8 g/100 seeds.

Yields showed no irrigation treatment interactions with row configuration or variety, however a significant interaction ($P<0.05$) was measured in the yield response to population (Figure 2).

Yields were highest where one irrigation was applied, increasing yield by 0.15 t/ha when plant population increased from 10 to 20 plants/m^2, before plateauing at populations of 20 and 40 plants/m^2. Yield in the dryland treatment progressively declined at populations greater than 20 plants/m^2. Yields were depressed where two in-crop irrigations were applied. Compared with the dryland treatment, there was no significant difference in yield where two irrigations were applied at populations of 20 plants m^2 or greater.
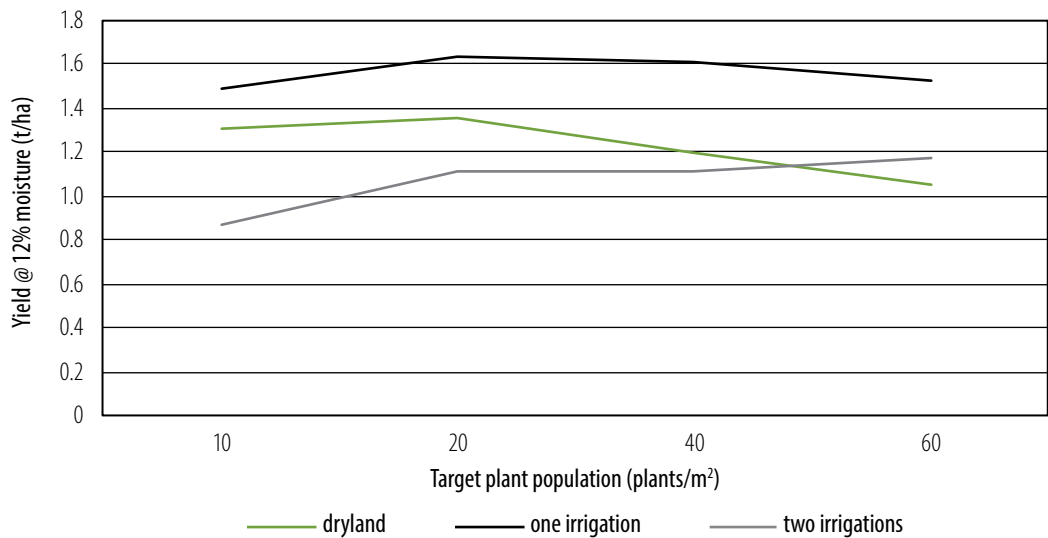
l.s.d. (*P*<0.05) = 0.47 t/ha

Figure 2　Interaction of irrigation with plant population on safflower yield in 2014.

Effects of row configuration

Plant architecture

Safflower planted in four plant rows at 34 cm row spacing were significantly taller at physiological maturity than when planted in three rows spaced at 60 cm (*P*<0.05; l.s.d. 1.1 cm) – 93.1 cm and 91.6 cm respectively. Row configuration had no significant effect (*P*<0.05) on the height of the lowest flower – average 61 cm.

Flowering timing and duration

Row configuration had small but significant effects on flowering. Safflower planted at 60 cm row spacing flowered 106.9 DAS, significantly quicker than safflower planted at 34 cm row spacing – 105.6 DAS (*P*<0.001; l.s.d. 0.3 days). The duration of flowering was 10 days for both 34 cm and 60 cm row spacings.

Yield and seed size

Safflower planted into four plant rows at 34 cm spacing yielded 1.48 t/ha, a 26% increase in yield compared with the three row 60 cm configuration (1.09 t/ha). The interaction between row spacing and plant population on yield were not significant (data not shown).

Row spacing had no significant effect on seed size (*P*<0.05).

Effects of population

Target populations were 10, 20, 40 and 60 plants/m². Crop establishment populations achieved were 17, 26, 44 and 61 plants/m² respectively.

Plant structure

Safflower planted to target populations greater than 20 plants/m² were significantly taller than plants planted to target populations of 10 plants/m², 92–94 cm and, 90 cm (*P*<0.001; l.s.d. 1.6 cm).

Population had a significant effect on the height of the lowest flower (*P*<0.001; l.s.d. 2.3 cm). At a target population of 10 plants/m² the lowest flower was 56 cm above ground level. There was no significant difference at target populations of 20 plants/m² and 60 plants/m² (92.4 cm and 92.6 cm respectively) or between 40 plants/m² and 60 plants/m² (64.4 cm and 63.6 cm respectively).

Flowering timing and duration

Safflower planted at a target population of 10 plants/m^2 and 20 plants/m^2 were quicker to reach F50 and were first to cease flowering compared with the higher target populations of 40 plants/m^2 and 60 plants/m^2. These flowering times were significantly different ($P<0.001$) in both cases, but differences amounted to one day or less (data not shown).

A small but significant ($P<0.001$) shortening of the flowering phase was measured as population increased, a difference of 1.5 days between 10 and 60 plants/m^2.

Yield and seed size

Safflower population showed distinct threshold effects on yield. Safflower yield was significantly higher at target populations of 20 plants/m^2 and 40 plants/m^2 ($P<0.05$; l.s.d. 0.11 t/ha) (Figure 3). At target populations of 10 plants/m^2 and 60 plants/m^2, yields were significantly lower.

$$y = -0.0502x2 + 0.2529x + 1.0303$$
$$R^2 = 0.8084$$

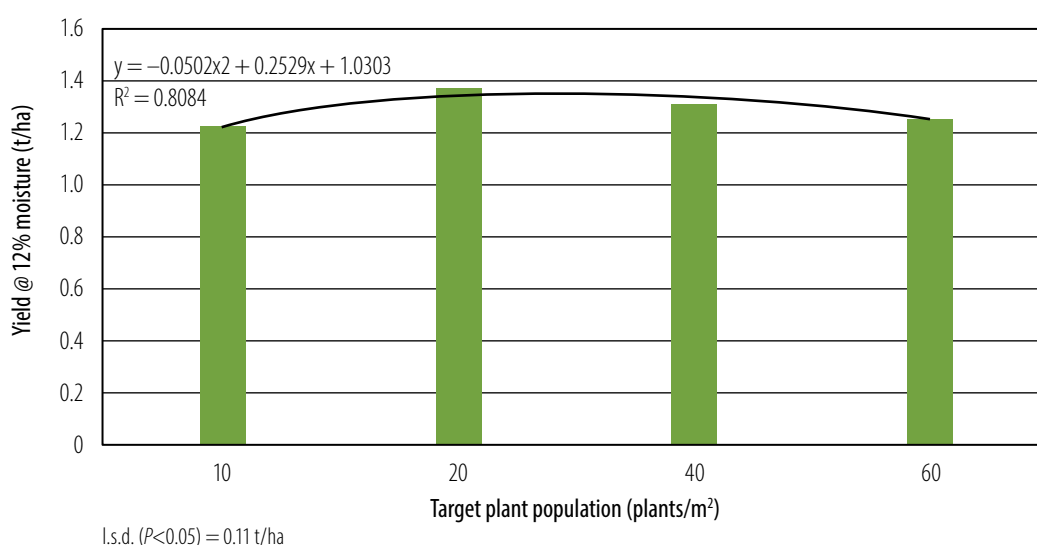l.s.d. ($P<0.05$) = 0.11 t/ha

Figure 3 Effect of population on safflower yield in 2014.

Seed size was significantly larger at a target population of 10 plants/m^2 – 2.3 g/100 seeds ($P<0.001$; l.s.d. 0.12 g). Seed size at a target population of 20 plants/m^2 or higher was smaller, showing a declining seed size as population increased (data not shown). The average seed size in this experiment was 2.78 g/100 seeds.

Effects of variety

The two varieties planted in this experiment were similar in all main agronomic characteristics that were investigated. There were no significant differences ($P<0.05$) in plant architectural characteristics; timing and flowering duration; yield and seed size (data not shown).

Conclusions

Currently Sironaria and S317 are the two most common varieties of safflower grown in northern NSW. Both varieties are similar in major agronomic traits including plant architecture, flowering time and yield performance, with the exception of oil quality and visual seed appearance.

Our research showed that plant population had the largest influence on yield. This suggests that historic industry seeding rates of safflower of up to 60 kg/ha could be incurring considerable yield penalties. Safflower demonstrated considerable ability to adapt yield across a range of populations where equivalent seeding rates were 10–20 kg/ha (cv. Sironaria). Distinct thresholds where yield declined were at populations of 10 plants/m^2 and 60 plants/m^2 across the irrigation regimes.

Safflower has deep roots. Accessing soil water deep in the soil profile maintained yield potential in this experiment at populations of 20 plants/m^2 in all irrigation treatments. We suggest an optimal population of 20 plants/m^2 for dryland production. The dryland treatment yield of 1.35 t/ha at 20 plants/m^2 compares favourably with the average commercial dryland yield of 1–1.2 t/ha reported by growers.

A single irrigation applied at early elongation, maintained yield potential at 20–40 plants/m^2. However, the additional water increased yield by only 0.28 t/ha (at 20 plant/m^2) and 0.41 t/ha (at 40 plants/m^2) compared with the dryland treatment. Our results highlight the type of information required when considering tactical irrigation management. Irrigation costs and the value of the potential yield response would be fundamental in deciding whether to irrigate or not.

Two in-crop irrigations depressed yield at all populations. We suspect that transient periods of waterlogging occurred in this experiment.

Further investigation of the water use patterns and safflower's crop lower limit in major soil types will enable guidelines to be developed for yield potential in situations with different seasonal outlooks, water costs and water availability. This information is required to develop tactical irrigation management strategies, especially in situations when there are low soil water levels at planting.

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Monitoring aphids as virus vectors in 2019 in northern NSW

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Key findings

- Aphid movements peaked during August and September 2019.

- Of the 19 aphid species found on chickpea, faba bean and lucerne at seven sites in 2019, the most recorded were cowpea aphid (*Aphis craccivora*), spotted alfalfa aphid (*Therioaphis trifolii*), blue-green aphid (*Acyrthosiphon kondoi*), pea aphid (*Acyrthosiphon pisum*), green peach aphid (*Myzus persicae*), oat aphid (*Rhopalosiphum padi*), and *Brachycaudus rumexicolens*.

- First seen in faba bean crops in Australia in 2017 Australia, the faba bean aphid (*Megoura crassicauda*) was not recorded in 2018 or 2019.

- Aphid numbers at all sites were significantly lower than previous years, probably due to the extremely dry conditions during the 2019 spring and the increased populations of beneficials.

Crop protection

Introduction

Aphids can be very destructive crop pests, especially in warm climates as found in the northern Australian grain belt. In temperate regions, the sexual phase of their lifecycle is usually missing, but the warmer climates allow aphids to reproduce extremely fast, depending on local conditions.

In northern NSW, aphid populations usually survive over summer on weeds in very low numbers. Aphid populations increase at the beginning of autumn when there is an abundance of host plants and mild temperatures. Winged aphids can build up under favourable conditions and can migrate over long distances transferring viruses from summer hosts to winter crops.

Dense aphid colonies can cause severe damage from feeding on the growing tips of young crops in autumn. In addition, aphids act as virus vectors and can transmit viruses either persistently or non-persistently, depending on the virus. Persistently transmitted viruses require the aphid to feed for a longer period on an infected plant's phloem, after which the aphid is infectious for the rest of its life. Non-persistently transmitted viruses are absorbed by the aphid in less than a minute, but the aphid will lose the virus after probing one or two healthy plants.

In chickpea there are several aphid-transmitted viruses that are considered problematic, including the *Turnip yellow virus* (TuYV) complex, *Bean leafroll virus* (BLRV), *Cucumber mosaic virus* (CMV), and *Alfalfa mosaic virus* (AMV).

The purpose of this experiment was to better understand virus vector epidemiology and to develop non-genetically based control strategies for the main pulse crop viruses. These strategies should aim to prevent virus transmission by aphids either by minimising aphid landings in the crop or by killing the aphid with an insecticide before plant probing occurs. Both approaches require an in-depth understanding of aphid movements and behaviour within pulse crops. To support this, a collaboration was developed across different institutions to ensure a broad approach for surveying and collecting data on aphid movement in a variety of pulse crops.

Site details

In 2019 aphid monitoring sites were established at seven locations:

1. Liverpool Plains Field Station (LPFS) Breeza, field #8 and field #2, GPS 31° 10' 41.3" S, 150° 25' 28.0" E
2. Breeza 2 (Pursehouse Rural), GPS 31°18'19.5"S, 150°25'24.4"E

3. Tamworth Agricultural Institute (TAI, Paddock 24), GPS 31°08′46.4″S, 150°58′11.1″E

4. Spring Ridge, Nowley Rd, GPS 31°20′47.4″S, 150°06′41.5″E

5. Australian Cotton Research Institute (ACRI) Narrabri, GPS 30°11′41.7"S, 149°36′28.7"E

6. Trangie Agricultural Research Centre (TARC) Trangie, GPS 31°58′24.8" S, 147°55′54.4"E

7. Commercial chickpea field Jandowae East (southern QLD), GPS 26°46′45.90"S, 151°12′33.61"E.

Aphid movement was monitored in different pulse crops:

- Chickpea: five sites – LPFS Breeza, field 8; Spring Ridge; ACRI Narrabri; TARC Trangie; Jandowae East.
- Faba bean: two sites – LPFS Breeza, field 2; Breeza 2.
- Lucerne: TAI, Paddock 24.

Methodology

Various trapping methods were used including yellow sticky traps (YST), yellow pan traps (YPT) and suction traps (ST). Depending on the trapping method and the time of the year, traps were checked every seven to 15 days. Species were identified using the morphological characteristics of collected aphids.

YPT were set up at LPFS Breeza in faba bean crops and in trials with four chickpea genotypes with contrasting leaf colour and growth habits.

ST were set up at three sites:

1. LPFS Breeza (chickpea and faba bean)

2. Spring Ridge (chickpea)

3. Jandowae East (chickpea).

Suction traps are designed to collect winged aphids without the assistance of a motorized fan. The trap spins on the top of a steel pole to face the current wind direction (Figure 1). Aphids are blown into a funnel and collected in a container filled with propylene glycol.

Figure 1   Suction trap in chickpea crop.

Chickpea and faba bean virus experiments were sown at LPFS Breeza to compare aphid movement. The transmission of two viruses (BLRV and AMV) was tested using three aphid species as vectors (cowpea aphid, pea aphid and blue–green aphid). The experiment was sown as a split-plot design with two replicates and plot sizes of 7.5 m × 6 m. AMV- and BLRV-infested faba bean plants with viruliferous

aphids were placed in the middle of each plot on 28 August 2019. At the end of the season, random plant samples taken from the chickpea and faba bean virus experiment were tested for virus presence using tissue blot immunoassay (TBIA).

Visual observation and scouting for faba bean aphids was conducted regularly (every 10–15 days) during winter 2017, 2018 and 2019 in faba bean crops at TAI and Breeza.

Results

Monitoring incoming aphids

Results from YST placed in chickpea at Breeza, Narrabri, Spring Ridge, Trangie, and Jandowae (Figure 2a), and in faba bean and lucerne at Breeza and TAI (Figure 2b), showed a similar pattern of aphid presence throughout the 2019 winter. The highest caught number was 5625 aphids/m^2/day in a lucerne crop at TAI in early July (Figure 2b). The highest recorded number in chickpea was 4469 aphids/m^2/day at Breeza in early August. Different species were recorded on YST, the main species being cowpea aphid, spotted alfalfa aphid, blue–green aphid, pea aphid, green peach aphid, oat aphid, and Brachycaudus rumexicolens.
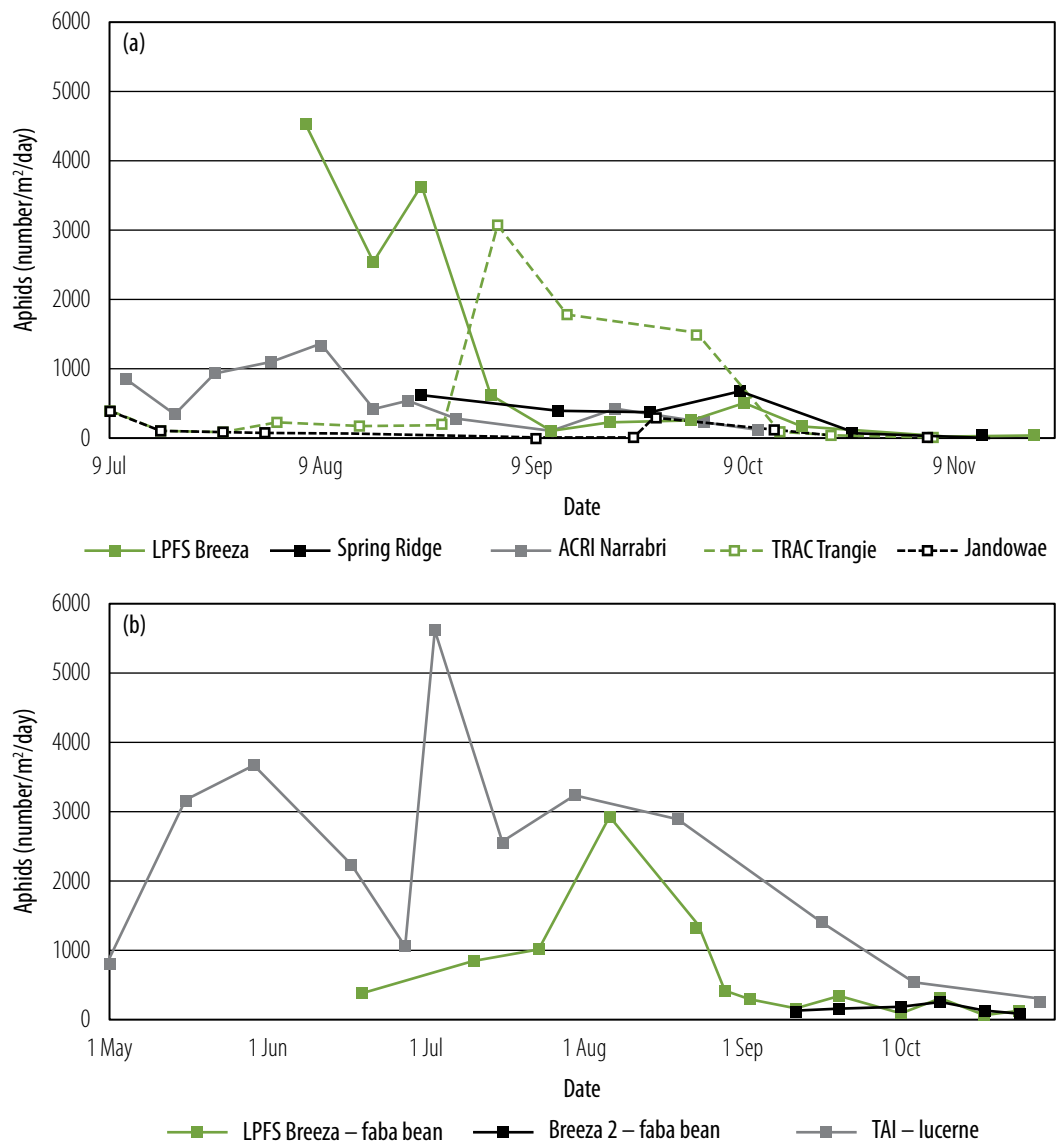
Figure 2   Aphids caught on yellow sticky traps in (a) chickpea and (b) faba bean and lucerne in 2019.

Aphid numbers captured on YST during 2019 (Figure 2) were higher than those in 2017 (Figure 3) and 2018 (Figure 4). One major peak was observed in the period from July–September. At the same time the population of beneficial insects increased, including ladybeetles, lacewings, hoverflies and parasitic

wasps (Figure 5). The aphid numbers on YST declined at Breeza and Narrabri from mid-August, and from early September at Trangie likely as the result of the increased temperatures and the presence of beneficial insects.
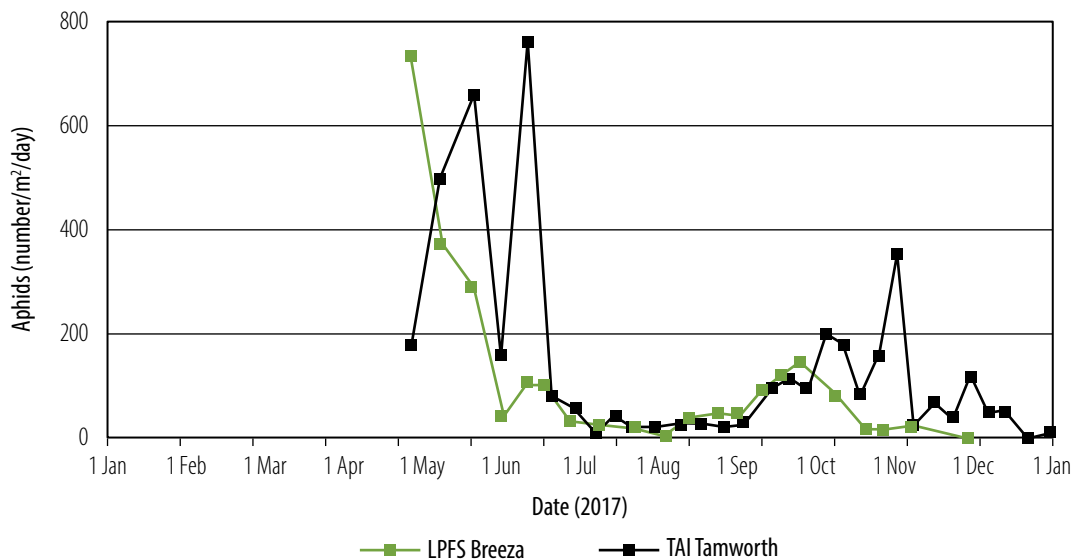
Figure 3   Aphids caught on yellow sticky traps, Tamworth Agricultural Institute and Liverpool Plains Field Station, 2017.
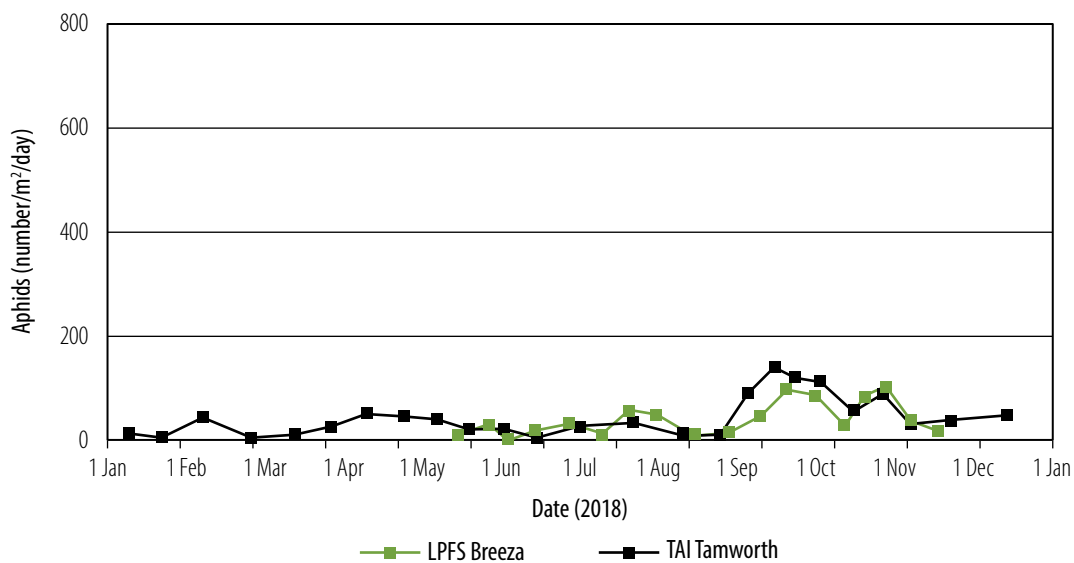
Figure 4   Aphids caught on yellow sticky traps, Tamworth Agricultural Institute and Liverpool Plains Field Station, 2018.

Figure 5   Ladybeetles in faba bean in LPFS Breeza on 28 August 2019.

The highest number of 23 aphids/day on ST was recorded in a faba bean crop on 6 August at Breeza (Figure 6). The number of aphids caught with ST appear to be lower than those caught on YST, because the YST calculations are based on the area of the traps. However, relative numbers between the different methods are comparable and incoming aphids at both trap types show similar patterns (Figure 2, Figure 6). One major advantage of the ST compared with YST is that aphids collected in these traps are well-preserved and not damaged and therefore easier to identify.
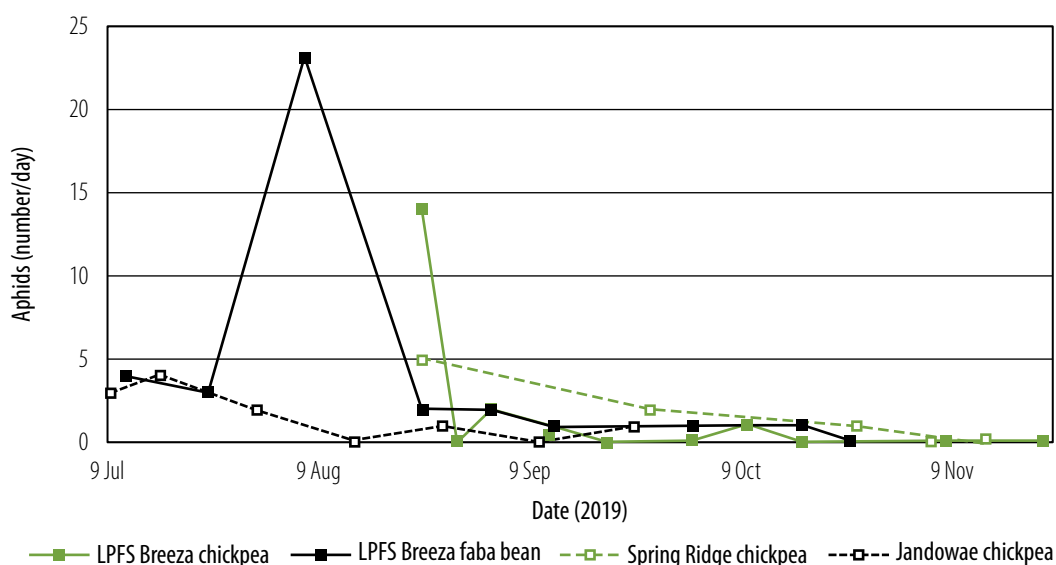
Figure 6   Aphids caught with suction trap in 2019.

Aphid landing rates

Aphid landing rates were tracked at Breeza using YPT from 20 July– 24 October 2019 in faba bean, and from 7 August–21 November 2019 in four chickpea genotypes (PBA HatTrickA, PBA MonarchA, Gully, and ICCO3996). The contrasting leaf colour and growth habits of these four genotypes were chosen to test their attractiveness to aphids.

There was a difference in aphid numbers at the beginning of the season, with the highest number found in the chickpea variety Gully (1056 aphids/m^2/day), followed by ICCO-3996 (1014 aphids/m^2/day), then PBA MonarchA (817 aphids/m^2/day) with the lowest number in PBA HatTrickA (397 aphids/m^2/day) (Figure 7). The number of aphids caught fell during September, probably the result of the drought and the increasing populations of beneficial insects.
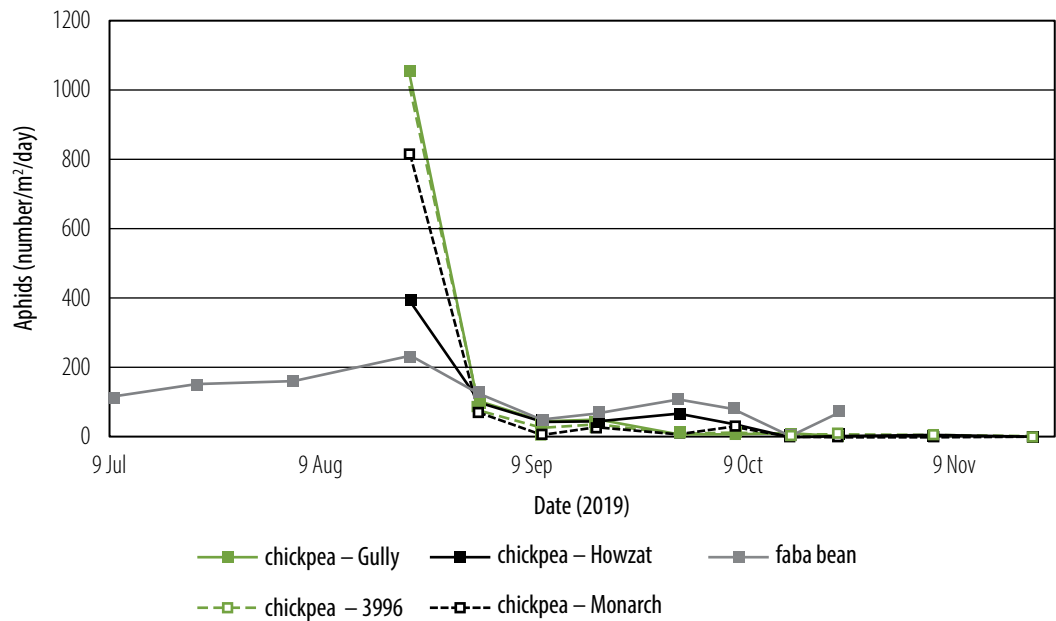
Figure 7   Aphids caught in yellow pan trap in 2019 in LPFS Breeza.

Identified aphid species

Table 1 shows the results of the aphid species collected using a range of trapping. Besides cowpea aphid, spotted alfalfa aphid, blue–green aphid, pea aphid, green peach aphid, oat aphid, Brachycaudus rumexicolens, and cabbage aphid (Brevicoryne brassicae), the other aphid species were found only in small numbers.

Table 1   Aphid species collected using different trapping methods.

No	Identified aphid species		
	Yellow pan traps	**Yellow sticky traps**	**Suction traps**
1	*Aphis craccivora*		
2	*Acyrthosiphon pisum*		
3	*Acyrthosiphon kondoi*		
4	*Therioaphis trifolii*		
5	*Myzus persicae*		
6	*Capitophorus eleagni*		
7	*Aphis gossypii*		
8	*Brachycaudus rumexicolens*		
9	*Lipaphis erysimi*		
10	*Rhopalosiphum maidis*		
11	–	*Tetraneura nigriabdominalis*	
12	–	*Rhopalosiphum padi*	
13	–	*Brevicoryne brassicae*	
14	–	*Macrosiphum euphorbiae*	–
15	*Brachycaudus helichrysi*	–	–
16	–	–	*Myzus cerasi*
17	–	*Diuraphis noxia*	–
18	–	*Uroleucon erigeronensis*	–
19	–	*Smynthurodes betae*	–

The first report of faba bean aphid in Australia was in October 2016 (Hales et al., 2017). In September 2017 the faba bean aphid was confirmed at TAI and LPFS Breeza. The infested paddocks were treated with Aphidex (500 g pirimicarb/kg) at the end of the 2017 season. Further observations in November 2017 did not reveal any faba bean aphid. No faba bean aphids were detected during the winters of 2018 and 2019.

Virus transmission experiment

Aphid natural enemies (ladybeetles, hoverfly larvae, parasitic wasps and lacewings) were present in large numbers in the field when the pots containing viruliferous aphids were placed in the crop. These had a major effect on the virus transmission results. TBIA only identified eight positives (5 BLRV and 3 AMV) out of 240 randomly collected plant samples.

Conclusions

During the 2019 winter aphid activity peaked in August, with numbers declining due to early drought-induced crop maturity and the high numbers of beneficial insects.

A comparison of sites in northern NSW and southern Queensland shows some similarities between locations during the 2019 winter season. The correlation between the monitoring sites is encouraging, however, more data is needed from average rainfall years to study similarities in aphid movement between geographically distinct sites in order to develop an aphid management strategy.

Reference

Hales DF, Gillespie PS, Wade S and Dominiak BC 2017. First detection of *Megoura crassicauda* Mordvilko (Hemiptera: Aphididae) in Australia and a review of its biology. *General and Applied Entomology* 45: 77–81.

Acknowledgements

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Crop protection

Stubble Olympics: the cereal pathogen 10 cm sprint – growth patterns of crown rot, common root rot and yellow leaf spot fungi in post harvest cereal stubble.

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Key findings

- The pathogens that cause cereal diseases such as crown rot (CR), common root rot (CRR) and yellow spot (YLS) can grow within cereal stubble after harvest under high humidity. Inoculum levels in cereal stubble can increase above harvest levels in wet weather.

- The levels of disease resistance to CR, CRR or YLS in the varieties and crops tested do not appear to slow or limit pathogen growth after harvest, and therefore did not influence post harvest inoculum accumulation. However, variety and crop selection for disease resistance in-crop is still a useful disease management strategy.

- In stubble with 100% relative humidity (wet/rainy/foggy/dewy weather), the CR fungus progressed fastest (1 cm/day) with the YLS pathogen the slowest (0.4 cm/day). This is likely to influence which pathogen dominates in following seasons if there are mixed infections in the same crop.

- A reduction in cereal stubble biomass might limit CR, CRR and YLS growth after harvest in stubble and reduce the amount of inoculum carried forward. Options could include selecting low-biomass varieties, low harvest heights or cutting for hay, but field validation is required.

Introduction

Fusarium crown rot, YLS or tan spot and CRR are important stubble-borne cereal pathogens. The diseases these pathogens cause are very difficult to control in cereal stubble-retention systems as the inoculum is preserved in the previous years' cereal rows. Not much is known about what these pathogens do in the stubble after harvest of an infected crop, except that they generally persist long enough to cause disease in following seasons.

Reports of pathogen growth in post harvest cereal stubble, also known as saprophytic growth (i.e. growth on dead or decaying matter), has been reported, but it is still unclear if this growth contributes to inoculum build-up or disease risks in future cereal crops. Saprophytic growth of CR can be rapid (1 cm/day) in cereal stubble if moisture is not limiting (Petronaitis et al., 2020). But how much moisture do we need for saprophytic growth to start, and is it the same for other pathogenic fungi such as *Bipolaris sorokiniana* (CRR causative agent) and *Pyrenophora tritici-repentis* (YLS causative agent) in different cereal stubbles?

Knowing how these pathogens behave in post harvest cereal stubble could be the key to controlling them effectively in conservation agriculture systems. To answer these questions an experiment, named the Stubble Olympics was set up, to explore the following questions:

1. What moisture conditions induce saprophytic growth in these different pathogens?
2. How far and fast will inoculum progress under such conditions?

3. Can crop selection or other management strategies be used to suppress saprophytic growth?

The Stubble Olympics experiment

Treatments

The contestants in the Stubble Olympics are two isolates each of *F. pseudograminearum*, *B. sorokiniana* and *P. tritici-repentis*. Each isolate was placed inside individual tillers of cereal stubble from four crop types (Table 1). Each was then tested for saprophytic fitness by measuring their growth under controlled moisture conditions ranging from 90% to 100% relative humidity (RH) in 2.5% RH increments. Two varieties of bread wheat and two varieties of barley were selected as having either a relatively susceptible or relatively resistant disease rating for each pathogen.

Table 1 Cereal stubble collection variety information and disease ratings for CR, CRR and YLS. Rating information from *Winter crop variety sowing guide 2019* (Matthews and McCaffrey, 2019).

Cereal species	Variety (class)	Crop location	CR rating	CRR rating	YLS rating
Bread wheat	EGA Gregory (APH)	Narrabri	S	MS–S	S
	LongReach Lancer (APH)	Narrabri	MS–S	S	MR–MS
Durum wheat	DBA Lillaroi (ADR)	Tamworth	S–VS	MS–S	MR–MS
Barley	Compass	Narrabri	S	MS	NA
	Rosalind	Narrabri	MS–S	S	NA
Oat	Eurrabie	Narrabri	NA	NA	NA

Abbreviations: Australian prime hard (APH), Australian premium durum (ADR), not applicable (NA), moderately resistant (MR), moderately susceptible (MS), susceptible (S), very susceptible (VS).

Method

Individual tillers were inoculated at the base with an agar plug with one of the six pathogen isolates. The tiller end was inserted onto a metal nail plate to simulate standing stubble. Humidity chambers (Figure 1) were run for 7 days at constant temperature (25 °C) under alternating ultra-violet light (12-hour light/12-hour dark). Saprophytic growth was measured as the number of tiller segments (1 cm length) and positions (1–10) the pathogen was recovered from the agar.
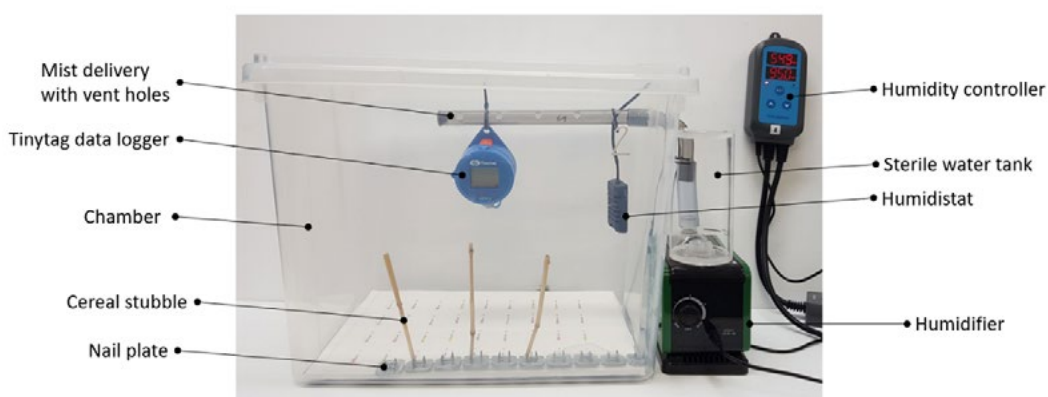

Figure 1 Example of controlled humidity chamber design containing standing stubble.

Experiment design

- Two replicates over time.
- Split-plot design.
- Relative humidity (RH) treatments main plots.
- Crop, variety, pathogen, isolate combinations were sub-plots.

Tamworth Agricultural Institute, controlled temperature room.

Results

Moisture induces saprophytic growth of pathogens in cereal stubble

Moisture (i.e. RH) had a profound effect on the saprophytic growth of all three of cereal pathogens (Figure 2). In general, all pathogens grew further within stems as moisture increased, with little to no growth occurring in the driest treatment (90% RH). Once the moisture was increased to 92.5% RH and 95% RH, the CR pathogen was able to colonise stubble twice as fast as the other two pathogens. The YLS and CRR fungi required moisture levels of 97.5% to progress significantly. The saturated (100% RH) treatment produced the greatest growth up the stubble and the most inoculum. Differences between isolates were not significantly different ($P = 0.05$), so the mean of both isolates are presented.
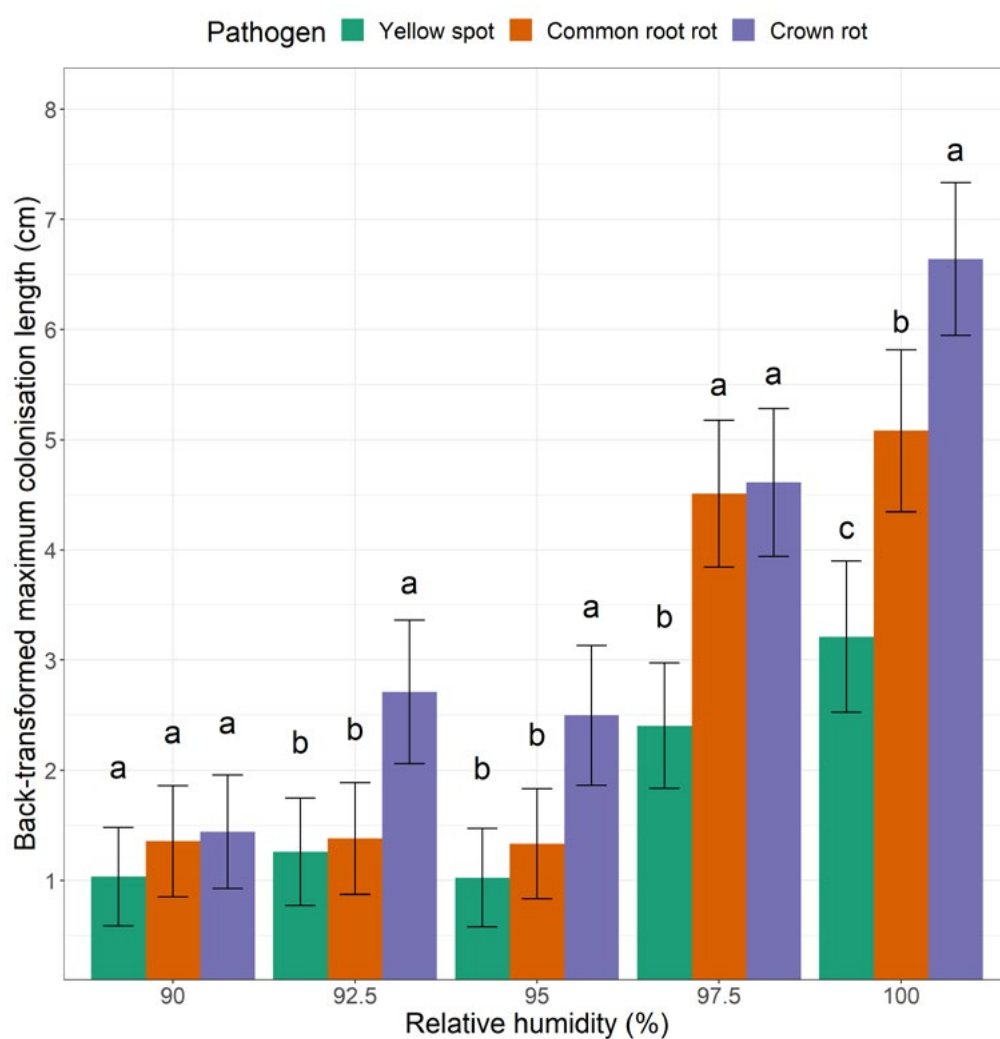
Note: LSD letters only enable comparisons between pathogens within a humidity treatment (not between humidity treatments). Values with the same letter are not significantly different ($P=0.05$).
Error bars represent approximate standard error of the mean.

Figure 2   Maximum colonisation (cm) of cereal stubble by three cereal pathogens subject to different moisture conditions for seven days.

Inoculum progressed most rapidly under moist conditions (which pathogen will take home the gold?)

At 100% RH, the CR pathogen grew significantly faster than the other two pathogens (~1 cm/day – takes home the gold!), while CRR was significantly faster (~0.7 cm/day – silver!) than YLS (~0.45 cm/day – bronze!) (Figure 2).

Multiple-pathogen infections (e.g. CR +CRR) are common in the northern region (Simpfendorfer and McKay, 2019), so it is possible that under saturated conditions (i.e. rainy, dewy or foggy weather) the CR pathogen could rapidly colonise pre-infected stubble, making the disease more likely to dominate in following seasons.

Selecting crops for resistance won't help suppress growth in the saprophytic phase

There were no differences in pathogen speed of progression (cm) (Figure 2) or the percentage of inoculum remaining (Figure 3) between two varieties of the same crop type, regardless of the resistance rating (Table 1). This suggests that varietal resistance does not reduce saprophytic growth (i.e. inoculum production) post harvest.
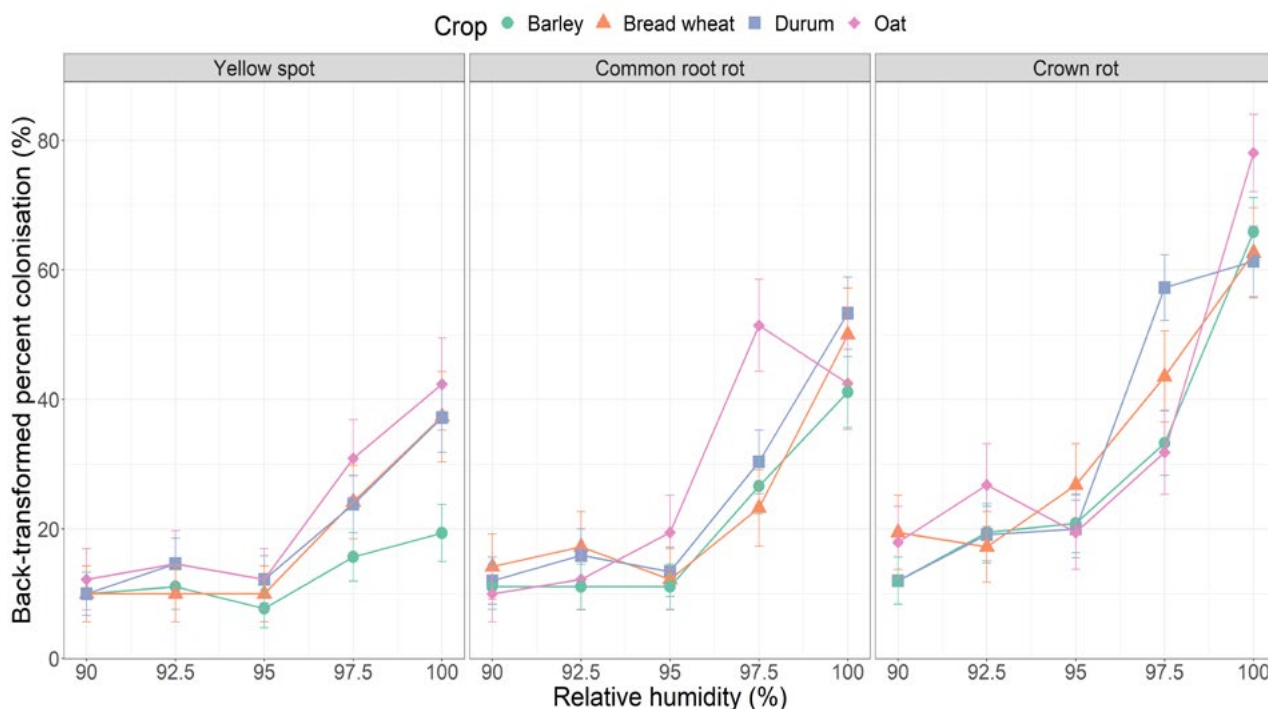
Differences between varieties of the same crop type were not significantly different ($P = 0.05$).
The mean of two varieties of bread wheat and barley are presented.
Error bars represent approximate standard error of the mean ($P=0.05$).

Figure 3   Inoculum produced by three cereal pathogens in different cereal stubble, as a percentage (%) of total stubble length colonised after seven days.

Oats, and barley have no resistance ratings for the selected diseases because they are not considered important hosts. The three disease pathogens produced the same or more inoculum on oat stubble at 100% RH (Figure 3). The YLS pathogen produced significantly less inoculum on bread wheat stubble (a recognised host) under moist conditions compared with the non-host oat ($P = 0.05$). Oat stubble might allow pathogens to progress faster as it has a less dense/hollow stem and a higher nutrient content (i.e. lignin) than wheat or barley. Even if there are only low levels of infection in the growing season, or the disease is not expressed due to favourable seasonal or plant tolerance, there can still be rapid colonisation saprophytically post harvest.

How may this knowledge be important to growers?

Harvest height to manipulate stubble biomass — still a work in progress

Lowering harvest height is a quick way to reduce standing cereal stubble biomass (Figure 4). This could be useful in severely infected paddocks by removing disease inoculum and/or limiting the amount of vertical stubble available for further saprophytic growth. In severe cases, such as CR-affected durum wheat in a dry season, the stubble might already contain high levels of the CR pathogen at harvest (Figure 4). Field testing is underway to determine if saprophytic growth is problematic in taller

stubble with increased inoculum levels after harvest. In addition, the ability of shorter stubble to limit saprophytic growth will be tested as a possible management strategy.

Durum wheat harvested at three heights: 10–15 cm (A), ~30 cm (B) and 40–45 cm (C).
Far right: recovery of CR pathogen (red–brown colonies) shows significant colonisation within the stem at harvest (up to 30 cm). Arrows indicate where the pathogen was recovered from along the stubble length.

Figure 4   Harvest-height disease management experiment.

Modelling saprophytic growth based on weather patterns/predictions — we're in the early days

A constant 25 °C temperature in the humidity chambers enabled a detailed investigation into the pathogen's response to moisture in stubble. Modelling saprophytic growth in the field would require knowledge of pathogen growth patterns across a range of temperatures. This is because the amount of water the air holds (total water) changes with temperature (more water at higher temperatures) even if the RH stays the same. Air gives up moisture more freely at lower temperatures as the dew point is lower, leading to more dewy/frosty or foggy mornings during winter. Determining whether the pathogens respond to total water or dew point/RH or both will be essential for modelling saprophytic growth.

Should growers be concerned about saprophytic growth of pathogens in cereal stubble?

The short answer: be alert, not alarmed

We are still trying to be understand if and how cereal pathogen saprophytic growth during fallow and non-host rotation affects disease risk in following seasons. It is possible that the recent high rainfall in many areas could have spiked pathogen levels before sowing, placing new crops at a higher risk than in previous, drier years. The extended dry conditions (2017–19 seasons) have allowed inoculum to persist at damaging levels for two to four seasons as stubble has not broken down. Be vigilant about checking this years' cereal crops for disease symptoms and consider appropriate in-crop management strategies if necessary.

Seasonal conditions can affect cereal stubble biota, both good and bad, during fallows and non-host rotations, with stubble not being dormant during these times.

Conclusions   **Dry conditions**: allow inoculum and cereal stubble to persist longer in paddocks, as beneficial microbes that suppress pathogens and promote stubble decomposition require high moisture to be effective. The CR pathogen is especially suited to survival and growth in drier conditions.

Wet conditions: can potentially increase inoculum (such as those applied in this study), but cereal stubble will also decompose faster in prolonged wet weather. Moisture can increase the activity of beneficial microbes, helping with stubble decomposition and pathogen suppression. Moist conditions also stimulate these pathogens to produce spores, which can persist in soil for many years even when there is no stubble (e.g. conidia of CRR pathogen).

PREDICTA® B testing is a very effective method for determining paddock disease risk if the correct sampling protocols are followed. If your paddock/s returns a low risk or below detection level in the PREDICTA® B test, continue following best practise agronomy for the next cereal crop.

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Crop protection

Importance of cereal seed testing before sowing in 2020

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Key findings

- Sowing good quality seed, free of fungal pathogens and with high levels of germination and vigour, maximises emergence and early crop growth.

- In 2020, 96 sources of grower-retained seed were tested for emergence and vigour before sowing. This was due to concerns around the planting quality older seed retained from the 2018 harvest or earlier, or from drought-affected crops from both 2018 and 2019.

- Sixty-three percent of seed lots had adequate emergence for sowing in 2020. Growers of 26% of lots were advised to consider increasing the sowing rate to compensate for lower emergence levels, and 11% of seed tested was unsuitable for sowing with emergence at less than 60%.

- The quality of seed at harvest and adequate storage conditions appear to be the important factors in ensuring sowing seed quality is maintained, rather than just the length of storage.

- Growers are urged to test the germination and vigour of all sowing seed each season well in advance of sowing to optimise early crop establishment and yield potential.

Introduction

Seed retained for sowing is a highly valuable asset. The way it was treated at harvest and in on-farm storage during summer, or between seasons, is critical to ensure optimum germination potential and crop establishment.

NSW DPI provided a cereal seed testing service to NSW growers at the start of 2020 given the lack of available sowing seed for 2020 due to recent droughts across much of central and northern NSW. Some growers were planning to sow seed retained from the 2017 or even 2016 harvest, which was wet during grain filling and which might have resulted in poor quality seed.

Poor quality seed that has been infected by fungal pathogens has low germination and/or poor vigour can result in reduced plant stands. This can then lead to issues with reduced weed competition, decreased yield potential and poor stubble cover after harvest.

Ensuring the highest quality sowing seed was used to establish cereal crops in 2020 was important to support growers when recovering from 2–3 years of largely drought conditions.

Location

Central and northern NSW (Figure 1).

Seed samples

In total, 96 grower-retained seed samples were submitted from across central and northern NSW (Figure 1). This seed consisted of samples of:

- 52 bread wheat
- 26 barley
- 15 durum
- two oat
- one triticale.

The year of harvest and hence storage length on-farm of the different seed lots varied with one from 2015, five from 2016, five from 2017, nine from 2018 and 76 from 2019 harvest (Figure 2).
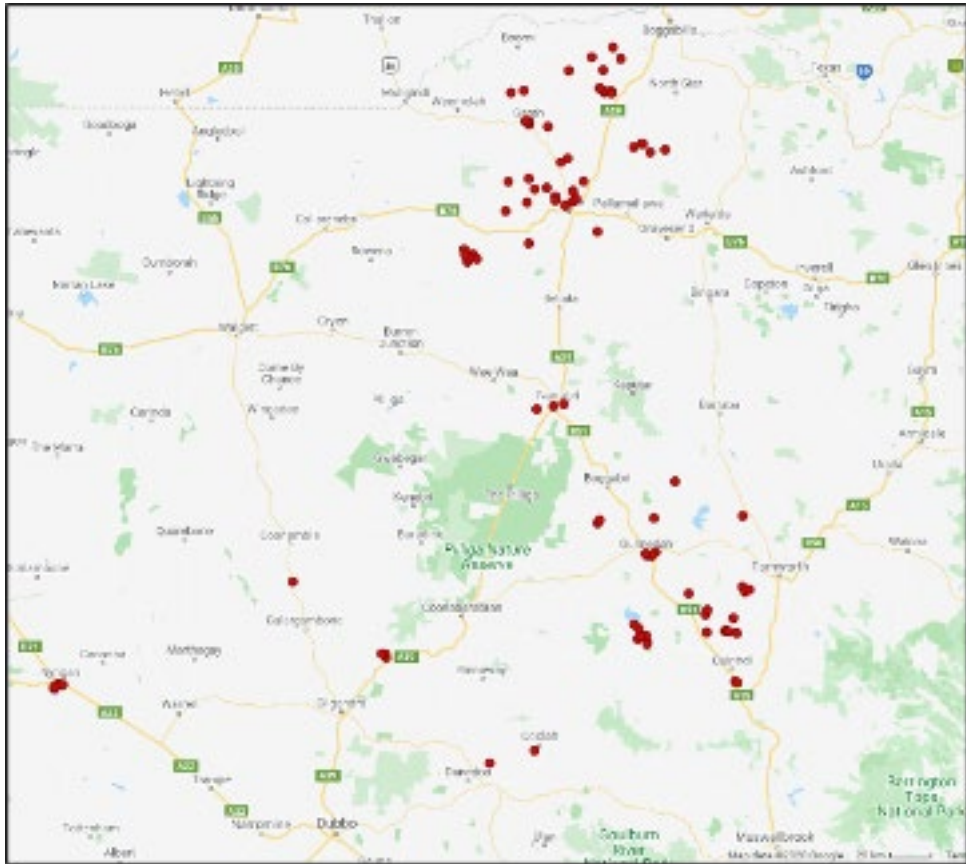

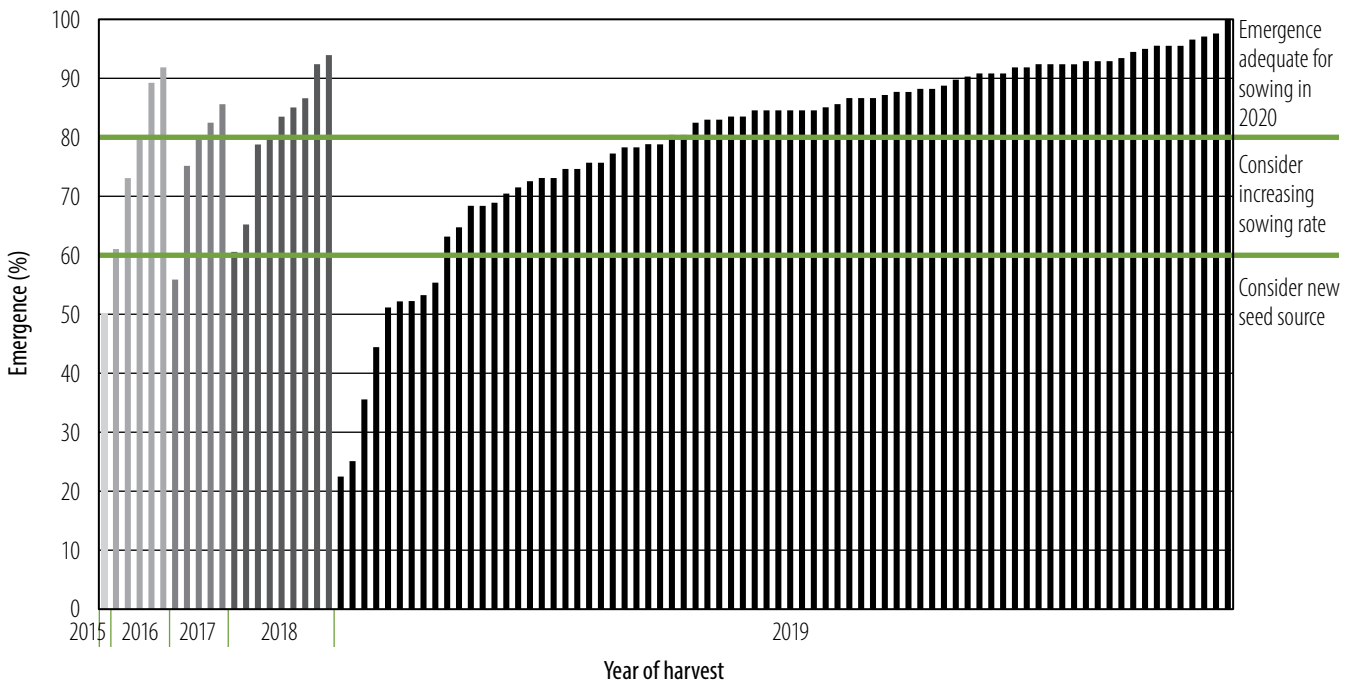Figure 1   Location (red dots) of 96 grower-retained cereal seed samples tested before sowing in 2020.

Figure 2   Emergence (%) of 96 grower seed lots tested in 2020 after 14 days in growth cabinet.

Seed-borne fungal pathogen testing

Two 100-grain sub-samples from each seed lot were surface sterilised, dried and then plated on laboratory media to determine the incidence of *Fusarium* spp., *Bipolaris sorokiniana* and *Eutiarosporella* spp. infections. Plates were assessed for fungal pathogen colonies emerging from surface-sterilised seeds after seven days incubation at 25 °C under alternating UV light (12 hour dark/12 hour light). The percentage of germination and general vigour were also recorded. This is not a certified germination and vigour test, but has been used previously as a guide to inform the grower to undertake further testing before sowing.

Germination and vigour testing

Additional plant establishment and vigour testing were conducted in 2020 to support growers across the northern region. Three replicates of 50 random seeds from each grower's seed lot were sown in potting mix at a depth of 5 cm and grown in a temperature-controlled growth cabinet (20 °C daytime and 15 °C night). The percentage emergence at 10 and 14 days was recorded, along with the shoot length. A control or 'check' seed source was included in each batch of testing in the growth cabinet. These were Spartacus CL[Φ] barley and the bread wheat LRPB Lancer[Φ]. This seed was sourced in 2019 from the Liverpool Plains Field Station grown under irrigated conditions, graded to remove any small grain and tested to ensure high levels of germination and vigour. Emergence and shoot length were recorded in both the check seed and the grower-supplied seed. The check data was supplied to the grower along with their results to assist with interpretation and to help guide decisions around planned sowing seed.

Results

- A total of 31% of grower-retained seed samples had some level of *Fusarium* infection (maximum 4.5% infection).

- 17% was infected with *Bipolaris* (maximum 2.0% infection).

- 4% was infected by *Eutiarosporella* (maximum 0.5% infection) (data not shown).

Grower-retained seed emergence after 14 days ranged from 22.7% to 100% (Figure 2). This does not appear to be associated with the year of harvest.

- The one seed lot from 2015 had 50.0% emergence.

- 2016: averaged 79.3% (range 61.3–92.0%).

- 2017: averaged 76.1% (range 56.0–82.7%).

- 2018: averaged 81.0% (range 60.7–94.0%).

- 2019: averaged 80.1% (range 22.7–100%) (Figure 2).

It is not just how long seed remains in storage that affects the future sowing quality of seed. The initial quality of the harvested seed and conditions under which this retained seed is stored on-farm can also play a significant part.

Two seed lots from the 2016 harvest were still amongst the highest emergence levels of the samples tested, with some 2019 harvested seed having the lowest emergence levels (Figure 2).

If emergence levels were less than 60% after 14 days, then growers were advised to consider sourcing new seed; this occurred with 11% of samples.

If emergence was between 60–80% then growers were advised to consider increasing their planned sowing rate to compensate; this occurred with 26% of samples.

The remaining 63% of grower-retained seed samples was above 80% emergence, which was considered adequate for sowing in 2020 (Figure 2).

| Conclusions | Individual reports outlining the laboratory testing results from seed plating for fungal pathogens, germination, emergence and vigour testing were emailed to each grower and their adviser. The reports were well received by growers and helped to prevent the poor plant stand establishment that would have been achieved with some retained seed sources. The benefit of this information before sowing is highlighted by a contrasting situation where an untested source of LRPB Lancer[Φ] wheat seed was sown on the Liverpool Plains in 2020. Crop establishment of only 25–30 plants/m^2 was recorded as opposed to the targeted plant population of 120 plants/m^2 with this sowing rate. This left the grower and their adviser with the difficult decision of whether to hold onto the crop with its low plant population (restrict yield potential if it is a good season) or spray out with herbicide and re-sow with new seed. This 3–4 week delay in sowing time would also reduce the yield potential. Fortunately, this situation is easily avoidable through seed testing before sowing. There are several commercial laboratories offering a certified testing service. |

The extra emergence and vigour testing conducted under this study in 2020 was used to highlight for growers the importance of seed testing before sowing. Growers are urged to consider the quality of the seed they retain for sowing at harvest and optimise storage conditions on-farm to maintain germination and emergence levels (Burrill 2019). However, they should still test the germination and vigour of all their seed well in advance of sowing each season to optimise early crop establishment and yield potential.

Crop protection

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Managing spot form of net-blotch in barley – Grafton 2018

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Key findings

- Spot form of net-blotch in barley is a significant barley disease, causing up to 23% yield loss in susceptible (S) – very susceptible (VS) varieties under favourable conditions.

- Early fungicide management using either the seed treatment Systiva® or a foliar application of Tilt® at GS31, reduced yield loss from SFNB from 23% to 13%.

- A two-fungicide input strategy involving the additional fungicide spray at GS39 was required to prevent the final 10% of yield loss.

- A return on investment of up to $156 was achieved with some two-fungicide strategies, where an earlier fungicide input followed by a foliar application at GS39, were applied.

- Effects on yield and using fungicides would be lower in varieties with improved levels of resistance to SFNB, or in environments or seasons less conducive to disease development.

Introduction

Spot-form of net blotch (SFNB), caused by the fungal pathogen *Pyrenophora teres* f.sp. *maculate*, is the main leaf disease of barley crops in northern NSW. SFNB incidence has risen as conservation cropping practices have been adopted, such as retaining barley residues, which retains this stubble-borne pathogen's inoculum.

Although levels of genetic resistance to SFNB are available, the main barley varieties grown in northern NSW have a resistance rating of very susceptible (VS) – susceptible (S): Spartacus CL[ϕ], RGT Planet[ϕ] and Rosalind[ϕ]; or have ratings of moderately susceptible (MS) – susceptible (S) to this disease: Compass[ϕ] and Commander[ϕ].

Barley growers in northern NSW are questioning their recommended fungicide management strategies for leaf diseases including SFNB. Some feel that their fungicide budget for barley has become excessive and are questioning the return on investment (ROI). This experiment aimed to provide growers with a better understanding of the relative control achieved using a range of fungicide strategies and the associated economics of adoption in commercial barley crops under conditions conducive to SFNB development.

Site details

Location	Grafton Primary Industries Institute, Grafton (S29°62'1297", E152°94'7413")
Rainfall	A total of 845 mm rainfall was recorded at the experiment site during 2018. The growing season rainfall was 244 mm (Table 1).
Sowing date	21 June 2018
Fertiliser	60 kg/ha Granulock® (N:P:S; 11:21.8:4) and 100 kg/ha urea at sowing
Sowing rate	Target 100 plants/m²

	Harvest date	14 November 2018
	Experiment design	Randomised complete block design, three replicates.

Table 1   Monthly rainfall (mm) at Grafton Primary Industries Institute in 2018.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
78.0	119.6	73.8	45.0	10.0	71.4	10.2	31.2	45.2	146.2	23.6	191.2

Treatments

Varieties (2)

Spartacus CL[φ] and Baudin[φ] both varieties S – susceptible-very susceptible (SVS) to SFNB

Fungicide strategies (13)

Two fungicide strategies:

1. early control using Systiva® (fluxapyroxad at 150 mL/100 kg seed)

2. foliar application at GS31 of Tilt® (propiconazole at 500 mL/ha).

Followed by a second fungicide input in-crop at GS39 of five different foliar fungicide treatments (Table 2).

Nil treatment and GS31 Tilt® treatments had a base level application of Vibrance® (difenoconazole + metalaxyl-M + sedaxane at 360 mL/ha) to control bunts and smuts (no SFNB activity).

Table 2   Active ingredient and application rate of fungicide treatments applied at GS39.

Fungicide treatment	Active ingredient(s) (concentration)	Application rate (mL/ha)
Tilt®	Propiconazole (250 g/L)	500
Prosaro®	Prothioconazole (210 g/L) + tebuconazole (210 g/L)	300
Amistar® Xtra	Azoxystrobin (80 g/L) + cyproconazole (31.3 g/L)	800
Opera®	Pyraclostrobin (85 g/L) + epoxyconazole (62.5 g/L)	1000
Aviator® Xpro®	Prothioconazole (150 g/L) + bixafen (75 g/L)	500

Results

The seasonal conditions in 2018 at Grafton were very conducive to SFNB development. The significant rainfall in October (Table 1) resulted in increased disease pressure at post GS39 growth stages. High levels of infection developed in untreated plots (Figure 1a) with marked differences in the retention of green leaf area evident between the control and many of the fungicide treatments during grain filling (figures 1b and c).

Yield

There was no significant difference in yield between the two SVS barley varieties used in this experiment, so all results are an average of Spartacus CL[φ] and Baudin[φ].

Yield ranged from 3.55 t/ha in the untreated control up to 4.63 t/ha in the Systiva® +Aviator Xpro® treatment (Table 3). This represents a 23% (1.08 t/ha) yield loss from SFNB under conducive conditions at Grafton in 2018.

All fungicide strategies, with the exception of the Tilt® at GS31 + Prosaro® at GS39, which appears to be an anomaly in the data, provided a significant yield benefit of between 13– 30% over the control (Table 3).

The early fungicide strategy of Systiva® seed treatment or GS31 Tilt®application provided the same yield benefit of 0.47 t/ha (13%) in the absence of a following in-crop fungicide spray at GS39 (Table 3).

Crop protection

There was a general trend for improved yield with strategies that used Systiva® as the early fungicide treatment compared with Tilt® at GS31, when combined with a follow up in-crop fungicide spray of the various products at GS39 (Table 3).
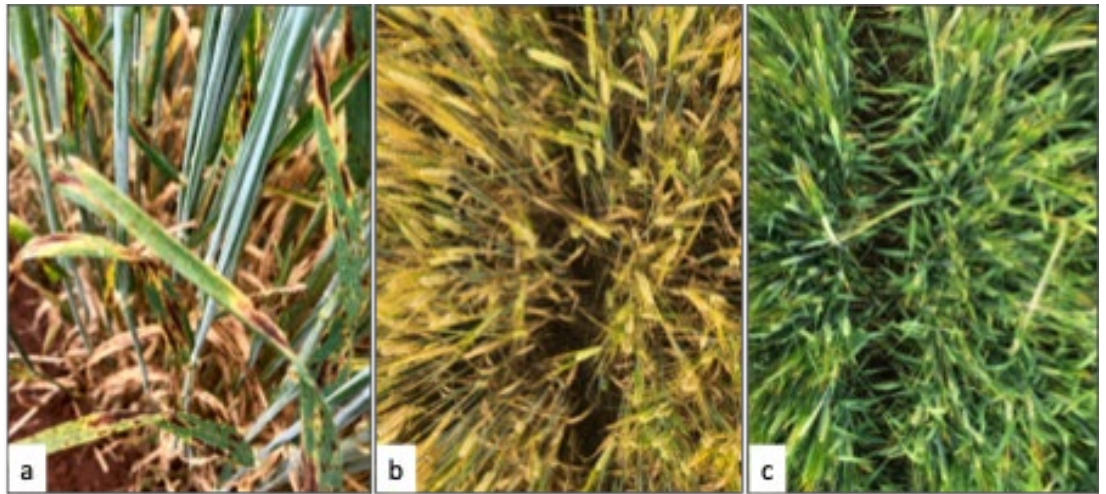

Figure 1   a) Significant levels of SFNB leaf infection in untreated control treatments at awn peep (GS49), b) level of green leaf retention at mid-grain fill (GS80) in untreated control of Spartacus CL⊕ compared with c) fungicide strategy of Systiva® + Aviator Xpro® at GS39. Grafton, NSW 2018.

Table 3   Yield (t/ha), cost of fungicide strategy and return on investment (ROI) for managing SFNB in SVS barley varieties – Grafton 2018

Early treatment	GS39 spray	Yield (t/ha)		Cost ($/ha)[A]	ROI ($/ha)[B]
Nil	Nil	3.55	f	0	0
Systiva®	Nil	4.02	de	22.03	71.97
	Tilt®	4.35	abcd	37.25	122.75
	Prosaro®	4.26	bcd	54.62	87.38
	Amistar Xtra®	4.48	ab	59.96	126.04
	Opera®	4.54	ab	65.08	132.92
	Aviator Xpro®	4.63	a	60.01	155.99
Tilt® GS31	Nil	4.02	de	15.22	78.78
	Tilt®	4.10	cde	30.44	79.56
	Prosaro®	3.87	ef	40.59	23.41[C]
	Amistar Xtra®	4.30	abcd	45.93	104.07
	Opera®	4.30	abcd	51.05	98.95
	Aviator Xpro®	4.55	ab	45.98	154.02
	l.s.d. ($P<0.001$)	0.349			

[A] Fungicide prices referenced from the NSW DPI Winter crop variety sowing guide and $8/ha application cost by ground-rig for each in-crop fungicide application. Sowing rate of 60 kg/ha assumed for Systiva® seed treatment costing.
[B] Return on investment (ROI) based on yield increase over nil control multiplied by $200/t grain price for barley minus the cost of the fungicide strategy. Readers might like to apply their own economics to these yield outcomes.
[C] Note that yield response was not significantly different from nil control, which appears to be an anomaly.

Economics

All fungicide strategies produced a positive ROI, which, excluding the Tilt® at GS31 + Prosaro® at GS39 treatment, ranged from $72/ha to $156/ha (Table 3). The highest returns were from the two strategies that applied Aviator Xpro® at GS39.

Conclusions	SFNB is a significant disease of barley that caused up to 23% yield loss in two SVS varieties under conducive conditions at Grafton in 2018 where no fungicide control was used.

A single early fungicide strategy of either:

1. Systiva® seed treatment at sowing

2. a foliar application of Tilt® at GS31 can reduce yield loss by 13%.

A second fungicide input at GS39 was required to prevent the remaining 10% of yield loss.

It is economical to control SFNB in SVS barley varieties with a range of fungicide strategies under disease-conducive conditions. However, ROI is likely to be lower and less warranted in varieties with improved resistance to SFNB, or in environments and seasons less favourable to disease development.

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Crop protection

Safflower: Optimising sowing date in northern NSW in 2014

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Key findings

- The current conventional safflower varieties Sironaria and S317 tested in 2014 had similar agronomic characteristics including plant structure, flowering time and yield potential.

- Sironaria and S317 demonstrated a broad adaptability to sowing dates: 23 June, 21 July and 29 August. Yield potential was greatest when sown in June.

- Averaged across all sowing dates, yield was maximised at a population of 34 plants/m^2. A 23 June sowing date showed the greatest flexibility in maintaining yield at a range of plant populations.

- Seed size declined by 6% as target plant population increased from 10 plants/m^2 to 60 plants/m^2.

- Time to flowering was progressively reduced as the sowing date was delayed from 23 June to 21 July to 29 August; 13 days, 106 days and 81 days respectively. Corresponding length of crop cycles were 178 days, 150 days and 112 days.

- The effects from sowing date and plant population on plant structure would not present harvest difficulties in either Sironaria or S317.

Introduction

Historically, safflower has been grown intermittently in northern NSW. Its end use has been limited to seed production for the birdseed and oleic oil markets, based on public varieties released in the mid 1980s. Cotton production systems have included safflower as a biological means to manage soil compaction.

The 'Tactical agronomy of minor crops (safflower, linseed, sunflower)' (DAN00197) was a co-funded project between NSW DPI and the Grains Research and Development Corporation (GRDC). A major objective was to determine the agronomic constraints to yield potential in safflower in northern NSW.

Grower experience with safflower has been limited. Industry consultation at the beginning of the project revealed a generalised view regarding optimal sowing dates, with the focus being the closure of barley sowing windows, rather than the optimal period for maximising safflower yield potential.

Our paper reports on the response of the two widely grown conventional varieties of safflower to three sowing dates (SD) and at four target populations at Narrabri in 2014. This information will be used to develop agronomic recommendations for safflower agriculture in northern NSW.

Site details

Location	Australian Cotton Research Institute (ACRI), Narrabri
Soil type	Grey vertosol
Configuration	2 plants rows at 100 cm row spacing on 2-metre-wide raised beds
Field history	2012 – mungbean and soybean, 2013 – wheat

Fertiliser	100 kg/ha Supreme® Z
Herbicide	Pre-emergent: 2.25 L/ha Stomp® (pendimethalin)
	Post emergent: 75 mL/ha Verdict® (haloxyfop)
Harvest dates	SD1: 19 December 2014 (178 DAS)
	SD2: 19 December 2014 (150 DAS)
	SD3: 20 December 2014 (112 DAS)
Soil characteristics	Soil at the experiment site was sampled and analysed before sowing (Table 1).
Seed quality	Seed used in the experiment was tested for seed size and germination before sowing.

Table 1   Soil chemical characteristics in June 2014.

Soil depth (cm)	pH$_{Ca}$	Nitrate N (mg/kg)	Ammonium N (mg/kg)	Colwell P (mg/kg)	Potassium (mg/kg) (Colwell)	Sulfur (mg/kg)	Zinc (mg/kg)	Salinity (dS/m)	Organic carbon (%)
0–10	7.7	11	4	55	507	28.3	32.65	0.214	1.89
10–20	8.1	13	3	37	354	46.7	17.81	0.273	0.69
30–60	8.4	5	3	41	336	23.4	-	0.164	0.51
60–90	8.6	3	2	51	381	21.8	-	0.196	0.54
90–120	8.7	3	2	58	399	32.8	-	0.214	0.49

Table 2   Seed size, germination percentages and seeding rates.

Variety	Seed size (g/100 seeds)	Germination (%)	Seeding rate (kg/ha)			
			10 plants/m²	20 plants/m²	40 plants/m²	60 plants/m²
Sironaria	3.5	81	5	10	20	32
S317	3.6	68	7	13	27	40

Seeding rates were calculated based on the assumption of 80% establishment.

Sowing	The experiment was sown into soil moisture suitable for germination. Seeding depths averaged 6 cm, 7 cm and 5 cm respectively for SDs 1–3 respectively. Soil temperatures at 10 cm depth at 9:00 am AEST at each successive SD was 9.9 °C, 10.6 °C and 14.1 °C respectively.
Climate	Daily temperature and rainfall throughout the experiment is shown in Figure 1. Temperature range and averages, and total rainfall during each crop cycle are shown in Table 3.
Experiment design	The split plot design with SD as the main block with variety and populations were randomised within each block; there were three replications.

Table 3 Climatic conditions during safflower crop cycles in 2014.

Crop cycle	Temperature (°C)				In-crop rainfall (mm)
	Minimum recorded	Average minimum	Maximum recorded	Average maximum	
SD1	−4.2	9.2	44.1	26.4	111.4
SD2	−4.2	10.7	44.1	28.0	103.4
SD3	−1.5	13.1	44.1	30.7	64.6
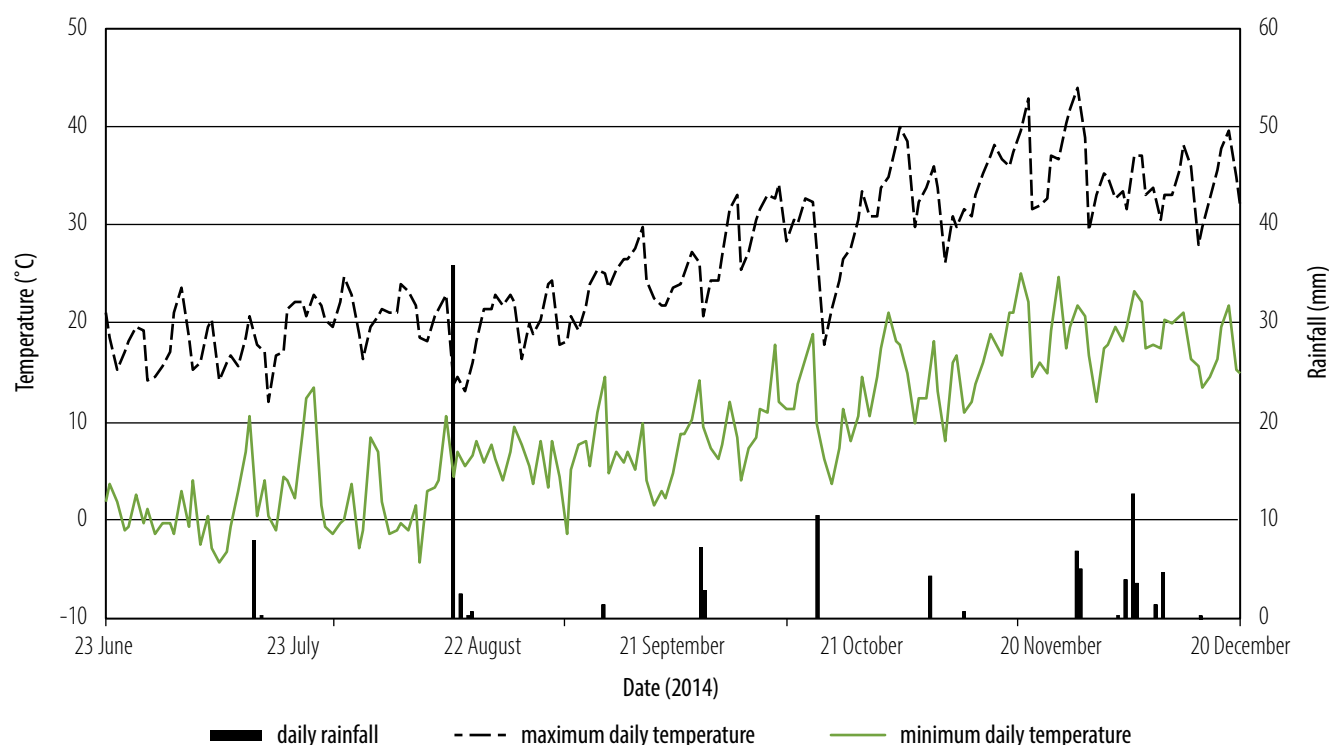
Figure 1 Experiment climate information in 2014.

Treatments		
	Sowing date	23 June, 21 July, 29 August
	Variety	Sironaria, S317
	Plant population	10, 20, 40, 60 plants/m^2

Results

Effects of sowing date

Crop establishment

At a target population of 60 plants/m^2, crop establishment significantly declined as SD was delayed (Figure 2). Sowing date had no significant ($P<0.05$) effect on crop establishment; the experiment averaged 27 plants/m^2.

Crop growth

The vegetative growth phase length was measured by the time taken from SD to 50% of plants flowering (F50). This is expressed as the number of days to flowering (DTF).

Sowing date had a significant effect on DTF; as SD was delayed the DTF progressively decreased.

- SD1: 132 days
- SD2: 106 days

- SD3: 81 days (*P*<0.001; l.s.d. 0.7 day).

Sowing date effects on early crop growth was observed in canopy development, measured at F50. The effects were recorded as leaf area index (LAI), which is a measure of the plant canopy, expressed as green leaf area per square metre of ground surface area. The LAI at SD1 was 3.53 m², significantly greater than SD2 at 2.46 m² and SD3 at 2.78 m² (*P*<0.001; l.s.d. 0.62 m²).
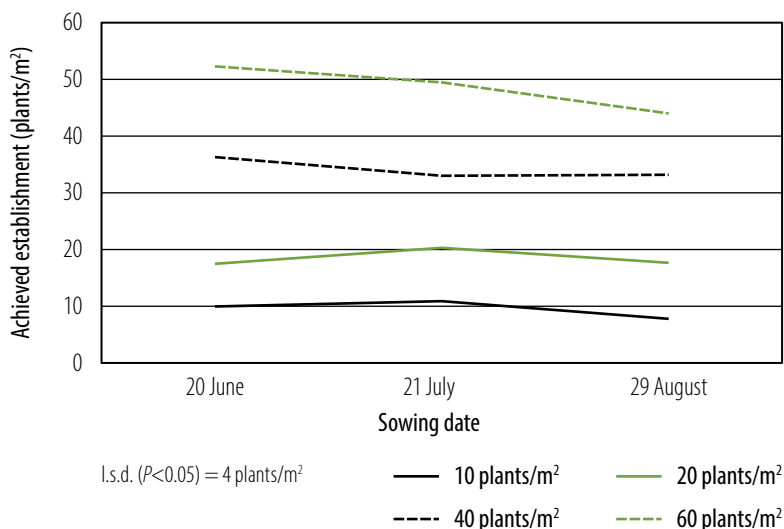
Figure 2   Interaction of sowing date with plant population on crop establishment in 2014.

Plant structure

The effect of SD on plant structure – crop height and the position of the lowest seed capsules – was significant (*P*<0.001). Figure 3 shows plant height and seed capsules position. Overall plant height progressively declined: SD1: 108 cm, SD2: 97 cm and SD3: 77 cm. By SD3, the height of the lowest seed capsule was reduced to 52 cm. However, these characteristics would present no difficulties at harvest.
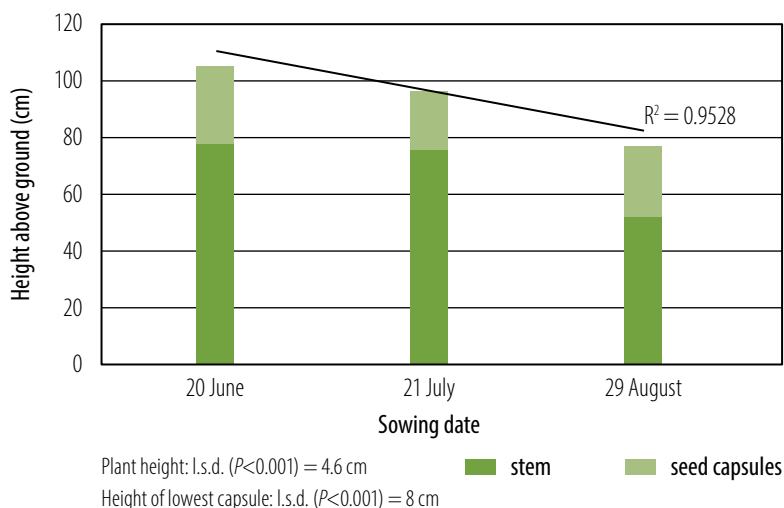
Figure 3   Effects of sowing date on safflower plant structure in 2014.

Yield and seed size

Sowing date effects on yield were not significant (*P*<0.05), with the experiment averaging 1.02 t/ha (at 8% moisture) (Figure 5). The trend with time was declining yield with later SDs.

The Sironaria and S317 yield responses were not significantly different (P<0.05) for all SDs, with one exception. Sironaria yielded 1.21 t/ha for SD1, significantly higher than S317 (0.85 t/ha) at SD3.

Sowing date interaction with plant population was significant (*P*<0.05) (Figure 5).

Yields were most consistent for SD1, regardless of plant population, with no significant differences. There was no significant difference (P<0.05) in yield at any plant population for SD2 and SD3.

The June and July SDs showed no significant difference in seed size: 2.98 g and 2.96 g. However, a significant increase, in the order of 10%, was measured when sown in late August (3.3 g).
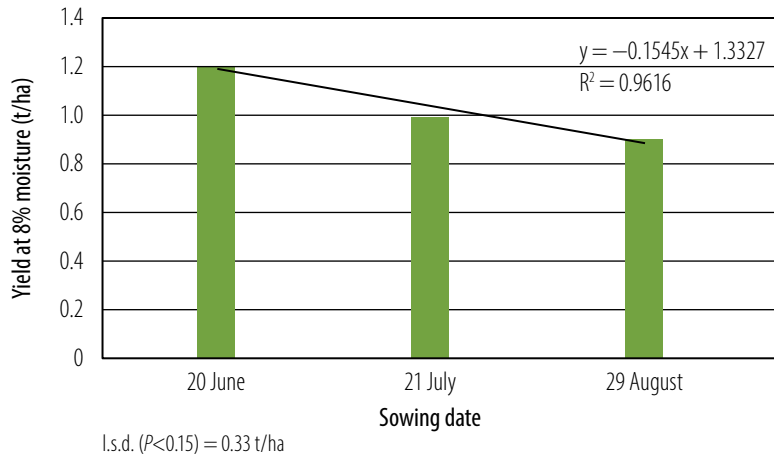
Figure 4   Effects of sowing date on safflower yield (t/ha) in 2014.
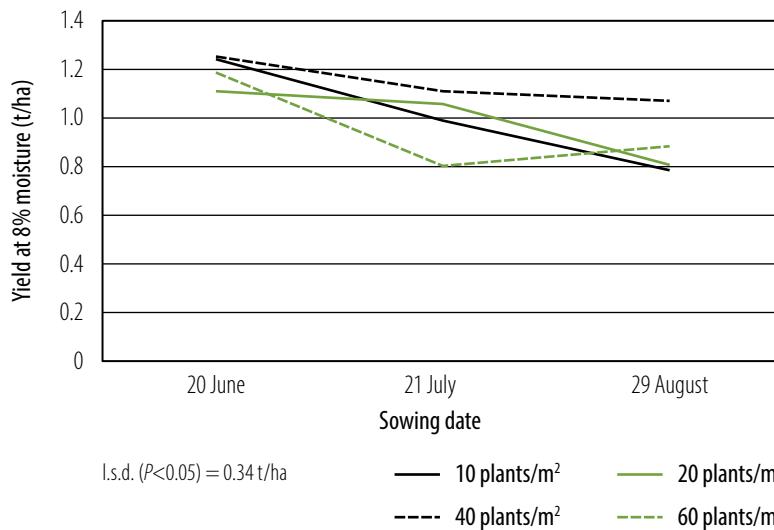
Figure 5   Interaction of sowing date and population on safflower yield in 2014.

Effects of population

Crop establishment

Plant establishment percentage declined as seeding rate increased (Figure 6). At target populations of 10 plants/m^2, 20 plants/m^2, 40 plants/m^2 and 60 plants/m^2, average establishment was 9 plants/m^2, 18 plants/m^2, 34 plants/m^2 and 48 plants/m^2 (*P*<0.05; l.s.d. 2 plants/m^2) respectively.

Crop growth

Plant population had no significant effect (*P*<0.05) on the time to flowering.

Plant structure

Plant population had no significant effect (*P*<0.05) on overall crop height. The average plant height for all populations was 93 cm.

However, plant population did have a significant effect on the height above ground of the lowest flower ($P<0.05$; l.s.d. 4 cm), increasing from 64 cm at 9 plants/m^2 to 72 cm at a population of 48 plants/m^2.

Yield and seed size

Yield response to plant population was only significant at 34 plants/m^2 ($P<0.05$; l.s.d. 0.07 t/ha) (Figure 7). Seed size declined as population increased, from 3.2 g to 3.0 g ($P<0.05$; l.s.d. 0.1 g).

l.s.d. ($P<0.001$) = 2 plants/m^2 ■ establishment   — establishment percentage
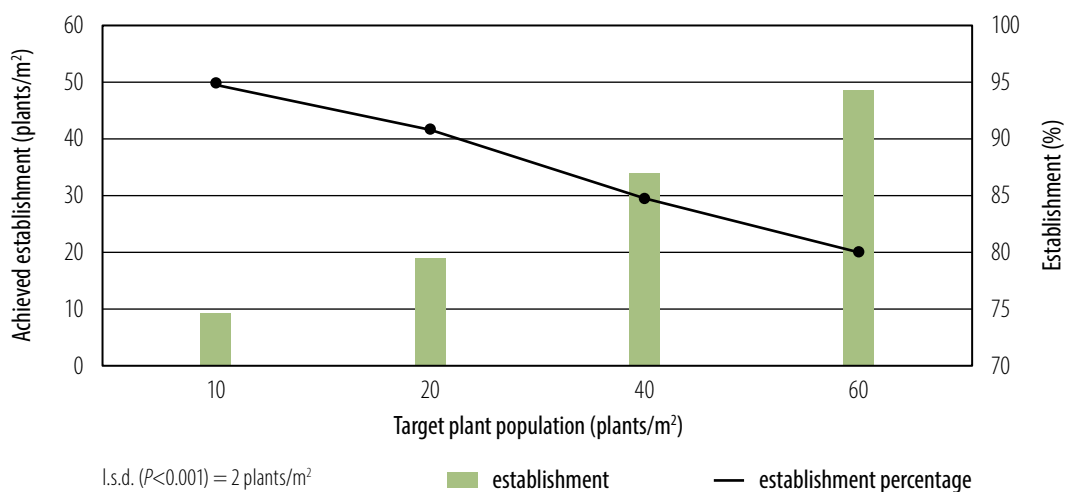
Figure 6   Safflower establishment at each target plant population in 2014.

l.s.d. ($P<0.001$) = 0.08 t/ha

Figure 7   Effect of plant population on safflower yield in 2014.

Effects of variety

Crop establishment

Crop establishment for Sironaria and S317 averaged 26 plants/m^2 and 29 plants/m^2 ($P<0.001$; l.s.d. 2 plants/m^2) respectively. These differences were small but significant ($P<0.05$) as target populations increased. The greatest difference was recorded at a target population of 60 plants/m^2: Sironaria – 45 plants/m^2 and S317 – 52 plants/m^2.

Plant structure

There was no significant difference ($P<0.05$) between Sironaria and S317 in the height of the plant or the height of the flower canopy. The average plant height was 93 cm and the height of the lowest flower was 69 cm.

Time to flowering

Differences in the DTF were not significant ($P<0.05$). Both varieties averaged 106 DTF.

Yield and seed size

No significant difference ($P<0.05$) in yield or seed size was measured between Sironaria and S317. The average yield and seed size were 1.0 t/ha and 3.1 g respectively.

Conclusions

In 2014 Sironaria and S317 were the two most commonly grown conventional safflower varieties for the birdseed and oleic oil markets respectively. Both varieties are similar in major agronomic traits including plant structure, flowering time and yield performance.

The yields attained in this experiment were consistent with the grower-reported average yields of 1.0–1.2 t/ha.

Increasing seeding rates consistently decreased crop establishment. Reduced establishment on wider row spacings is consistent with findings in other winter crops. This experiment was sown on 100 cm row spacing, thereby limiting plant access to space, light, moisture and nutrients. In an adjoining safflower experiment in the same season, increasing row spacing from 34 cm to 60 cm reduced yield by 25% (Hertel et al., 2021). The wide row spacing in this experiment effectively limited agronomic responses across the tested populations and sowing dates.

Delaying sowing date shortened the crop cycle. This limits vegetative biomass production and shortens the flowering period. Flowering and seed fill occur when average daily temperatures are rising and the risk of temperature and/or moisture stress increases.

The lack of yield response to population in this experiment was likely to have been influenced by the wide row spacing. Adjoining research conducted during the same season demonstrated safflower's adaptability to a broad range of plant populations. The results support reducing seeding rates from reported industry rates as high as 60 kg/ha. Targeting plant populations considerably less than some common industry seeding rates would not compromise yield potential.

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Acknowledgements

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Diagnostic PREDICTA®B testing for Phytophthora inoculum of chickpea during waterlogged soil conditions.

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Key findings

- PREDICTA®B testing in media sown to chickpea in transient flooding events detected increased level of phytophthora root rot (PRR) disease and inoculum levels.

- Long-term waterlogging significantly increased Phytophthora inoculum levels detected in the PRR susceptible line Rupali[⌀], but not PRR resistant chickpea lines, 04067-81-2-1-1 or Yorker[⌀].

- Chickpea lines with higher resistance to PRR resulted in reduced root disease and inoculum load under long-term waterlogging conditions.

- PREDICTA®B testing should be used cautiously when determining the PRR risk for chickpea as Phytophthora inoculum can survive across seasons undetected in suitable soil pockets or medic weeds, and can aggressively develop into disease within a crop.

- PREDICTA®B testing is best suited as a diagnostic tool to confirm PRR is present for paddock history and rotation purposes.

- When collecting soil samples for PRR diagnostic PREDICTA®B testing include suspect root tissues.

Introduction

Phytophthora root rot, caused by the oomycete (*Phytophthora medicaganis*) and waterlogging, are difficult to differentiate in chickpea (*Cicer arietinum*) during a wet season as symptoms are quite similar.

PRR symptoms include:

- reduced growth
- leaf chlorosis
- foliage desiccation
- premature senescence
- wilt
- decay in lateral roots
- reddish-brown stem canker
- yield loss
- plant death.

Waterlogging symptoms are identical except with a delayed onset and no stem canker or unique root lesions (Chen et al., 2011; Moore et al., 2015).

Under high soil moisture conditions Phytophthora can aggressively develop disease and under waterlogging conditions the pathogen accelerates even further. However, Phytophthora are obligate aerobes, which means it requires oxygen. A key characteristic of waterlogging is the lack of oxygen in the soil. It is therefore possible that waterlogging in some scenarios could suppress soil-borne Phytophthora.

A controlled environment experiment was conducted to investigate the effect of repeated transient flooding and long-term waterlogging on populations of *P. medicaganis*. PREDICTA®B detects levels of DNA using genes specific to *P. medicaganis* using quantitative polymerase chain reaction (PCR) (PREDICTA®B; PIRSA, SA) (Figure 1). Genetic material screened included the PRR resistant (R) wild *Cicer* backcross line, 04067-81-2-1-1, along with the moderately resistant (MR) domestic chickpea variety Yorkerᐤ and susceptible (S) variety Rupaliᐤ. Information gained from this experiment can be used to guide PREDICTA®B sampling times during high rainfall seasons for accurate in-crop PRR diagnosis in chickpea crops.

Figure 1   Phytophthora inoculum, which can be detected using PREDICTA®B. Mycelium in the background with spores annotated in the foreground.

Experiment details	**Location**	Controlled environment growth rooms – Tamworth Agricultural Institute (TAI), Tamworth, NSW. Diurnal temperatures 18–25 °C with a 12-hour light cycle.
	Experiment design	Randomised block design with six replicates.
	Media and watering	• Experiment conducted using potting media (1:1:1, loam, sand, Greenlife® garden blend) in closed plastic cups (Figure 2). • All cups pre- and post-waterlogging were maintained at 85% field capacity for the duration of the experiment.
Treatments	**Breeding lines/varieties**	04067-81-2-1-1 (R to PRR), Yorkerᐤ (MR to PRR), and Rupaliᐤ (S to PRR)
	Phytophthora (T)	• T1: Control: not inoculated (maintained at 85% field capacity). • T2: Phytophthora inoculated (two-leaf stage) maintained at 85% field capacity (non-waterlogged). • T3: Phytophthora inoculated (two-leaf stage) with initial flooding (waterlogged – watered to soil surface). T4: Phytophthora inoculated (two-leaf stage) with initial flooding and a second flooding five days later (waterlogged – watered to soil surface × 2). • T5: Phytophthora inoculated (two-leaf stage) and flooded for 10 days (waterlogged – continuous waterlogging to soil surface).

Figure 2   Experiment in a growth room at TAI.
Inoculated at the two-leaf stage.

Results and discussion   Mean inoculum load increased in treatments T3 and T4 after each flooding event in all chickpea lines (Figure 3). Inoculum load for the susceptible line Rupali[Φ] peaked under the extended waterlogging conditions (T5), which was significantly higher than all other water treatments for Rupali[Φ], the Phytophthora-resistant line 04067-81-2-1-1, and moderately resistant variety Yorker[Φ] (Figure 3). It has been reported previously that inoculum loading was highest where root tissue was severely infected (Bithell, Hobson et al., 2018).
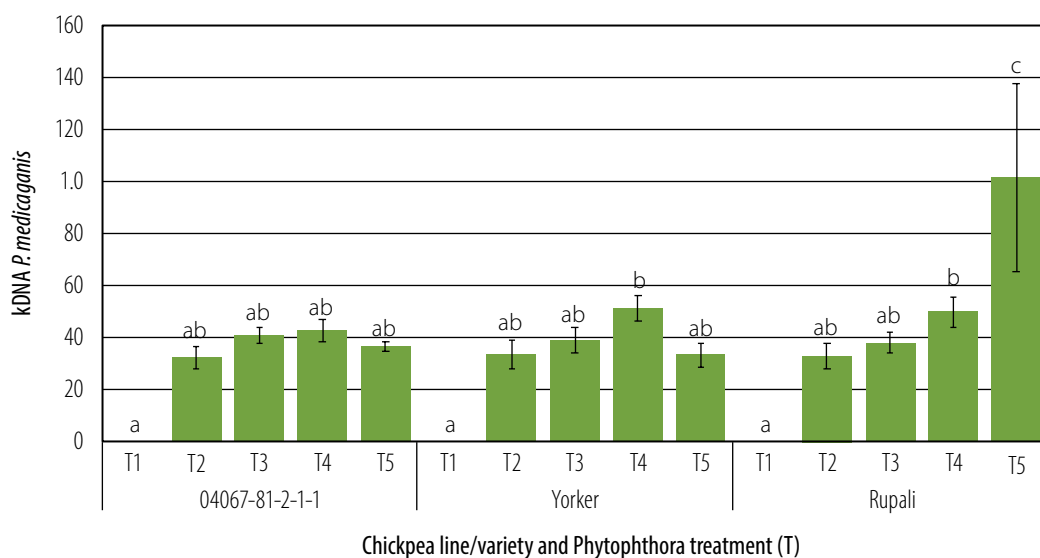

Figure 3   Mean kDNA copies detected for chickpea lines under PRR and flooding treatments (T1–T5). Analysed using an ANOVA, bars with the same letter are not significantly different at 95% confidence level using the bonferroni method (*P*=0.05).

Under continuous waterlogging (T5) the two chickpea lines with higher resistance had less severe root disease symptoms compared with the susceptible variety Rupali[Φ] (Figure 4). Under transient and non-waterlogged conditions (T2, T3, and T4) 04067-81-2-1-1 and Yorker[Φ] showed no significant difference in root disease. Yorker[Φ] had significantly higher disease levels following continuous flooding (T5) when compared with non-waterlogged (T2) and transient flooding (T3 and T4) treatments (Figure 4).

The increase in root disease severity could explain the high inoculum levels detected under waterlogging conditions for Rupali[Φ] (Figure 3 and Figure 4). Phytophthora are hemibiotrophic, which means the pathogen can survive in both living and dead plant tissue, consecutively. In Rupali[Φ] root tissues, it is likely that the pathogen started the destructive secondary hyphal growth within the dead plant tissues. In the resistant lines under these conditions, Phytophthora hyphal growth may be restricted to the living phase and is characterised by a lower primary hyphal growth, therefore resulting in less detectable *P. medicaganis* DNA (Lee and Rose 2010).
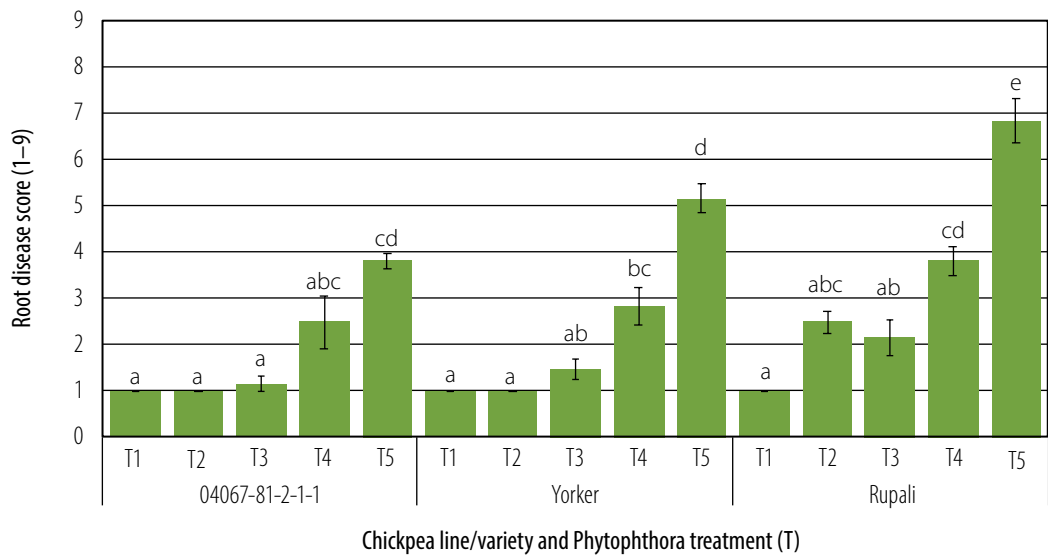
Figure 4 Mean root disease score (1: no symptoms; 9: severe symptoms) for chickpea lines under PRR and flooding treatments (T1–T5). Analysed using an ANOVA, bars with the same letter are not significantly different at 95% confidence level using the bonferroni method (*P*=0.05).

It is often assumed that all waterlogging increases *P. medicaganis* proliferation in soil. Severe waterlogging, which depends on soil characteristics and duration, can reduce the oxygen availability to below critical levels required by both the plant and Phytophthora (Erwin et al., 1983). The lower amounts of inoculum detected following the extended waterlogging treatment (T5) of the resistant lines, compared with the susceptible Rupali[Φ], could also be attributed to the Phytophthora's inability to survive in the oxygen-limited soil before root infection. A small hydroponic experiment done in conjunction demonstrated a significant reduction in the number of motile zoospores in severely oxygen deficient (hypoxic) conditions when compared with the aerated control (694 compared with 2431 zoospores, *P*>0.05, two sample T-test). Hypoxic treatment had oxygen reduced (0.2–0.5 ppm) from the solution for three days following inoculation. The control remained aerated (8.5–9.7 ppm oxygen).

Conclusion

Growers and advisors can consider PREDICTA®B soil sampling to confirm PRR presence in diseased chickpea paddocks. Findings from this experiment recommend delaying collection for at least eight days after waterlogging when characteristic Phytophthora lesions are not already present. Waterlogging can reduce the likelihood of detection due to the hostile conditions for *P. medicaginis* to proliferate. This delay in sampling should allow soil to reaerate, allowing infection to begin where *P. medicaganis* is present and helping to identify suspect root tissue for soil sample inclusion. PREDICTA®B is a useful tool to identify if chickpea crop losses are from waterlogging alone, or in combination with *P. medicaganis* infection. This information can then be used to guide future paddock selection, rotation sequence, and chickpea variety choice. This experiment showed that resistant varieties can reduce inoculum levels in a short period, whilst also reducing root damage caused by *P. medicaganis*.

In drier conditions and following break crops, *P. medicaganis* is difficult to detect pre-sowing as the resting oospore structures have been found to be randomly scattered in patches across paddocks that carry the pathogen across seasons. The aggressive nature of the disease and unreliable sampling when Phytophthora inoculum levels are low means the PREDICTA®B tool is more suitable for use as a diagnostic tool and not necessarily as a pre-sowing test for *P. medicaganis*. As previously advised, any *P. medicaginis* detection in a PREDICTA®B test pre-sowing should be considered a high risk for PRR development. However, a nil detection using PREDICTA®B pre-sowing should still be considered as a low risk for PRR as inoculum can carry forward in medic weeds and suitable pockets of soil (Dale and Irwin 1990; Bithell et al., 2018.

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Crop protection

Can winter planted sorghum be successfully established at Mungindi?

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Key findings

- The planting time for sorghum can be moved earlier than September when the traditional 16–18 °C soil temperature is reached.

- Defining the minimum soil temperature required is tenuous as temperatures are variable in the late winter–early spring with the additional risk of mild and severe frosts.

- Planting winter sorghum in late July–early August at Mungindi allowed successful crop establishment, but emergence was slower, and establishment was reduced compared with planting in September.

- Based on results from experiments in other regions of northern NSW; winter planted sorghum achieves earlier flowering and harvest, which subsequently increases the fallow length to the next crop, allowing increased double cropping opportunities.

Introduction

Dryland grain sorghum farmers need to produce high yields to achieve positive gross margins. One of the major limiting factors for increasing yields in the northern grains region (NGR) is hot temperatures during the critical growth stages of flowering and grain fill.

In the Mungindi region, planting dryland grain sorghum under current management practices is considered a high risk–low reliability option due to the inherent climatic factors as the small area planted demonstrates. The traditional sorghum planting window at Mungindi is considered to open in mid–late September when soil temperatures at 8 am EST reach the recommended 16–18 °C and the risk of frost has passed. These crops flower and fill grain in late December and January when temperatures above 35 °C are common.

Since 2017, the Grains Research Development Corporation (GRDC), University of Queensland (UQ), NSW DPI and QDAF have partnered in a research program to test the boundaries of planting sorghum earlier than normal and measuring the effects on plant establishment, crop development, grain yield and quality. Research experiments have been conducted in central and southern Queensland, and at Moree and the Liverpool Plains in northern NSW. In the 2019 season, an additional two sites at Mungindi were added to the program.

This paper includes results relevant to the Mungindi region with two experiments established in 2019 at Bullawarrie north west of Mungindi and Morialta south of Mungindi. Site details for the 2019–20 season are outlined in Table 1. Due to the drought, both experiments at Mungindi failed after establishment and before flowering.

Location and paddock history

Table 1   Site location details.

Location	Co-operator	GPS Coordinates	Paddock history
Bullawarrie, Mungindi	Andrew Earle	S28° 51' 755" E148° 46' 320"	2017 failed wheat 2018 failed wheat 2016 chickpea
Morialta, Mungindi	Tom Greentree	S29° 17' 313" E149° 07' 550"	2018 failed chickpea 2017 failed chickpea 2016 wheat

Soil type and nutrition

The soil type at Bullawarrie is described as a grey–brown heavy clay; the soil at Morialta is more typical of the grey clay vertosols of northern NSW (Table 2).

Soil coring was completed before planting and results indicated there was 95 kg N/ha (nitrogen) at Bullawarrie and 279 kg N/ha at Morialta to 1.2 m deep.

Table 2   Site soil chemical characteristics for 0–10 cm depth at Bullawarrie and Morialta in 2019.

Site	Bullawarrie	Morialta
Characteristic	Depth (0–10 cm)	Depth (0–10 cm)
pH_{Ca}	7.3	7.8
Nitrate nitrogen (mg/kg)	33	47
Phosphorus (Colwell) (mg/kg)	4	9
Phosphorus buffering index (PBI)	104.1	158.8
Zinc (mg/kg)	0.45	0.94
Sulfur (mg/kg)	22	6.1
Organic carbon (OC) (%)	0.35	0.36
BSES phosphorus (mg/kg)	45.65	110.96

Rainfall

A total of 9.4 mm of rainfall was recorded at Bullawarrie and 12.8 mm at Morialta from 24 July– 4 November when both experiments were abandoned due to drought. Average annual rainfall at Mungindi is 475 mm and the long-term average for this period is 118.9 mm. During the drought conditions of 2019 only 10% of the average rainfall fell for this period.

Table 3   Long-term average rainfall at Mungindi between July and October.

Month	July	August	September	October	Total
Rainfall (mm)	30.8	23.9	27.2	37.0	118.9

Source: Farm online weather

Due to the lack of planting and post emergence rainfall, all experiments were watered up using dripper irrigation with the equivalent of 33 mm of rain concentrated on the row. Planting date 1 (PD1) received a second post emergence irrigation using the same method (Table 4).

Table 4   Site characteristics for the Mungindi sorghum experiments planted in the 2019/20 season.

Planting date (PD)		Soil temp. at 8am[#] (°C)	Plant available water (PAW)[##] at planting to 120 cm (mm)	In-crop rainfall (mm)	Post plant (PP) irrigation* (mm)	Post emergent (PE) irrigation* (mm)
Bullawarrie Mungindi, QLD						
1	22 and 23 July	7.7 at planting 9.3 average for following 7 days	19 (pre water)	10	33	33
2	2 and 3 September	11.5 at planting 14.1 average for following 7 days	43 (post water)	10	33	-
Morialta Mungindi, NSW						
1	30 July	9.8 at planting 4.7 average for following 7 days	105 (pre water)	12	33	33
2	10 September	5.9 at planting 6.4 average for following 7 days	158 (post water)	12	33	-

[#]   8am soil temperature (°C) at planting depth averaged over the seven days after planting.

[##]   Soil water (mm, 0–1.2 m) at the time of planting.

*   Bore water was applied post planting using dripper lines to ensure even establishment due to dry seedbed moisture conditions. Additional in-crop watering was applied using the same method to try and prevent trial failure.

Experiment design

Randomised complete block design with time of planting as the main block and population as the sub-plot and hybrids randomised; three replications.

The trial was planted on 150 cm solid plant rows using a Monosem Precision Planter.

Fertiliser

110 kg/ha of urea was applied in March 2019.

43 kg/ha Granulock 12 Z planted with the seed.

Treatments

Planting dates (2)

1. Winter planted – 22 and 30 July at Bullawarrie and Morialta respectively.

2. Normal planting time – 2 and 10 September at Bullawarrie and Morialta respectively.

Hybrids (9)

A66, A75, Agitator, Cracka, HGS114, MR Taurus, MR Buster, Sentinel IG, MR Bazley.

Target plant populations (4)

3, 6, 9 and 12 plants/m^2

Results

Establishment

Bullawarrie Mungindi – 2019/20

The first planting date (PD1) was targeting soil temperatures of 12 °C. The decision to plant was based on a rising plane of soil temperatures. There was quite a bit of fluctuation in soil temperatures in the weeks following PD1 at Bullawarrie (Figure 1). This resulted in an average soil temperature at 8 am of 9.3 °C for the 7 days following planting. This was also accompanied by some cold temperatures post emergence, but which did not result in plant death. Some minor signs of frost on plant leaves were noted.
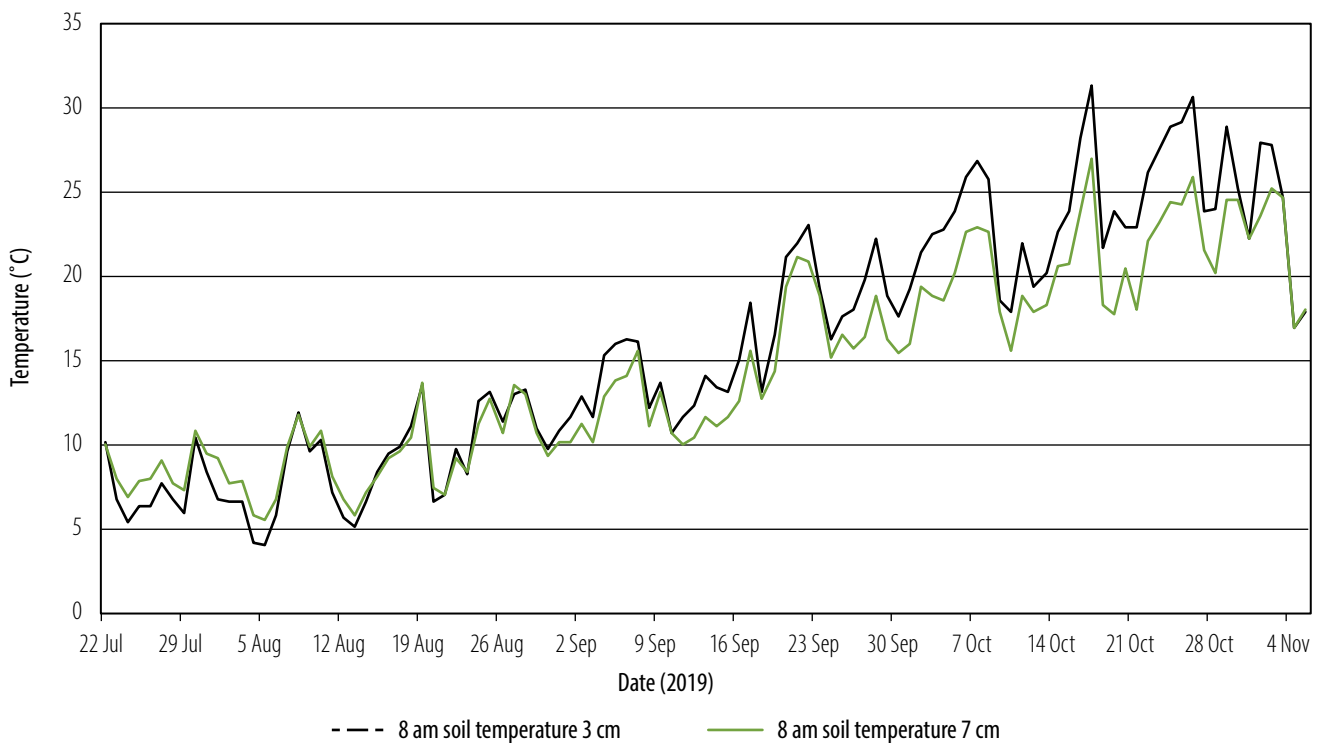
Figure 1   Soil temperatures at Bullawarrie – 2019.

The first plant counts were recorded 22 days after PD1 (22 July). Plant counts were conducted each week until the experiment succumbed to the drought. No rainfall fell for the three months following planting.

Planting date two (PD2) was quicker to emerge, with the first plant counting 15 days after planting. It had the benefit of warmer soil temperatures, with a seven-day average of 14.1 °C post planting.

Planting date had a significant effect on plant establishment with PD2 having better establishment than PD1 (Figure 2). PD2 established better than PD1 for all target plant populations, except the lowest population of 3 plants/m^2 (Figure 2). Any negative effect on plant establishment is important, but as the target population reduces, it is more critical for plants to establish and persist. At higher plant populations, there are more plants to compensate for any gaps in a plant stand.
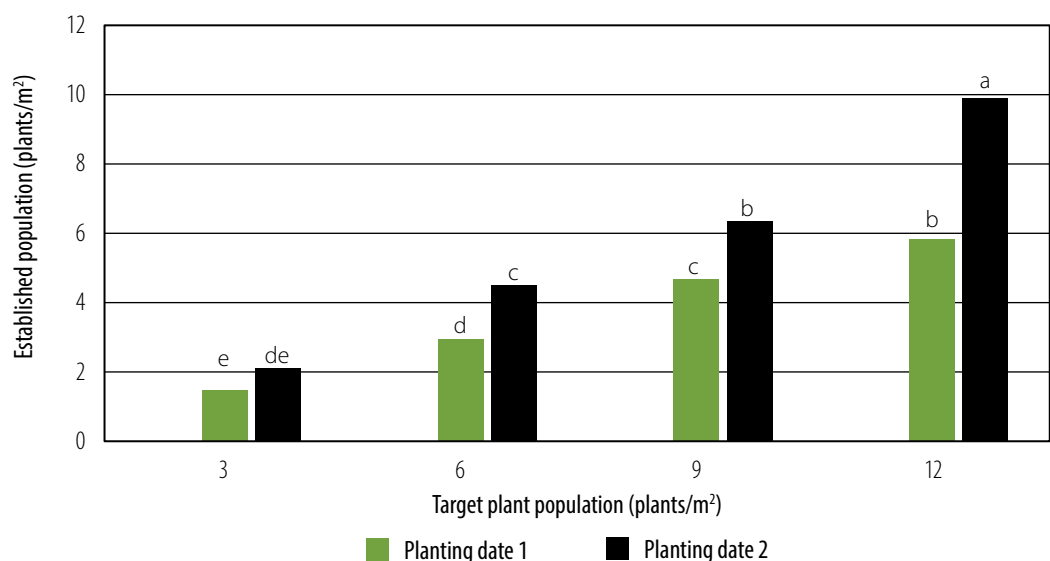

Figure 2   Sorghum plant establishment at different target plant populations (averaged across hybrids) at Bullawarrie – 2019–20 for PD1 and PD2.

There were also differences between hybrid establishment, with the variety Agitator having the lowest plant populations (data not shown). This establishment was commensurate with the results from seed quality testing.

Plants continued to emerge in the weeks following planting and then started to die due to the lack of moisture. The maximum emergence was recorded at the second plant count, which was either 25 or 31 days after planting (PD1 or PD2 respectively). On average, 40% of the seeds planted for PD1 and 60% of seeds planted for PD2 emerged.

Morialta Mungindi – 2019/20

The first plant emergence counts were recorded 29 days after PD1(30 July). This was longer than the time taken for emergence at Bullawarrie due to a cold snap and soil temperatures declining well below the 12°C target (Table 4). The average soil temperature at 8 am for the seven days following PD1 was only 4.7 °C.

Like the Bullawarrie site, PD had a significant effect on established plant population at Morialta (Figure 3). Establishment from PD2 was much closer to the target populations than PD1.

Plants continued to emerge over the weeks following planting and then started to die due to the lack of moisture. No plant deaths were recorded as a result of frost at this site (data not shown). Maximum emergence was recorded at the second plant count, which was either 37 or 20 days after planting (PD1 or PD2 respectively). On average, only 50% of the seeds planted for PD1 emerged compared with 75% for PD2.
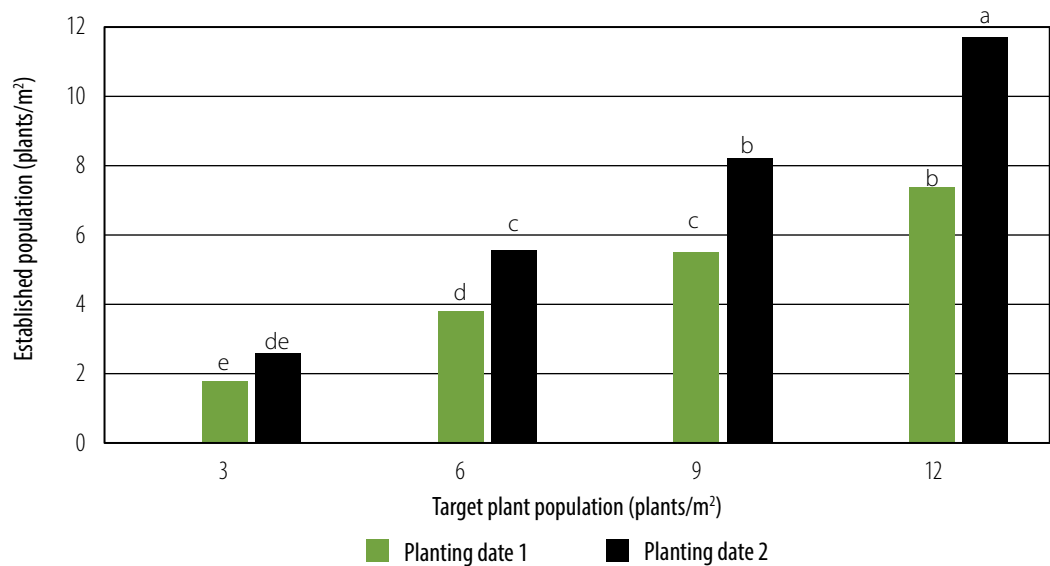

Figure 3   Sorghum plant establishment at different target plant populations (averaged across hybrids) at Morialta – 2019–20 for PD1 and PD2.

Discussion

Commercially acceptable sorghum establishment rates are around 75–80%. Only 40–50% of PD1 seeds established at both Mungindi sites which during higher rainfall seasons could be acceptable as later planted crops tend to fail due to heat across this region. To some extent, poor establishment can be mitigated by planting more seed, however, any seed losses result in poor plant uniformity, which negatively affects weed suppression and crop resource capture. The cost of additional seed also needs to be considered.

Moisture content and temperature are the primary drivers for germination and emergence of quality hybrid sorghum seed. Hybrid emergence in the field experiments showed a similar trend to laboratory germination tests, suggesting that seed quality testing is valuable for winter planted sorghum.

Commercially, this means a larger focus on selecting the best quality seed available for winter planted sorghum, particularly as establishment is likely to be reduced.

In these field experiments, seedbed moisture was not continuously monitored, however, we can assume because the crop stopped developing or developed at such a slow rate that the seedbed dried out before emergence. Pest and disease can also have a large effect on emergence at sub-optimal temperatures, but no evidence of biotic constraints was observed at either site.

The positive results that can be taken from this data set is that some plants did emerge and establish under these cold and dry conditions. In the Mungindi region, this gives some hope to the possibility of establishing a sorghum crop up to two months before normal sorghum planting in September.

Early planting provides a seasonal advantage in moving the flowering date earlier to a cooler period, most likely towards early–mid December, however, this will come at a cost. Seed will need to be planted with the acceptance that a large percentage might never establish, emergence time will be extended, and plant stand uniformity can be compromised.

At both sites, plant emergence and growth continued until the 4–6 leaf stage after which terminal moisture stress slowly resulted in plant death.

In these experiments, the plants were able to germinate and emerge under these conditions and in this season were not killed by frost with temperatures of −1.7 °C and 0.0 °C measured at 1.2 m above the ground at Bullawarrie and Morialta respectively. However, microclimatic factors including crop residues, soil moisture, topography and soil type influence the actual temperature of the plant and the possibility of a killing frost should not be forgotten.

Reliable weather forecasting that can accurately predict soil temperatures for 2 weeks in advance would be invaluable in making winter sorghum planting decisions. A 2 week period of increasing 8 am temperatures (above around 12 °C) would probably allow enough time for seed to germinate and emerge.

Conclusions

While only one season of establishment data has been collected in the Mungindi region, the conclusions reached in this paper are in line with the previous season's data at other sites in northern NSW. It is possible to establish winter planted sorghum at lower than recommended soil temperatures, if there is acceptance that reduced establishment percentages and slower emergence will result. To some extent an increased planting rate can compensate for the reduced establishment. The greater challenge is to ensure that uniform emergence occurs before the seedbed dries out and to ensure the benefits of planting early are not lost due to increased time for germination and emergence, which can potentially negate the early planting date.

To minimise the risk of patchy, poor plant stands, the focus should remain on using the best quality seed available with applying an appropriate seed treatment to reduce the risk of pest or disease attack. Ensure seedbed and profile soil moisture are not limited and use available weather forecasting tools to help predict when a reasonable period of warming temperatures is likely to occur.

There is still an inherent risk of frost (either killing or mild) from planting earlier than traditionally recommended. Exactly how cold the temperature needs to be to cause significant plant death in sorghum remains undefined.

The earlier planting time for sorghum also provides an opportunity for greater cropping intensity in the system as harvest is brought forward, thus allowing the fallow recharge period to start earlier than normal. This increases the probability of planting a double crop such as chickpea into a profile with more plant available soil water compared with a traditional sorghum planting time.

Ultimately it seems if early crop establishment can be achieved in marginal sorghum production zones there are more potential benefits than drawbacks. These experiments are likely to be repeated in the coming season, with the hope of more favourable conditions to also allow grain yield and quality outcomes to be measured.

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Soybean variety evaluation – Tabulam, NSW 2018–19

Nathan Ensbey, Nguyen Nguyen, Natalie Moore and Sam Blanch (NSW DPI, Grafton)

Key findings

- The two new lines T171A-2 (2.74 t/ha) and NK94B-25 (2.51 t/ha) had yields that were statistically similar to the industry standard variety RichmondA (2.28 t/ha).

- Richmond[ϕ] had a grain protein concentration of 45.2% on a dry matter (DM) basis, which was significantly higher than the varieties T171A-2 (43.0 %) and NK94B-25 (43.4%).

- There was significant difference in seed size between varieties. Richmond[ϕ] produced the largest seed size (25.7 g/100 seeds), followed by T171A-2 (23.4 g/100 seeds) and NK94B-25 (21.3 g/100 seeds).

- No significant difference in grain oil concentration, plant height, and lodging score was observed between the three lines.

- Downy mildew, a leaf disease, was identified in the experiment, but not at an economically significant level.

- Adaptation of the two unreleased lines to the North Coast region of New South Wales (NSW) was validated through this experiment.

Introduction

In recent decades, the Australian Soybean Breeding Program (ASBP) has transformed Australian soybean (*Glycine max*) varieties in response to industry calls for varieties with superior quality grain traits. These include high protein, large seed size and clear hilum to supply the high value human consumption markets in Australia and internationally. In 2017, the Grower Variety Selection Committee (GVSC) was formed, and in consultation with the ASBP re-focused on selecting high yielding lines for northern NSW. Data from past seasons were assessed and several high yielding lines with adequate grain quality levels were chosen for on-farm evaluation in the summer of 2018–19.

The GVSC was formed to allow growers greater involvement in selecting new varieties from the breeding program and to participate in data review and on-farm evaluation. It consists of six grower members from the north coast region of NSW, and three NSW DPI representatives. The growers include Kevin Twohill (Murwillumbah), Paul Fleming (Codrington), Kate Dowley (Tabulam), Ben Clift (Codrington), Shane Causley (Warregah Island) and Alan Munro (Woodford Island). The NSW DPI representatives are Dr Natalie Moore (Research Agronomist), Nathan Ensbey (Technical Officer) and Sam Blanch (Technical Assistant).

A replicated, on-farm experiment was conducted at Tabulam in northern NSW to assess two advanced, unreleased high yielding lines against the known Australian industry standard variety, Richmond[ϕ].

Site details

Location	Growvale Trust, Plains Station Road, Tabulam, NSW 2469 (Latitude 28°57'23.2"S, Longitude 152°32'52.0"E)
Paddock history	• Summer 2017–18: Soybean • Winter 2018: Wheat
Co-operator	Kendall and Kate Dowley, Growvale Trust

Soil type and nutrition	• Brownish loam pH$_{Ca}$ 5.6
	• Subsoil constraints were not evident at this site.
	• Table 1 shows the soil chemical analysis.

Rainfall and temperature Total rainfall from November 2018 to April 2019 was 346.2 mm, which is 53% less than the long-term average of 742.3 mm for this location. There was no rainfall in January 2019, with the remaining months receiving substantially less than long-term rainfall averages (March excluded) (Figure 1). Higher than average temperatures were recorded during the growing season, which could have negatively affected plant growth.

Experiment design
- Randomised complete block design.
- Three replicates and three varieties.
- Each plot was 4.87 m (6 rows) wide and approximately 95 m long.
- Row spacing was 0.8 m.

Planting date 29 December 2018

Fertiliser 400 mL/ha Como® (cobalt 1% and molybdenum 6%) applied over crop rows on 4 February 2019

Target plant population 20 plants/m^2

Weed management
- Starane® Advanced 450 mL/ha (333 g/L fluroxypyr), fallow weed control.
- Weedmaster® Argo® 1.8 L/ha (540 g/L glyphosate) was applied on 23 November 2018.
- Spinnaker® 140 g/ha (700 g/kg imazethapyr) and Dual Gold® 2.0 L/ha (960 g/L s-metolachlor) was banded over at planting.
- Weedmaster® Argo® 1.8 L/ha (540 g/L glyphosate), mixed with enhance oil at 500 mL/100 L and applied on 6 February 2019.
- Reglone® 2.2.0 L/ha (200 g/L diquat) applied on 5 May 2019 before harvest.

Insect management
- Targeting larvae of *Helicoverpa armigera*: ViVus® Gold 375 mL/ha (polyhedral inclusion bodies of the *Nucleopolyhedro* virus of *Helicoverpa armigera*) applied 5 February 2019.
- Targeting brown eggs and hatchling to small larvae of *Helicoverpa* spp: DuPont™ Steward® EC 400 mL/ha (150 g/L indoxacarb) applied on 18 February 2019.
- Controlling Lepidopteran species: DuPont™ Altacor® (350 g/kg chlorantraniliprole) at 70 g/ha applied on 7 March 2019.

Disease management No diseases of economic significance developed in the experiment. Some downy mildew (*Peronospora manshurica*) was present, but not at an economically significant level.

Harvest date 10 May 2019.

Table 1   Soil analysis of Growvale Trust, Tabulam, NSW, 2018–19.

Measurement	Value
Soil pH (1:5 water)	5.6
Estimated organic matter (% OM)	2.9
Sulfur (mg/kg)	5.6
Nitrate nitrogen (mg/kg)	17.4
Ammonium nitrogen (mg/kg)	2.2
Phosphorus (mg/kg) [Bray 1 test]	33
Phosphorus (mg/kg) [Bray 2 test]	63
Phosphorus (mg/kg) [Colwell test]	71
Potassium (%)	5.4
Calcium (%)	75.3
Magnesium (%)	17.2
Sodium − ESP (%)	0.7
Aluminium (%)	0.5
Electrical conductivity (dS/m)	0.062
Effective cation exchange capacity (ECEC) (cmol+/kg)	8.2
Zinc (mg/kg)	4.8
Copper (mg/kg)	0.6
Iron (mg/kg)	195
Manganese (mg/kg)	14
Silicon (mg/kg)	33

Total annual rainfall 2018–2019 season: 346.2 mm

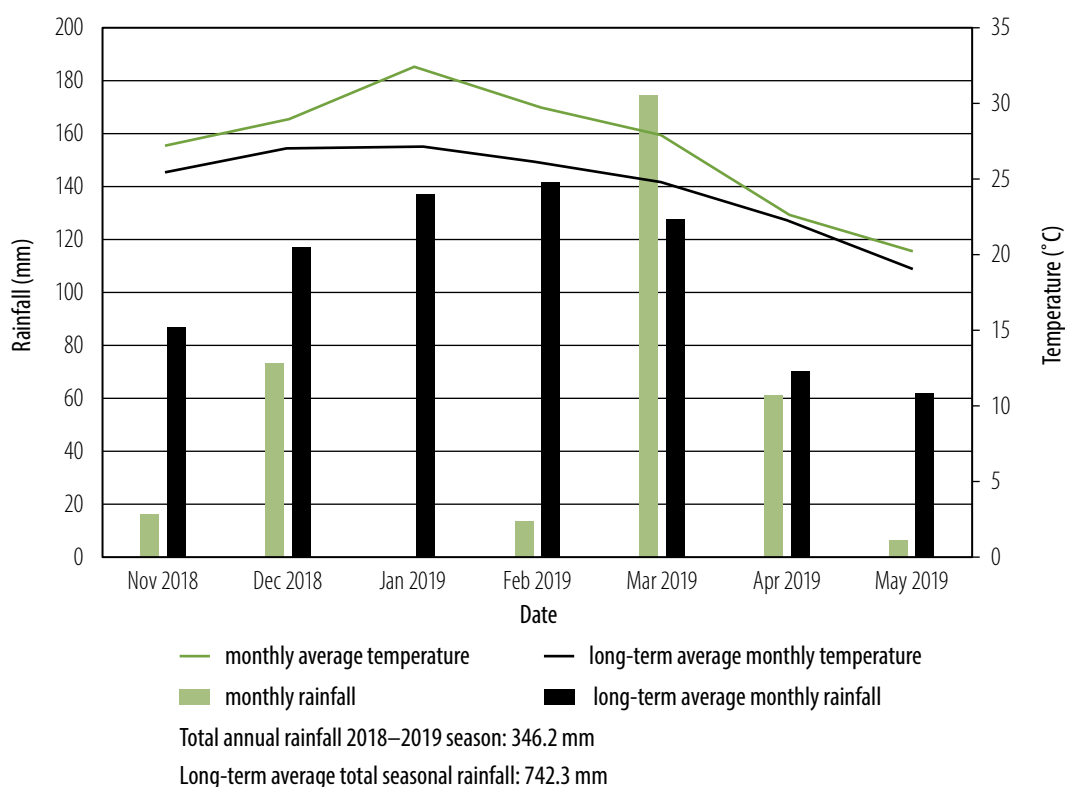Long-term average total seasonal rainfall: 742.3 mm

Figure 1   Comparison of growing season rainfall and temperature at Tabulam, NSW 2018–19 with long term average rainfall and temperature data. Raw data was obtained at http://www.bom.gov.au/climate/data/ (BOM 2019.)

Summer crops

Varieties (3)

Commercial standard Richmond$^\Phi$ and unreleased lines NK94B-2 and T171A-2.

Table 2 contains a short description of variety traits and why they were included.

Table 2   Description of soybean varieties in the experiment at Tabulam, NSW 2018–19.

Treatment number	Variety	Variety traits and reason for inclusion in the experiment
1	Richmond	Industry standard with high weathering tolerance, high protein, clear hilum and high yield, suited to an early–mid planting date in the North Coast and northern slopes regions of NSW.
2	NK94B-25	Unreleased line with high yield potential, clear hilum, suited to an early–mid planting date.
3	T171A-2	Unreleased line with high yield potential, clear hilum, suited to an early planting date, resistant to soybean leaf rust, narrow leaf shape.

Results

Establishment

The planting date was three weeks later than planned due to prolonged dry weather. However, all varieties established well and evenly in the experiment (Figure 2).

Figure 2   An on-farm evaluation of unreleased soybean lines was conducted at Growvale Trust, Kendall and Kate Dowley's property at Tabulam. The farming system uses wide (0.8 m) row spacing and double cropping soybean with winter cereal. Photo N. Ensbey NSW DPI.

The established plant population ranged from 243,000 plants/ha to 270,000 plants/ha, within the target range. The unreleased line NK94B-25 developed the bushiest growth habit and line T171A-2 appeared to adapt well to the hot, dry weather with a dense canopy and good pod set (Figure 3). As the grower inadvertently planted over Replicate 2 of line T171A-2, data was only taken from two replicates of this treatment, not from three replicates as for the other treatments.

Figure 3 Soybean line T171A-2 in the on-farm evaluation at Tabulam. Photo N. Moore NSW DPI.

Lodging, leaf diseases and maturity

All soybean varieties in the experiment showed high stand-ability with no lodging observed. Downy mildew leaf disease was detected, but there was no significant damage to soybean plants that would results in yield loss. All varieties matured at an acceptable time for harvest.

Plant height at maturity

Plant height was measured at crop maturity. Line NK94B-25 was the tallest variety at 54.8 cm, followed by line T171A-2 at 51.37 cm and the commercial variety Richmond[ⓘ] the shortest at 45.43 cm (Table 3). There was no significant difference in the data for plant height.

Grain yield

The data was analysed by Stephen Morris (Biometrician, NSW DPI Wollongbar) using spatial analysis with an ASReml package (Butler et al., 2017) in the R environment (R Development Core Team 2017). Differences between results that exceed the estimate of least significant difference (l.s.d.) can be regarded as statistically significant at the 5% critical value (*P*<0.05).

Line T171A-2 yielded 9% higher than line NK94B-25 and 17% higher than variety Richmond[ⓘ] (Table 3), however, when analysed there was no statistically significant difference between the yields of the three varieties in this experiment. Figure 4 gives a visual representation of the variation in yield between the field replicates in the experiment.

Table 3 Analysed data of soybean variety evaluation at Tabulam, NSW 2018–19.

Soybean variety	Grain yield (t/ha)	Seed size (g/100 seed)	Grain oil content (% DM)	Grain protein content (% DM)	Plant height (cm)
T171A-2	2.74 [a]	23.4 [c]	20.3 [a]	43.0 [b]	51.4 [a]
NK94B-25	2.51 [a]	21.3 [b]	20.8 [a]	43.4 [b]	54.8 [a]
Richmond[ⓘ]	2.28 [a]	25.7 [a]	19.8 [a]	45.2 [a]	45.4 [a]
l.s.d. (P<0.05)	1.16	1.79	1.08	1.15	10.23

l.s.d. = least significant difference at the 5% critical value (*P*<0.05)
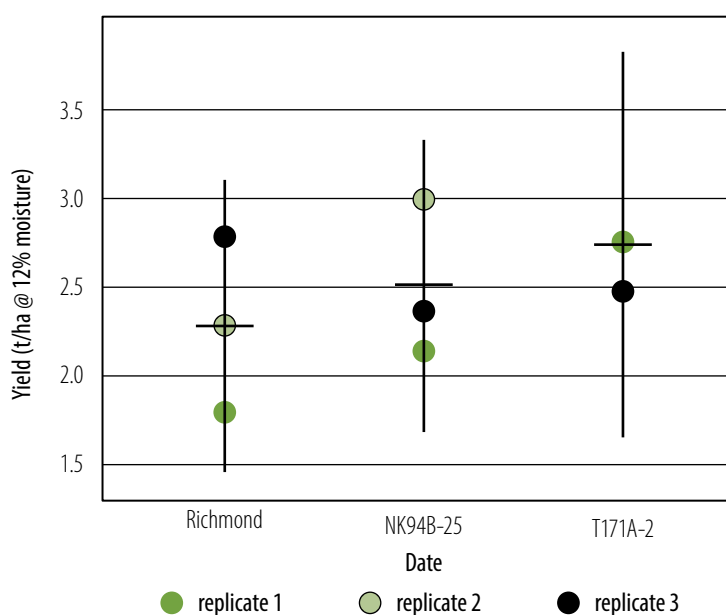Note: values with the same letter are not significantly different

Figure 4   Average yields of the three varieties plotted with the mean of three replicates (replicate 2 of T171A-2 is not included) at Tabulam, NSW 2018–19.

Seed size

Seed size was measured as the weight of 100 seeds at 12% moisture content. The difference in seed size between three lines was significant, ranging from the largest for standard variety RichmondA (25.7 g/100 seeds) to the smallest, NK94B-25, at 21.3 g/100 seeds. T171A-2 was the mid-size seed size recorded at 23.4 g/100 seeds (Table 3).

Grain protein and oil content

All varieties produced protein content above the industry standard of 40% DM. The protein content of variety Richmond[ϕ] (45.0% DM) was significantly higher than the two unreleased lines NK94B-25 (43.4% DM) and T171A-2 (43.0% DM) (Table 3). There was no statistically significant difference between the protein content of NK94B-25 and T171A-2.

For grain oil content, the three treatments NK94B-25 (20.8% DM), T171A-2 (20.3% DM), and Richmond[ϕ] (19.8% DM) were statistically similar (Table 3).

Conclusions

Average rainfall during the growing season was 53% of the long-term average for the region. This, combined with the higher temperature during the growing season, could have negatively affected plant growth and decreased the experiment's overall yield. The collaborating grower confirmed that soybean yield was lower than average for their farm this season. However, the two unreleased lines and Richmond[ϕ] adapted well to the unfavourable conditions and established evenly. Results indicate that the two unreleased soybean lines (NK94B-25 and T171A-2) performed similarly to the high yielding commercial variety Richmond[ϕ] and produced acceptable protein content and seed size, confirming their adaptation to the North Coast region of NSW. The growers commented favourably on the establishment and yield of line T171A-2, and expressed interest in evaluating the variety again. Although no soybean leaf rust developed in this experiment, the resistance of line T171A-2 to this disease is considered as a valuable trait to protect high yield potential in high rainfall seasons.

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Summer crops

Soybean variety evaluation Narrabri, NSW 2019–20

Mathew Dunn[1], Nguyen Nguyen[2], Natalie Moore[2]

[1] NSW DPI, Australian Cotton Research Institute, Narrabri

[2] NSW DPI, Grafton Primary Industry Institute, Grafton

Key findings

- The unreleased soybean line NK94B-25 produced the highest yield (2.67 t/ha) followed by two other unreleased lines T171A-2 (2.49 t/ha), 17-410 (2.49 t/ha), compared with the commercial varieties Richmond[ɸ] (2.48 t/ha), and Moonbi[ɸ] (2.33 t/ha).

- The variety Moonbi[ɸ] was the earliest to mature, reaching 95% physiological maturity (P95) at 131 days after planting (DAP). There was no significant difference between the four other varieties in the time taken to reach maturity (138–139 DAP).

- Grain protein concentrations were acceptable for all varieties, with the highest being 17-410 at 41.5%, Richmond[ɸ] at 41.3% and NK94B-25 at 41.1%.

- Richmond[ɸ] and 17-410 produced in largest seed size (19.3 and 19.2 g/100 seeds, respectively) followed by Moonbi[ɸ] (18.5 g/100 seed), T171A-2 (17 g/100 seeds), and NK94B-25 (16.7 g/100 seeds).

- The grain yield and quality results indicate that the soybean varieties tested are adapted for growing in this region in an irrigated cotton farming system. No diseases or lodging developed during the experiment.

Introduction

The Australian Soybean Breeding Program (ASBP) develops Australian varieties of soybean (*Glycine max*) in response to market signals for superior grain quality traits. These include high protein, large seed size and clear hilum, to supply high value human consumption markets in Australia and internationally.

In 2017, a group of leading soybean growers from northern NSW formed the Grower Variety Selection Committee (GVSC) in consultation with the ASBP. The group assessed variety evaluation data from past seasons with the objective of selecting high-yielding lines for northern NSW. Several lines with adequate grain quality were chosen for on-farm and regional evaluation in the summer of 2019–20, including a replicated experiment in an irrigated, raised-bed, cotton farming system at Narrabri, NSW. Five varieties were assessed: three unreleased lines, NK94B-25, T171A-2 and 17-410 and two commercial varieties, Richmond[ɸ] and Moonbi[ɸ].

Site details

Location	Australian Cotton Research Institute (ACRI), Narrabri, NSW (Latitude 30°11′37.99″S, Longitude 149°37′6.24″E)
Paddock history	• 2019 winter: fallow • 2018 winter: wheat • 2016–17 summer: soybean and mungbean experiments
Soil type and nutrition	Soil type: grey, cracking clay (vertosol) (Isbell, 1996). See for Table 1 details.

Rainfall and temperature	Irrigation was applied pre-planting and after planting (November to December 2019). The site received good rainfall in January to harvest so the irrigation requirement was lower over this period. Very high rainfall was recorded in February 2020 (Figure 2), which coincided with full flowering and the beginning of pod set. The temperature was higher than the long-term average in November and December, but was lower than the long-term average in February, March and April. (Figure 1). Raw data was obtained at http://www.bom.gov.au/climate/data/ (BOM, 2020)	
Experiment design	• Randomised complete block design. • Five treatments (varieties) with four replicates. • Plot size: 2 m wide and 18 m long, 4 rows per plot at 0.36 m row spacing.	
Planting date	22 November 2019.	
Fertiliser	100 kg/ha of starter fertiliser applied at sowing (N:6%, P:12%, K:23%, S:2%, Zn: 0.6%).	
Target plant population	45 plants/m^2.	
Weed management	Roundup UltraMax® 2 L/ha (570 g/L glyphosate) was applied before planting. Any other weed germinations were controlled with hand chipping throughout the season.	
Insect management	Aerial application on 7 March: Altacor® 150 g/ha (350 g/kg chlorantraniliprole), Canopy® 2 L/ha (792 g/L paraffinic oil), and Transform™ 120 g/ha (500 g/kg sulfoxaflor).	
Disease management	No fungicide applications.	
Harvest date	22 April 2020.	

Table 1   Soil chemical properties of the field site at ACRI, Narrabri, NSW, 2019–20.

| Soil characteristic	Depth (0–10 cm)	Depth (10–30 cm)
pH$_{Ca}$	7.5	7.7
pH (1:5 water)	8.0	7.8
Sulfur (mg/kg)	10.9	6
Nitrate nitrogen (mg/kg)	36	9
Ammonium nitrogen (mg/kg)	<1	<1
Organic carbon (%)	0.97	0.69
Phosphorus (mg/kg) [Colwell test]	27	20
Potassium (mg/kg) [Colwell test]	433	306
Electrical conductivity (dS/m)	0.13	0.14
Zinc (mg/kg)	2.11	1.15
Copper (mg/kg)	1.59	1.68
Iron (mg/kg)	28.6	33.7
Manganese (mg/kg)	7.32	4.89

Summer crops
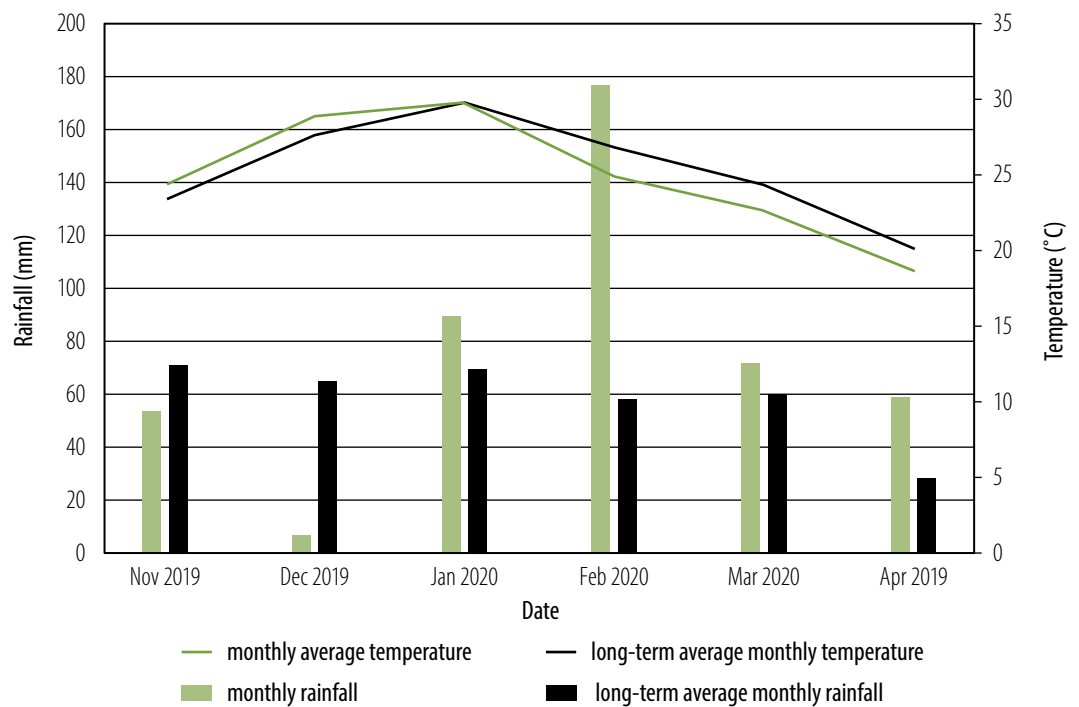
Figure 1   Australian Cotton Research Institute, Narrabri monthly rainfall and temperature for 2019–20 compared with long-term averages.

Treatments

Varieties (5)

- Commercial varieties: Richmond[Φ] and Moonbi[Φ].
- Three unreleased lines from ASBP NK94B-25, T171A-2 and, 17-410.

Table 2 lists a short description of variety traits and reason for inclusion in the experiment.

Table 2   Description of soybean varieties in the experiment at ACRI, Narrabri, NSW 2019–20.

Treatment number	Variety	Variety traits and reason for inclusion in the experiment
1	Richmond[Φ]	Industry standard for northern NSW, high yield potential, weathering tolerance, high protein, clear hilum, high tolerance to lodging, resistant to powdery mildew. Suited to early–mid planting dates (mid November–mid December) in the Northern Tablelands, slopes, Liverpool Plains and coastal regions of NSW.
2	Moonbi[Φ]	Industry standard for central and northern NSW. Compact plant shape, quick maturity, clear hilum, high protein, high tolerance to lodging, resistant to powdery mildew. Suited only to early planting dates (mid November) in central west, Liverpool Plains, northern slopes, tablelands and coastal regions of NSW. *Needs high plant population for optimum yield (e.g. 45 plants/m^2).
3	17-410 (2B05-1204-28)	Pending release as 'New Bunya HB1'. This is the first variety for northern NSW to be released from the breeding program with tolerance to halosulfuron-methyl herbicide conferred by one als gene (APVMA Permit Number 88483 for Sempra® to control nut grass).
4	NK94B-25	High yield potential, clear hilum, suited to early–mid planting dates (mid Nov–Mid Dec), performed well in NSW northern slopes and coastal evaluations in previous seasons.
5	T171A-2	High yield potential, compact plant shape, clear hilum, suited to an early planting date, fast maturing (not as fast as Moonbi[Φ]), narrow leaf shape. This line was included as it is a potential new release for northern NSW with resistance to soybean leaf rust.

Data analysis

Analysis of variance was conducted on the grain yield, grain quality and plant establishment measurements using the ANOVA feature in GenStat (Version 18, VSN International Ltd., UK). Fisher's least significant difference (l.s.d.) was used with a *P* value of 0.05 for the separation of mean differences.

Plant establishment

Plant establishment was even for each plot and ranged from 25 to 34 plants/m², which is within the recommended range for this inland environment and this farming system (raised beds with four rows at 0.35 m row spacing).

Figure 2 shows that T171A-2 and 17-410 established significantly higher plant populations than varieties Richmond[Φ], NK94B-25, and Moonbi[Φ].

- T171A-2: 33.9 plants/m²
- 17-410: 33.8 plants/m²
- Richmond[Φ]: 28.4 plants/m²
- NK94B-25: 27.3 plants/m²
- Moonbi[Φ]: 25.6 plants/m².
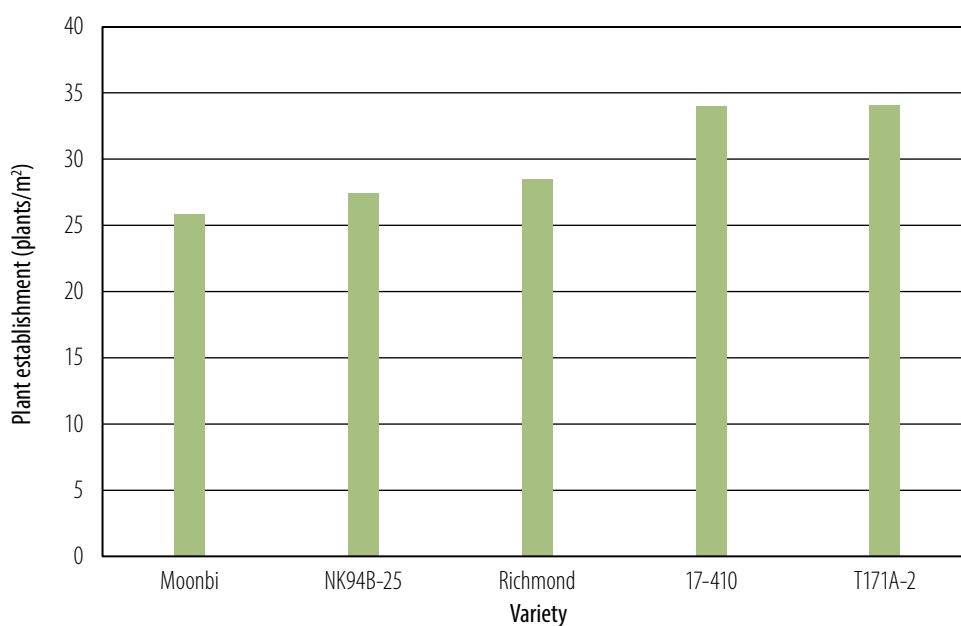
Figure 2   Average plant establishment of each variety, Narrabri, NSW.

Maturity

The variety Moonbi[Φ] was the quickest to reach flowering 45.5 DAP, followed by T171A-2, 17-410, Richmond[Φ], and NK94B-25. In relation to maturity, Moonbi[Φ] maintained its reputation for quick maturity and reached P95 maturity at 131 DAP, one week earlier than the other varieties (Figure 3). There was no statistical difference in time to reach maturity between the other four varieties (138–139 DAP, Table 3).

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Figure 3   Aerial photo of showing Moonbi⁽ᵇ plots reaching maturity one week earlier than the other varieties in the experimwent. Photo M. Dunn, NSW DPI.

Table 3   Average grain yield and quality, and maturity data for five soybean varieties.

Variety	Yield (t/ha)	Protein (% DMB)	Oil (% DMB)	Seed size (g/100 seed)	Seed size (seed/kg)	DAP to flowering (F50 stage)	DAP to maturity (P95 stage)	Height at maturity (cm)
NK94B-25	2.67[a]	41.1	21.1	16.1	6210	53.3	138	61.3
17-410	2.49[b]	41.5	20.6	19.2	5210	51.5	139	45.3
T171A-2	2.49[b]	38.4	21.0	17.0	5880	49.8	139	49.1
Richmond	2.48[b]	41.3	21.0	19.3	5180	51.8	138	45.3
Moonbi	2.33[b]	40.0	21.7	18.5	5400	45.5	131	67.5
P value	0.008	<0.001	0.047	<0.001	-	<0.001	<0.001	<0.001
l.s.d.(P=0.05)	0.16	0.99	0.71	6.26	-	1.16	1.12	5.84

Grain yield is expressed at 12.5% moisture; grain yield that is statistically different is denoted by different letters; protein and oil are expressed as dry matter basis (DMB); flowering date defined as when 50% of plants have at least one flower (F50).

Grain yield and quality

The unreleased soybean line NK94B-25 produced the highest yield (2.67 t/ha) followed by the other two unreleased lines 17-410 (2.49 t/ha), T171A-2 (2.49 t/ha). The commercial variety yields were Richmond⁽ᵇ (2.48 t/ha) and Moonbi⁽ᵇ (2.33 t/ha).

Recent studies indicate that Moonbi⁽ᵇ requires a higher plant population than other varieties to obtain optimum yield. The average plant population of Moonbi⁽ᵇ in this experiment (25.6 plant/m²) is likely to have reduced the yield variety's potential.

The protein concentrations were within the range preferred for culinary markets (i.e. >40% DMB), except for variety T171A-2, which was slightly lower at 38.42%. The reason for the lower than expected protein in this variety in this experiment is unknown.

Richmond[ɸ] (19.3 g/100 seed), had the largest seed size followed by 17-410 (19.2 g/100 seed), Moonbi[ɸ] (18.5g/100 seed), T171A-2 (17.0 g/100 seed), and NK94B-25 (16.7 g/100 seed) (Table 3).

Lodging and leaf diseases

There was no significant lodging or disease development during the season.

Conclusions

The experiment was successful with even growth across the site and no major pest, disease or weed issues that would have compromised plant growth or grain yield. From January onwards, the season was wetter than average for this environment.

Results from this experiment indicate that the unreleased soybean line NK94B-25 produced significantly higher yield than the four other varieties, but also had the smallest seed size, which would be acceptable to most markets in Australia but could limit access to high value overseas culinary export markets. Unreleased varieties 17-410 and T171A-2 produced higher yields than the two industry standard varieties Richmond[ɸ] and Moonbi[ɸ], however, this difference was not statistically significant (P=0.05).

The variety Moonbi[ɸ] had a disappointingly lower than expected plant population for all plots and this is likely to have reduced the yield potential. In general, soybean plants compensate for lower plant population by producing extra branches. However, recent studies (Moore and Dunn, 2019) have shown that Moonbi[ɸ] has a limited capacity to compensate and requires a higher plant population than other varieties to obtain optimum yield (e.g. 45 plants/m^2). The reason for this lower than expected population is unknown, but suggests that there could have been an issue with the seed storage conditions.

All varieties produced grain of acceptable quality for most soybean markets, however, the protein concentration for variety T171A-2 (38.4% DMB) was slightly lower than preferred for culinary markets. This variety is not known for low protein and has consistently produced protein above 40% DMB in field experiments in other environments in northern NSW.

This replicated experiment confirms that all the varieties tested are acceptable for this production environment and for use in an irrigated cotton farming system.

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Acknowledgements

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Summer crops

Soil water dynamics in spring and summer mungbean under rainfed and irrigation production systems – Narrabri 2016–17

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Key findings

- Planting date was the main agronomic factor affecting production and water use efficiency. Compared with a late spring planting, which suffered excessive heat stress and water deficit, the late summer planting gave the highest yield and water use efficiency.

- Irrigation scheduled at the late bud initial growth stage gave the highest yield and water use efficiency from the late spring and late summer plantings. Delaying irrigation to early podding resulted in a measurable increase in the amount of water unused by the crop remaining in the soil profile at crop maturity.

- Plant populations of 40 plants/m^2 used more water than populations of 20 plants/m^2. Differences in water use efficiency between populations were not significant.

- Mungbean water use was reduced under conditions of high evaporative demand.

- Stressed plants (November planting) used less water in vegetative phase and more in reproductive phase.

- Where adequate soil was available (February planting), mungbean used almost equal amounts of water both in vegetative and reproductive phases.

- Water extraction was highest at a depth of 55–75 cm of the soil profile for both spring and summer planting dates; consistent at crop populations of 20 plants/m^2 and 40 plants/m^2.

Introduction

The 'Northern Pulse Agronomy Initiative – NSW' (DAN00171) is a joint project between NSW DPI and the Grain Research and Development Corporation (GRDC). The project aims include identifying management strategies to optimise the yield and overall reliability of new mungbean varieties across different growing regions.

Mungbean is grown under rainfed and irrigated management systems. Industry guidelines currently recommend irrigating around flowering and early pod development. On-farm yield varies widely, irrespective of irrigation management, across the industry.

This experiment investigated the effects of key agronomic management practices:

1. planting date
2. irrigation scheduling
3. plant population

on:

- soil water dynamics

- production
- water use efficiency.

Site details		
Location	Australian Cotton Research Institute, Narrabri (30° 11′ 622″ S; 149° 36′ 594″ E).	
Soil type	Grey vertosol	
Configuration	Raised beds with 2 m centres, with four plant rows 35 cm apart	
Variety	Jade_AU$^{\Phi}$	
Inoculum	Group I (peat formulation applied immediately before planting)	
Fertiliser	80 kg Granulock® Z at sowing	
Herbicide	Pre-emergent: 2.25 L/ha Stomp® (pendimethalin); Post-emergent: 75 mL/ha Verdict® (haloxyfop).	
Soil nitrogen (N)	154 kg/ha (0–120 cm) at commencement of experiment	
Soil characteristics	Refer to Table 1	
Harvest date	12 February 2017 (112 days after planting) 29 May 2017 (102 days after planting)	
Planting	The experiment was sown into soil moisture suitable for germination 10–11 days after irrigation. Daily maximum soil temperatures during mid January to mid February varied between 36 °C and 41 °C, delaying planting due to concern about the effects on germination. Maximum soil temperatures during crop germination averaged 28.6 °C.	
Experiment design	A split-split block design with planting date as the main block was established, and irrigation treatment as sub-plots with plant population randomised within sub-plots; three replications.	

Treatments		
Planting dates	3 November 2016, 15 February 2017	
Irrigation schedule:	1. Rainfed after planting (irrigation 10 days before planting) 2. Late bud initial growth stage (just prior to flowering) 3. Early podding (growth stage R3)	
Population:	20 plants /m^2; 40 plants /m^2	

Irrigation and soil water measurements

Siphons supplied irrigation into furrows for an average of 11 hours at each irrigation. Actual water application was not measured in this experiment.

The soil water content (SWC) was measured weekly, the day before irrigation and approximately three to four days after irrigation to calculate the amount of water contributed to the profile. SWC was measured at soil depth intervals of 0–15 cm and then at 10 cm increments down to 85–95 cm. Additional readings were made immediately before and after significant rainfall as required.

Table 1   Soil chemical characteristics in October 2016.

Soil depth (cm)	pH$_{Ca}$	Nitrate N (mg/kg)	Ammonium N (mg/kg)	Colwell P (mg/kg)	Potassium (mg/kg) (Colwell)	Sulfur (mg/kg)	Zinc (mg/kg)	Salinity (dS/m)	Sodicity (% ESP)	Organic carbon (%)
0–10	6.8	2.6	2.7	43.8	374	7.3	8.94	0.08	1.8	0.8
10–20	7.3	3.1	3.7	25.4	271	15.7	2.17	0.15	3.3	0.6
30–60	7.4	4.9	6.1	24.2	237	25.4	1.14	0.21	4.6	0.6
60–90	7.7	6.5	6.3	34.6	256	48.6	1.14	0.26	7.0	0.5
90–120	7.7	1.8	5.7	38.2	285	51.2	0.57	0.27	7.7	0.5

Total SWC to a depth of 95 cm was measured throughout the crop cycle of each planting date.

The SWC was measured using neutron moisture meters (NMM). Access tubes were placed in the middle of the raised bed between the two inner plant rows within uniform representative plant populations.

Supplementary irrigation was applied to November planting date plots when extreme crop stress was observed five weeks after planting. This effectively brought all treatments back to similar moisture content.

At each NMM reading, crop growth stage was recorded. Irrigations were determined by crop growth stage.

Climate

The long-term average annual rainfall for Narrabri is 591 mm. The region is characterised by summer dominant rainfall patterns. Table 2 details the climate data at the experiment site for the 2016–17 summer season.

Table 2   Climate conditions during the 2016–17 summer crop growing season at Narrabri.

Year	Month	Mean T$_{max}$ (°C)	Mean T$_{min}$ (°C)	RH$_{max}$ (%)	RH$_{min}$ (%)	Mean radiation (MJ m^{-2})	Total rainfall (mm)	Mean daily ETc[*] (mm)
2016	November	31.0	14.0	95.7	45.7	27.6	5.8	2.61
	December	35.6	19.7	90.3	47.6	27.9	18.0	6.67
2017	January	38	22.4	94.1	50	30.4	37.2	8.45
	February	37.7	20.8	93.1	38.5	29.8	36.2	6.01
	March	30.8	18.1	95.4	61.4	20.6	105.2	2.79
	April	26.5	11.1	94.8	60.4	18.6	10.4	6.17
	May	24.3	8.2	96.0	60.7	14.1	29.4	2.47

Source: Australian Cotton Research Institute

[*] ETc — Crop evapotranspiration refers the amount of water that is lost through evaporation from the soil and via transpiration by the crop. The ETc is estimated from the weather data and crop coefficient at different development stages.

Results

Irrigation, rainfall and water balance

Water infiltration and subsequent changes in SWC varied with irrigations.

The November planting showed an average 19 mm increase to the soil profile, infiltrating to 25 cm deep after the supplementary irrigation. Subsequent irrigations applied at the late bud initial growth stage and at early pod development measured no significant change in total SWC.

Additional data analysis (not presented) showed that irrigation applied at the late bud initial growth stage in the February planted crop increased SWC by a 7 mm average to 35 cm deep. Subsequent irrigation at early podding added 65 mm to the soil profile at 65 cm deep.

The reasons for these differences are unclear. Differences could be due to water loss from evaporation and evapotranspiration during the three to four-day period after irrigation, or to NMM measurements and/or soil surface sealing that prevented water infiltration. These dynamics could have affected the overall water balance and irrigation efficiency.

Total in-crop rainfall for the November and February plantings was 43 mm and 153 mm respectively. For the November planting, the total crop water requirements (ETc from Table 1 × days in the ground) was estimated at 616 mm, while it was 382 mm for February planting. The rainfall contribution to the crop water requirements of each crop cycle from in-crop rainfall varied: 7% for the November planting and 40% for the February planting.

Soil water dynamics — full soil profile

Planting date influenced the length of the crop cycle, 105 days and 88 days for the November and February planting dates respectively.

Table 3 details the changes to the soil profile SWC (0–95 cm) from planting date to physiological maturity, and immediately before each irrigation. The change from initial planting SWC to that at crop maturity was less than 100 mm for all treatments. The rainfed treatment for the February planting measured the greatest depletion in total SWC. For the November planting, records from the late bud initial treatment showed lower finishing soil water than the rainfed treatment, although differences were marginal.

For both planting dates, the changes in soil profile was smallest when irrigation was applied at early podding. This scheduled irrigation for the November planting was applied 39 days before maturity, and in the February crop, 48 days before crop maturity.

The changes in total SWC over the crop cycle in the late bud initial, and rainfed and treatments for the November planting were 89 mm and 78 mm respectively. The early podding treatment was the lowest, decreasing total SWC by 59 mm.

The ranking order for the February planting was distinctly different. The rainfed crop depleted total SWC the most – 94 mm, followed by the late bud initial treatment – 65 mm and only a 26 mm reduction when irrigation was scheduled at early podding.

Table 3   Average soil profile (0–95 cm depth) soil water content (SWC) at various mungbean growth phases and change in SWC at two planting dates at Narrabri.

Planting date	Irrigation timing	SWC (0–95 cm) at planting	Total SWC (mm) to 95 cm depth, immediately prior to irrigation			SWC at physiological maturity	Changes in SWC (starting SWC – SWC at maturity) (mm)
			Supplementary irrigation	Late bud initial	Early podding		
3 November 2016	Days after planting	0	40	54	65	105	
	Rainfed	374	345	352	327	296	78
	Late bud initial	374	341	350	320	285	89
	Early podding	374	339	335	319	315	59
15 February 2017	Days after planting	0	–	40	49	88	
	Rainfed	309	–	352	317	215	94
	Late bud initial	309	–	358	363	244	65
	Early podding	309	–	354	321	283	26

Soil water dynamics — soil profile depths

November planting

The crop was growing when increasing daily temperatures broke new weather records for prolonged high temperatures, coinciding with the crop's reproductive phase of the. There was an 18 mm rainfall when the crop was at mid seed formation.

All irrigation treatments were at similar volumetric water content (VWC) in the 0–35 cm layer at the end of the season for the November planting (Figure 1).

The late bud initial and rainfed treatments followed similar levels of changes in VWC, with the greatest change in VWC at around 55 cm deep.

Irrigating at early podding resulted in slightly higher residual soil water at physiological maturity at the 0–45 cm depth range, and further increases in residual soil water at 55–75 mm, relative to the other two irrigation treatments (rainfed and bud initial).
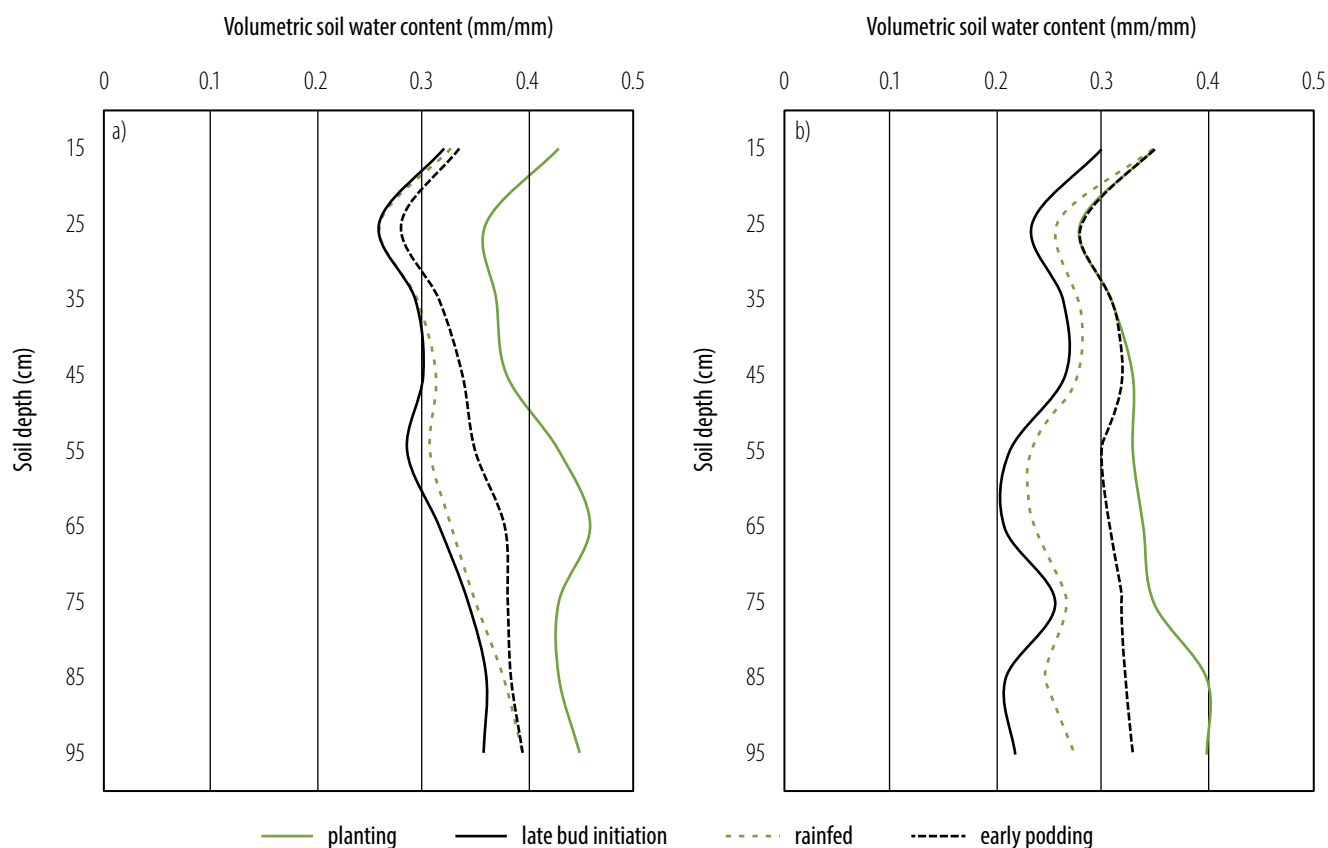

Figure 1   Volumetric water content at soil depths at planting (solid green line) and physiological maturity for a) November 2016 and b) February 2017 planting dates at Narrabri.

February planting

Decreasing daily temperatures and radiation during the crop growth period combined with 153 mm in-crop rainfall, resulted in minimal differences in water depletion between treatments in the 0–35 cm depth soil profile at physiological maturity for the February planting (Figure 1).

At all depths, VWC was most depleted at the late bud initial treatment; the 55–75 cm layer showing the greatest losses compared with the VWC at planting. A similar pattern was measured in the rainfed treatment.

VWC at the 0–45 cm depth remained unchanged, with the irrigation scheduled at early podding irrigation re-filling the upper layers of the profile. Significant differences were observed below 45 cm. The early podding irrigation treatment had considerably more soil moisture remaining in the profile below 45 cm when the crop reached physiological maturity.

Effects of plant population

Plant population is a key management factor affecting yield. Industry recommendations for dryland crops are 20–30 plants/m² and 30–40 plants/m² for irrigated areas. These recommendations are based on numerous and widespread research in central and northern NSW, and Queensland over many years.

Crop population had consistent effects on changes in SWC of the soil profile for both planting dates. Across all timed irrigation treatments, when compared with the 20 plants/m² treatments, the 40 plants/m² plant population treatments averaged 31 mm less soil water remaining at physiological maturity from the November plant timing and 17 mm less from the February timing (Figure 2).
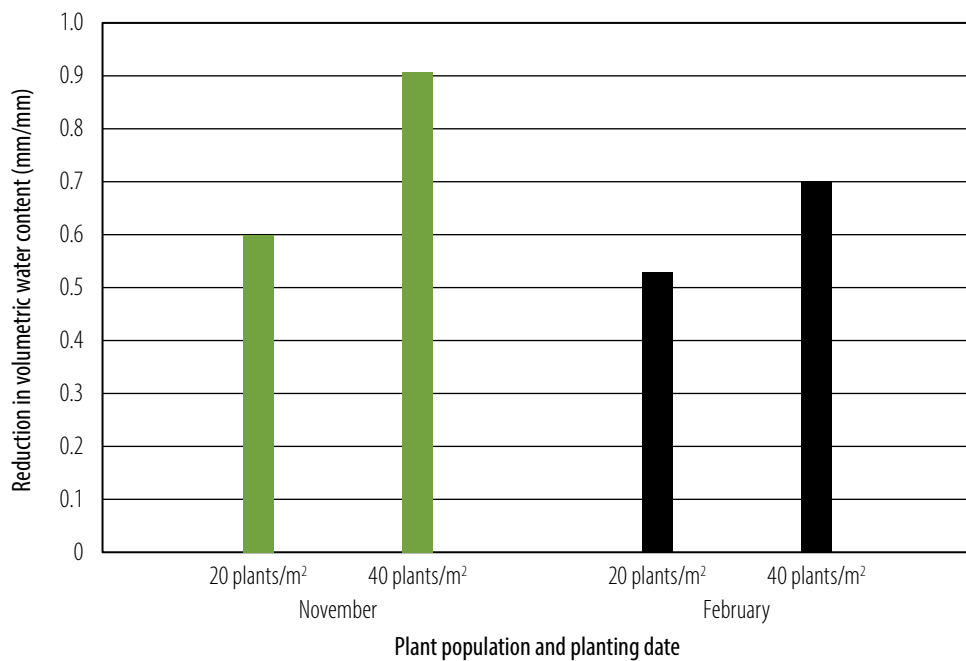

Figure 2   Effect of plant population on changes in volumetric water content in soil profile to 95 cm depth over spring and summer crop cycles.

Figure 3(a–f) show the effects of changes in plant populations (20 v 40 plants/m²) down the soil profile relative to each irrigation treatment. The differences in water extraction between the two populations at each planting date, from planting to crop maturity, revealed distinct differences. The greatest change in SWC between the two populations was often at soil depths of 55–75 cm for both planting dates.

Smaller changes in the February planted populations are attributed to the combination of lower starting soil water, higher in-crop rainfall, effective water infiltration at irrigation, lower crop demand and shorter crop cycle compared with the November planted crop.
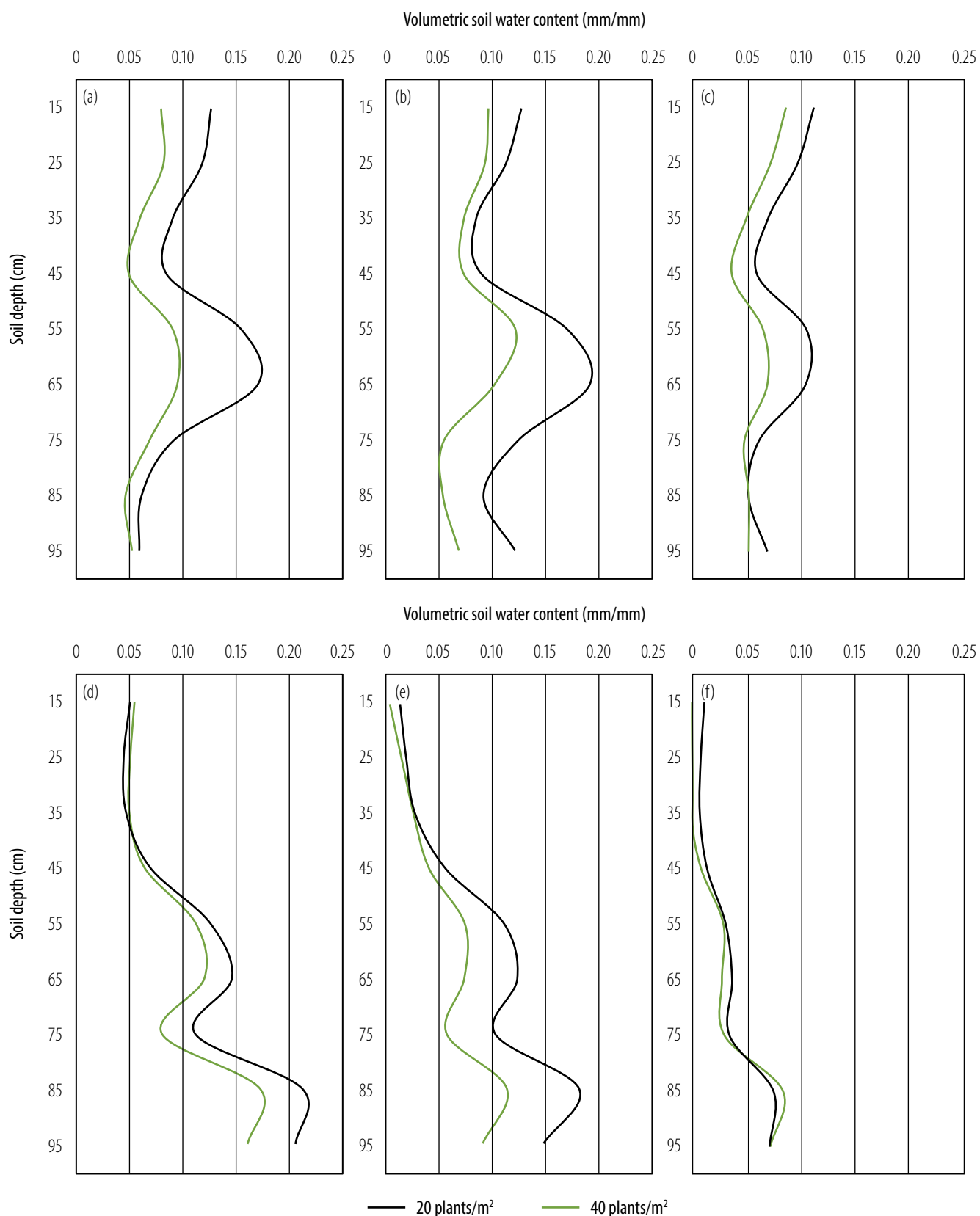
Summer crops

Figure 3   Effect of plant population and irrigation schedule [(a) and (d) rainfed; (b) and (e) late bud initial; (c) and (f) early podding] on changes in volumetric water content over spring [(a), (b) and (c) November plant date] and summer [(d), (e) and (f) February plant date] crop cycles for mungbeans.

Crop water use

The average crop water use over the full crop cycle of all irrigation treatments totalled 170 mm for the November and 284 mm for the February plantings. The total amount of water used by the crop showed marked differences between the vegetative and reproductive crop phases (Figure 4). The visibly stressed plants during the early to mid vegetative growth phase of the November crop used very little soil water compared with that of the February crop.

Of the total water the February crop used, approximately little over half was used during the reproductive phase with the remainder during the vegetative phase. The water use was slightly higher in the higher population treatment, but it was not significant.
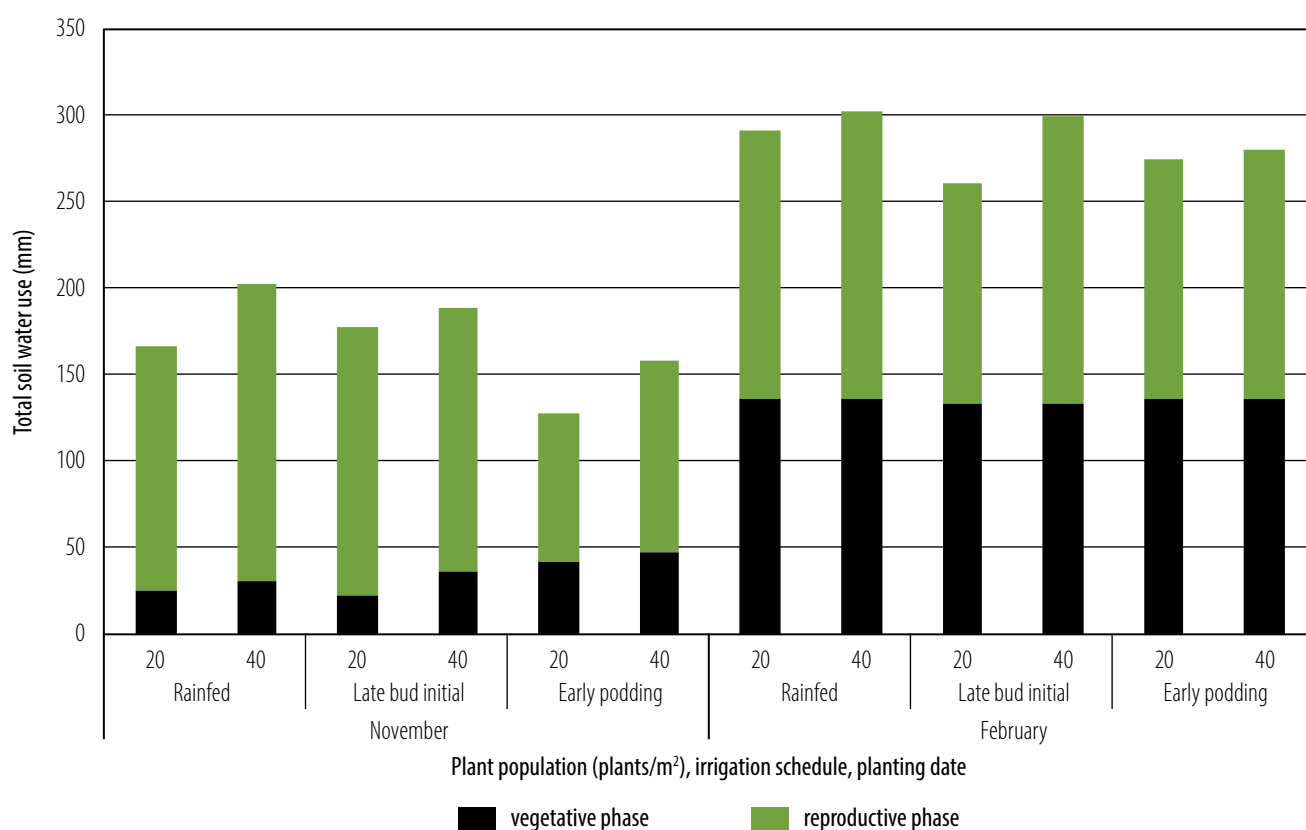

Figure 4   Mungbean water use during vegetative and reproductive phases for two plant populations and three irrigation schedules planted on two dates.

Crop yield and water use efficiency

The crop yields from the early November planting were very low. The record hot weather combined with the delayed planting and lower in-crop rainfall resulted in an average yield of 0.23 t/ha (12% moisture) across all treatments. In order of increasing yield, the early podding, rainfed and late bud initial treatments yielded 0.14 t/ha, 0.23 t/ha and 0.33 t/ha respectively.

Similarly, the delayed summer planting resulted in an average yield of 1.0 t/ha (12% moisture). In order of increasing yield, the rainfed, early podding and late bud initial treatments yielded 0.94 t/ha, 0.99 t/ha and 1.07 t/ha respectively.

Water use efficiency (WUE) is calculated by dividing grain yield by the total water the crop used. The results indicate how efficiently the crop has converted the water to grain. The February planting had twice the WUE than the November plant (Figure 5).

Scheduling irrigation at the late bud initial growth stage was the most effective management practice to maximise WUE at both planting dates.
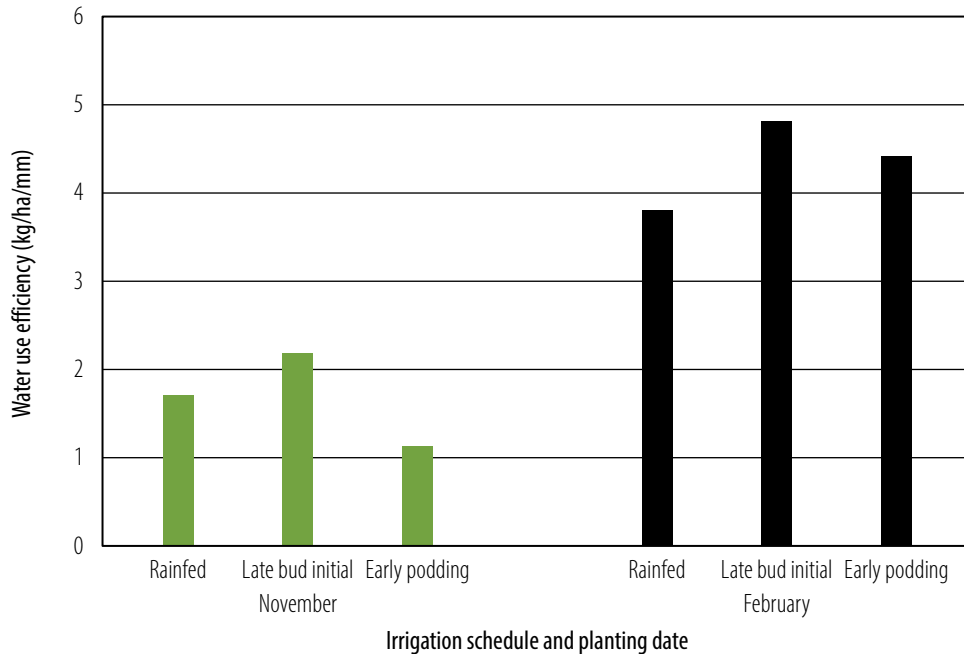
Figure 5   Effect of planting date on mungbean water use efficiency under different irrigation schedules.

Conclusions

Planting dates in this experiment were outside the optimum recommended planting windows, thereby effecting potential yields and WUE. However, the results offer insights into soil water dynamics in the soil profile throughout the crop growth cycle and the relative efficiency of rainfall and irrigation applications. The effects of crop population on changes in SWC require further investigation to determine potential opportunities for advancing agronomic management to improve WUE.

Water infiltration effectiveness under the furrow irrigation system on the soil compromised the irrigation schedules in this experiment. Similar inefficiencies might exist in an industry setting. Developing strategic management practices in field preparation and irrigation could be required to counter this variability.

Better understanding the critical crop stages and crop water use patterns throughout the season under different irrigation schedules will enable targeted water inputs during the growing season. This has the potential to increase returns per ML and WUE in mungbean.

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