The residual N benefits of temporary intercropping field pea with wheat

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Abstract
Intercropping research in Australia has focussed on the productivity benefits in the year of the intercrop. However, cereal-legume intercrops may provide residual nitrogen (N) to subsequent crops. In a two-year field experiment at Cunderdin, WA, the residual N benefits of wheat-pea intercrops were examined. Treatments established in 2013 included (i) field pea monoculture var. Kaspa, (ii) wheat monoculture var. Mace, (iii) Wheat-pea intercrop, (iv) wheat-pea intercrop with the peas removed by selective herbicide in September, and (v) wheat-pea intercrop with the peas removed in October. No N fertiliser was applied to any treatment. The wheat monoculture yielded 2.6 t/ha with intercropped wheat yields reduced ($p<0.001$) by 44% (Sep removed peas) and 69% (Oct removed peas and full intercropped peas). There was additional soil N following both field pea and intercrop treatments. In 2014 the site was sown to wheat var. Mace. The wheat after wheat treatments received either no N fertiliser or 100 kg N/ha. All other treatments received no fertiliser N. Wheat yield responded to the previous crop ($p<0.001$) with the highest yields for wheat following wheat with fertiliser N (4.4 t/ha); intermediate yields for wheat after peas or intercrop, regardless of duration at 3.2 t/ha and lowest for wheat after wheat with no fertiliser N (1.9 t/ha). Protein content also varied and reflected the available soil N. Wheat-pea intercrops were as good as a pea crops at providing additional N to subsequent crops. They warrant further investigation as potential components of sustainable cropping rotations.

Introduction
Intercropping, growing two or more crop species simultaneously in a field, is widely practiced in low input farming systems. However, there has only been limited intercropping research in Australia (Fletcher et al. 2015). Most of this research has focused on the productivity of the intercrop itself with no research on the residual effects of intercrops on the productivity of subsequent crops in rotation. Annual cereal-legume intercrops can increase cereal yields in the intercrop season due to the benefit of N fixation from the legume to the cereal component (Hauggaard-Nielsen et al. 2009b). It is possible that the increased soil nitrogen concentration resulting from N fixation following the legume crop will continue into subsequent crops (Hauggaard-Nielsen et al. 2009a).

A new approach, "temporary intercropping of legumes and cereals" was examined by Tosti and Guiducci (2010). This is where a legume is sown with a cereal, but then killed before maturity so that N becomes available to the cereal. Tosti and Guiducci (2010) used cultivation to kill a faba bean crop and incorporate the residue. The appropriate time to terminate the legume crop would be determined by estimating legume growth and subsequent N fixed, likely rainfall to maturity of the wheat crop for the legume DM to break down to assist the intercrop wheat and early enough to ensure no major resource competition with the wheat crop. It is likely that the legume crop would have to be killed before the start of wheat flowering when rates of water use typically increase. Such an approach has not been examined in Australia.

This paper reports the results of a two year field experiment in WA that tested the hypothesis that the yield of wheat grown after a wheat/field pea intercrop will be greater than wheat grown after wheat and similar to the yield of wheat grown after a sole field pea crop. A secondary hypothesis was that the N supply to the second year wheat crop from temporary pea intercrops (killed with herbicides in spring) would be similar to intercropped peas grown for yield (full season intercrop), but crop competition would not reduce wheat yields in the first year.

Materials and methods
A two year field experiment was undertaken at the WANTFA long term cropping site near Cunderdin (31.64°S, 117.25°E) in WA. This site was a red sandy clay loam with moderate N fertility. In the first year of the experiment (2013) a range of monoculture crops and intercrop treatments of field pea var. Kaspa and wheat var. Mace were sown at 60 and 120 kg seed/ha, respectively (Table 1) on 11 June 2013. The intercrop

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treatments were additive in design (i.e. 60 kg/ha of wheat seed and 120 kg/ha of field pea seed). Two of the three intercrop treatments were sprayed with a selective herbicide (1.5ml/ha of Torpedo; ai Clopyralid 300g/L and Florasulam 50g/L) to kill the field pea during spring. No N fertiliser was applied in 2013. The experiment comprised a total of 6 treatments with 4 replicates in a randomised complete block design. Plot dimensions were 2.2 X 12m. Grain yields were assessed on 28 Nov 2013 from a 0.8 m^2 quadrat. Samples were split into wheat and field pea grain and oven dried to constant weight. Wheat grain was analysed for total N content using LECO combustion. These were converted to grain protein content (%) using a factor of 5.7. The whole plot was harvested with a small plot harvester with all residue retained.

Table 1. Outline of treatments used in experiment.

Treat-ment	2013			2014	
	Crop	Spraying of pea crop	N applied	Crop	N applied (kg N/ha)
1	Pea	Not sprayed	0	Wheat	0
2	Pea – wheat intercrop	Sprayed 5 Sep	0	Wheat	0
3	Pea – wheat intercrop	Sprayed 3 Oct	0	Wheat	0
4	Pea – wheat intercrop	Not sprayed	0	Wheat	0
5	Wheat	-	0	Wheat	0
6	Wheat	-	0	Wheat	100

In 2014 the whole site was sown to wheat var. Mace on 16 May 2014. The wheat monoculture 2013 treatment was split into two treatments that received either 0 or 100 kg N/ha as urea on 10 June 2014 (2-3 leaf stage). All other treatments received no N fertiliser. Grain yields were assessed on a 1.2m^2 quadrat from each plot on 19 November 2014. Grain samples were analysed for total N content using LECO and converted to protein content (%) using a factor of 5.7.

Soil samples were taken for the 0-20 cm layer on 5 September and 28 November 2013 (harvest); and 0-20 and 20-40 cm layers on 20 May 2014. Samples were analysed for mineral N (Ammonium and Nitrate). This was converted to kg/ha using an assumed soil bulk density of 1.6 g/cm^3.

All variables were analysed using a one-way Analysis of Variance in Genstat with means separation using Fischer's Protected least significant difference (LSD; $\alpha = 0.05$). Where treatments did not include a particular crop that treatment was not included in the ANOVA. Thus, in 2013 the monoculture pea crops were not included in the analysis of wheat yield or protein and the monoculture wheat crops and wheat-pea intercrops sprayed on 5 Sep. were not included in the analysis of field pea yield.

Results

Growing season rainfall (Apr-Oct) in 2013 was 229 mm which is much less than the long term average of 278 mm. Rainfall was particularly low in both April and June when 4 mm fell in both months compared to long term averages of 24 and 57 respectively. The 2014 growing season rainfall of 320 mm was much greater than the long term average particularly in Apr and May when a total of 120 mm of rain fell.

2013 Crop performance

The wheat monoculture crop yielded 2.6 t/ha and the field pea monoculture crop yielded 1.7 t/ha (Table 2) in 2013. Due to resource competition, wheat yields in the intercrops were reduced compared to the wheat monoculture ($p<0.001$). In the temporary intercrop where the field peas were sprayed out early (5 Sep) the wheat yield was 1.5 t/ha. This was greater than for a late temporary intercrop (3 Oct spray) or a full intercrop (field peas not sprayed out) which yielded an average of 0.8 t/ha. The wheat protein content was 10.6% as a monoculture crop. This increased markedly ($p<0.001$) to ~13.0% when grown as part of an intercrop. Resource competition also resulted in field pea yield being reduced ($p<0.01$) in the intercrop to 0.5 t/ha. Some field pea grain growth (0.2 t/ha) had occurred in the late temporary intercrop before it was sprayed out.

Table 2. Crop yields (t/ha) and protein contents of wheat (%), and soil (kg/ha) mineral N across the two years.

Treat-ment	2013					2014			
	Soil N (0-20cm)	Pea Yield (t/ha)	Wheat Yield (t/ha)	Wheat Protein (%)	Soil N (0-20cm)	Soil N (0-20cm)	Soil N (20-40cm)	Wheat Yield (t/ha)	Wheat Protein (%)
Date	5 Sep	28 Nov	28 Nov	28 Nov	28 Nov	20 May	20 May	19 Nov	19 Nov
1	22.4	1.67	-		29.6	33.5	39.8	3.47	9.1
2	23.6	-	1.49	12.6	28.0	32.7	32.7	2.96	9.0
3	23.6	0.17	0.73	13.3	21.6	38.3	50.3	3.21	9.8
4	23.6	0.45	0.93	13.0	12.0	40.7	39.9	3.19	9.0
5	17.6	-	2.60	10.6	8.4	32.2	31.14	1.94	9.0
6								4.38	9.6
Sig (p<)	n.s.	0.01	0.001	0.001	n.s.	n.s.	n.s.	0.001	n.s.
LSD (α = 0.05)		0.66	0.52	1.28				847	

2014 Crop performance

Growing season rainfall (Apr-Oct) in 2014 was 270 mm. The highest wheat yields (4.4 t/ha) were achieved when wheat was grown after wheat and supplied with 100 kg N/ha as fertiliser. The lowest yields (1.9 t/ha) occurred when wheat followed wheat but without any N fertiliser supplied. This indicated that N supply was severely limiting yield. The yields of wheat after field peas or intercrop (regardless of duration) all fell between these yields and were not different to each other. There were no differences in wheat protein content across the treatments (Table 2).

Available Soil N measurements

There were no differences in soil mineral N at any date (Table 2). However, there was a trend at the harvest of the 1st year (28 Nov) for the pea monoculture and intercrop treatments to have higher soil N than the wheat treatment ($p = 0.121$). This was supported by orthogonal contrasts that found no difference between the soil N in the intercrops (Treatments 2, 3 and 4) and the sole pea crop (Treatment 1); but that treatments containing peas (Treatment 1, 2, 3 and 4), either as a monoculture or an intercrop, had more ($p<0.05$) soil mineral N than the wheat (Treatment 5).

Discussion

In 2014 there was a strong growth response of wheat to the intercrops and monoculture pea treatments compared with the wheat after wheat treatments with no N fertiliser (Figure 1). However, the strongest growth response was for wheat after wheat with 100 kg N/ha fertiliser (Table 2). The intercrops were as good as the monoculture pea crops in supplying residual N. Although, the soil N results were inconclusive (Table 2), the extra wheat growth and yield obtained in 2014 with 100 kg N/ha suggested that the residual benefits of the pea crops and intercrops over the wheat after wheat unfertilised crop (Table 2) was due to an increased soil N. Additionally, the protein levels were all low (<10%) indicating that N was limiting yield (Table 2). It was likely that mineralisation of organic N occurred during the cropping season which was not measured.

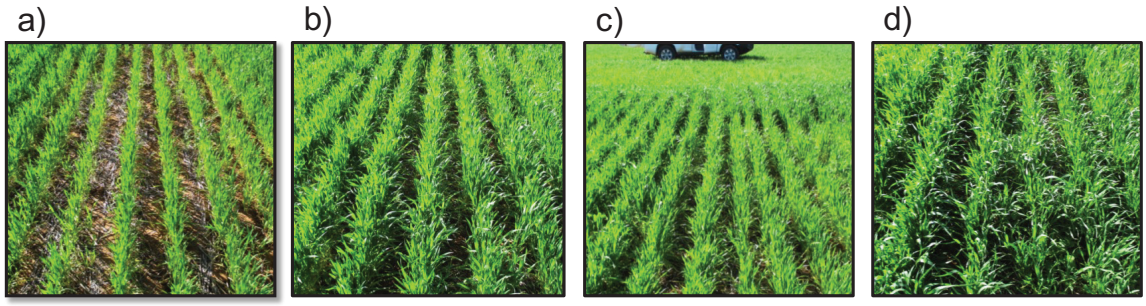

Figure 1. Growth of wheat on 1 Aug 2014. Wheat grown after: a) Wheat with no N fertiliser, b) field pea, c) wheat-pea intercrop, and d) wheat with 100 kg N/ha (2014).

There was a wheat yield penalty in the first season from growing these intercrops. This was due to the increased resource competition from the field peas when they were grown in intercrops (Table 2). The low land equivalent ratio (LER) of 0.64 (data not shown) is much less than for other intercropping experiments in Australia (Fletcher et al. 2015). The LER is a measure of the relative amounts of land needed to grow an equivalent amount of field pea and wheat as if they were grown as sole crops. A LER less than 1 indicates that more land is required. Our low LER indicated that there was no benefit and a likely overall productivity loss in the intercrop in the first year. This may be related to the intercrops being additive and not substitutive.

There was a large wheat yield decrease in the intercrops in 2013 compared with the wheat monocultures, but this was made up for by an increase in wheat yields in the second season (table 2). Across the two seasons mean total wheat yields were 4.3 t/ha in all of the intercrop treatments and the wheat after wheat treatment with no fertiliser N (treatment 5). However, the total yields of wheat after wheat with 100 kg N fertiliser (treatment 6) were much greater (7.1 t/ha; $p<0.001$). Even though the wheat yields decreased in the intercrops in 2013 the protein content increased (Table 2), this can be interpreted in two ways. Firstly, the N_2 fixation by the field pea component of the intercrop supplied extra N to the wheat and increased protein content. Alternatively, the increase in protein content may be due to the smaller grain yields with a natural dilution of N. The latter is more likely as an analysis of total protein yield found that wheat crops yielded more wheat protein/ha than the intercrops (data not shown).

It was possible to reduce the loss in wheat yield by spraying out the field peas in September (Treatment 2). In the second year this treatment produced similar wheat yields to those following the other intercrops and the pea monoculture. Spraying the peas out early in year 1 may be a useful strategy to obtain a residual benefit in year 2 while still obtaining a good wheat yield in year 1. Perhaps, if the field peas had been sprayed out earlier the competitive effects would have been less. The 1st year wheat yields in temporary intercropping treatments are not consistent with those of Tosti and Guiducci (2010). Their temporary intercrops did not reduce wheat yields compared with monocultures. This may be because we sprayed our pea crops, whereas they incorporated their pea crops. Thus, in their experiment the field pea residues would have broken down much quicker. Alternatively, we delayed the spraying of the pea crop too late. They incorporated their legume crop at wheat stem extension, whereas we waited until wheat anthesis. Research with dual purpose crops has shown that wheat crops can recover from grazing up until the beginning of stem elongation (GS 30) (Harrison et al. 2011). This may have been a more appropriate time to spray the peas in our experiment. Furthermore, Tosti and Guiducci (2010) used faba bean, which may be less competitive than the field peas.

Overall, our experiment demonstrated that full and temporary intercrops are an innovative strategy that can supply N to subsequent crops in a rotation without completely forgoing the opportunity to grow wheat. Temporary intercrops warrant further investigation to identify how best to manage the competition between the legume and wheat. The appropriate legume species, cereal varieties, sowing rates and dates of the two components, and the best time to kill the legume, all need to be identified.

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References

Fletcher AL, Peoples MB, Kirkegaard JA, Roberston MJ, Whish JPM and Swan AD (2015). A review of annual intercrops in rainfed farming systems of southern Australia. “Building productive, diverse and sustainable landscapes”, Proceedings of the 17th Australian Agronomy Conference, Hobart, Australia.

Harrison MT, Evans JR, Dove H and Moore AD (2011). Dual-purpose cereals: can the relative influences of management and environment on crop recovery and grain yield be dissected? Crop and Pasture Science 62, 930-946.

Hauggaard-Nielsen H, Gooding M, Ambus P, Corre-Hellou G, Crozat Y, Dahlmann C, Dibet A, Fragstein P, Pristeri A, Monti M and Jensen ES (2009a). Pea–barley intercropping and short-term subsequent crop effects across European organic cropping conditions. Nutrient Cycling in Agroecosystems 85, 141-155.

Hauggaard-Nielsen H, Gooding M, Ambus P, Corre-Hellou G, Crozat Y, Dahlmann C, Dibet A, von Fragstein P, Pristeri A, Monti M and Jensen ES (2009b). Pea–barley intercropping for efficient symbiotic N2-fixation, soil N acquisition and use of other nutrients in European organic cropping systems. Field Crops Research 113, 64-71.

Tosti G and Guiducci M (2010). Durum wheat-faba bean temporary intercropping: Effects on nitrogen supply and wheat quality. European Journal of Agronomy 33, 157-165.