An update on the role and agronomy of safflower in southern Australia

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Abstract
Safflower (Carthamus tinctorius) is a deep rooted oilseed crop that can be incorporated into cropping systems using existing machinery. It has a high water requirement with 1.0, 2.5 and 4.0 t/ha crops using about 275, 400 and 500 mm respectively. Winter-sown safflower can yield over 4 t/ha, but it uses 120 mm more water than canola to produce similar yields. Where conditions limit water use to less than 300 mm, canola, mustard or LinolaTM are likely to be more reliable winter oilseed options. Under drier conditions in the Victorian Wimmera, safflower yields decline by 5% per week that sowing is delayed after mid-July, but under wetter conditions yields of 3.5 t/ha have been achieved from plots sown as late as mid-October and this late sowing has certain weed control, workload and risk management benefits. Sowing rates between 20 and 80 plants/m² have little effect on safflower yields in wetter situations, but exceeding 40 plants/m² can reduce yields under drier conditions. Whilst the Australian developed cultivar Sironaria is still reliable in terms of yield, additional market opportunities will become evident with other cultivars that have different oil profiles. A broad discussion on issues and future possibilities for safflower is provided.

Key Words
Water use, yield, sowing time, oilseed, Carthamus tinctorius, break crop

Introduction
The value of oilseeds as rotation crops within the cereal growing regions of southern Australia has been demonstrated by the success of canola (Brassica napus) over the past 15 years. However, canola is not adapted to all situations and 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. Safflower (Carthamus tinctorius) is a deep rooted oilseed crop that can be included in broadacre cropping systems without additional capital investment. It has similar soil and nutrient requirements to canola and similar ‘break crop’ benefits when grown in rotation with cereals. A survey established that growers sometimes use safflower to dewater wet soil profiles, reducing water logging in following crops and helping to manage dryland salinity (Wachsmann et al. 2001). Some growers also sowed safflower in spring to spread sowing and harvesting workloads or to re-plant land where winter crops failed. Spring sown crops can assist the management of herbicide resistance by allowing income to be generated from paddocks that receive additional cultivations or other controls, to manage problem winter weeds.

Despite these benefits, safflower remains a minor crop in Australia and growers have indicated that poor or variable yields, unstable markets, lack of adapted cultivars and limited agronomic information limit their use of this crop. A series of experiments was undertaken in southern Australia to compare safflower with other crops, evaluate a range of safflower cultivars and investigate responses to sowing time and rate. This paper summarises the main findings, collates data such as water use across experiments and discusses some applied aspects of safflower production learned from this research and experiences with the safflower industry.

Methods
Most experiments were conducted at Longerenong (36.7 °S, 142.3 °E) in the Wimmera region of Victoria in 2000 or 2001. Long term average annual rainfall (AAR) is 420 mm and the soil type is a slightly alkaline vertosol. All experiments were repeated over at least two site-years, with contrasting amounts of available water achieved using ~200 mm of pre-sowing irrigation or by duplication at sites in South Australia or Tasmania (AAR = 525 to 635 mm). All sites received adequate nutrition and best practice weed and pest control. Unless otherwise specified, recommended sowing rates were used for all crops. One series of experiments, sown in mid-winter, compared safflower (cv. Sironaria) with canola (cv. Monty), mustard (Brassica juncea cv. JN04), Linola™ (Linum usitatissimum cv. Argyle) and wheat (Triticum aestivum cv. Goldmark). Another series, sown in mid-spring, compared safflower (cv. Sironaria and S517) with Linola™ (cv. Argyle), sunflower (Helianthus annuus cv. Advantage and Galah), buckwheat (Fagopyrum esculentum cv. Hitachi), sorghum (Sorghum bicolour cv. Western Red and 86G87) and maize (Zea mays cv. 3394).
Separate agronomic experiments investigated the effect of sowing time and seed rate on safflower (cv. Sironaria). The sowing time treatments were mid July, August, September and October (sowing rate = 40 plants/m²), whilst the seed rates tested were 20, 40, 60 and 80 plants/m² (sown late July). Further experiments compared up to 13 open pollinated (OP) safflower cultivars sown in late winter or spring at 40 plants/m². Finally, four hybrid cultivars (GW9009, GW9023, GW9024 and GW9025) were compared to three OP cultivars (Sironaria, S517 and 120045) sown in mid-August at 20 plants/m². 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 m depth plus rainfall between specified intervals. Oil analysis was conducted by the Agseed Oilsseed Laboratory in Horsham using standard procedures. Further details can be obtained from the authors.

Results and Discussion

Some pests and diseases were encountered in most site years, including red-legged earth mites (*Halotydeus destructor*), Rutherglen bugs (*Nysius vinitor*) and rust (*Puccinia carthami*). Alternaria leaf blight (*Alternaria carthami*) was also observed in one site year, but severity was low. The range of site-years provided contrasting amounts of available water resulting in a wide range of seed yields (Figure 1). In general, the cultivar Sironaria yielded ~1t/ha when TWU was 275 mm and this increased to ~4 t/ha as TWU increased to 500 mm.

![Figure 1. Relationship between total water use (mm) and seed yield (t/ha) of safflower cv. Sironaria across the range of treatments and experiments.](image)

When sown as a winter crop, safflower matured 4 to 7 weeks after canola, mustard, wheat and Linola™. Wheat produced the highest seed yields (2.1 to 6.0 t/ha) in all site years. In general, the seed yield of mustard was similar to canola and both crops yielded up to 0.6 t/ha more than Linola™. Safflower (2.0 and 3.7 t/ha) produced similar seed yields to canola (2.2 and 3.4 t/ha) in two wetter site-years where the TWU of safflower was 438 and 507 mm, compared to 322 and 387 mm for canola. Where conditions limited TWU to less than 300 mm, safflower yields (0.4 and 0.8 t/ha) were less than half of that achieved by canola (1.2 and 1.8 t/ha). Compared to the other crops tested, the higher sensitivity of safflower to water availability is demonstrated by a 9 fold difference in seed yields over the four site years, compared to a 3 fold difference for wheat and canola. In wetter site years, safflower used 73 to 146 mm more (*P*<0.05) water than wheat, canola, mustard and Linola™, and much of this additional water was extracted from below 1 m in the soil profile. For example, at one site safflower extracted 74 mm from between 1.25 and 2.00 m depth, compared to less than 31 mm for the other crops. Winter-sown safflower can be a viable rotation crop within the cereal growing regions of southern Australia providing that stored soil water and rainfall allow TWU to exceed 300 mm. Where conditions limit TWU to less than 300 mm, canola, mustard or Linola™ are likely to be more reliable winter oilseed options. The soil profile can be drier after safflower compared to other crops which may be beneficial in some situations to reduce waterlogging in subsequent crops 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 and this should be considered in rotation planning. Safflower was not harvested until December or January allowing harvesting workloads to be spread over a longer period.

Spring-sown crop options were tested on sites with total soil water contents of 737 and 902 mm to 2 m depth at sowing and both sites received 70 mm of rain between sowing and maturity. 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. Overall, these results confirm that under rainfed conditions, safflower is one of the best options currently available for spring sowing in the cereal growing regions of southern Australia. Sorghum, maize and buckwheat may be more suited to later sowing under irrigation.

Delaying the sowing of safflower from July to October reduced the time taken to reach maturity by 8 to 11 weeks, largely by shortening the duration 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, under wetter conditions (mean TWU = 456 mm) sowing between July and September produced similar seed yields (mean = 4.2 t/ha), but delaying until October reduced \( P < 0.01 \) yield to 3.4 t/ha. Increasing sowing rates from 20 to 80 plants/m\(^2\) had little effect on seed yield (mean = 4.3 t/ha) at a wetter site (mean TWU = 450 mm), but yield 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 a 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 a greater deficit during seed growth. Overall, these results indicate that where sufficient water is available safflower can produce seed yields exceeding 3 t/ha when sown in spring, but under drier conditions early sowing (July) is important to maximise yields. Growers should also be careful with exceeding sowing rates of 40 plants/m\(^2\) (~17 kg/ha) in drier situations.

The 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. The Australian cultivar 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%. Sironaria has white seeds and is suited for birdseed or linoleic oil markets. The oil of some other cultivars (e.g. S6005) had more than 75% oleic acid expanding marketing opportunities. Further results from these experiments are documented in Jochinke et al. (2003). Growers should consider potential markets, as well as adaptation and disease resistance when selecting safflower cultivars. 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 high oleic OP cultivar S517. Further work is required to fully evaluate the potential of these and hybrids from other sources in Australia.

**Current issues with safflower production**

Given that safflower has a higher water requirement than wheat, canola and other winter crops, the series of dry years that have persisted over the last decade has inhibited the expansion of safflower production in the cereal growing regions of southern Australia. This may change with the return of wetter seasons, but even then safflower will only be generally adapted to regions or situations which allow TWU to exceed 300 mm. The high water requirement of winter-sown safflower is largely a consequence of its growing season being up to 7 weeks longer than wheat and canola. While this can be beneficial in some situations to de-water wet soil profiles, it is also likely to contribute to poor or variable yields in drier conditions. The range of flowering dates observed in the safflower cultivar experiments was less than 12 days, which was far less than differences in maturity recorded among the winter crops tested. An opportunity may therefore exist to increase the seed yield of winter sown safflower in the rainfed cropping regions of southern Australia by developing short seasoned cultivars of similar maturity to canola. When sown in winter, safflower grew well producing similar or more biomass than canola, but this did not translate into higher seed yields as the harvest index (HI) was generally less than 0.2. 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 around 3.5 t/ha suggesting that a relatively high biomass is not always necessary to produce high safflower seed yields. These observations indicate that it may be possible to increase the water use efficiency and yield of winter sown safflower through plant breeding to reduce stem height and increase HI.

Compared to more widely grown crops, fewer pesticides are registered for use in safflower. A number of pre-emergent and grass selective herbicides are available, but there are currently no registered post-emergent...
herbicides to control broadleaf weeds. Many growers use products containing metsulfuron-methyl and in 2004 the Australian Oilseed Federation obtained a ‘general use’ permit for these products in safflower until 2010. 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 bugs with deltamethrin has also been issued.

Many farmers see safflower as an ‘opportunity’ crop sown in wet springs with minimal inputs. The work reported here showed that safflower can be useful for this purpose, but under rainfed conditions yields are more reliable when crops are sown in winter. Farmers need to understand that high yielding safflower crops should be treated like other cash crops and sown at the optimum time with adequate inputs. Only a handful of safflower cultivars are currently available to Australian safflower growers. Several new cultivars have been introduced from overseas by private companies, but due to testing and seed bulking it may be several years before they are commercially available. These cultivars may also only become available on a ‘closed loop’ selling arrangement, limiting access to growers wishing to pursue alternative markets.

Future possibilities for safflower
Markets for Australian safflower have traditionally been small and easily flooded leading to price volatility. With increasing health awareness and more recently demand for bio-diesel, the world demand for vegetable oils, including safflower, is increasing. Countries including Japan (oleic) and India (linoleic) are currently importing safflower seed or oil from Australia. A number of projects around the world have or are attempting to genetically engineer safflower to produce pharmaceutical, industrial or other products which may create new market opportunities. 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 opportunities for safflower if climate variability results in autumn or winter conditions that prevent the establishment of traditional winter crops, or more frequent wet springs. Similarly, safflower could have a role as a rainfed crop in current irrigation regions if water restrictions or prices make other crops unviable.

Conclusions
Safflower can produce economic yields (>1 t/ha) in southern Australia, providing that TWU can exceed 300 mm. Where conditions limit TWU to less than 300 mm, other oilseeds are likely to be more viable winter options. Under wetter conditions where TWU can exceed 400 mm, winter-sown safflower can produce similar yields to canola with similar ‘break crop’ benefits in cereal rotations. When sowing safflower as a cash crop, early sowing (mid-winter) and moderate sowing rates (20 – 40 plants/m²) appear to be important to maximise yields where water availability is marginal. As a winter crop, safflower used 120 mm more water than canola and therefore has potential as a strategic crop in rotations to de-water wet soil profiles. Strategies to maximise the de-watering ability of safflower might include early sowing (mid-winter), using relatively high sowing rates (>40 plants/m²) and selecting long season cultivars. Where sufficient water was available, safflower produced seed yields exceeding 3 t/ha when sown as late as mid-spring. As such, safflower can be useful in managing risk and spreading sowing and harvesting workloads. The number of safflower cultivars available to growers in Australia is still limited, but suitable types for birdseed, linoleic and oleic oil markets are currently available. To improve yields in drier conditions, future cultivars would ideally have a similar maturity to canola, a higher HI, resistance to Alternaria and desirable marketing traits. The industry would also benefit from increased investment into research, a wider range of pesticide options, more stable markets and in some cases, changed farmer attitudes. Future opportunities for safflower may come through increased demand for vegetable oils, genetic engineering or climate change.

References