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Growing safflower in Australia: Part 2 - Agronomic research and suggestions to increase yields and production

Nick Wachsmann[1,4], David Jochinke[2], Trent Potter[3], Rob Norton[4]
[1]Longerenong College, Longerenong Rd, Horsham 3401, Australia, nwachsma@bigpond.com
[2]A.V. Jochinke & Co, Blue Ribbon Rd, Murra Warra 3401, Australia, david@jochinke.com.au
[3]SARDI, Penola Rd, Struan 5271, Australia, potter.trent@saugov.sa.gov.au
[4]The University of Melbourne, Natimuk Rd, Horsham 3401, Australia, rnorton@unimelb.edu.au

Abstract
A series of experiments compared safflower (*Carthamus tinctorius*) to a range of winter and spring sown crops, investigated sowing times, sowing rates and cultivars on sites with different amounts of available water. Depending on the site year, the total water use of safflower ranged from 166 to 536 mm and seed yields from 0.2 to 4.5 t/ha. From these results and the constraints reported in Part 1 of this paper, a series of suggestions are made to improve the productivity of safflower. Compared to the other crops tested, winter sown safflower produced large amounts of biomass on all sites and seed yields between 0.4 and 3.7 t/ha. However, the mean harvest Index (HI) was only 0.14, compared to 0.26 for canola (*Brassica napus*) providing a breeding objective to increase HI, possibly by reducing plant height. Safflower matured 6 to 7 weeks after canola resulting in an additional ~120 mm of water being used to produce similar yields. The higher water requirement of safflower results in poor yields under drier conditions and earlier maturing cultivars adapted to 350 to 550 mm annual rainfall zones are required. Sowing time experiments showed that safflower can produce satisfactory yields when sown in spring in wetter situations, but under drier conditions yields decline by 5% for each week that sowing is delayed beyond mid-winter (mid-July). In at least some situations, safflower has gained a reputation as being a summer crop, but these results indicate that yields are more reliable when safflower sown in winter.

Key words: Water use – harvest index – adaptation – breeding objectives

Introduction

The value of profitable oilseeds as rotation options within cereal based cropping systems has been demonstrated by the success of canola (*Brassica napus*) in Australia over the past two decades. In comparison, safflower (*Carthamus tinctorius*) has received limited research resulting in only small improvements in production, a limited range of cultivars and deficiencies in the awareness of adaptation and agronomic requirements. Oilseed production in southern Australia relies heavily on Brassica crops, particular canola. In terms of management flexibility and reducing economic, biological and abiotic risks, there are benefits in increasing the diversity of crop species grown in rotations. As a rainfed crop, safflower is adapted to some regions and sown by growers when environmental and economic conditions are suitable. Safflower is also being used as a *strategic* or *opportunity* crop in certain situations with wider farming system benefits, but adoption as a mainstream *cash* crop has been limited by the factors described in Part 1 of this paper (Jochinke *et al*. 2008, these proceedings). These issues need to be overcome to make safflower more attractive as a *cash* crop in the cereal growing regions of Australia, especially where average annual rainfall (AAR) is 350 to 550 mm. This can be achieved by improved agronomy, higher yielding cultivars and secure markets to make the profitability of safflower comparable to canola.

A series of experiments compared safflower with a range of winter and spring sown crops, investigated sowing times, sowing rates and cultivars on sites with different amounts of available water. The other crops were canola, mustard (*Brassica juncea*), Linola™ (*Linum usitatissimum*), peas (*Pisum sativum*), wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), maize (*Zea mays*), sorghum (*Sorghum bicolour*), buckwheat (*Fagopyrum esculentum*) and sunflower (*Helianthus annus*). This paper reports the main findings of this work and collates selected data across the experiments. From these results and the constraints in reported in Part

1 of this paper, a series of suggestions are made to increase safflower yields and production in Australia.

Materials and Methods

Most experiments were conducted at Longerenong (36.7°S, 142.3°E), near Horsham in the Wimmera region of Victoria in 2000 or 2001. The soil is a slightly alkaline Vertosol and AAR is 420 mm. All experiments were repeated over at least two site years with contrasting amounts of available water, achieved using pre-sowing irrigation (~200 mm) or by duplication at other sites (AAR = 525 to 635 mm). One series of experiments sown in mid-winter compared safflower (cv. Sironaria) with canola (cv. Monty), mustard (cv. JN04), Linola™ (cv. Argyle) and wheat (cv. Goldmark). Another series sown in mid-spring compared safflower (cv. Sironaria and S517) with Linola™ (cv. Argyle), sunflower (cv. Advantage and Galah), buckwheat (cv. Hitachi), sorghum (cv. Western Red and 86G87) and maize (cv. 3394). Separate experiments investigated the effect of sowing time and rate on safflower cv. Sironaria. The sowing time treatments were mid-July, August, September and October (sowing rate = 40 plants/m^2), whilst the sowing rates tested were 20, 40, 60 and 80 plants/m^2 (sown late July). Further experiments compared up to 13 open pollinated (OP) safflower cultivars sown in late winter or spring at 40 plants/m^2 and four hybrid cultivars (GW9009, GW9023, GW9024 and GW9025) with three OP cultivars (Sironaria, S517 and 120045) sown in mid-August at 20 plants/m^2.

Additional experiments were conducted near Naracoorte (36.96°S, 140.73°E) in the South East of South Australia between 1999 and 2003 to evaluate a range of cultivars of safflower, canola, mustard, wheat, barley and peas when sown in spring. Soils varied between clay loams and heavy black clays overlying limestone and AAR from 500 to 650 mm. Data from the highest yielding cultivar at each site year are used here to further evaluate safflower as spring sown crop option in higher rainfall situations. Unless otherwise specified, recommended sowing rates were used for all crops and all sites received best practice nutrition, weed and pest control.

A range of plant, soil and environmental data were recorded, only a selection of which is reported here. Seed yields are presented at 8% moisture and total water use (TWU) is given as the change in soil water content to 2.0 m depth, plus rainfall between specified intervals. Treatment means for 'Sironaria, 40 plants/m^2' which was sown in most experiments are used to explore trends across sowing times and site years.

Agronomic Research

When sown as a winter crop, safflower matured 6 to 7 weeks after canola and at least 4 weeks after mustard, wheat and Linola™. Safflower produced similar or more biomass than these crops by maturity, but this did not always translate into higher seed yields due to terminal drought stress (Table 1). Wheat had the highest yields in all site years. In general, the seed yield of mustard was similar to canola and both Brassica crops yielded up to 0.6 t/ha higher than Linola™. Safflower produced similar seed yields to canola in the two wetter site years, but it also used an extra ~120 mm of water. Where conditions limited the TWU of safflower to less than 300 mm seed yields were less than half of that achieved by canola. Compared to the other crops tested, the higher sensitivity of safflower to water availably is demonstrated by a 9 fold difference in seed yield over the four site years, compared to a 3 fold difference for wheat and canola. No significant differences in water use efficiency (WUE) were recorded at one site. Wheat had the highest WUE (9.3 to 15.1, mean = 12.4 kg/ha/mm) in all other site years and the WUE of safflower (1.3 to 7.3, mean = 3.8 kg/ha/mm) was significantly (P<0.01) less than canola (4.9 to 8.9, mean = 6.9 kg/ha/mm), but often similar to mustard and Linola™. The harvest index (HI) of safflower (0.07 to 0.21, mean = 0.14) was consistently lower (P<0.001) than wheat (0.38 to 0.42, mean = 0.40) and the other winter oilseeds tested (0.20 to 0.31, mean = 0.26).

Winter sown safflower can be a viable rotation crop in the cereal growing regions of southern Australia providing stored soil water and rainfall allow TWU to exceed 300 mm. Where conditions limit TWU to less than 300 mm, canola, mustard and Linola™ are likely to be more reliable winter oilseed options. Safflower is often sown with fewer inputs than other crops and is so considered to be low risk by many growers. However, the large disparities in seed yield recorded between the four site years suggest that safflower is highly sensitive to water availability and therefore a high risk crop in drier situations. Furthermore, compared to canola the WUE and HI data from these experiments indicate that safflower is less efficient in converting biomass and available water into seed. The soil profile can be drier after safflower than other crops which may be beneficial in some situations to reduce water logging in the subsequent year or help control dryland salinity. However, under drier conditions the yield of following crops may be penalised due to less plant available water in the soil profile.

Table 1. Total water use (TWU mm) from sowing to maturity of each crop, maturity biomass (Dry Matter, t DM/ha) and seed yield (t/ha) of the five crops sown in winter over four site years.

Year	2000						2001					
Site	Frances			Longerenong			Longerenong			Longerenong#		
Crop	TWU	DM	Yield	TWU	DM	Yield	TWU	DM	Yield	TWU	DM	Yield
Wheat	338^{a}	6.5^{ab}	2.9	237	4.9^{b}	2.1^{c}	337	10.0^{c}	4.2^{d}	401^{a}	13.4^{b}	6.0^{d}
Mustard	344^{a}	8.6^{b}	2.7	268	3.7^{ab}	0.8^{b}	250	8.3^{b}	2.0^{c}	409^{a}	9.3^{a}	2.8^{ab}
Canola	322^{a}	7.7^{ab}	2.2	252	4.3^{ab}	1.2^{b}	256	8.0^{b}	1.8^{c}	387^{a}	10.5^{a}	3.4^{bc}
Linola™	365^{a}	4.6^{a}	1.4	191	3.1^{a}	0.8^{b}	307	4.6^{a}	1.4^{b}	360^{a}	10.0^{a}	2.8^{a}
Safflower	438^{b}	9.4^{b}	2.0	266	3.8^{ab}	0.4^{a}	288	9.7^{c}	0.8^{a}	507^{b}	16.7^{c}	3.7^{c}
LSD (5%)	66*	3.2*	n.s.	n.s.	1.4***	0.4***	n.s.	1.2***	0.3***	57***	2.1***	0.7***

^{a,b,c} means with the same script are not significantly different at *P*=0.05, ****P*<0.001, **P*<0.05, n.s. = not significant at *P*=0.05.
#Longerenong site that received ~200 mm of pre-sowing irrigation.

Safflower was evaluated as a spring sown crop option at Longerenong sites with total soil water contents of 737 and 902 mm to 2.0 m depth at sowing. Both sites received 70 mm of rain between sowing and maturity. Under these conditions, safflower and sunflower produced the highest seed yields which approached 1.0 and 3.5 t/ha at the drier and wetter site, respectively. Linola™ yielded 0.7 t/ha, and the yield of sorghum, maize and buckwheat was poor (0.1 to 0.3 t/ha) largely due to poor establishment during cool spring conditions, frost injury and/or water stress. These results confirm that safflower is one of the best options currently available for spring sowing as a rainfed crop in cereal growing regions of southern Australia where AAR is ~420 mm. Sorghum, maize and buckwheat are more suited to later sowing under irrigation.

With higher AAR in the South East of South Australia, traditional winter crops like barley and canola can also be sown in spring (Table 2). Under these conditions safflower produced acceptable yields in higher rainfall conditions, yielding similar to canola or mustard in many experiments (except Glenroy in 2001). The yield of safflower ranged between 35 and 48% of barley in most site years, whilst the yield of canola/mustard varied more widely. As sowing was delayed later into spring the yield of all crops decreased.

Table 2. Winter and spring rainfall, sowing date and seed yield (t/ha) of the highest yielding cultivar in each spring sown experiment in the South East of South Australia between 1999 – 2003. Figures in brackets are % yield of barley.

Year	1999		2000			2001				2003
Site	Frances	G'ways	Frances		C'murra	Frances		Glenroy		Glenroy
Date sown	31 Aug	1 Sep	20 Sep	10 Oct	11 Oct	6 Sep	4 Oct	20 Sep	16 Oct	22 Sep
Rainfall#	238	366	357	357	507	374	374	388	388	473
Barley	2.2$^{(100)}$	5.1$^{(100)}$	4.4$^{(100)}$	2.9$^{(100)}$	2.2$^{(100)}$	5.6$^{(100)}$	3.6$^{(100)}$	4.7$^{(100)}$	4.0$^{(100)}$	3.0$^{(100)}$
Wheat	-	-	3.0$^{(68)}$	-	2.9$^{(129)}$	4.9$^{(88)}$	-	5.5$^{(117)}$	-	3.2$^{(108)}$
Safflower	0.8$^{(36)}$	3.0$^{(58)}$	1.7$^{(39)}$	1.4$^{(48)}$	1.0$^{(45)}$	1.8$^{(31)}$	1.7$^{(46)}$	2.0$^{(41)}$	1.5$^{(37)}$	1.2$^{(42)}$
Canola##	0.5$^{(24)}$	3.0$^{(58)}$	1.2$^{(27)}$	0.1$^{(2)}$	1.1$^{(53)}$	1.9$^{(33)}$	1.9$^{(53)}$	2.7$^{(57)}$	2.6$^{(65)}$	0.6$^{(20)}$
Peas	2.0$^{(90)}$	3.8$^{(74)}$	1.7$^{(39)}$	1.2$^{(41)}$	1.4$^{(60)}$	4.3$^{(77)}$	3.5$^{(74)}$	5.3$^{(111)}$	3.4$^{(84)}$	1.8$^{(61)}$

#Winter plus spring rainfall (June to November). ##Includes mustard. Data from separate cultivar evaluation experiments, therefore no statistics.

In the sowing time experiments at Longerenong, delaying the sowing of safflower from mid-winter (July) to mid-spring (October) reduced the duration between sowing and maturity by 8 to 11 weeks, largely by shortening the period of vegetative growth. Under drier conditions (mean TWU = 202 mm) seed yields declined almost linearly with delayed sowing between July (0.9 t/ha) and October (0.3 t/ha), equating to a yield penalty of 5% for each week that sowing was delayed after mid-July. In contrast, where water availability allowed the mean TWU of all treatments to be 456 mm, sowing in mid-July, August and September resulted in similar seed yields (mean = 4.2 t/ha), but delaying until October reduced (P<0.01) yield to 3.4 t/ha. In at least some situations, safflower has gained a reputation as being a summer crop. These results confirm that seed yields exceeding 3 t/ha are possible from spring sown safflower in wetter situations, but under drier conditions early sowing (July) is important to maximise yields where safflower is grown as a *cash* crop.

Increasing sowing rates from 20 to 80 plants/m^2 had little effect on seed yields (mean = 4.3 t/ha) at the wetter site (mean TWU = 450 mm), but yields declined linearly as sowing rate increased from 20 or 40 plants/m^2 (0.7 t/ha) to 80 plants/m^2 (0.4 t/ha) at the drier site (mean TWU = 340 mm). The latter is ascribed to higher sowing rates leading to a higher leaf area, thus water use, early in the season resulting in greater water deficit during seed growth. Growers should therefore be careful with exceeding sowing rates of 40 plants/m^2 (~17 kg/ha) in drier situations.

The safflower cultivar evaluations were conducted at five sites where water availability allowed the mean TWU of all cultivars to range from 285 to 498 mm. The period between sowing and flowering differed by 9 to 12 days between the earliest (120045) and latest flowering (120043) cultivars evaluated, with Sironaria flowering at a similar time to the mean of all cultivars tested. Seed yields ranged from 0.2 to 0.7 t/ha at the driest site and 3.4 to 4.2 t/ha at the wettest site. Sironaria proved reliable in terms of yield across the sites, but its oil content was less than 34%. Other cultivars produced higher seed yields at some sites and had oil contents of up to 39%. Additionally, the oil profile of some other cultivars (e.g. S6005) had more than 75% oleic acid expanding marketing opportunities. The GW hybrids evaluated in a further two experiments only gave a small yield advantage over the OP cultivars at one site. They also had lower oil contents and lower levels of oleic acid than the oleic OP cultivar S517. Further work is required to fully evaluate the potential of these and additional hybrids from other sources.

Overall, the range of site years provided contrasting amounts of available water resulting in a wide range of seed yields. In general, Sironaria sown at 40 plants/m^2 yielded ~1 t/ha when TWU was 275 mm and this increased to ~4 t/ha as TWU increased to 500 mm (Figure 1a and 1b).

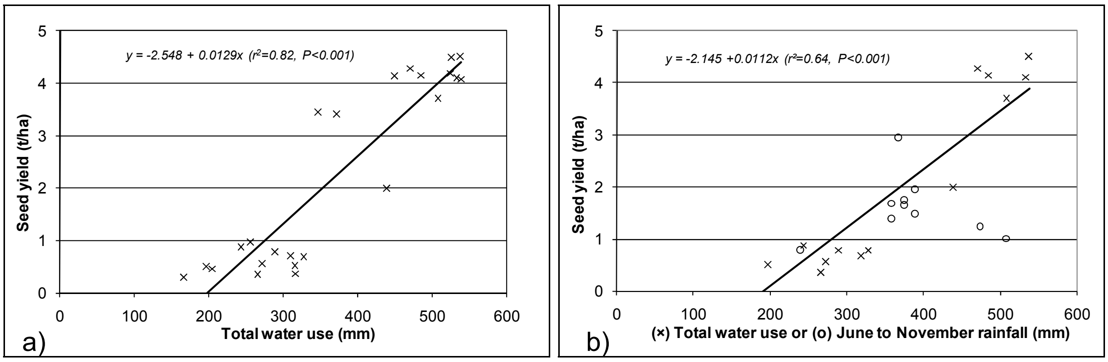

Figure 1. Relationship between the total water use (mm) and seed yield (t/ha) of Sironaria sown at 40 plants/m^2 a) across the range of sowing times and site years in the Longerenong based experiments (×) and b) when combined with yield and June to November rainfall data are added from the experiments in the South East of South Australia (o).

Across the experiments, differences in the seed yield of Sironaria due to sowing time were smaller than differences recorded due to water availability between drier (TWU = 166 to 327 mm) and wetter site years (TWU = 346 to 536 mm). Delaying sowing from mid-winter until mid-spring generally reduced seed yields (Figure 2a), although the magnitude of this response was smaller than the effect on maturity biomass (Figure 2b). The latter can be ascribed to a reduced period of vegetative growth resulting in shorter crops. For example, in the sowing time experiments, delayed sowing between July and October reduced the height at maturity from 0.75 to 0.37 m at LRF00 and 1.16 to 0.72 m at LPW01. Consequently, HI increased with delayed sowing over this period (Figure 2c) and in at least wetter site years, WUE followed a similar trend (Figure 2d). Winter sown safflower yielding around 4 t/ha of seed was typically 1.20 m high with total biomass near 17 t/ha. The highest HI achieved by safflower was 0.3 from spring sowing in wetter site years. These plots had a seed yield of 3.4 t/ha suggesting that a relatively high biomass is not always necessary to produce high safflower seed yields.

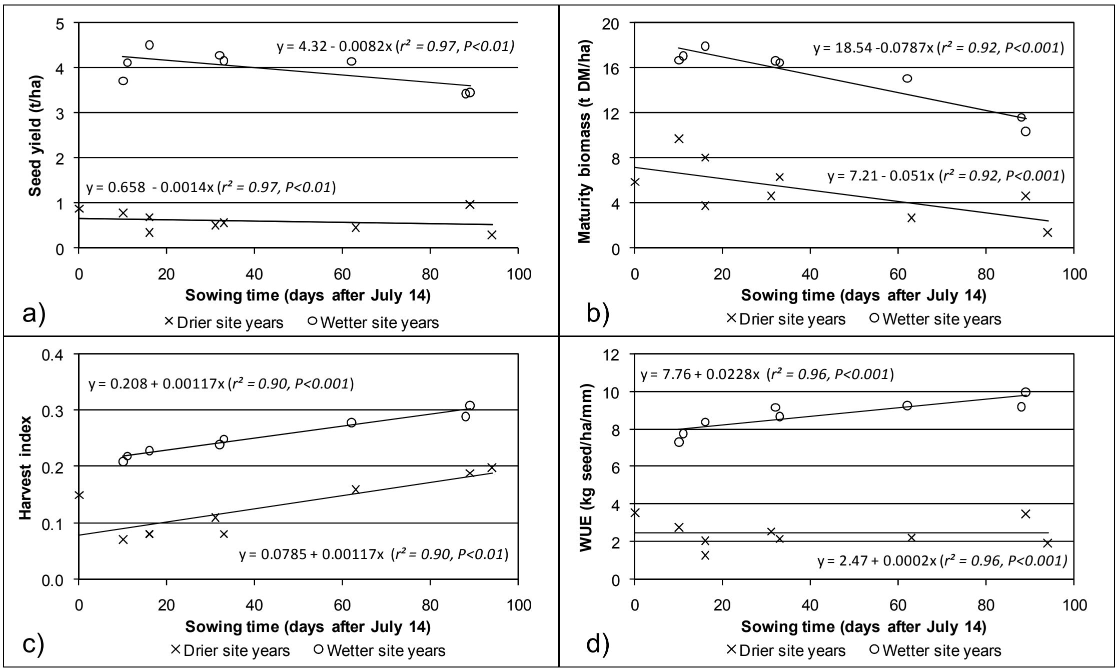

Figure 2: Relationship between the sowing time of Sironaria at 40 plants/m^2 and a) Seed yield (t/ha), b) Maturity biomass (t DM/ha), c) Harvest index and d) WUE (kg seed/ha/mm) over the range of site years. Analysis performed with Genstat 7.2 using the simple linear regression with groups on separate lines option (TWU: drier site years <327 mm, wetter site years >346 mm).

Suggestions to Increase Yields and Production

Part 1 of this paper reported that safflower production in Australia has historically been limited by disease, unsuitable cultivars, unfavourable seasons and competition from more profitable crops. It also reported that these problems are still present, along with a range of yield and price issues leading to poor gross margins for many growers. Safflower is adapted to some higher rainfall regions where in addition to being a *cash crop*, it is also grown as a *strategic crop* to de-water wet soil profiles or as an *opportunity crop* sown in spring. The experimental results reported here support these roles for safflower in wetter situations, however expansion of the industry will require the above issues to be addressed so that safflower can reliably produce economic yields as a *cash crop* in the cereal growing regions where AAR is typically 350 to 550 mm. Oilseed production in these regions is currently dominated by canola and to compete, safflower will need to offer at least similar benefits and profitability to growers.

Given that safflower has a higher water requirement than canola and other winter crops, production is likely to have been limited by the series of dry years that have persisted over the last decade. This may change with the return of wetter seasons, but even then safflower will only be generally adapted to situations which allow TWU to exceed 300 mm. Even then, canola may still be more reliable unless conditions allow the TWU of safflower to exceed 400 mm. The higher water requirement of safflower is a consequence of the growing season being up to 7 weeks longer than canola and this is likely to cause poor or variable yields in drier conditions.

Breeding Objectives
The range of flowering dates observed in the safflower cultivar experiments was less than 12 days, which is far less than differences in maturity recorded among the winter crops tested. An opportunity may therefore exist to increase the reliability and yield of winter sown safflower by developing short seasoned cultivars of similar maturity to canola. Shorter season cultivars may also be able to escape summer storms decreasing the risk of pre-harvest sprouting, especially where safflower is spring sown in northern Australia.

Compared to canola, winter sown safflower usually had a lower HI and WUE due to a long period of vegetative growth and the production of high amounts of biomass. Delayed sowing between mid-winter and mid-spring generally reduced seed yield, plant height and biomass, but it did increase HI and WUE. Seed yields of 3.4 t/ha were achieved from spring sowing in wetter situations suggesting that safflower can produce high seed yields without excessive growth. A further objective for plant breeders is therefore to reduce stem height, allowing more of the available water to be used for seed production, rather than biomass production. This may also be a default consequence of the development of shorter season cultivars.

The Australian safflower industry is based on a handful of commercially available cultivars. Further cultivars are needed to increase adaptation and marketability. In addition to the maturity, HI and WUE issues previously discussed, new cultivars would also ideally be resistant to Alternaria (*Alternaria carthamii*) which may become more prevalent if safflower production increases due to additional sources of inoculum. They would also need to meet current or future market specifications to ensure demand. Australia has not attempted to breed new safflower cultivars since the release of Sironaria and Sirothora in 1986 and the past decade has seen significant advances in plant breeding technology. The application of this technology to safflower could therefore result in significant improvements in a relatively short period of time.

The performance of the hybrids evaluated was less than anticipated under the conditions at Longerenong. However, safflower hybrids have shown significant yield improvements over OP cultivars overseas (*e.g.* Hill 2001; Singh *et al*. 2001) and the availability of adapted hybrids has been important to the sunflower industry in Australia (Halloran and Luckett 1994). Developing adapted safflower hybrids could therefore be another means of improving safflower yields in the cereal growing regions of Australia.

Agronomic Research and Extension
In addition to developing new cultivars, there is also a need to continue agronomic research and extension. Many growers perceive safflower as an *opportunity crop* and often sow crops with minimal inputs at a less than optimal time of the year. To produce maximum yields as *cash crop*, safflower needs to be sown at the optimum time, especially where water availability is limiting. In some situations this will require a change in grower and advisor attitudes. Safflower also requires adequate inputs including fertiliser, crop monitoring and pesticides. As a minor crop fewer pesticides are registered for use on safflower, even though some can be used safely. In 2004 the Australian Oilseed Federation obtained a 'general use' permit from the Australian Pesticides and Veterinary Medicines Authority for the use of products containing metsulfuron-methyl to control broadleaf weeds in safflower. The permit recommends that products are applied at the same rates used in cereal crops after safflower has reached the 4 to 6 leaf stage. It also warns that crop damage may occur under adverse conditions, particularly on acid soils. A permit to control Rutherglen (*Nysius vinitor*) bugs with deltamethrin has also been issued. In terms of disseminating this and other existing information, as well as new research there is a need to produce an updated grower guide for safflower production in Australia.

Marketing and Other Opportunities
To be competitive with other winter oilseeds like canola, safflower will need to return similar profits and market stability to growers. Some issues pertaining to these aspects of safflower production were outlined in Part 1 of this paper and there is a strong need to develop stable and

profitable markets. Domestic demand for safflower oil is currently small, but export markets in India, Japan and other countries are being developed. Other opportunities may come through increased demand for edible vegetable oils or more recently biodiesel. For example, Riverina Oils and Bioenergy Pty Ltd have proposed to construct an oilseed factory at Wagga Wagga to process 165,000 t of safflower and canola per year into biodiesel and refined vegetable oil (Grimson 2008). Genetically modifying safflower to produce other products may also create new market opportunities. One example is a project being undertaken by the Commonwealth Scientific and Industrial Research Organisation to transform safflower into a bio-factory to produce epoxy fatty acids that could be used to produce biodegradable plastics (Taylor 2008). Reducing the proportion of seed husk or developing more lucrative markets for meal may also increase the profitability of safflower to processors with flow on benefits to growers.

The continued run of dry seasons in Australia combined with concerns for the health of many waterways is placing increased pressure on some irrigated cotton (*Gossypium hirsutum*) and rice (*Oryza sativa*) growers. Limited availability or increases in the price of water may increase the attractiveness of other crops such as safflower in these regions in the future. Safflower has deep roots and providing sufficient water is available, it is tolerant of maturing under hot summer conditions. This combined with a flexible time of sowing could create further opportunities for safflower if climate variability results in more frequent wet springs or autumn or winter conditions that prevent the establishment of traditional winter crops.

Conclusions

Winter sown safflower has a higher water requirement than other crops grown in the cereal growing regions of southern Australia. Nevertheless, yields in excess of 4 t/ha when sown in winter and 3 t/ha when sown in spring are possible, providing soil water availability is high. The high water requirement of safflower is largely due to an extended growing season resulting in the production of large amounts of biomass. Consequently winter sown safflower has a lower HI and WUE than other oilseeds like canola. To produce similar yields to canola, safflower requires an additional ~120 mm of water and where conditions limit TWU to less than 300 mm, other winter oilseeds may be more reliable crop options. For safflower to compete with canola as a cash crop in the 350 to 550 mm AAR broadacre cropping zones, it will need to return a similar profitability to canola. The results presented here suggest that yield reliability in drier situations might be improved by increasing HI and WUE and that this could be achieved by developing cultivars with a shorter growing season and stature. Such cultivars should have resistance to Alternaria, other diseases and desirable marketing attributes. Other suggestions to increase safflower production in Australia include the development of more stable markets, improving gross margins to growers, greater weed and pest control options and improved dissemination of available and new information throughout the industry. Future opportunities for safflower may come through increased demand for vegetable oils, genetic engineering or climate change.

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