Effect of sowing time, sowing rate and soil water regime on yield, water use efficiency and soil water dynamics of faba bean (*Vicia faba* L.)

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Abstract
Crop yield and water use efficiency are determined by its genotype, environment, GxE and agronomic management. The performance of faba bean (*cv*. Samira) under different sowing time, sowing rate and soil moisture conditions was evaluated. Sowing time and soil moisture regimes were found to have significant effects on grain yield, water use efficiency and grain quality. Yield penalty associated with delayed sowing was not significant when the crop was irrigated in spring; irrigation water use efficiency was higher for late sown than for early sown faba bean. Late sown faba bean left higher amount of residual moisture in the soil than the early sown faba bean. Faba bean yield and water use efficiency could be improved by timely sowing and/or supplemental irrigation.

Key words
Gypsum blocks, soil water tension, supplemental irrigation, Wagga Wagga

Introduction
As a legume, faba bean is an important break crop in rotation to break disease cycles and for adding nitrogen to the soil (Felton et al. 1998). However, in semiarid regions its yield is severely affected by the limited and variable rainfall (Cowling et al. 2005). Supplemental irrigation, correct sowing time and sowing rate could be used to maximise yield and stabilise production. Early sown crops have a longer growing season which could potentially increase above-ground dry matter (AGDM) and grain yield. At the same time, bulky canopies of early sown crops in favourable environments can lead to lodging and disease pressure (Turner and Asseng 2005). The recommended faba bean sowing window in south-eastern Australia is the fourth week of April to the second week of May (Matthews et al. 2017). However, depending on the autumn break rainfall or other factors such as farming operations timeline, weed and crop disease issues, the crop could be sown earlier or later (French 2010). For optimal management of supplemental irrigation and sowing time decisions, it is important to understand the effect of sowing time, soil moisture regimes and sowing rates on yield and water use efficiency. In this study, a field experiment was used to investigate the relationships between sowing time, sowing rate and irrigation on canopy growth, AGDM, grain characteristics, yield, and water use efficiency of faba bean.

Materials and method
The experiment was conducted at the Charles Sturt University experimental farm, Wagga Wagga. There were 24 experimental plots each separated by buffer plots treated similarly to the respective adjacent experimental plots. In-between all the plots there were 50 cm wide strips serving as foot path during data collection. It was laid out as a randomised factorial design experiment of sowing date, sowing rate, and irrigation with three replications. A mid-flowering cultivar of faba bean (*cv*. Samira) was inoculated and sown on two sowing dates: 21 April (ST1) and 26 May (ST2) 2018. The seeds were sown at 5 cm depth, 35 cm row spacing, 6 m long plots, for target populations of 21 (LD) and 39 plants/m^2 (HD). There were two watering regimes: dryland and irrigated. The crop data collected at harvest were grain yield, AGDM, number of pods per plant and 100 seed weight. The crop was harvested by cutting the plants at the ground level from the central 2 m length of each plot. The harvested plant material was dried in a drying oven for 48 h at 70°C and weighed to determine the AGDM. The grain was separated from the thrash by threshing out the harvested dried plant material.

The winter season during which this experiment was conducted was one of the driest on record with April–October rainfall of only 153 mm (45% of the long term average). Irrigation was applied using drip irrigation system with 30 cm spaced pressure compensated drips applying 1.6 L h^{-1}. Four drip laterals were laid out per plot at 40 cm spacing. Irrigation was applied, when average gypsum bock reading is 75-100 kPa, to bring the water content to field capacity. Accordingly, the total amount of irrigation was 247 mm and 185 mm for ST1 and ST2, respectively, the difference being irrigation of ST1 in autumn due to drought. Although both received the same amount of irrigation water in spring, 62 mm (34%) more water was applied to ST1 in autumn. Soil water content was measured, on average every two weeks, using neutron moisture meter calibrated at the site. One access tube per plot was installed to a depth of 120 cm. Gypsum blocks for soil water tension monitoring were installed at 15, 45, and 75 cm depth. The gypsum bocks data were logged every 30 min.

As a drip-irrigated system, the deep percolation below the rootzone was assumed to be negligible. There were no major rainfall events to cause runoff. Therefore, crop evapotranspiration (ET) was determined using the following soil water balance equation:

$$ET_a = P + I - \Delta S$$

Where P is precipitation (mm) and ΔS is change in soil water storage (mm). Water use efficiency on a grain yield basis (WUE_{gr}) and irrigation water use efficiency (IWUE) were determined as:

$$WUE_{gr} = \frac{Y}{ET_a}; \qquad IWUE = \frac{Y_i - Y_r}{\mathrm{I}}$$

Where Y is grain yield (kg/ha), ETa is actual evapotranspiration (mm), Y_i is the irrigated yield (kg/ha), Y_r is rainfed/dryland yield, and I is irrigation (mm). Statistical analysis was done with R statistical program (R Development Core Team 2016).

Results and discussion

The mean effects of sowing time (ST) and watering regime (W) had significant effect on all of the crop growth and harvest parameters except water use efficiency (Table 1). Sowing rate did not have any effect on any of the traits (Table 1). The only significant interaction (ST:W) effect was for seed weight. Early sown dryland faba bean had 55% higher yield than late sown faba bean. There was no significant difference between irrigated, early-sown and irrigated, late-sown crop yields. This indicates that supplemental/spring irrigation, when water is available, plays an important role in offsetting any yield loss due to delayed sowing. Unirrigated, late-sown crop had the lowest seed size implying reduced grain filling. Considering the fact that early sown crops are prone to lodging and disease, the results suggest that, if spring irrigation is available, it would be better to sow faba bean in late May than late April. However, if the crop is not irrigated, it is better to sow early as late sown crops will not be able to develop enough biomass and grain yield. Although irrigated, late-sown treatment had significantly fewer pods per plant than that of irrigated, early-sown treatment, there was no significant difference in grain yield. This is due to the significantly higher seed size for the irrigated, late-sown treatment than that of irrigated, early-sown treatment. Pods per plant of the unirrigated, late-sown treatment were not significantly different from the other unirrigated treatments. The lowest yield of this treatment was, therefore, due to its lowest seed weight. Irrigated, early-sown faba beans were the tallest and significantly taller than the other treatments while the unirrigated, late-sown treatments were the shortest. Sowing time had significant effect on irrigation water use efficiency; irrigated, early-sown faba bean had the lowest irrigation water use efficiency while irrigated, late-sown faba bean had the highest irrigation water use efficiency. Irrigation of early-sown faba bean resulted in 50% yield increase over unirrigated treatment while irrigation of late-sown faba bean resulted in 100% increase.

Sowing date significantly affected harvest index (HI) with late sown crops having higher HI. Irrigation did not have significant effect on HI. However, irrigation and early sowing resulted in higher AGDM which was not translated into grain yield, hence low HI. This illustrated that in early sown crops, high moisture availability leads to a higher vegetative rather than reproductive growth, thus reducing the harvest index. As shown in Table 1 and Figure 1, both sowing time and watering regime had significant effect on evapotranspiration.

Figure 2(a) shows that for the dryland crop sown on 21 April, the soil water tension at the 15 cm depth started increasing even during the early period of the cool winter months due to the relatively dry winter. In late winter, the soil water tension at the two deeper depths was increasing gradually. However, as the season progresses, in late spring, the soil water tension increased sharply indicating that crop water stress has developed during the spring period. Fig. 2(b) indicates that early sown irrigated faba bean maintained the soil moisture tension at low levels at all the three depths. However, in late spring the soil water tension at the two shallow depths rose sharply while the soil water tension at the deepest depth rose only gradually. Fig. 2(c) shows that for the unirrigated, late-sown treatment, the soil water tension at the two deeper depths was only slightly increasing throughout the season indicating that the crop root did not reach these depths. Although there was moisture at deeper depths, the crop was not able to extract it. With later sowing, within the constraints of the growing season, the plants did not have sufficient time to develop deeper rooting. Fig. 2(d) shows that the soil water tension of the irrigated, late-sown treatment was very low (close to saturation) throughout the season. Late-sown faba bean did not develop deeper rooting system which can extract water and nutrients from deeper soil depths. This leaves high residual water in the soil which can be used by the subsequent crop.

Table 1: Grain yield, AGDM, plant height, WUE, number of pods per plant, 100 seed weight, HI of faba bean sown early (ST1, 21 April) and late (ST2, 26 May) under either dryland or irrigation. Values within a column with different letters are significantly different ($P < 0.05$)

Sowing time (ST)	Water regime (W)	Grain yield (t/ha)	AGDM (t/ha)	HI (-)	100 Seed (g)	ETa (mm)	WUE_{gr} (kg/m^3)	Plant height (cm)	Pods/ plant (-)	$IWUE_{gr}$ (kg/m^3)
ST1	Dry	3.23b	9.73b	0.33cd	66.3b	263.7c	1.24a	97b	5b	-
	Irrigated	4.63a	16.30a	0.30d	67.3b	447.7a	1.03a	143a	8a	0.57b
	Dry	3.14b	10.50b	0.30d	66.6b	254.3c	1.23a	101b	5b	-
	Irrigated	4.89a	16.23a	0.30d	63.9c	455.0a	1.08a	145a	8a	0.71b
ST2	Dry	2.04c	4.33c	0.47a	63.4bc	187.0d	1.09a	60c	5b	-
	Irrigated	4.33a	11.27b	0.38bc	73.1a	377.3b	1.14a	103b	5b	1.24a
	Dry	2.08c	4.80c	0.43ab	61.2c	173.0d	1.19a	65c	4b	-
	Irrigated	4.17a	11.17b	0.37c	73.3a	372.3b	1.08a	101b	6b	1.13a

AGDM = above-ground dry matter; WUE_{gr} = water use efficiency of grain yield; ETa = actual evapotranspiration; $IWUE_{gr}$ = irrigation water use efficiency of grain yield

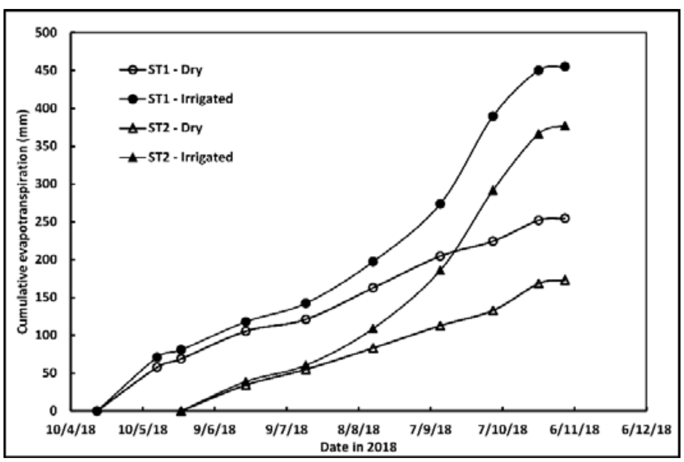

Figure 1. Cumulative actual evapotranspiration of dryland and irrigated treatments.

Early sown faba bean develops a larger canopy and deeper rooting which can extract water and nutrients from deeper soil profile. In addition to the amount of rainfall/irrigation received during the season, the amount of residual water remaining after crop harvest depends on the sowing time of the crop. Yield loss due to delayed sowing of winter crop can be compensated by yield increase of the summer crop or next season winter crop as a result of increased soil moisture. Irrigation of shallow rooted crops such as faba bean can leave higher soil moisture in deeper soil profile.

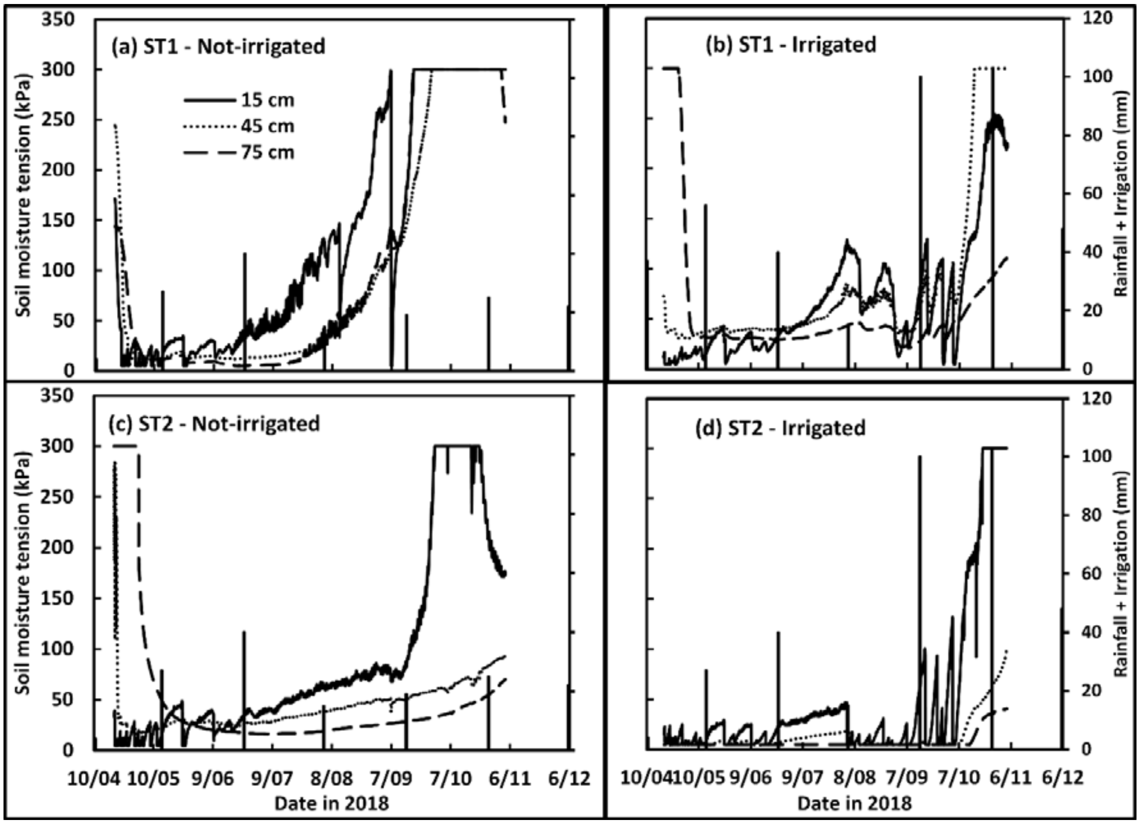

Figure 2. Soil water tension (kPa) at three depths for early (ST1) and late sown (ST2) irrigated and non-irrigated faba bean. Vertical bars represent monthly Rainfall or Rainfall + Irrigation.

Conclusion

In south-eastern Australia, for maximum yield, dryland faba bean should be sown early while supplemental (spring) irrigated faba bean can be sown late (late May). Increasing sowing rate of late sown faba bean did not increase yield. Delayed sown crop leaves significant amount of residual soil water. Because of high evaporative demand in late spring, irrigation of late sown faba bean was found to be more productive than irrigation of early sown faba bean.

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