Water use of cereal, oilseed and grain legume crops within intercropping systems of southern Australia

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Abstract
Intercropping, where multiple crop species are grown together, has potential to improve productivity of the grains industry. In the rainfed cropping systems of southern Australia, where crops are often water limited, it is important to understand the potential implications of intercropping on crop water use, to identify situations where intercropping can be reliably adopted. Field experiments were undertaken at Horsham and Rutherglen in 2019 and 2020 to measure yield and water use of a range of winter crop species under intercropped and monoculture conditions. Species tested included wheat, barley, canola, faba bean, field pea and lentil. Water use ranged from 212 to 443 mm and in some cases, significant (*P<0.05*) differences were observed across species mixtures. This was related to increasing the proportion of cereals or canola in mixtures with legumes, potentially indicative of different rooting patterns of these species. Water use was not consistently correlated with productivity increases from intercropping and additional metrics are needed to investigate any mechanisms driving the potential benefits of intercropping under dryland conditions in southern Australia.

Keywords
Water use efficiency, grain yield, soil water, crop mixtures.

Introduction
Water availability is the primary driver of grains production across most of Australia's rainfed cropping systems; often due to increasing water stress during the grain filling phase. Intercropping, where multiple species are simultaneously grown together may improve utilisation of available resources including water, light and nutrients thereby increasing total grain yield compared to monocultures (Keating and Carberry 1993; Morris and Garrity 1993a; Morris and Garrity 1993b). While the productivity improvements from intercropping can be significant (Fletcher et al. 2016), understanding the mechanisms driving such improvements is important to guide decisions about where and when such benefits can be realised.

Given the importance of water availability to grains production and the potential improvements from intercropping, we undertook a study which aimed to test a range of winter crops under both monoculture and intercropped conditions. This study included intensive monitoring of crop water use to assess its relationship with likely increased productivity from intercropping.

Experimental methods
Field experiments were located at Horsham (mean annual rainfall 420 mm, grey Vertosol) and Rutherglen (mean annual rainfall 583 mm, brown Chromosol) during 2019 and 2020 with the purpose of measuring water use and yield of a range of winter crop species under intercropped and monoculture conditions. Intercropped combinations included faba bean-wheat, lentil-wheat (Horsham only), field pea-canola, barley-canola and faba bean-canola (Rutherglen only). Each combination was tested at a range of target plant densities relative to their monoculture equivalent including 25:75 %, 50:50 % (2020 only) and 75:25 % as well as monocultures for each species. Intercropped treatments were sown in a 'mixed stand' with both species sown in the same furrow at the same depth, except for canola which was sown shallower. Experiments were arranged in a randomised complete block design with four replicates.

Soil sampling to a depth of 1.6 to 1.8 m (depending on conditions) was undertaken in all plots prior to sowing (averaged across replicates) and following harvest for each plot. Two cores were taken per plot, split into ten depth increments and combined. Samples were dried at 105 ^{o}C to measure soil water content and bulk density. Imidazolinone tolerant cultivars were chosen for each species (except field pea) to improve herbicide management and plots were sown on 5-June and 13-May at Horsham and 4-June and 7-May at Rutherglen in 2019 and 2020 respectively. Plots were otherwise managed according to local practice with minimal pest and disease limitations. Unless otherwise stated, analysis of variance was utilised for statistical analyses.

Results

Rainfall varied significantly between sites and years, ranging from 268 mm in 2019 at Horsham to 600 mm in 2020 at Rutherglen (Table 1). Growing season rainfall (April-October) was 226 and 315 mm at Horsham and 216 and 403 mm at Rutherglen in 2019 and 2020 respectively. At Horsham in 2019 grain yield of monoculture barley and canola averaged 3378 and 971 kg/ha respectively. In 2020 this increased to 6900 and 4610 kg/ha while grain yield of monoculture wheat, faba bean, field pea and lentil averaged 7652, 7559, 3706 and 5008 kg/ha respectively. At Rutherglen monoculture grain yields were 5800 and 8600 kg/ha (barley), 800 and 3400 kg/ha (canola), 4200 and 7900 kg/ha (wheat), 1600 and 5700 kg/ha (faba bean) and 1400 and 5800 kg/ha (field pea) in 2019 and 2020 respectively.

Table 1. Monthly and annual rainfall totals at each experimental site during 2019 and 2020. Deciles are presented in parentheses based on long term data from the nearest Bureau of Meteorology site.

Month	Horsham rainfall (mm)		Rutherglen rainfall (mm)	
	2019	2020	2019	2020
January	0.2 (1)	51.8 (9)	10 (3)	29 (6)
February	11.2 (5)	11.4 (5)	36.4 (7)	18.2 (4)
March	3.4 (2)	14.2 (5)	24.6 (5)	103.6 (10)
April	0.8 (1)	54.8 (10)	0.8 (1)	136.2 (10)
May	62.0 (8)	42.4 (6)	85 (9)	30.4 (4)
June	62.4 (9)	26.6 (5)	45 (5)	41 (4)
July	35 (4)	15.4 (1)	35.6 (3)	15.8 (1)
August	31.6 (4)	51.8 (7)	20.6 (2)	73 (7)
September	19.2 (2)	58.2 (8)	19.8 (1)	39.2 (4)
October	14.6 (3)	65.4 (9)	8.8 (1)	67 (7)
November	24 (5)	14 (3)	41 (6)	22.2 (3)
December	3.4 (2)	13.6 (4)	16 (3)	24.8 (4)
Total	**267.8 (1)**	**419.6 (6)**	**343.6 (1)**	**600.4 (6)**

Crop water use varied significantly between sites and years, particularly in response to the increased biomass (data not shown) and grain production measured in 2020 (Table 2). At Horsham, there were no significant differences (*$P<0.05$*) in water use measured between treatments in either year despite significant differences in grain yield. However, where wheat was grown as mixtures with either faba bean or lentil in 2020, there was a trend towards greater water use under the wheat monoculture in comparison to increasing proportions of the legume species. This observation may relate to the relative tolerance of wheat to subsoil constraints such as salinity in comparison with these legumes (Page et al. 2021). At Rutherglen, significant differences (*$P<0.05$*) in water use were measured between several treatments. Similar to results at Horsham, increasing proportions of wheat in a mixture with faba bean tended to increase water use. In addition to this, increasing the proportion of canola in the mixture with either field pea, barley (2019) or faba bean also resulted in increased water use compared with monocultures of either the legumes or barley.

To explore the importance of crop water use to any potential benefits of intercropping, water use was compared with the corresponding land equivalent ratio (LER); an indicator of the relative benefit of intercropping compared with monocultures (Figure 1). In most cases, this relationship was poor. Moderate correlation between these two parameters were only found for the barley-canola mixture at Horsham in 2020 and Rutherglen in 2019. Furthermore, linear regression indicated that at Horsham the relationship between water use and LER was weakly negative (Fig. 1b), while at Rutherglen this relationship was moderately positive (Fig. 1c).

Table 2. Water use (mm) of various species grown under intercropped and monoculture conditions at Horsham and Rutherglen in 2019 and 2020. Superscripts indicate significant differences (*P<0.05*) within each species mixture group.

Treatment	Horsham		Rutherglen	
	2019	2020	2019	2020
Barley-Canola: 100-0	241	326	233[b]	400
Barley-Canola: 75-25	233	302	233[b]	401
Barley-Canola: 50-50	-	327	-	396
Barley-Canola: 25-75	254	298	259[a]	415
Barley-Canola: 0-100	231	345	259[a]	417
Field pea-Canola: 100-0	-	320	220[b]	383[b]
Field pea-Canola: 75-25	-	336	243[ab]	417[a]
Field pea-Canola: 50-50	-	296	-	411[a]
Field pea-Canola: 25-75	-	321	246[a]	430[a]
Field pea-Canola: 0-100	-	315	257[a]	420[a]
Faba bean-Wheat: 100-0	-	291	212[b]	383[c]
Faba bean-Wheat: 75-25	-	328	236[ab]	403[abc]
Faba bean-Wheat: 50-50	-	291	-	396[bc]
Faba bean-Wheat: 25-75	-	324	240[a]	419[a]
Faba bean-Wheat: 0-100	-	340	253[a]	416[ab]
Lentil-Wheat: 100-0 / Faba bean-Canola: 100-0	-	310	214[b]	386[c]
Lentil-Wheat: 75-25 / Faba bean-Canola: 75-25	-	314	242[a]	413[b]
Lentil-Wheat: 50-50 / Faba bean-Canola: 50-50	-	306	-	416[b]
Lentil-Wheat: 25-75 / Faba bean-Canola: 25-75	-	363	243[a]	430[ab]
Lentil-Wheat: 0-100 / Faba bean-Canola: 0-100	-	364	241[a]	443[a]
P-value	***0.057***	***0.290***	***0.002***	***<0.001***
LSD (P<0.05)	***-***	***-***	***24***	***23***

These results show positive effects of water use on LER in the dry year at Rutherglen (Figure 1c) and Horsham (Figure 1a) but no relation in the wetter year of 2020 (Figure 1d) with a negative relationship between water use and LER at Horsham (Figure 1b). These negative or zero responses indicate that intercropping benefits may result from increased radiation capture and water use efficiency, while a positive relationship may indicate that intercropping is leading to increased access to available water that is likely in the drier years. Nonetheless, as highlighted by Morris and Garrity (1993a) "evidence for similarities among water use from sole and intercrops is abundant" although "differences may be large when species contrast in root distributions". It is suggested that water use in isolation may not be an appropriate indicator or mechanism to explain intercrop advantage across diverse water supply and a more comprehensive assessment of other factors that impact growth and yield (e.g. water use efficiency, canopy morphology and plasticity) is required, noting that the complexity of such measurements in mixed species is significant.

Conclusions

Intercropping a range of winter grain crops was shown to influence water use, where species with varying root patterns and tolerance to soil constraints were grown in mixtures. This effect was also variable across sites and years. Furthermore, changes in water use were not necessarily correlated with intercropping advantage (measured using LER). It is suggested that examination of water relations of mixtures be paired with other metrics, including water use efficiency to provide insight into the mechanisms behind intercropping advantage where it occurs.

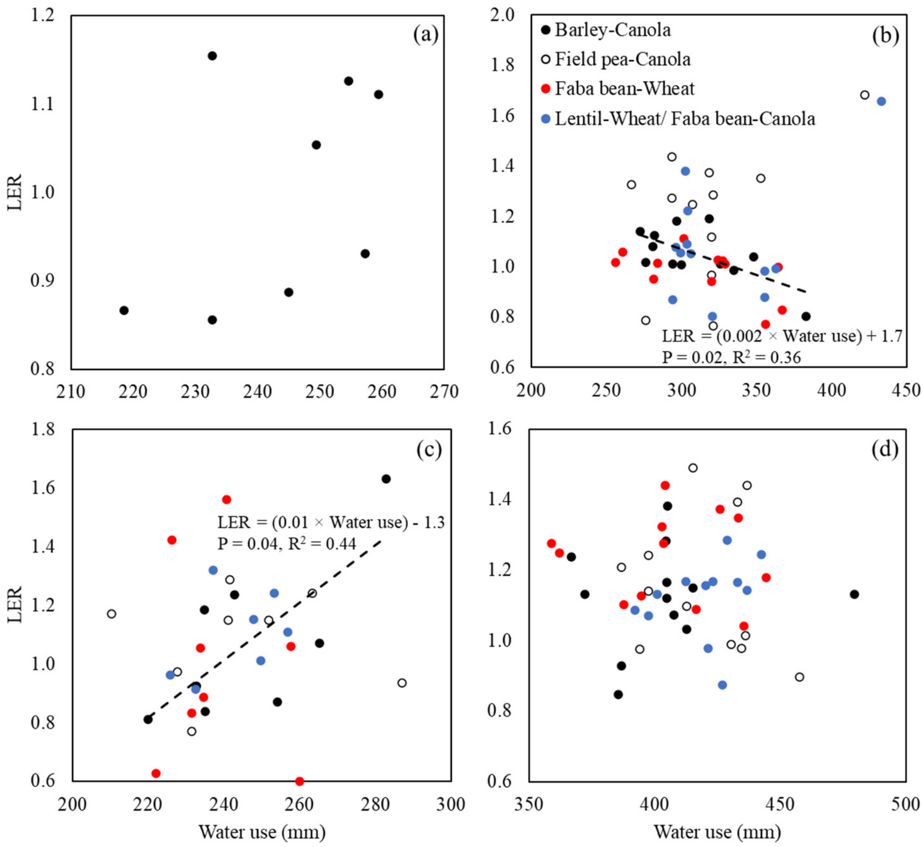

Figure 1. Relationship between land equivalent ratio (LER) and water use of various species grown under intercropped conditions at Horsham in 2019 (a) and 2020 (b) and Rutherglen in 2019 (c) and 2020 (d). Results of linear regression are presented where significant for a given species mixture *(P<0.05)*.

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References

Fletcher AL, Kirkegaard JA, Peoples MB, Robertson MJ, Whish J, Swan AD (2016). Prospects to utilise intercrops and crop variety mixtures in mechanised, rain-fed, temperate cropping systems. Crop and Pasture Science 67, 1252-1267. (doi:10.1071/CP16211).

Keating BA, Carberry PS (1993). Resource capture and use in intercropping: solar radiation. Field Crops Research 34, 273-301. (doi:10.1016/0378-4290(93)90118-7).

Morris RA, Garrity DP (1993a). Resource capture and utilization in intercropping: water. Field Crops Research 34, 303-317. (doi:10.1016/0378-4290(93)90119-8).

Morris RA, Garrity DP (1993b). Resource capture and utilization in intercropping; non-nitrogen nutrients. Field Crops Research 34, 319-334. (doi:10.1016/0378-4290(93)90120-C).

Page KL, Dang YP, Martinez C, Dalal RC, Wehr JB, Kopittke PM, Orton TG, Menzies NW (2021). Review of crop-specific tolerance limits to acidity, salinity and sodicity for seventeen cereal, pulse, and oilseed crops common to rainfed subtropical cropping systems. Land Degradation & Development 32, 2459-2480. (doi:10.1002/ldr.3915).