Soil water availability determines optimum sowing rates for safflower in southern Australia

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Abstract

The effect of four sowing rates on the growth and yield of safflower (*Carthamus tinctorius*) was investigated at two sites in the Victorian Wimmera. One site was rainfed (RF), whilst the other pre-watered (PW) prior to sowing. By the start of branching, increasing sowing rate between 9 and 35 kg/ha had improved biomass production by about threefold at both sites. Individual plants subsequently compensated for low sowing rates by growing larger. This resulted in the biomass at maturity (mean; RF = 7.1, PW = 17.3 t DM/ha) and number of capitula/m^2 (mean; RF = 196/m^2, PW = 353/m^2) being similar for all treatments within each site, although there were substantial differences between the two sites. Seed number per capitulum (13.4 to 6.7) and seed mass (28.6 to 24.2 mg) generally declined with increasing sowing rate at the drier site (RF) and total seed yield declined accordingly from 0.70 (9 kg/ha) to 0.36 t/ha (35 kg/ha). Sowing rate had a smaller relative effect on seed number per capitulum (35.1 to 28.3) and no significant effect on seed mass (mean = 38.7 mg) at the wetter site (PW). The seed yield of all treatments was similar at this site (mean = 4.3 t/ha).

Media summary

Increasing sowing rate between 9 and 35 kg/ha improved the early growth of safflower without penalising yield under wetter conditions, but yields did decline where water was limiting.

Key Words

Phenology, yield components, harvest index, water use

Introduction

Safflower (*Carthamus tinctorius*) is an oilseed crop adapted to the higher rainfall (>450 mm), cereal growing regions of Australia. It is suited to cereal based cropping systems as it is normally sown and harvested later than winter cereals, requires no additional machinery to produce and is a good 'break crop' for disrupting the life cycle of cereal pathogens (Stanley *et al.* 1995). Although safflower is a minor crop in Australia, recent increases in the export demand for safflower oil and the introduction of new cultivars from California are reasons to be optimistic about its future. As a winter crop, safflower is a poor competitor with weeds during early growth stages (Colton 1988) and its high water requirement can result in low yields if water reserves are depleted before maturity (Wachsmann *et al.* 2003). Adjusting sowing rate is one means of manipulating the balance between pre- and post-anthesis water use (Connor 1975) and the ability of crops to compete with weeds. Recommended sowing rates for safflower in South Australia and New South Wales range from 8 to 25 kg/ha (Colton 1988; Stanley *et al.* 1995). There is no current advice for Victoria, but Naughtin (1975) did suggest that at least 17 kg/ha was required to obtain satisfactory yields in the Wimmera. The experiments reported here investigated the effect of sowing rate on the growth and yield of safflower at two sites with different amounts of available water at sowing in the Wimmera region of Victoria.

Methods

Both sites were located less than 1 km apart on the same property at Longerenong (36.7 ?S, 142.3 ?E). One site was entirely rainfed (RF), whilst the other was pre-watered (~200 mm) prior to sowing (PW). Average annual rainfall at Longerenong is 420 mm and the soil type was a deep, cracking grey clay (Vertosol) with a topsoil (0 – 15 cm) $pH_{(CaCl2)}$ of 7.5 (RF) and 6.3 (PW). RF was fallowed in the season prior to these experiments, whilst PW was under lucerne (*Medicago sativa*). Conventional seed beds were prepared using glyphosate and tyned implements. Grain legume super (15% P, 7% S, 2% Zn) and urea (46% N) were drilled at both sites before sowing at 126 and 93 kg/ha, respectively. Weed control was achieved by applying the herbicides trifluralin (480 g a.i./ha) prior to sowing and metsulfuron (2.4 g a.i./ha) at stem elongation (September). The safflower cultivar Sironaria was sown at both sites on the 30 July 2001 and the row spacing was 220 mm. Recommended insecticides were used to control pests as required.

A Latin square experimental design (4 ? 4) was used for both sites and the plot size was 20 m (RF) or 15 m (PW) ? 3.4 m. The sowing rate treatments were 9, 17, 26 and 35 kg/ha to achieve 20, 40, 60 and 80 plants/m^2. Climate data were recorded by a Bureau of Meteorology weather station located at Longerenong. Biomass (dry matter = DM) was sampled at five growth stages between stem elongation and physiological maturity (PM) at each site (Table 2). Soil water contents were estimated from 42 mm aperture cores taken to 2 m depth at sowing and at these growth stages. The degree of crop water stress was estimated using an infrared thermometer to measure canopy temperatures on 4 occasions over 3 days between 143 and 147 days after sowing (0900 to 1300). Total water use (TWU) is given as the change in soil water between growth stages, plus rainfall received over the same period. Seed yield, its components and oil contents were estimated from hand samples taken at PM (4.5 m row) and are reported at 8% moisture. Harvest index (HI) was calculated with seed moisture at 0%. All data were analysed with ANOVA.

Results and discussion

Rainfall for the 2001/02 season at Longerenong was below average, with 304 mm falling between April and January, compared to the long term mean (LTM) of 372 mm for the same period. The season was also unusually cool during flowering and seed growth, when the mean daily temperature (December and January) was only 17.9 ?C, compared to the LTM of 20.4 ?C. At sowing, the total amount of water stored in the upper 2 m of the soil profile was 749 (RF) and 823 mm (PW). Target plant populations were reasonably achieved at both sites with on average, 9 and 35 kg/ha producing 21 and 75 plants/m^2, respectively.

Sowing rate had little effect on phenological development at PW, but at RF increasing rates from 9 to 35 kg/ha reduced the time taken to reach flowering and PM by 5 and 3 d, respectively (Table 1). Although the sites were in close proximity and identically managed except for the pre-sowing irrigation at PW, all treatments reached budding (2 to 3 d), flowering (7 to 9 d) and PM (12 to 14 d) earlier ($P<0.001$) in the drier conditions at RF, compared to PW. With reduced transpirational cooling under water deficit (Patel *et al.* 2001), the higher degree of water stress experienced at RF was evident from crop canopy temperatures being 2.4 to 9.7 ?C (mean = 6.4 ?C) warmer ($P<0.01$) than at PW on the four occasions it was assessed. Safflower development is partly controlled by temperature (Zimmerman 1975) and the warmer canopy temperatures at RF are likely to have caused thermal time to accumulate more rapidly, thereby at least partly explaining the earlier flowering at this site, compared to PW. Although no significant differences in canopy temperature were detected between treatments within each site, more intensive measurements may have shown the earlier flowering at higher, compared with lower sowing rates at RF to also be related to water stress.

Table 1. Effect of sowing rate on the time (d) taken to reach certain phenophases at a drier (RF) and wetter (PW) site in the Wimmera region of Victoria.

Sowing	Stem	Early branching	Budding	Flowering	PM

rate	elongation									
(kg/ha)	RF	PW	RF	PW	RF	PW	RF	PW	RF	PW
35	53[a]	52[a]	67	65	102	104	140[a]	150	174[a]	187
26	54[bc]	52[a]	67	66	101	104	141[b]	149	175[ab]	188
17	53[ab]	52[a]	66	66	102	104	143[c]	151	176[ab]	189
9	54[c]	53[b]	66	66	103	104	145[d]	152	177[b]	189
Mean	*53.4*	*52.3*	*66.4*	*65.6*	*101.8*	*103.9*	*142.1*	*150.2*	*175.3*	*188.1*
LSD (5%)	*0.7**	*0.4***	*n.s.* *(P=0.57)*	*n.s* *(P=0.29)*	*n.s.* *(P=0.06)*	*n.s.* *(P=0.46)*	*0.7****	*n.s.* *(P=0.14)*	*2.5**	*n.s.* *(P=0.16)*
CV%	*0.7*	*0.5*	*0.8*	*0.6*	*0.5*	*0.2*	*0.3*	*0.9*	*0.8*	*0.5*

[a,b,c] means with the same superscript are not significantly different at P=0.05, ***P<0.001, *P<0.05, n.s. denotes not significant at P=0.05.

The early growth of safflower was improved by increasing sowing rates at both sites (Table 2). When sown at 35 kg/ha it produced two to four times more biomass by stem elongation and branching, compared to the 9 kg/ha rate. At budding there were no significant differences in biomass between sowing rates at either site, unless data from the two sites were combined (site ? treatment ANOVA). This analysis showed the 35 kg/ha sowing rate to at least on average (6.93 t DM/ha), still have significantly (P<0.001) more biomass than 9 kg/ha rate (5.22 t DM/ha). By flowering and PM, the total biomass of all treatments was similar (P>0.05) within each site, because individual plants compensated for lower densities by growing larger. Compared to the RF site, all treatments had at least twice the amount of biomass at flowering and PM at the PW site, and this is primarily ascribed to the availability of additional stored soil water at this site. The general decline in total biomass between flowering and PM is attributed to the loss of senesced leaves from plants and the utilisation of stored energy reserves from stems, exceeding weight gains due to seed growth.

Table 2. Effect of sowing rate on the biomass produced (t DM/ha) by safflower at a drier (RF) and wetter (PW) site in the Wimmera region of Victoria.

Sowing rate	Stem elongation		Early branching		Budding		Flowering		PM	
(kg/ha)	RF	PW	RF	PW	RF	PW	RF	PW	RF	PW
9	0.07[a]	0.10[a]	0.29[a]	0.49[a]	4.23	6.22	6.76	17.2	6.27	16.9

17	0.16^{b}	0.18^{b}	0.47^{ab}	0.94^{b}	5.65	6.39	8.48	18.5	8.03	17.9
26	0.18^{b}	0.24^{c}	0.66^{bc}	1.39^{c}	5.91	7.33	7.87	17.5	7.02	17.2
35	0.23^{b}	0.39^{d}	0.76^{c}	1.59^{c}	6.28	7.58	7.51	17.7	6.98	17.2
Mean	*0.16*	*0.23*	*0.55*	*1.10*	*5.52*	*6.87*	*7.66*	*17.8*	*7.08*	*17.3*
LSD (5%)	*0.08**	*0.06****	*0.20***	*0.26****	*n.s.*$_{(P=0.08)}$	*n.s.*$_{(P=0.08)}$	*n.s.*$_{(P=0.34)}$	*n.s.*$_{(P=0.87)}$	*n.s.*$_{(P=0.12)}$	*n.s.*$_{(P=0.75)}$
CV%	*27.8*	*15.7*	*21.0*	*13.6*	*17.1*	*10.2*	*16.5*	*13.3*	*12.0*	*7.5*

^{a,b,c} means with the same superscript are not significantly different at *P*=0.05, ****P*<0.001, ***P*<0.01, **P*<0.05, n.s. denotes not significant at *P*=0.05.

The 9 and 17 kg/ha sowing rates produced similar seed yields at RF, but yields steadily declined with further increases in sowing rate at this site (Table 3). In contrast, sowing rate had no significant effect on seed yield at PW where all treatments produced seed yields that were six (9 kg/ha) to twelve (35 kg/ha) times higher (*P*<0.001), than at RF. With no significant differences in maturity biomass between treatments at RF, but substantial differences in seed yield, HIs progressively decreased (*P*<0.001) from 0.10 to 0.05 as sowing rate increased between 9 and 35 kg/ha. The HI of all treatments was significantly higher (*P*<0.001) at PW and although there were small differences (*P*<0.05) between some sowing rates, here the range for all treatments was only 0.22 (35 kg/ha) to 0.25 (9 kg/ha).

Table 3. Effect of sowing rate on the seed yield, oil content and yield components of safflower at a drier (RF) and wetter (PW) site in the Wimmera region of Victoria.

Sowing rate	Seed yield (t/ha)		Oil content (%)		Seed mass (mg)		Seeds/capitulum		Capitula/m^2	
(kg/ha)	RF	PW	RF	PW	RF	PW	RF	PW	RF	PW
9	0.70^{c}	4.50	31.4^{c}	33.4	28.6^{b}	39.0	13.4^{c}	35.1^{c}	181	329
17	0.68^{c}	4.52	30.3^{b}	32.9	27.8^{b}	38.9	12.9^{c}	33.0^{bc}	189	350
26	0.52^{b}	4.19	29.9^{a}	33.3	27.9^{b}	38.0	9.4^{b}	30.1^{ab}	197	359
35	0.36^{a}	4.08	29.6^{a}	33.1	24.2^{a}	39.0	6.7^{a}	28.3^{a}	218	372
Mean	*0.56*	*4.32*	*30.3*	*33.2*	*27.1*	*38.7*	*10.6*	*31.8*	*196*	*352.6*

LSD (5%)	*0.15*[**]	*n.s.*$_{(P=0.41)}$	*0.40*[**]	*n.s.*$_{(P=0.14)}$	*1.45*[***]	*n.s.*$_{(P=0.32)}$	*2.57*[**]	*4.00*[*]	*n.s.*$_{(P=0.21)}$	*n.s.*$_{(P=0.34)}$
CV%	*14.9*	*9.5*	*0.40*	*0.50*	*3.10*	*2.2*	*14.0*	*7.3*	*11.2*	*8.8*

[a,b,c] means with the same superscript are not significantly different at *P*=0.05, [***]*P*<0.001, [**]*P*<0.01, [*]*P*<0.05, n.s. denotes not significant at *P*=0.05.

With increased branching at lower sowing rates, all treatments produced a similar number of capitula/m^2 at each site (Table 3). In terms of seed yield, this allowed safflower to compensate for plant density at PW, where sowing rate had no significant effect on seed mass and a relatively small effect on seed number per capitulum. However, with less available water at RF, seed mass and particularly seed number per capitulum tended to decline as sowing rate increased, the latter accounting for 87% of the variation in seed yield at this site (*seed yield t/ha = -0.0189 + 0.05477 ? seeds/capitulum*, *P*<0.001). Seed oil contents declined at RF as sowing rate increased between 9 and 35 kg/ha, but were not significantly affected at PW. The oil content of all treatments was 2.0 to 3.5% higher (*P*<0.001) at PW, compared with RF.

When data for both sites was combined, TWU between sowing and branching generally increased (*P*<0.05) with increasing sowing rates between 9 (111 mm) and 35 kg/ha (150 mm). This additional water used early in the season, appeared to result in less water being available for the period between branching and flowering when TWU tended (*P* = 0.11) to decrease as sowing rates increased from 9 (274 mm) to 35 kg/ha (242 mm). As a result, all treatments used a similar amount of water between sowing and flowering at each site (Table 4). No significant differences in TWU were detected between sowing rates for the periods from flowering to PM or sowing to PM when the sites were analysed individually, or together. The apparent negative water use for the period between flowering and PM at RF is attributed to 6 mm of rain which fell 3 d before harvest (PM), and possibly due to capillary rise which resulted in a 21 mm increase in the soil water content between 1 and 2 m depth during this period. Between sowing and branching, mean TWU was similar at both sites, but for the period between branching and budding it was 59 mm higher (*P*<0.001) at PW than RF, indicating that water stress commenced during this period at RF. Differences in mean TWU between the two sites increased as the season progressed and by PM, an additional (*P*<0.001) 213 mm was used at PW, compared to RF, accounting for the large differences in maturity biomass and seed yields between the two sites.

Table 4. Total water use (mm) between sowing and flowering (TWU_{sow_flw}), flowering and PM (TWU_{flw_PM}) and sowing to PM (TWU_{sow_PM}) and the water use efficiency of biomass at maturity (WUE_{DM}) and seed (WUE_{seed}) production (kg/ha/mm) for safflower sown at four rates at a drier (RF) and wetter (PW) site in the Wimmera.

Sowing rate	TWU_{sow_flw}		TWU_{flw_PM}		TWU_{sow_PM}		WUE_{DM}		WUE_{seed}	
(kg/ha)	RF	PW	RF	PW	RF	PW	RF	PW	RF	PW
9	336	435	-26.6	89.8	309	524	20.6	32.3	2.3[b]	8.6
17	366	436	-39.1	99.9	327	536	25.0	33.4	2.1[b]	8.4

26	329	459	-14.5	64.1	315	523	22.5	33.0	1.7[a]	8.0
35	330	456	-13.3	82.0	316	538	22.6	32.1	1.2[a]	7.6
Mean	*340*	*446*	*-23.3*	*83.9*	*317*	*530*	*22.7*	*32.7*	*1.80*	*8.2*
LSD (5%)	*n.s.(P=0.26)*	*n.s.(P=0.23)*	*n.s.(P=0.86)*	*n.s.(P=0.56)*	*n.s.(P=0.95)*	*n.s.(P=0.63)*	*n.s.(P=0.41)*	*n.s.(P=0.87)*	*0.79*[*]	*n.s.(P=0.30)*
CV%	*7.8*	*4.2*	*206.6*	*33.1*	*13.8*	*3.7*	*14.0*	*7.6*	*25.2*	*8.8*

[a,b,c] means with the same superscript are not significantly different at P=0.05, [*]P<0.05, n.s. denotes not significant at P=0.05.

All treatments are assumed to have used all available water at both sites and the lower use at RF, compared with PW is attributed to drier profiles at sowing and a narrow band of (~0.10 m) dry, hard setting, calcareous soil which fluctuated between 0.6 and 1 m depth. As a result, 92% of total soil water extraction (109 mm) between sowing and PM at RF came from the upper 0.75 m. This layer was not present at PW allowing safflower to extract 322 mm from soil, 44% of which came from between 1 and 2 m soil depth. Sowing rate had no significant effect on the water use efficiency of biomass (WUE_{DM}) production at either site or the WUE of seed (WUE_{seed}) production at PW. However, the WUE_{seed} did decline with increasing sowing rates at RF, corresponding to the decline in seed yield recorded at this site (Table 4). Compared to RF, the WUE of seed and biomass production was significantly (P<0.001) higher for all sowing rates at PW.

Increasing sowing rates between 9 and 35 kg/ha improved the early growth of safflower, which should improve its ability to compete with weeds. By maturity, all treatments had produced a similar quantity of biomass and number of capitula/m^2, indicating that safflower had the potential to produce similar yields from all rates tested. Whilst this did occur in the wetter conditions at PW, a substantial decrease in number of seeds per capitula at higher sowing rates in the drier conditions at RF resulted in yields being approximately halved as sowing rates increased over the range tested.

Conclusion

These experiments demonstrate that the optimum sowing rate for safflower in the Victorian Wimmera can vary with moisture availability. At the wetter site, safflower produced similar yields from a range of sowing rates between 9 and 35 kg/ha. Under these conditions the choice of sowing rate for commercial crops will therefore depend on seed costs, as well the need for crops to compete with weeds. In contrast, at the drier site, seed yields declined when sowing rates exceeded 17 kg/ha and this is attributed to a greater proportion of available water being exploited early in the season. Lower sowing rates (9 to 17 kg/ha) should therefore produce more reliable yields under drier conditions. These results apply to July sown crops and sowing rates may need to be increased if sowing is delayed into spring to compensate for reduced branching potential.

References

Colton RT (1988). Safflower growing. AGFACT P5.2.2. Department of Agriculture, New South Wales.

Connor DJ (1975). Growth, water relations and yield of wheat. Australian Journal of Plant Physiology 2, 253-66.

Naughtin JC (1975). The influence of agronomic practices on the yield and oil content of safflower (*Carthamus tinctorius*) in the Wimmera region of Victoria. Australian Journal of Experimental Agriculture and Animal Husbandry 15, 270-275.

Patel NR, Mehta AN and Shekh AM (2001). Canopy temperature and water stress quantification in rainfed pigeonpea (*Cajanus cajan* L. Millsp.). Agricultural and Forest Meteorology 109, 223 – 232.

Stanley M, Hanney J and Potter T (1995). Safflower - agronomy. Factsheet: AGDEX 146/10. Primary Industries South Australia; South Australian Research and Development Institute.

Wachsmann N, Norton R, Jochinke, D and Knights S (2003). Proceedings of the 11th Australian Agronomy Conference, Geelong, Victoria, (Australian Society of Agronomy). http://www.regional.org.au/au/asa/2003/c/4/wachsmann.htm

Zimmerman LH (1973). Effect of photoperiod and temperature on the rosette habit of safflower. *Crop Sciences*, 13 (1), 80 – 81.