Pushing the limit for water-use efficiency in early-sown canola

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Abstract
Early sowing of canola (late April to early May) in eastern Australia is known to increase canola yield potential and water-use efficiency, but the opportunity to capture further benefits from earlier April sowing is uncertain. The risk of frost or excessive early biomass production are concerns, especially for modern vigorous hybrid varieties, but could be managed by selecting varieties with appropriate phenology and managing canopy development. We conducted 6 experiments in eastern Australia during 2014 to investigate the yield and water-use efficiency of modern canola cultivars sown from early April. Sowing early (April 1 to 15) maximised the yield at all sites, except Condobolin where frost and water stress reduced yield of early-sown crops. Variety choice was critical for early-April sowing - slower developing varieties had highest yield from early sowing, while faster developing varieties developed pods in mid-winter which suffered frost damage and could not compensate where spring drought was severe. The transpiration efficiency of the highest yielding, early-sown varieties equalled or exceeded the previously established benchmark of 15 kg/ha/mm for canola. These results suggest that early April sowing of canola may be feasible to boost yield and water use efficiency in low-medium rainfall zones with correct variety choice and suitable management.

Key words: water use, early vigour, drought, water stress, deep roots

Introduction
Canola is the third most important grain crop in Australia worth around $2.7Bill in 2012/13 and is also the most widely grown and important break crop for cereal-based farming systems. The importance of early-sowing to maximise yield potential and water-use efficiency in canola has been known for some time, with yield loss of around 5% per week delay in sowing from the recommended late-April sowing (Robertson and Kirkegaard 2005; Lisson et al., 2007). Changing seasonal conditions and improved agronomy have created interest in the feasibility to move canola sowing into early April to capitalise on higher yield potential. However as well as the potential for increased frost risk if flowering time is not well matched to early-sowing, there is also concern regarding the risk of excessive early water use by high vigour hybrids causing increased risk of water stress during flowering and pod-fill. Early April sowing is advised for the higher rainfall zones with later-maturing winter-type canola (Christy et al., 2013) and for grazed canola (Kirkegaard et al., 2012), but there is little commercial or experimental experience of spring-type canola sown in early April in low-medium rainfall zones. From a physiological point of view, the water-use efficiency of early-sown canola could be increased through (i) rapid soil coverage to reduce evaporative loss (E) and increase transpiration (T), (ii) more efficient T during vegetative growth due to cooler conditions and lower vapour pressure deficit (VPD), (iii) reduced heat and water stress during reproductive stages in spring and (iv) increased access to deep stored water due to longer vegetative stage and deeper rooting (Robertson and Kirkegaard 2005). We report outcomes of a series of experiments in eastern Australia during 2014 investigating the yield and water-use efficiency of canola crops sown from early April.

Methods
A series of replicated canola variety x sowing time experiments were conducted at 6 sites across eastern Australia in 2014 (Breeza, Trangie, Condobolin, Greenethorpe, Ganmain, Junee). The experiments comprised 3 or 4 replicates arranged as blocks with individual plot size 10m x 2m. The 7 varieties included a range of current modern spring hybrid and triazine-tolerant (TT) varieties (Hyola575CL, 45Y88CL, 44Y87CL, 44Y84CL, 43C80CL, Hyola559TT, ATR-GEM). Only Hyola575CL and 44Y87CL were grown at all sites, with 3-5 varieties representing commonly grown commercial varieties selected for each site. The sowing date treatments spanned the window from April 1 to May 23 and usually consisted of 4 sowing dates around 14 days apart. All trials were sown into moisture so germination commenced at sowing rather than on a subsequent rainfall. At each site, the canola was sown to establish a target population of 45 plants m^{-2} based on seed size and germination percentage. At some sites a lower plant population (15 plants m^{-2}) was included, and although the interactions with density are not considered here, yield data for each site are presented for the highest yielding plant population. Weeds were managed at each site using recommended

herbicides, and crop nutrition was managed using pre-sowing soil tests and top-dressing to guide fertiliser management to avoid nutritional constraints to crop growth. Crop measurements included established plant population, flowering date, biomass at 50% flowering, seed yield and yield components. Biomass, yield and yield components were measured from 1m^2 quadrat cuts (2 x 0.5 m^2) cut at ground level at 50% seed colour change on the main stem. Seed yield was also measured from machine harvested strips taken from each plot, however difficulty in harvesting mechanically at the optimum time to avoid shattering loss at some sites meant that the yield data from hand quadrat cuts was used for consistency.

Water use efficiency was estimated as [yield (kg/ha)/ET (mm)], where ET = rainfall from sowing to harvest plus the stored soil water used. Measurements of soil water use were from gravimetric soil water measurements on soil cores (to 1.8m) taken pre-sowing and post-harvest at the sites, or from calibrated neutron moisture probes. Where soil water was not measured (Condobolin, Trangie, Ganmain), soil water use was estimated assuming 30% of summer fallow rainfall (December to March) was available at sowing, and that no plant available water remained at harvest due to the dry spring finish at the sites. Thus 30% of January to March rainfall was assumed to be used by the crops in addition to the in-crop rainfall to estimate ET. Frontiers for transpiration efficiency were considered using different estimated evaporative losses.

Results

Seasonal conditions in 2014

The 2014 season at all sites was characterised by average to above average fallow (Jan – March) rainfall (100 to 200 mm) which facilitated early April sowing into reasonable levels of stored water (see Table 1). The good early start was followed by average autumn and winter rainfall, but the spring was very dry at all sites, and the crops relied on stored soil water during the flowering and pod-filling period. Although in-crop rainfall ranged from 177 (Trangie) to 396 mm (Greenethorpe), very little of this occurred after August. The autumn and early winter temperatures were above average which accelerated the development of some varieties especially from early sowing. At Condobolin, Ganmain, Junee frosts were severe during mid-July to early August which affected varieties that were at the susceptible water-filled pod stage at that time. No significant frost damage occurred at Greenethorpe and no observations are available for Breeza or Trangie.

Table 1. Components of WUE estimates including fallow and seasonal rainfall, change in soil water and maximum canola yield recorded at each site in 2014

	Sites in 2014					
	Greenethorpe	Breeza	Junee	Ganmain	Trangie	Condobolin
Rain (Jan-Mar) (mm)	46[a]	100[a]	90[a]	100	202	180
In-crop Rain (mm)	396	184	229	270	177	180
Total ET (mm)	442	284	280	230	178	174
Maximum yield (t ha^{-1})	6.01 (S1)[d]	3.50 (S1)	2.69 (S1)	3.14 (S2)	2.22 (S2)	1.22 (S3)
WUE (Yield/ET)[b]	13.6	12.3	8.4	10.5	9.3	5.1
TE (Yield/(ET - 60)[c]	15.7	15.6	10.5	13.1	12.5	7.0

[a] Measured change in soil water (sowing to harvest) shown was used in ET calculation rather than 30% Jan-Mar rainfall
[b] WUE=Water Use Efficiency [Yield/ET] where ET=[Sow to harvest rainfall] + [change in soil water]
[c] TE=Transpiration Efficiency [Yield/(ET-60)] (the slope of frontier assuming evaporation E of 60mm)
[d] S1= the sowing time at which the maximum yield used for WUE calculations was observed

Crop yield

Crop yield at the different sites reflected the amount of water available to the crops, and the incidence of frost. Maximum yield at the sites ranged from 6.0 t/ha at Greenethorpe (high water availability and no frost) to 1.2 t/ha at Condobolin (dry and frosty site) (Figure 1). The main effects of sowing date and variety were highly significant ($P<0.001$) at most sites, with significant interactions at all sites except for Greenethorpe and Breeza. At the high yielding Greenethorpe site, yield was highest in all varieties from the earliest (April 1) sowing, and declined by 50 kg ha^{-1} day^{-1} as sowing was delayed. At the other sites, highest yields were achieved from both early (April 1) and mid-April sowing (April 10-16), although the specific variety that achieved that yield varied with site and sowing date. For example at Junee, Ganmain and Condobolin the fastest developing variety Hyola575CL suffered a yield penalty when sown on April 1, but was among the highest yielding in mid-April. In contrast the variety 45Y88CL (Junee and Ganmain) and 44Y87CL (Condobolin) had similar or higher yield when sown in early April compared to mid-April. With the exception of the dry and frosty Condobolin site, overall yields for all varieties declined after mid-April.

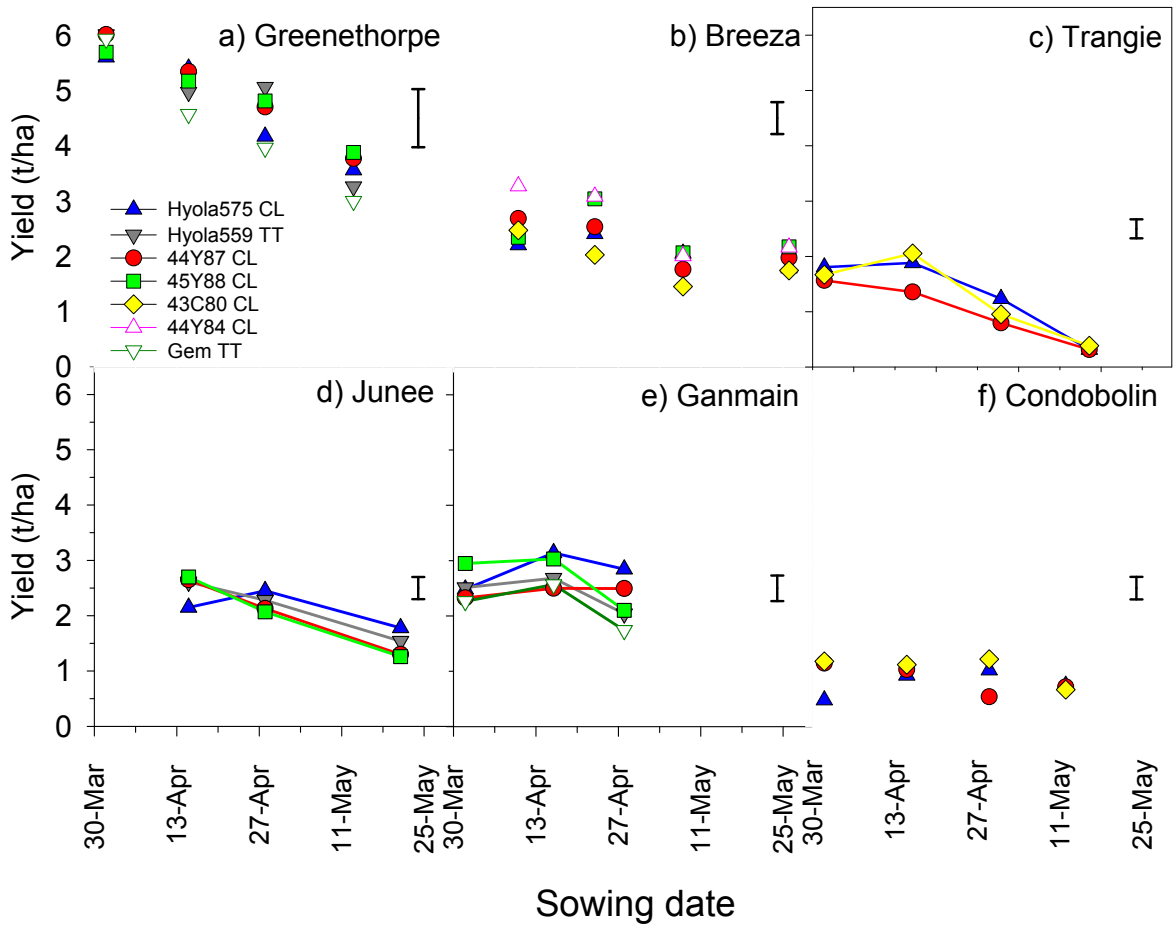

Figure 1. The effect of sowing date on the seed yield of a range of spring canola cultivars at 6 sites in eastern Australia in 2014. The vertical bars show the LSD (P<0.05).

Water Use Efficiency

The WUE and TE at Greenethorpe, Breeza and Junee were calculated using in-crop rainfall and the change in soil water measured from sowing to harvest (Table 1). At the other sites, starting soil water use was estimated from fallow rainfall and final soil water assumed to be negligible due to the prolonged, dry spring. Estimated maximum WUE and TE in Table 1 are calculated for the highest yielding combination of sowing date and variety at each site. The WUE ranged from 5.1 to 13.6 kg/ha/mm, while the TE calculated assuming a maximum evaporation (E) of 60 kg/ha/mm ranged from 7 kg/ha/mm at the hot, dry and frosty site at Condobolin, to 15.7 kg/ha/mm at Greenethorpe.

Figure 2 shows the relationship between crop yield and seasonal water supply of the six 2014 early sown crops alongside data published by Robertson and Kirkegaard (2005) for a series of experimental canola crops grown between 1991 and 2003. The crops were considered to have achieved water-limited potential, with the variation observed mostly due to differences in rainfall distribution and sowing date. The highest levels of TE above an estimated evaporation of 120mm for that data set was around 15kg/ha/mm (upper black dotted line) while the lower boundary was around 8 kg/ha/mm. Interestingly the six crops sown in April (17 to 30) within that dataset all lie close to the upper TE boundary shown. The results for the 2014 crops (red dots), with the exception of the dry frosty site at Condobolin, all fall on or above the upper boundary shown by Robertson and Kirkegaard (2005). Given the relatively dry 2014 season and the reliance on subsoil water, it is likely the evaporation component was lower than the 120mm assumed by Robertson and Kirkegaard, and the red dashed line in Figure 2 assumes 60mm evaporation and TE of 15.0. Early-sown hybrids are clearly pushing the boundaries of previously reported WUE through lower E and high TE.

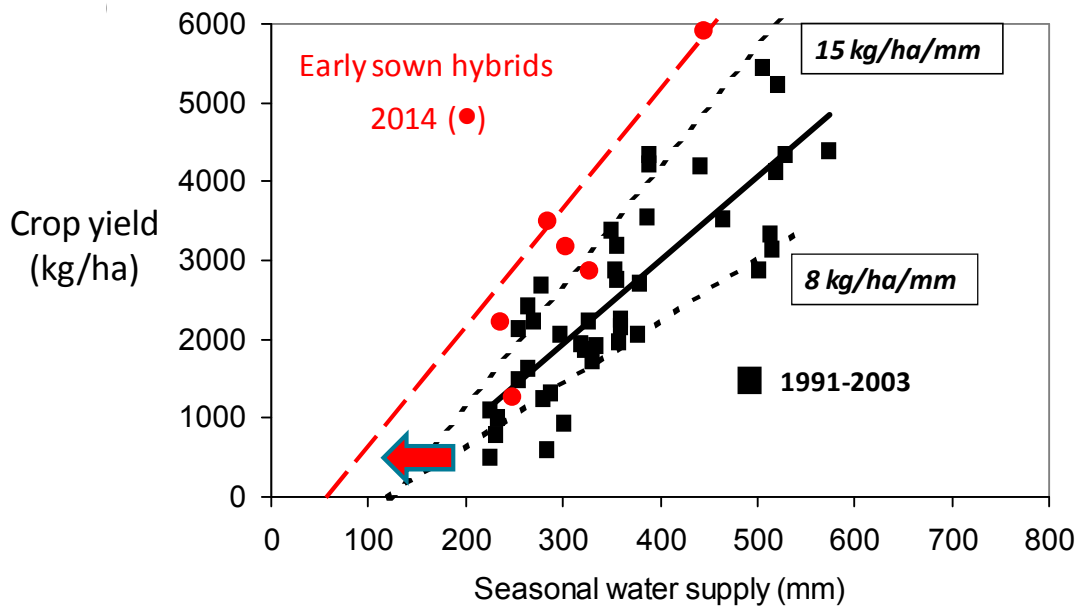

Figure 2. **The relationship between yield and seasonal water supply (in-crop rainfall + change in soil water) for 42 well-grown experimental canola crops in southern NSW between 1991 and 2003 (black squares). The TE ranged from 8 to 15 kg/ha/mm above an assumed evaporative loss of 120mm (black dotted lines). The early-sown hybrids in 2014 (shown as red dots) pushed the boundary (data from Table 1), presumably due partly to lower evaporative loss E (red arrow) along with high TE.**

Conclusion

In 2014, despite an unfavourable season with a warm May (leading to rapid development), significant late-winter frost events and dry spring, early-sown canola crops were able to equal, and in many cases exceed the yield of main season (25 April-sown) crops. The response of specific varieties to early sowing was critical. Spring varieties that were relatively slow to develop (e.g. 45Y88 CL) had their highest (or equal highest) yield from April 1 sowing at all sites, despite the dry spring and harsh late-winter frosts at some sites. Varieties that were relatvely fast to develop (e.g. Hyola575CL) should be avoided for early sowing situations, as they flower early in winter, exposing developing pods to frost, and may also generate insufficient biomass prior to the reproductive phase to support optimum yields. The early-sown hybrid varieties used water very efficiently, often exceeding the upper boundaries reported in previous studies. Though the rainfall pattern may have contributed to lower evaporation, other factors contibuting to efficient water use were the rapid ground coverage of early-sown hybrids, deeper rooting, higher transpiration efficiency and the avoidance of late-season heat and drought. Tactical agronomy packages that manage the risks and costs in early sowing systems (weeds, disease, input costs) are the target of ongoing research.

Acknowledgements

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