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Intercropping for sustainability: Research developments and their application

Effect of intercropping designs of spring wheat and faba bean on crop productivity and resilience to weather extremes

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Summary

Spatial arrangement of component crops in intercropping (IC) systems may affect the functioning and crop performance by regulating between-species competition for above- and below-ground resource use and responses to stresses. Faba bean (*Vicia faba* L.) and wheat (*Triticum aestivum* L.) established in different IC spatial designs; alternating rows, same row and in varying seeding proportions, were co-designed and tested in 2018 and 2019 in Southern Sweden. Due to extreme drought in 2018, dry matter grain yield and crop biomass of faba bean in sole crops (SCs) were only 1.08 t ha^{-1} and 3.63 t ha^{-1}, respectively. However, the reduced yield in faba bean was compensated to a great degree in the IC treatments, with increased contribution from wheat in the combined yield. There was lower weed abundance in IC treatments compared to SC faba bean. The results shows the potentials of IC for increasing agro-biodiversity, productivity and reducing climatic risk.

Key words: Co-design, crop diversification, drought, intercropping, land equivalent ratio, grain legume

Introduction

Current large-scale agriculture in Sweden (and in Europe) relies heavily on very few crop species and external inputs such as fertilisers, pesticides, and fossil fuels, with severe negative environmental impacts (Engstrom, 2010). Large uniform areas of one crop may have temporary short-term advantages such as easy crop management, but in the long run they are highly vulnerable to risks, e.g. pests and weather extremes (Peltonen-Sainio, 2012). Large areas of sole crops also have negative side-effects on farmland biodiversity, pollution, development of resistance to herbicides/pesticide and dependence on agrochemicals (Gliessman, 2014). Organic production can decrease some of these risks and negative side effects, but it has several challenges in terms of low yields, weeds and pest attacks (Chongtham *et al*., 2016). This calls for a need to design innovative cropping systems, which are more sustainable, resilient, productive and multi-functional (Tilman *et al*., 2002; Bommarco *et al*., 2012). One way to achieve this is via applying agroecological approaches (Wezel *et al*., 2014; Altieri & Nicholls, 2012). Designing new cropping systems based on agroecological approaches, such as intercropping of cereals and legumes, requires farmers and other stakeholders to collaborate and share experiences in co-designing, and acquiring knowledge collectively on the new systems by implementing and assessing the systems (Meynard *et al*., 2012).

Intercropping, i.e. growing two or more crop species simultaneously in the same field and in the whole or part of the growing season, is based on ecological principles which provides beneficial biological interactions (of competition, complementarity and facilitation), between crops and generate agro-environmental services (Jensen, 1996; Hauggaard-Nielsen *et al*., 2008). Therefore, incorporating grain legumes in cereal-based systems is seen as a strong component in organic agricultural systems that can address several economic and environmental sustainability concerns (Stagnari *et al*., 2017). Proper design and management of grain legume-cereal intercrop systems is essential for optimal resource use efficiency, crop yield (and stability) and delivery of additional ecosystem services (Raseduzzaman & Jensen, 2017; Bedoussac *et al*., 2018). However, the spatial arrangement of component crops in intercropping (IC) systems may affect the functioning and performance of crops by regulating the between-species competition for above- and below-ground resources and response to biotic and abiotic stresses (Jensen, 1986). This study aims to determine the effects of IC wheat and faba bean in various spatial arrangements on crop yields, weed control and resilience to climatic risk in organically managed cropping systems.

Materials and Methods

Experimental design

In co-design workshops, researchers from Swedish University of Agricultural Sciences (SLU), Alnarp, worked together with organic farmers, advisors and a county official from Halland to identify several important cereal and legume crops in Southern Sweden for intercropping. One of the mixtures was the intercropping of spring faba bean (*Vicia faba* cv. Boxer) and spring wheat (*Triticum aestivum* cv. Diskett) in various spatial arrangements that is described in Table 1.

Field experiments of intercropping wheat and faba beans were conducted in farmers' fields and in SLU's research station, SITES Lönnstorp in 2018 and 2019. This paper focuses on the experiment established at SITES Lönnstorp. The intercrop treatments were sown in a replacement design based on each species sowing density in sole crop (SC) and with four replicates of each treatment in a complete randomized block design (Table 1). The size of each plot was 1.6 m *12 m and the crops were sown on the same day at *c*. 3.5 cm depth with an inter-row distance of 12.5 cm. The experiment was established on fields, which have been converted to organic farming since 1993 and was managed according to organic farming practices, but without weeding. No fertilisers were applied in the current experiment. The soil pH was 7.7 and with 42% sand, 30% silt and 3.1% organic matter content.

Table 1. *Treatments and seeding densities in 2018 and 2019. 1:1 row- one row of wheat alternating with one row of faba bean; 1:3 row- one row of wheat alternating with three rows of faba bean; 3:1 row- three rows of wheat alternating with one row of faba bean; 1:1 mix- both the crops are mixed and sown in the same row*

Year	Treatments	Wheat seeding rate (kg ha^{-1})	Faba bean seeding rate (kg ha^{-1})
2018	1:1 row IC	120	140
	1:3 row IC	60	210
	3:1 row IC	180	70
	Wheat SC	240	
	Faba bean SC		280
2019	1:1 row IC	120	140
	1:2 row IC	80	186
	1:1 mix IC	120	140
	Wheat SC	240	
	Faba bean SC		280

Crop grain yield and aboveground biomasses of crops and weeds were determined in all treatments at crop maturity (grain harvest) by cutting biomass at 2 cm height from an area of 0.5 m^2 from all plots. The samples were oven-dried at 55°C until they reached a constant weight.

Data analyses

Weed biomass, grain yield and crop biomass were analysed using a two-way anova model with year, treatment and the interaction of year and treatment as independent factors. Estimated marginal means were calculated for each treatment and compared using pairwise Tukey *post-hoc* tests (using the emmeans R package). Results were considered statistically significant if $P<0.05$. Plots were produced using the ggplot2 R package. Errors bars in bar charts denote standard errors.

Land equivalent ratio (LER) is the most common index adopted in intercropping to measure the resource use and often used as an indicator to determine the performance of intercropping. The LER is a standardised index which is defined as the relative area required by sole crops to produce the same yield as intercrops, and calculated according to the formula (Mead & Willey, 1980):

$$\text{LER} = \text{YwI}/\text{YwS} + \text{YfI}/\text{YfS}$$

where Yw= Yield of wheat, Yf=Yield of faba bean; I and S refers to intercrops and sole crops, respectively.

Results

Grain yields and LER

The extreme drought condition during 2018 summer in southern Sweden, severely affected the faba bean crops, in both sole and intercrops. This resulted in dry matter grain yields of only 1.08 t ha^{-1} and crop biomass of 3.63 t ha^{-1} in SC faba bean, compared to the faba bean grain yield of 3.38 t ha^{-1} and crop biomass of 5.76 t ha^{-1} in 2019 (Tables 2 and 3). Grain yield of SC wheat in 2018 was also much lower than in 2019. However, the reduced yield in faba bean in 2018 was compensated to a great degree in the IC treatments in 1:1 and 3:1 row IC treatments, with increased contribution from wheat in the combined (total) yield. In particular, wheat and faba bean in 1:1 row IC showed the highest grain yield among the intercropped treatments across both the years. In this mixture, wheat grain yield was 77.5% (2018) and 77.7% (2019) of SC wheat, despite only 50% of the SC wheat seeding. On the other hand, faba bean in the 1:1 row IC obtained lower grain yield (less than half of SC grain yield) in relation to its sowing proportion in SC faba bean. In the same 1:1 row IC, the land equivalent ratios (LER) were 1.01 and 1.24 in 2018 and 2019, respectively, confirming the yield advantage of IC over SCs. The land equivalent ratios were higher than 1.0 in two of the treatments in 2018 (Table 2). When three rows of faba been were grown alternatively with one row of faba bean, there was very little contribution from faba bean as the faba bean crops were severely damaged by drought, resulting in an LER value below 1.0. In 2019, all the intercrop treatments had LER values higher than 1.0. Highest LER values of 1.07 and 1.24 were observed in 2018 and 2019 respectively, when the two crops were grown in alternating rows (1:1 row IC). A complete summary of grain yields, as components in the IC and Total IC grain yields per treatment can be found in Fig. 1 and Table 2 (including LER).

Crop and weed biomass

In 2018, the total above-ground biomass of crops was highest in SC wheat among the five treatments, followed by 1:1 row intercropping (Fig. 2). However, across the 2 years, highest total crop biomass of 9.97 t ha^{-1} was observed in 1:1 row IC in 2019. In both the years, total biomass was found to be lowest in SC faba bean. Table 3 shows the dry matter biomass weights of component crops and weeds.

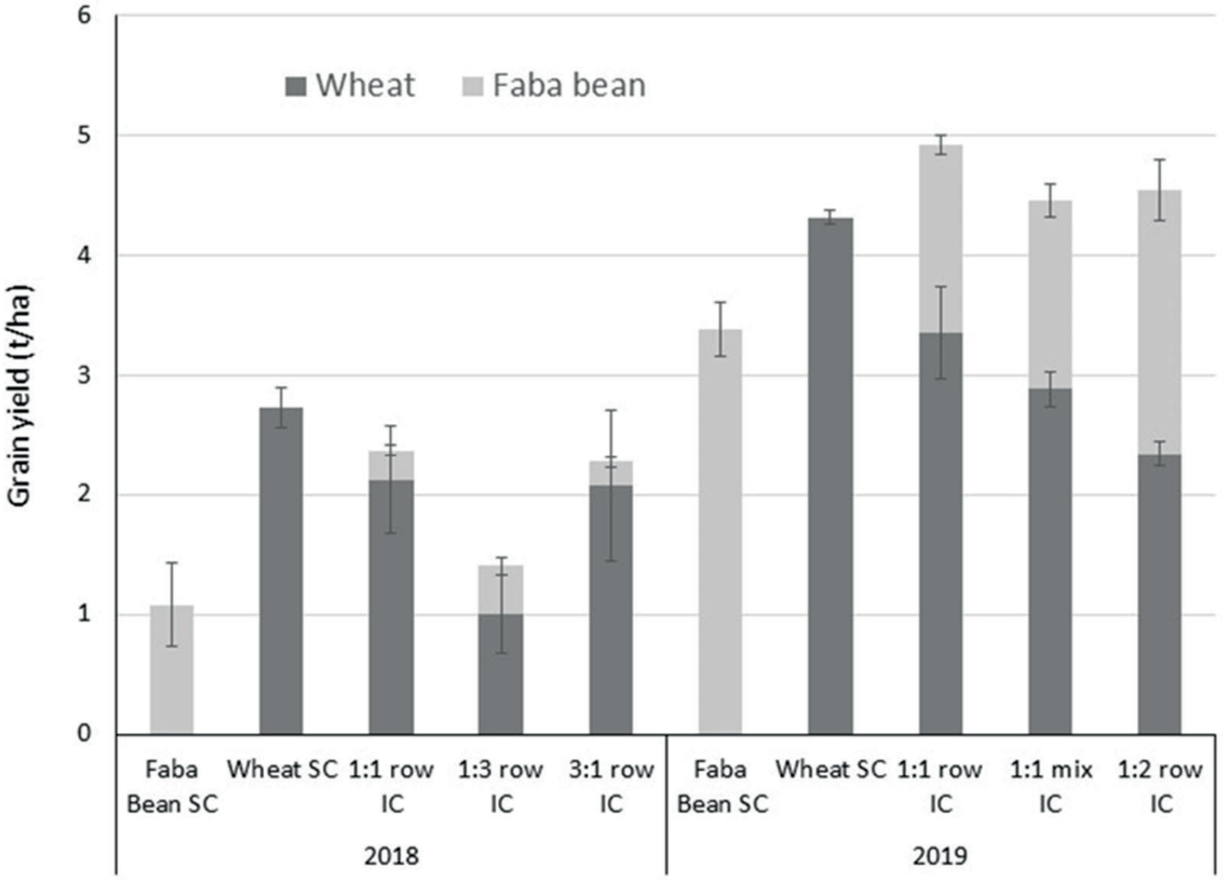

Fig. 1. Grain yields in 2018 and 2019.

Table 2. *Mean grain yields of wheat, faba bean and total yield (wheat + faba bean) in t ha^{-1} and LER values. Treatments with the same superscript letters in total grain yield are not significantly different within and across years*

Year	Treatment	Wheat	Faba bean	Total grain	SE of Total	LER
2018	Faba Bean SC		1.08	1.08^{a}	0.35	
	Wheat SC	2.73		2.73^{abc}	0.35	
	1:3 row IC	1.0	0.40	1.40^{a}	0.35	0.83
	3:1 row IC	2.07	0.20	2.28^{ab}	0.35	1.07
	1:1 row IC	2.12	0.25	2.37^{ab}	0.35	1.01
2019	Faba Bean SC		3.38	3.38^{bcd}	0.35	
	Wheat SC	4.31		4.31^{cd}	0.35	
	1:1 mix IC	2.88	1.57	4.45^{cd}	0.35	1.16
	1:2 row IC	2.34	2.20	4.54^{d}	0.35	1.19
	1:1 row IC	3.35	1.56	4.91^{d}	0.35	1.24

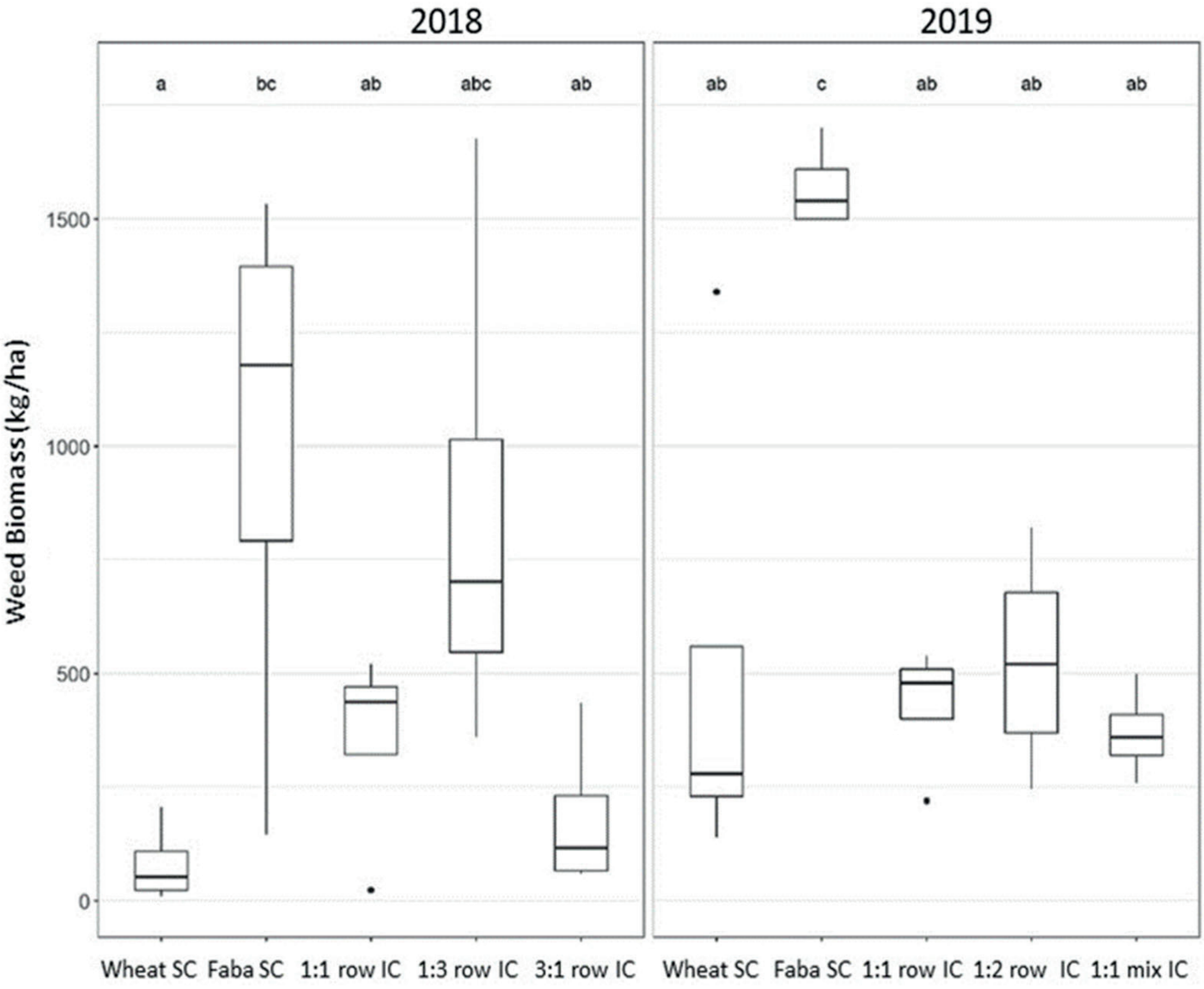

Fig. 2. A box plot showing variability in weed biomass outside the upper and lower quartiles in 2018 and 2019. Treatments with the same letters are not significantly different within and across years.

Table 3. *Mean crop (including grains) and weed biomasses in 2018 and 2019. Values are mean ± standard errors (SE) in t ha^{-1}. Values with the same superscript in the same column are not significantly different*

Year	Treatment	Faba bean biomass	Wheat biomass	Weed biomass
2018	Faba Bean SC	3.63 ± 0.36^{c}		1.01 ± 0.17^{bc}
	Wheat SC		5.62 ± 0.57^{b}	0.08 ± 0.17^{a}
	1:3 row IC	1.59 ± 0.36^{ab}	1.86 ± 0.57^{a}	0.86 ± 0.17^{abc}
	3:1 row IC	0.19 ± 0.36^{a}	4.50 ± 0.57^{ab}	0.18 ± 0.17^{ab}
	1:1 row IC	0.41 ± 0.36^{a}	4.40 ± 0.57^{ab}	0.35 ± 0.17^{ab}
2019	Faba Bean SC	5.76 ± 0.36^{d}		1.57 ± 0.17^{c}
	Wheat SC		9.17 ± 0.57^{c}	0.51 ± 0.17^{ab}
	1:1 mix IC	2.68 ± 0.36^{bc}	6.23 ± 0.57^{b}	0.37 ± 0.17^{ab}
	1:2 row IC	3.80 ± 0.36^{c}	5.03 ± 0.57^{b}	0.53 ± 0.17^{ab}
	1:1 row IC	2.94 ± 0.36b^{c}	7.02 ± 0.57^{bc}	0.43 ± 0.17^{ab}

In both the years, weed biomass was highest in faba bean SCs (Table 3). There was tendency of high weed pressure in treatments where the proportion of faba bean in the IC were high as observed in 1:3 and 1:2 row ICs compared to 1:1 (Fig. 2). Despite this, weed abundance in the IC treatments was reduced by 15 to 80% in 2018, and by 67 to 76% in 2019, compared to SC faba bean.

Discussion

The current findings highlight the multiple benefits of IC compared to SCs, such as providing resilience to drought, higher grain yield, LER values above one and higher weed suppression ability. In 2018, between 01 May–31July the study area received only 25 mm of precipitation (recorded at Malmö, about 7 km from the experimental area, Source: www.smhi.se). During the same period in 2019, it received 131 mm, which was closer to the 30-year average (1961–1990) of 154 mm during this period. The drought in 2018 had a strong bearing on both the wheat and faba bean crops, but faba bean was the most affected one. However, it was also observed in 2018 that wheat grain yield compensated the loss of faba bean crops to some extent in the IC treatments. By having two cash crops in IC instead of one, IC is a good strategy to spread out or minimise risks associated with extreme events such as drought, or fluctuating grain price. The benefits of IC and crop diversity to better deal with extreme situations (expected or unexpected) than SCs have also been reported by Elsalahy *et al*. (2020).

The current finding that the 1:1 alternate row and 1:1 mix IC of faba bean and wheat had promising yields in both years compared to the other intercropping strategies (1:2, 1:3 and 3:1 alternate row intercropping) hints at the differential niche partitioning, canopy development and root intimacy between the species for above-and below-ground resources. This in turn translated into higher crop yield and weed- suppressing potentials in 1:1 row and 1:1 mix treatments. It seems that closer root intimacy between faba bean and wheat in 1:1 row and 1:1 mix intercropping enhance complementary utilization of available above-and below-ground resources including efficient use of plant available soil N and soil moisture thereby positively affecting the intercrop productivity. Jensen (1986) and Bulson *et al*. (1997) reported that higher faba bean densities led to increase wheat biomass and wheat N-content in the IC compared to SCs. These results are in line with the findings of Hauggaard-Nielsen & Jensen (2005).

The lower yield of faba bean in the 1:1 row IC compared to SC faba bean in terms of seeding proportion, is likely due to its weaker competitive ability for soil water compared to wheat under drought conditions. Husain *et al.* (1990) showed the weak tolerance of faba bean to drought, with implications on crop yields. In addition, Jensen (1986) explained that wheat was more competitive than faba bean in IC with respect to uptake so soil mineral N.

The advantages of IC over SC has been demonstrated in both the years in almost all the IC treatments by LER values which were above 1.0. Similar results on the yield advantages from IC over SC have been reported in wheat-kidney bean and wheat-faba bean IC by Chapagain & Riseman (2014), indicating that IC requires less land than respective SCs to produce the same yield level.

It is a big challenge for farmers to control weeds in organic low-input systems (Chongtham *et al*., 2016). Weed biomass was considerably lower in IC treatments compared to SC faba bean in the current study. Cannon *et al*. (2020) also reported similar results of lower biomass in wheat-faba bean IC than the SCs. The lower weed biomass recorded in this study on IC compared to SCs could be due to the crop mixtures out-competing weed species for the acquisition of both above- and below-ground resources, which effected their growth and development. This has been been suggested by Bedoussac *et al.* (2015).

The trends and tendencies observed in this study indicate that having diverse crops and optimal spatial arrangement of components crops in cropping systems could have positive effects on the crop performances. Future studies on N-use efficiency and resource (water sunlight, P, etc.) competitions can provide new insights into the plant-plant interaction mechanism that can help in designing optimal crop mixtures combinations in space for more productive and resilient cropping systems.

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