Vegetative competition between crops grown in intercropping systems

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Abstract
Sowing multiple crops together as an intercrop is proposed to improve yields and profit relative to crops sown as monocultures. Any yield improvement is hypothesized to be due to greater competition between species, leading to enhanced exploitation and use of light, nutrient and water resources. An improved understanding of in-crop competition between crops for these resources will help inform the design of new cropping systems. The relative growth of two crops (combinations of canola, faba bean, wheat, barley and field pea) sown at 25%, 50% and 75% within mixes were compared to their monocultures at Hamilton and Rutherglen in Victoria in 2019 and 2020. Non-destructive imaging techniques and biomass of each crop component at anthesis provided additional information on differences in canopy architecture and biomass production due to the companion crop with which they were sown. Barley appeared to dominate the mix with canola at anthesis regardless of sowing density. This dominance reduced canola grain yields relative to canola yields sown with either faba bean or pea at Hamilton but not at Rutherglen. Combining dry matter data, non-destructive RGB imaging and analysis provided a new method to capture canopy arrangement. Differences in the relationship between canopy area and dry matter at anthesis indicate crops have different growth habits depending on the companion crop with which they are grown. These findings will help identify optimum species combinations that maximise resource use and provide intercropping management recommendations to growers.

Keywords: RGB images, Image J

Introduction

Intercropping is defined as growing two or more crops together in the same space at the same time. The aim of intercropping is to improve overall productivity through more efficient capture and use of resources including water, nutrients and light. This can be achieved through the complementary use of resources whereby crops are able to exploit different spaces (e.g. different root and canopy architectures) or timings (e.g. phenology), the facilitation of resources whereby one intercrop component increases the availability of a resource to another component (e.g. nitrogen fixation by a legume) and through the reduction of abiotic or biotic stress (e.g. pest and disease infestation or light quality) (Fletcher et al 2016, Slattery et al 2013). However, productivity of these systems has been found to be intermediate or comparable to their monocultures due to competition for limited resources between the crops (Andersen et al 2007). Competition can be reduced through species selection, sowing time, relay cropping, sowing density and planting configuration (Dowling et al 2020). Identifying the optimum species combination and intercrop design to increase productivity and minimise competition relies on a good understanding of the complex interactions between crops and resource availability.

To better understand these interactions, an intercropping study was conducted in 2019 and 2020 in SW and NE Vic, specifically to determine if canola and faba beans behave differently when grown with other crop species. Differences were detected through dry matter production and Image J software analysis near flowering and through grain yield at maturity. The Image J data provided an estimate of the percentage area occupied by each crop visible in the upper layer of the canopy, thus providing new insights into crop behaviour and competition for light between species in the mixes.

Methods

Experiments were sown at two high rainfall locations, Hamilton (South West Victoria) in 2019 (annual long-term average (LTA) rainfall, 690 mm) and Rutherglen (North East Victoria) in 2020 (LTA 583 mm). Crops were either sown in a mixture of two species or as a monoculture and were selected based on contrasting canopy and root architectures and crop types (i.e legume, cereal or oilseed). Canola (*cv* Hyola® 580 CT) was sown in combination with either Barley (*cv* Sparticus CL), Faba bean (*cv*. PBA Bendoc) or Field pea (*cv* PBA Butler). Faba bean was sown with either canola (*cv* Hyola® 580) or wheat (*cv* Sheriff CL). At Hamilton, crop monocultures (100%) were compared to species mixes sown at 75% and 25% of their respective monocultures. The same combinations were grown at Rutherglen, but at this site an additional 50:50 ratio treatment was included. Variety selection was based on crops with a similar phenology and, except for field pea, herbicide tolerance including imidazoline tolerant (CL) or triazine and imidazoline tolerant (CT).

Crops were sown onto raised beds on 26 June 2019 at Hamilton and on flat ground at Rutherglen on May 7, 2020. At Hamilton, row spacing was 15 cm and plot size was 3 beds (each 1.75 m furrow to furrow) by 20 m long giving a total plot area of 105 m^2. At Rutherglen row spacing was 25 cm and plot size was 4.5 x 20 m, giving a total plot area of 90 m^2. At flowering (October 21 at Hamilton and September 24 at Rutherglen), two representative regions (0.5 m x 4 inner rows) which reflected the target plant numbers and ratios were marked in each plot to measure percentage area of each crop in the upper canopy and dry matter production. RGB images were collected from each region using a smart phone camera (12MP) mounted on a pole and a selfie stick at a constant height of 2m above the soil. Plant material within the same area was then cut to ground level and dried to a constant weight in a fan forced oven to determine dry matter. All RGB images captured from the smart phone camera were automatically analyzed using the 'Trainable Weka segmentation' machine learning tool available in Image J software. Images were segmented and classified for crop species 1, crop species 2 and background soil using a train classifier. Percentage canopy cover of each crop was analyzed based on the automated setup colour threshold. Grain yields were taken from 4 quadrat cuts per plot (0.5 m x 4 inner rows) when both crops within the treatment had reached maturity.

The experiments were randomised block designs each with four replicates. Differences between treatments (species x density combinations) in dry matter and relative crop area (derived from RGB images) at anthesis and grain yield at maturity were determined by ANOVA with significance nominated at the 5% level. Results in this paper focus on canola and faba bean crops as these were the only crops that had treatments with more than one other crop in the mix. All data was analysed using GenStat for Windows 18th Edition.

Results

Canola

At both sites and for each sowing density, the percentage of canola dry matter at anthesis in the mix was significantly less when sown with barley than with faba bean or field peas (Table 1). For the 25% canola:75% barley ratio, canola only represented 4% and 10% of the total dry matter at Rutherglen and Hamilton respectively. The maximum percent of canola dry weight in the canola:barley mix was 32% at Rutherglen and 50% at Hamilton when sown at the highest density of 75%. This indicates that barley is the dominant crop when sown with canola. By contrast, at Hamilton canola dominated the canola:faba bean and canola:field pea mix accounting for up to 93% of the total weight when sown at the higher density with field pea. At Rutherglen, dry matter of canola sown with peas and faba beans more closely reflected the sown proportions.

At Hamilton, despite the differences in dry weights, the percent area occupied by the crop in the upper canopy as determined from the RGB images closely reflected the sowing percentages. At Rutherglen, except for the mixes with faba bean and pea at the lower density, the percent of the canopy area occupied by canola tended to be less than the sown proportions. A smaller canola canopy area relative to its corresponding dry matter value indicates that the companion crop is positioned higher in the canopy, displaying a greater surface area captured by the image. This was particularly the case at Hamilton where, for example, at the 25% sowing canola:pea treatment, canola accounted for half the dry matter produced but only 21% of the area in the top of the canopy. This likely captures the trellising habit of peas when grown with a companion crop.

Canola grain yields were greatest when sown with faba beans and least when sown with barley at Hamilton. At Rutherglen, canola yields were greatest when sown with field peas. Except for the 25% canola:75% barley mix which produced the least amount of canola, there was little difference between relative canola performance when sown with either barley or faba bean at this site.

Table 1. Canola performance when sown in a companion mix at different densities and sowing arrangements with either barley, faba bean or field pea at Rutherglen in 2020 and Hamilton in 2019. Area is the percent area in the upper canopy at anthesis as determined through analysis of RGB images taken above the crop. Crops were sown as a random mix. P value (<0.001) at Rutherglen were: anthesis dry weight (%) 7.6; Area (%), 5.5. At Hamilton, were: anthesis dry weight (%) 9.6; Area (%) 3.4.

		Rutherglen			**Hamilton**		
		Companion Crop			**Companion Crop**		
	Sowing %	**Barley**	**Faba Bean**	**Pea**	**Barley**	**Faba Bean**	**Pea**
Anthesis dry	**25**	4%	31%	26%	10%	56%	50%
weight	**50**	24%	38%	51%			
(% of the mix)	**75**	32%	62%	75%	50%	91%	93%
Canopy area	**25**	14%	46%	37%	25%	26%	21%
at anthesis	**50**	47%	43%	44%			
(% of mix)	**75**	55%	57%	69%	75%	76%	74%
Grain yield	**25**	69	106	211	105	248	173
(g m^{-2})	**50**	191	144	294			
	75	263	245	331	255	445	355
	100	348	385	419	433	447	445

Faba bean

Table 2. Faba bean performance when sown in a companion mix at different densities and sowing arrangements with either canola or wheat at Rutherglen in 2020 and Hamilton in 2019. Area is the percent area in the upper canopy at anthesis as determined through analysis of RGB images taken above the crop. Crops were sown as a random mix. P value (<0.001) at Rutherglen were: anthesis dry weight (%) 7.6; Area (%), 5.5. At Hamilton, were: anthesis dry weight (%) 9.6; Area (%) 3.4.

		Rutherglen		**Hamilton**	
		Companion Crop		**Companion Crop**	
	Sowing %	**Canola**	**Wheat**	**Canola**	**Wheat**
Anthesis dry	**25**	32%	17%	9%	9%
weight	**50**	56%	51%		
(% of the mix)	**75**	62%	48%	44%	40%
Canopy area	**25**	36%	29%	21%	19%
at anthesis	**50**	51%	53%		
(% of mix)	**75**	47%	49%	70%	43%
Grain yield	**25**	298	242	65	68
(g m^{-2})	**50**	360	438		
	75	435	613	276	292
	100	551	573	744	719

Except for the 50% random mix with wheat and canola (both sites) and 25% mix with canola (Rutherglen), faba bean produced relatively less anthesis dry matter than its companion species (Table 2). The percent canopy area generally reflected the sown proportions except for the 25% sowing density for both wheat and canola at Rutherglen (36 and 29% respectively) and the 75% wheat treatment at Hamilton (43%).

Faba bean grain yields at Hamilton were significantly reduced relative to the monoculture when sown as a companion with either canola or wheat. Yields were less impacted at Rutherglen where there were indications of a positive response when sown at 75% with wheat.

Conclusion

Results from this intercropping study show that crops differ in their dry matter production, growth habit and grain yield depending on the companion species with which they are grown. RGB imagery and analysis offer a non-destructive method for capturing different growth habits of crops growing in mixes. Combining dry matter data, non-destructive RGB imaging and analysis provided a new method to capture canopy arrangement. Differences in the relationship between canopy area and dry matter at anthesis indicate crops have different growth habits depending on the companion crop with which they are grown.

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