A review of annual intercrops in rainfed farming systems of southern Australia.

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Abstract
We undertook a literature review of intercropping in the southern Australia wheatbelt. Literature included published peer reviewed journal articles and conferences; and grey literature sources (technical reports, thesis and un-refereed conferences). The review found very little published research on intercropping in this zone. Four groups of intercropping research in Australia were identified: 1. 'Peaola' (Canola-field pea intercrops); 2. Cereal-grain legume intercrops; 3. A single experiment where faba bean and field pea were intercropped; 4. Mixtures of cereal varieties. The land equivalent ratio (LER) was used to evaluate the potential productivity benefits of intercropping. An LER greater than 1.0 indicates that there is a productivity benefit from sowing the intercrop. Peaola intercrops had the greatest productivity increase with 70% having a LER greater than 1.5 (n=34). The cereal-legume intercrops (mostly lupins and chickpea) had 64% with LERs greater than 1.0 (n=22), but there were no published Australian example of wheat-field pea intercropping. None of the five Australian examples of cereal variety mixtures increased grain yield, which is at odds with published international research. This review highlights the potential for yield increases with intercropping in Australia (particularly peaola). Other possible residual benefits (increased N supply, reductions in weed and disease pressure) to subsequent crops should be considered.

Keywords farming systems, intercrop, mixtures

Introduction
Intercropping, the practice of planting two or more crop species simultaneously in a field. There can be substantial productivity and efficiency benefits from the practice (Lithourgidis et al. 2011). However, intercropping requires increased amounts of management and labour to deal with the extra complexity of the system. Intercropping is widely practiced in subsistence and organic. Mostly, these systems have access to sufficient labour to manage the extra complexity. In contrast, intercropping has not been widely practiced in large scale mechanized agricultural systems, such as in Australia, due to a scarce and expensive labour resource. Nevertheless there is a renewed interest in examining these systems in Europe, North America, China and South America due to potential increases in resource use efficiency and environmental benefits (Lithourgidis et al. 2011). For a number of reasons it is timely to re-evaluate the potential for annual intercrops in Australian grain cropping particularly in the temperate zones. There is evidence that intercrops can use soil water more efficiently than sole crops (Morris and Garrity 1993). Herbicide tolerant crops may also enable some innovative weed management strategies. Annual intercrops are a method to increase diversity of species in cropping systems that are now dominated by a few major crops. In this paper we report the results of a literature review of intercropping (including variety mixtures of a single species) in the rainfed farming systems of Southern Australia.

Scope of review
Peer reviewed (journal and conference) and grey literature (technical reports, theses and un-refereed conferences) were reviewed. The review was restricted to annual intercrops in rainfed farming systems of Southern Australia (with winter dominant rainfall patterns) and did not include mixtures with perennial species or summer crops. Mixtures of multiple varieties of a single species were included.

Productivity benefits were quantified by the land equivalent ratio (LER; Equation 1) (Mead and Willey 1980).

$$LER = \frac{ICY_a}{SCY_a} + \frac{ICY_b}{SCY_b} \qquad \text{(Equation 1)}$$

Where ICY_a = the yield of crop *a* as a component of an intercrop, SCY_a= the yield of crop *a* as a sole crop, ICY_b = the yield of crop *b* as a component of an intercrop and SCY_b= the yield of crop *b* as a sole crop . An LER greater than 1 indicates a productivity advantage of the intercrop.

In each of the cereal variety mixture experiments the grain was not separated into its component varieties.

Therefore it was impossible to examine the LER instead we reported relative total grain yield.

Results and discussion

There were only a small number of peer-reviewed journal articles on ‘classical’ intercropping experiments in Australia, i.e. two different crop species sown and harvested in the same season (Gardner and Boundy 1983, Jahansooz et al. 2007). There was more data available in theses, conference proceedings and online sources (Walton 1980, Turay 1996, Soetedjo et al. 1998a, Soetedjo et al. 1998b, Anon 1999, Soetedjo et al. 1999, Barraclough and Martin 2001, Soetedjo et al. 2003, Jahansooz and Coventry 2004, Bennet 2009, Sharma et al. 2011). Furthermore, when cultivar mixtures of a single crop were included there was yet more available information (Davidson et al. 1990, Abbott et al. 2000, Paynter and Hills 2008, Sharma et al. 2011, O'Callaghan and Johnston 2012). There were four groups of intercropping experiments (Figure 1): 1. Six publications with fieldpea-canola intercrops (‘Peaola’). 2. Three publications with wheat-legume intercrops; 3. A single publication with faba bean-fieldpea intercrops; and 4. cereal variety mixtures publications. The yield results of the interspecies mixtures are summarised in figure 1.

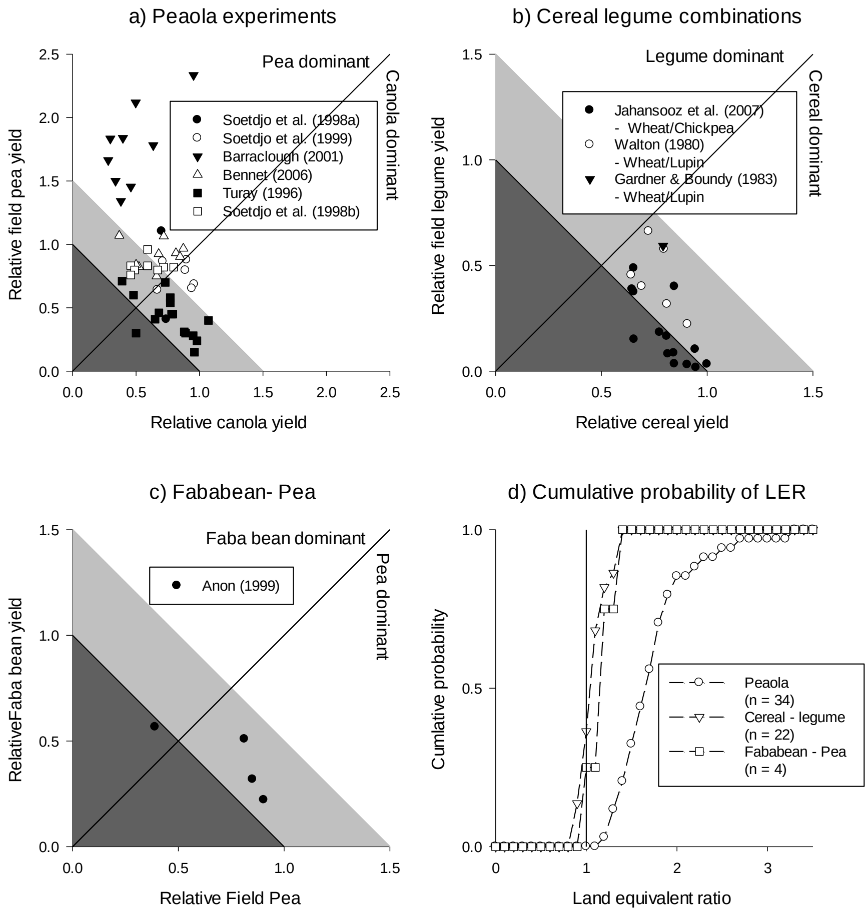

Figure 1. Summary of intercropping experiments in Southern Australia for (a) field pea-canola mixtures (b), wheat – legume mixtures (c) and faba bean – field pea mixtures (d); and the cumulative probabilities of LER across experiments (d). Each data point is a separate treatment. The dark grey area indicates the LER< 1.0; the light grey area indicates the 1.0< LER < 1.5; and the white area indicates the LER >1.5. The solid line in a, b and c is *y*=*x* for comparison of the competitiveness of each component crop.

There were 34 intercropping treatment combinations of peaola principally from WA. Peaola intercrops had high LER’s (Figure 1a) with the LER exceeding 1.0 in all but one case and 1.5 in nearly 70% of cases (Figure 3d). The high field pea yields relative to their sole crops (> 1.5) found by Barraclough and Martin (2001) indicated that canola facilitated field pea yield possibly due to increased harvestability. With the exception of Barraclough and Martin (2001) the relative pea and canola yields were similar indicating that they had similar competitiveness. There is a potential for increased use of peaola intercrops in Australia. Identifying the basis of the yield benefit and the situations where peaola intercrops can contribute to farm profitability are critical issues. Furthermore, despite clear productivity benefits there has not been widespread uptake of peaola crops. The factors limiting this uptake also need to be identified.

There were 22 intercropping combinations across the three wheat-legume intercropping publications from Victoria, SA and WA (Figure 1b). Lupins (Walton 1980, Gardner and Boundy 1983) and chickpeas (Jahansooz et al. 2007) were the two legumes used. The LER exceeded 1.0 in 64% of cases (Figure 1d). Most of the cases where LER was less than 1 were in the experiments of Jahansooz et al. (2007). In all cases, the relative cereal yields exceeded the relative legume yields indicating that the cereal was more competitive than the legume. Surprisingly there were no Australian examples of wheat-field pea intercrops. There are many opportunities to further explore the role of annual wheat –legume intercrops in Australia.

In a single WA experiment (Anon 1999) field pea and faba bean were intercropped. The LER ranged from 0.95 to 1.30 (Figure 1c). The rationale was that it would result in more stable yields across seasons. However, it was impossible to test this with the results of only 1 season.

There were five publications examining cereal variety mixtures. None of the experiments found evidence of grain yield increases (Davidson et al. 1990, Abbott et al. 2000, Paynter and Hills 2008, Sharma et al. 2011, O'Callaghan and Johnston 2012). The median of the mixture yields relative to the expected average yields of the components of each mixture was 1.01 (Figure 2a). However a more appropriate comparison would be the mixture yield relative to the yield of the highest yielding variety. In this case the median relative yield was only 0.94. These demonstrate that there was little direct productivity benefit in growing mixtures of cereals. In contrast a global meta analysis of cereal variety mixtures found a -30 to +100% grain yield increase (Kiær et al. 2009). It is unclear why similar yield gains are not realised in Australia.

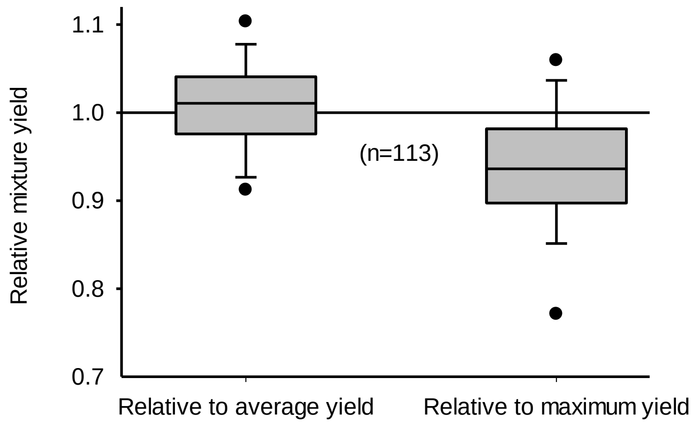

Figure 2. Box plots of relative yields of cereal crop variety mixtures compared with either average or maximum yields of the component varieties.

Even though there were no grain yield increases, the experiment of Davidson et al. (1990) showed that growing a mixture of short season spring and long season winter wheat varieties could provide early season grazing, from the spring wheat, with very little loss in the subsequent grain yield of the winter wheat. There is the potential to use variety mixtures of cereals to produce asynchronous crop reproductive development to manage the risks of frost and heat stress that can impact yield in many regions. This approach is likely to improve the stability of cereal yields rather than increase average yields.

The review has focussed on the immediate productivity benefits of crop mixtures as measured by the LER. This simple measure examines the efficiency with which a given land area is used to produce grain. However, there are a myriad of other benefits that need to be assessed in Australian systems. For example, intercrops may have more or less weeds than sole crops (Lithourgidis et al. 2011), they may decrease disease pressure (Boudreau 2013), they may contribute to yield stability rather than just average productivity, they may provide soil N benefits to subsequent crops (Hauggaard-Nielsen et al. 2009), may contribute to increase P uptake (Gardner and Boundy 1983) or more efficient complete and efficient use of soil water (Morris and Garrity 1993). All these aspects need to be examined in order to fully evaluate the use of annual intercrops in Australian cropping systems.

Conclusions

There is scant research on intercropping in the rainfed farming systems of Southern Australia. The limited research suggests that there are potential productivity benefits that could be obtained. Furthermore, there are some further potential rotational benefits that need to be researched. Despite these potential benefits there has not been widespread uptake of intercropping in southern Australia. This may be due to the perceived logistical challenges to managing these systems. The factors limiting the uptake and use of intercropping also need to be identified.

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