The comparative growth, yield and water use of safflower, Linola™, mustard, canola and wheat in southern Australia

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Abstract

It has been proposed that safflower's vigorous root system and late maturity may enable the crop to be utilised in southern Australian farming systems to deliberately dry soil profiles, thereby reducing deep drainage. To compare the water use of safflower with other common winter crops, four sites were sown in western Victoria, two each in 2000 and 2001. On the drier sites in each year, all crops used similar amounts of water, but on the wetter sites, safflower used about 100 mm of additional water compared to wheat. The water use of wheat, canola, mustard and Linola™ was similar. At the wetter sites, daily water use was similar for all species and the extended growing season of safflower (34 – 40 days more than wheat) allowed safflower to use the additional water. Overall, wheat produced the highest yields at all sites, followed by the Brassicas, Linola™ and safflower. Safflower (3.71 t/ha) produced similar yields to canola (3.44 t/ha) on the wettest site (885 mm of soil water to 2 m depth + 209 mm rainfall), but required an additional 120 mm of water to do so. Although safflower produced similar amounts of total biomass to wheat and canola, depletion of soil water reserves before maturity led to very low seed yields at the drier sites. At the lowest yielding site, safflower produced 0.35 t/ha of seed and had a harvest index of < 0.1, compared to 2.05 t/ha and a harvest index of 0.4 for wheat.

Key Words
Winter crops, oilseeds, water use, yield

Introduction

Safflower (*Carthamus tinctorius*) is a minor oilseed crop that is usually sown in late winter or spring in southern Australia. It is generally considered to have a deep taproot and an extended growing season enabling it to use water longer into the season, compared to other winter crops. Because of these features, safflower has been proposed as a crop that can be used to "dewater" wet soils and utilise subsoil moisture that may be beyond the reach of other winter crops. This may have positive implications to the whole farming system where waterlogging or rising saline water tables threaten production. However, the same features can lead to poor or variable yields in dry environments. This paper presents data from four experiments in southern Australia on the growth, yield and water use of safflower compared to four winter crops grown in the region. The other crops were Linola™ (*Linum usitatissimum*), canola (*Brassica napus*), mustard (*Brassica juncea*) and wheat (*Triticum aestivum*).

Methods

Four sites were selected, two in 2000 and two in 2001. The 2000 sites were at Minimay (*Site 1*, 36.6 °S, 141.1 °E) near the Victorian/South Australian border and at Longerenong in the central Wimmera (*Site 2,* 36.7 °S, 142.3 °E). In 2001, both sites were at Longerenong, one being pre-irrigated with approximately 200 mm of water (*Site 3*), and the other site was rainfed (*Site 4*). Sites 2 and 3 were under lucerne in the year prior to the experiments, whilst Site 1 was in cereal in 1999. Site 4 was fallowed during 2000. All sites had clay loam soils and the $pH_{(CaCl2)}$ for Sites 1 to 4 was 4.8, 7.5, 6.3 and 7.5, respectively. In 2000, Site 1 was sown on August 03 and Site 2 on July 14. Sites 3 and 4 were both sown on July 24, 2001. The experiments were sown at recommended seeding rates for each crop and trifluralin was used for pre-emergent weed control on all sites. Grain legume super was drilled at 126 and 171 kg/ha in 2000 and 2001, respectively. Urea was drilled at 110 kg/ha in 2000 and 93 kg/ha in 2001. The cultivars sown were; Goldmark (wheat), Argyle (Linola™), Monty

(Canola), JNO4 (Mustard) and Sironaria (safflower). Further details of site management and establishment methods can be obtained from the authors.

The experiments were designed as randomised blocks with four replications. In 2000, plots at Site 1 were 3.2 × 10 m and at Site 2, 3.4 × 10 m. This was increased to 3.4 × 15 m at Site 3, and 3.4 × 20 m at Site 4 in 2001. Prior to sowing, the soil moisture content was estimated gravimetrically using a minimum of three cores to 2.0 m depth per replication. Crop growth was estimated using biomass samples taken at physiological maturity. At this time, the soil water content was measured on core samples taken from within the hand-sampled areas. Rooting depth was estimated on core samples taken during the growing season and the maximum depth to which roots were observed was noted (core-break method). The harvest samples were threshed and the grain yields were determined from these hand-harvested samples with grain moisture content adjusted to 8%. Crop water use is given as the change in soil water between sowing and physiological maturity to 2.0 m depth, plus rainfall during the same period. These data were analysed using ANOVA.

Results and discussion

Both the 2000 and 2001 seasons were drier than average, with Longerenong recording April to December rainfalls of 278 and 293 mm, respectively, compared to the long-term average of 349 mm over this period. The 2000/2001 season had a typical cool winter and hot summer, but the following season had an unusually mild winter with few frosts and a cool summer. For December 2001, the mean daily maximum temperature was 24.2 °C, which was 3.4 °C lower than the long term mean, and equal to the lowest mean recorded at this site. In 2000, the Minimay site suffered from a period of waterlogging during September, with the wheat and Linola™ crops being most severely affected at this site.

Crop establishment was satisfactory at all sites. Wheat was the first crop to emerge (16 – 17 days after sowing, DAS), followed closely by the Brassicas. Safflower was the last crop to emerge (20 – 22 DAS) with Linola™ being intermediate. Due to differences in sowing time and available water, there was substantial variation in the time from sowing to the start of flowering between sites. Depending on the site, wheat flowered between 100 and 114 DAS. The Brassicas flowered between 26 (Site 1) and 31 (Site 4) days before wheat, and Linola™ between 12 days before (Site 2) and 3 days (Site 3) after wheat. Safflower commenced flowering much later than the other crops, *i.e.* 29 (Site 2) to 52 (Site 3) days after wheat and at about the same time that wheat approached maturity. The sequence of physiological maturity (Table 1) was similar to that for flowering, with safflower being 34 to 40 days later than wheat. Overall, wheat appeared to have the strongest early growth followed by the Brassicas. Linola™ and safflower had the poorest early growth and required the longest period of time to attain complete ground cover.

Table 1: Time, in calendar days, from sowing to physiological maturity for five crops at the four sites.

Site	1	2	3	4
Canola	126	131	146 [a]	135 [a]
Mustard	128	134	148 [a]	134 [a]
Wheat	133	137	156 [b]	146 [b]
Linola	133	140	155 [b]	150 [c]
Safflower	173	171	192 [c]	180 [d]
LSD (5 %)	*Only basic notes taken, therefore*		*2.70* ***	*0.78* ***
CV%	*no statistics*		1.1	0.3

[a,b,c] means with the same superscript are not significantly different at $P = 0.05$, *** $P < 0.01$

Site 1 had 681 mm of total soil water (TSW) to 2 m depth at sowing and depending on the maturity of the crop, received 243 to 275 mm of rainfall between sowing and maturity. On this site, Linola™ produced less biomass than the other crops but there was no significant difference in seed yield between the species (Table 2a). Safflower used significantly more water (438 mm) than all other species (mean = 342 mm). At sowing, TSW for Site 2 was 678 mm and 161 to 181 mm of rainfall fell for the duration of the experiment. Again, Linola™ produced the lowest biomass, but safflower had a

significantly lower seed yield (0.35 t/ha) than all other species. Wheat had the highest seed yield (2.05 t/ha) with the remaining oilseeds having similar seed yields (0.81 – 1.19 kg/ha). No significant difference in total water use between sowing and physiological maturity was detected at this site.
At Site 3, 885 mm TSW was present at sowing and 198 to 209 mm of rainfall fell between sowing and maturity. The additional water at this site allowed safflower to produce more biomass than all other species and a seed yield comparable to canola (Table 2b). Safflower also used at least 98 mm more water than all other species. Wheat had the second highest biomass at maturity, but the greatest seed yield. Site 4 had 709 mm of TSW at sowing and received between 193 and 204 mm of rainfall from sowing to maturity. Here, wheat and safflower produced similar amounts of biomass by maturity, but wheat had the highest (4.18 t/ha), and safflower the lowest (0.78 t/ha) seed yields. Mustard and canola performed similarly. Linola™ had the lowest biomass, but yielded significantly more seed than safflower. No significant differences in total water use between species were detected at Site 4.

Table 2a: Water use, growth and seed yield of five crops at Minimay (Site 1) and Longerenong (Site 2) during 2000/2001. All measurements were determined at physiological maturity of the species.

	Site 1			*Site 2*		
Species	**Water Use (mm)**	**Biomass (t/ha)**	**Yield (t/ha)**	**Water Use (mm)**	**Biomass (t/ha)**	**Yield (t/ha)**
Wheat	338.2 [a]	6.46 [ab]	2.91	236.6	4.92 [b]	2.05 [c]
Mustard	343.9 [a]	8.56 [b]	2.70	268.3	3.72 [ab]	0.81 [b]
Canola	321.6 [a]	7.67 [ab]	2.15	252.0	4.34 [ab]	1.19 [b]
Linola	365.1 [a]	4.63 [a]	1.42	190.9	3.11 [a]	0.82 [b]
Safflower	437.5 [b]	9.43 [b]	1.99	265.5	3.78 [ab]	0.35 [a]
LSD (5 %)	*65.9* [*]	*3.21* [*]	*n.s.*	*n.s.* *(P=0.06)*	*1.44* [***]	*0.43* [***]
CV%	11.0	25.8	29.4	14.9	23.2	26.7

[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

Table 2b: Water use, growth and seed yield of five crops at Longerenong pre-watered (Site 3) and Longerenong rainfed (Site 4) during 2001/2002. All measurements were determined at physiological maturity of the species.

	Site 3			*Site 4*		
Species	**Water Use (mm)**	**Biomass (t/ha)**	**Yield (t/ha)**	**Water Use (mm)**	**Biomass (t/ha)**	**Yield (t/ha)**
Wheat	400.6 [a]	13.43 [b]	6.04 [d]	337.3	9.95 [c]	4.18 [d]
Mustard	408.5 [a]	9.32 [a]	2.82 [ab]	249.5	8.32 [b]	2.01 [c]
Canola	387.4 [a]	10.51 [a]	3.44 [bc]	256.3	7.99 [b]	1.75 [c]
Linola	359.7 [a]	10.03 [a]	2.78 [a]	307.1	4.58 [a]	1.38 [b]
Safflower	506.9 [b]	16.65 [c]	3.71 [c]	288.4	9.70 [c]	0.78 [a]
LSD (5%)	*57.1* [***]	*2.10* [***]	*0.66* [***]	*n.s.*	*1.15* [***]	*0.32* [***]
CV%	9.0	11.4	11.4	19.6	9.2	10.3

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

Overall, wheat was the highest yielding crop at all sites, despite the relatively late sowing for that crop. Mustard and canola produced similar amounts of biomass and seed yields. Linola™ produced the lowest amount of biomass on most sites and seed yields were generally somewhat less than the Brassica oilseeds. Safflower grew well and produced large amounts of biomass at all sites, but this did not necessarily translate to high seed yields. Safflower yielded less seed than all other crops at the two drier sites (Sites 2 and 4), but yields were similar to canola at the wetter sites. Safflower had the lowest harvest index (HI) being less than 0.2, while Linola ™ and the Brassicas ranged from 0.2 to 0.3. Wheat had the highest HI, being around 0.4 at all sites. On the drier sites (2 and 4), safflower appeared to have fully exploited the soil water reserves before seed growth, which led to lower HI's on these sites (< 0.1). On the wetter sites, safflower used more water than the other crops, but no significant differences were detected between any of the species at the drier sites. In these experiments at least, the crops other than safflower used similar amounts of water.

The seed yield of individual species at each site was at least partly related to the total amount of water used. For safflower the relationship was linear, and for these sites, $Yield\ kg/ha = -2637 + 11.59 \times$

total water use (P< 0.001, r^2 = 79 %). Under these growing conditions, safflower requires large amounts of water to produce satisfactory yields, *i.e.* a 1, 2 and 3 t/ha crops would require about 313, 400 and 486 mm of water, respectively.

On Sites 1 and 2, no significant differences were detected in the rooting depth of the different species (approximately 60 cm at both sites). At maturity at Site 4, wheat was the shallowest rooted crop (59 cm) while safflower, mustard and canola were all approximately 85 cm. These sites were all characterised as having very little plant available water below these levels. On Site 3, where the soil profile had a gravimetric water content of at least 30 % for the whole sampling depth, the roots of safflower were found at 160 cm, and mustard at 129 cm was intermediate between wheat (114 cm) and safflower. Linola™ was the shallowest rooted crop with the deepest roots observed at 78 cm. These trends in rooting depth mirrored the trends in the depths to which water was used by each crop, although the actual depth of water extraction was deeper than the depths at which roots were observed.

Safflower reached physiological maturity 34 - 40 days after wheat, and where water was available, it was able to exploit these reserves that were not available to the other crops. When wheat was mature, safflower still had green leaves, even at the driest site. The mean daily water use of the crops (Table 3) shows that on the wetter sites (1 and 3), all species had a similar daily water use, but the extra time for safflower to mature meant that the crop used about 100 mm more water than wheat. Similarly, total water use for canola and mustard at these sites, reflects the shorter duration of these crops compared to safflower. The total water use of these Brassica crops was similar to wheat. On the drier sites (2 and 4), safflower's daily water use was lower than at the other sites, as it depleted the available soil water. The other crops, while also affected by drought, also used less water per day at these sites.

Table 3: Mean daily crop water use (mm/day) for the five crops at the four experimental sites. All measurements were determined at physiological maturity of the species.

Site	1	2	3	4
Canola	2.44	1.88 ^{bc}	2.58	1.91
Mustard	2.61	2.00 ^{c}	2.72	1.86
Wheat	2.56	1.69 ^{ab}	2.55	2.31
Linola	2.77	1.36 ^{a}	2.29	2.10
Safflower	2.54	1.53 ^{ab}	2.63	1.59
LSD (5 %)	*n.s.*	*0.41* ***	*n.s.*	*n.s.*
CV%	*11.4*	*15.7*	*9.3*	*19.6*

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

Conclusion

On drier sites, the production of considerable amounts of biomass and the extended growing season for safflower appeared to result in depletion of soil water reserves before the crop had matured. This resulted in low seed yields and low HIs compared to the other crops tested. On wetter sites, safflower had a similar mean daily water use to the other species, but the extended growing season into a time concurrent with high evaporative demands allowed it to use additional water. On the wetter sites, safflower reached physiological maturity 34 – 40 days after wheat and subsequently used an additional 100 mm of water. The water use of the other species was similar. These results confirm that in addition to being a cash crop, safflower offers wider benefits to southern Australian farming systems where it is advantageous to deliberately dry soil profiles. Furthermore, safflower requires large amounts of water to produce similar yields to other oilseeds such as canola. Overall, wheat produced the highest grain yields and canola and mustard appear to be the most reliable oilseeds. However, safflower can produce similar yields to canola providing sufficient moisture is available.

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