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Core Ideas

1. Flax is more competitive than chickpea, and alternative row configuration has less interspecies competition than mixed rows.

2. A seeding rate of 50% chickpea and 50% flax resulted in the maximum combined yield and land productivity.

3. Intercropping chickpea with flax showed reduced Ascochyta blight incidence and severity.

Abbreviations: disease incidence (DI), disease severity (DS), land equivalent ratio (LER)

Abstract

Ascochyta blight (caused by *Ascochyta rabiei*) is a primary concern of chickpea production worldwide. Intercropping chickpea with a non-host crop has the potential to suppress this disease and improve resource use efficiency for enhanced crop yield. This study aimed to evaluate the effects of seeding rate and row configuration of chickpea (*Cicer arietinum*, L.)-flax (*Linum usitatissimum*, L) intercropping on 1) yield and seed quality, 2) disease incidence and severity of Ascochyta blight of chickpea, and 3) land productivity of this intercropping

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system. Field trials were conducted at the Eastern Agricultural Research Center (EARC), Sidney, MT, and the Southern Agricultural Research Center (SARC), Huntley, MT, in 2020 and 2021. Chickpea was planted with flax in 4 intercropping configurations (70% chickpea – 30% flax in mixed rows, 50% chickpea – 50% flax in alternate rows, 50% chickpea – 50% flax in mixed rows, and 30% chickpea – 70% flax in mixed rows). Chickpea yield decreased with increased flax proportion in the mixed rows intercrop. Flax displayed higher competitiveness than chickpea, resulting in decreased yield and protein concentration in chickpea but increased yield and protein content in flax. Land equivalent ratio (LER) of intercropping was greater than 1, showing improved land productivity (2% -23% greater than monocropping). Intercropping reduced Ascochyta blight disease incidence and severity; the 50% chickpea – 50% flax and 30% chickpea – 70% flax intercropping configurations could reduce the disease severity to 50% (in Hunley) and 67% (in Sidney) of that in the monocropping. These results indicated that seed ratio and planting configurations of chickpea-flax intercropping may be manipulated to increase land use efficiency and reduce Ascochyta blight in chickpea. CDC Leader yielded greater than Royal in the higher disease pressure environment in Huntley indicated that selection of disease resistant cultivar is important for managing Ascochyta blight on chickpea.

1. INTRODUCTION

Intercropping is defined as an agronomic practice of growing two or more crops in the same field at the same time (Ofori & Stern, 1987). The reported benefits of intercropping involve increased productivity, improved resource use efficiency, and enhanced pest control (Adeniyan et al., 2014; Chapagain & Riseman, 2014; Fenández-Aparicio et al., 2007). Land Equivalent Ratio (LER) is the key metric for measuring the total yield of an intercrop compared to its individual components grown as a monocrop, which can display the yield advantage and land use efficiency of an intercropping system (Fletcher et al., 2016). A LER greater than one indicates a yield advantage of the intercropping over monoculture. The results from Echarte et al. (2011) suggested that intercropping sunflower (*Helianthus annuus*)-soybean (*Glycine max*) with an optimal seeding ratio can improve the total yield and LER compared to the solo soybean. Chapagain and Riseman (2014) found that intercropping barley (*Hordeum vulgare*)-pea (*Pisum sativum*) with 2:1 and 1:1 planting ratios showed 12-32% higher LER than monocrop of either crop. Compared to solo barely, intercropped barley displayed higher biomass N and grain protein. Intercropping also increased nodulation and symbiotic N_2 fixation of intercropped pea. Seeding rate and row configuration affected the competition of companion crops, and thereby yield and land use efficiency. Chen et al. (2004) reported that pea produced lower biomass in mixed barely-pea intercrop than in separated row arrangement. However, barely-pea in mixture showed greater total biomass yield and higher LER than in a separated row arrangement. In an oat-pea intercropping system, land productivity based on grain yield increased with the sowing ratio of oat due to higher competition of oat than intercropped pea (Neugschwandtner & Kaul, 2014).

Chickpea (*Cicer arietinum* L.) was grown on approximately 69,000 hectares of land in Montana during 2020 (USDA-NASS, 2020). Montana is also the leading producer of organic chickpea in the US, where 700 ha were produced in 2019 (USDA-NASS, 2020). Ascochyta blight is the most threatening disease affecting chickpea production resulting in reduced seed quality and yield (Pande et al., 2005). Ascochyta blight is a host-specific disease caused by the fungal pathogen *Ascochyta rabiei*, which can cause black round lesions on all above-ground parts of chickpea plants (Nene, 1982). In the asexual stage, conidia released from infected tissue disperse to nearby plants via wind and rain splash. In the sexual stage, pseudothecia play an important role in the long-distance dispersal of ascospores, serving as primary inoculum to infect distant chickpea fields (Kaiser, 1997). The pathogen can survive in the field for at least five years under favorable conditions (Gossen & Miller, 2004). Therefore, rotation with non-host crops and the planting of disease-free seeds are critical strategies to prevent pathogen introduction.

Integration of several different strategies is critical in Ascochyta blight management and include the use of resistant cultivars, planting disease-free seed, fungicide seed treatment, foliar fungicide application, and crop rotation (Chongo et al., 2003; Gan et al., 2006; Wise et al., 2009b). However, lack of durable resistance of chickpea cultivars to the disease and reported resistance of pathogen to fungicides makes Ascochyta blight a major concern in conventional chickpea production (Chongo & Gossen, 2001; Wise et al., 2009a). In organic farming systems, disease management is based mainly on maintaining biological diversity and soil health using balanced crop rotations, including nitrogen-fixing and cover crops, intercrops, addition of manure and compost, and reductions in soil tillage (van Bruggen et al., 2016). There is no biological fungicide registered for use in organic chickpea production for control of Ascochyta blight (Gan et al., 2006).

Intercropping may offer significant assistance in pest management due to variations in host physiology, direct pathogen inhibition, altered canopy microclimates, reduction in host plant density, and barrier effects of intercrops (Boudreau, 2013; Schoeny et al., 2010). Previous studies have reported that two intercropped species can effectively control foliar disease in pulse crops (Fernández-Aparicio et al., 2010; Schoeny et al., 2010). Fernández-Aparicio et al. (2010) suggested that when pea was intercropped with faba bean (*Vcia faba*), barley, oat (*Avena sativa*), triticale (*Triticosecale*), or wheat (*Triicum aesivum*), the disease severity of pea Ascochyta blight and vertical progress of lesions were significantly decreased.

Similar results were observed by Schoeny et al. (2010) that intercropping pea-wheat decreased the splash dispersal of conidia in a controlled environment and reduced disease severity of Ascochyta blight in pea under moderate to severe disease pressure. The disease reduction was associated with a reduction of host plant density, an altered microclimate, and physical barriers to spore dispersal. Although some producers have tested intercropping chickpea-flax (*Linum usitatissimum*, L.) in the Northern Great Plains, research needs to be conducted to investigate its effect on disease management and seed yield potential (Reid et al., 2020).

Previous legume-based intercropping research initially focused on general performance metrics, such as land productivity, nutrient uptake indices, disease pressure, and crop competition (Njira et al., 2021). Since chickpea is the major cash crop in the chickpea-flax intercrop, it is important to know how intercropping affects chickpea yield in addition to the total combined yield and LER. The effect of planting configuration and spatial arrangement in intercropping chickpea-flax on protein content of intercrops, oil content of flax, land use efficiency, and Ascochyta blight management has not been investigated. The objectives of this study were to (i) evaluate the effects of seeding rate and row configuration on yield, protein, and LER, and (ii) investigate the seeding rate and row configuration effect on Ascochyta blight incidence and severity.

2. MATERIALS AND METHODS

2.1. Trial Sites

A chickpea-flax intercropping study was conducted at the Eastern Agricultural Research Center (EARC) in Sidney, MT and the Southern Agriculture Research Center (SARC) in Huntley, MT. In Sidney, the field trials were located at the EARC dryland farm (47◦46′ N, 104◦14′ W; 670 m asl) and the EARC irrigated farm (47◦73′ N, 104◦15′ W; 594 m asl) in 2020 (April 21st to August 25th) and in 2021 (May 12th to August 16th), respectively. In Huntley, the field trails were located at the SARC irrigated farm (45.92′ N, 108◦24′ W, 594 m asl) in 2020 (April 27th to August 24th) and 2021 (April 28th to August 31st). The soil and weather conditions varied among locations. The soils are William clay loam (fine-loamy, mixed, superactive, frigid Vertic Argiustolls) at the dryland farm in Sidney, Savage clay loam (fine, smectitic, frigid Vertic Argiustolls) at the irrigated farm in Sidney, and Lohmiller silty clay loam (fine, smectitic, calcareous, mesic Torrertic Ustifluvents) in Huntley. A composite soil sample was collected prior to planting the intercrop. The soil test results of nitrate and phosphate are listed in Table 1. Monthly average precipitation and air temperature from April to August at each location in 2020 and 2021 are summarized in Table 2. Field trials in Sidney were conducted under partly irrigated conditions during the 2021 season due to extreme drought conditions on the dryland farm in Sidney and received 100 mm irrigation to help crop germination and establishment. No additional irrigation was applied during the growing season. The intercrop trials conducted in Huntley during 2020 and 2021 seasons received 120 mm and 180 mm irrigation, respectively.

2.2. Experiment Design and Field Management

During the 2020 and 2021 season, two chickpea cultivars, CDC Leader (moderately resistant to *A. rabiei*) and Royal (susceptible to *A. rabiei*) and a flax cultivar, Glas, were selected for the intercropping study. The Glas flax was selected because it is not a Ascochyta host plant and had a maturity date close to the chickpea for easy harvesting. Monocrop seeding rates were 40 seeds m^{-2} for chickpea and 730 seeds m^{-2} for flax at all locations. These seeding rates were based on local crop production guidelines. Seeding rates for the intercrop treatments are expressed as percentages of the monocrop rates. The experiment was a randomized complete block design. Treatments included chickpea grown 1) as monocrop,

2) as mixed rows with 30% chickpea and 70% flax (30C/70F in mixture), 3) as mixed rows with 50% chickpea and 50% flax (50C/50F in mixture), 4) with 50%-50% ratio of chickpea and flax in alternate rows (50C/50F in alternate rows), 5) as mixed rows with 70% chickpea and 30% flax (70C/30F in mixture), 6) flax planted as monocrop. Each of the two chickpea cultivars was planted as either monocrop or intercrop in treatment one through five. Treatments were randomly assigned to each plot within the block and replicated 4 times. Plot size and row spacing varied between locations based on planter specifications. Plot sizes were 1.5 m × 6 m in Sidney and 1.5 m × 7 m in Huntley. In Sidney, each plot contained six rows of crop at 23 cm row spacing (Figure 1A). In Huntley, plots were four rows at 37 cm row spacing for monocrop and mixed rows intercrop (Figure 1B). For plots with 50% chickpea and 50% flax in alternate rows, each plot contained four rows of flax and three rows of chickpea planted alternatively with a row spacing of 18 cm (Figure 1B). In Sidney, chickpea and flax were planted at 2.5 cm depth to accommodate the flax on April 21st, 2020 and May 12th, 2021. In Huntley, the sowing depth of component crops was adjusted for chickpea at 3.8 cm. The planting dates were April 27th, 2020 and April 28th, 2021 in Huntley.

Chickpea and flax seeds were treated with thiamethoxam (Cruiser® 5FS, BASF Corporation, Research Triangle Park, NC) insecticide at a rate of 0.5 g a.i. kg^{-1} seed and fluxapyroxad, pyraclostrobin, and metalaxyl (Obvius® fungicide, BASF Corporation, Research Triangle Park, NC) fungicide at a rate of 0.18 g a.i. kg^{-1} seed prior to planting. At planting, chickpeas were inoculated with a commercial rhizobial inoculant (Primo GX2 Verdesian Life Sciences, Cary, NC).

Table 1. Initial soil test results of field locations in Sidney and Huntley for 2020 and 2021

Field trial	Year	Depth	NO_3-N	P-Olsen
		cm	ppm	
Sidney-Dryland Farm	2020	0-61	11	21
Sidney-Irrigated Farm	2021	0-61	5	23

Huntley-Irrigated Farm	2020	0-61	23	17
Huntley-Irrigated Farm	2021	0-61	26	20

Table 2. Maximum, minimum, and mean temperature and total precipitation (± SE) from April–September for Sidney, MT and Huntley, MT in 2020 and 2021.

Month	Precipitation	Temperature			Precipitation	Temperature		
	2020				2021			
	-mm-	C°			-mm-	C°		
		Maximum Air Temperature	Minimum Air Temperature	Average Air Temperature		Maximum Air Temperature	Minimum Air Temperature	Average Air Temperature
Sidney								
April	0.51(±0.012)	11.52(±1.68)	-3.67(±1.20)	3.92(±1.40)	4.32(±0.003)	14.32(±1.49)	2.61(±0.69)	5.85(±0.93)
May	40.67(±0.64)	19.63(±1.07)	5.18(±0.85)	12.40(±0.89)	41.66(±0.02)	18.79(±1.06)	4.52(±0.66)	11.65(±0.74)
June	26.67(±0.49)	25.87(±0.64)	11.24(±0.63)	18.56(±0.65)	52.60(±0.04)	28.50(±0.72)	11.91(±0.57)	20.21(±0.56)
July	45.21(±0.64)	29.16(±0.76)	13.52(±0.47)	21.34(±0.49)	0.51(±0.00)	32.22(±0.67)	15.76(±0.47)	24.08(±0.47)
August	23.14(±0.57)	31.33(±0.76)	7.12(±11.72)	22.52(±0.58)	27.18(±0.02)	28.20(±1.03)	11.89(±0.55)	20.05(±0.64)
September	8.38(±0.24)	22.82(±0.96)	7.12(±0.69)	14.97(±0.76)	10.62(±0.01)	26.01(±0.93)	7.05(±0.51)	16.53(±0.57)
Total	144.58				136.89			
Huntley								
April	20.07(±0.38)	12.61(±1.57)	-3.56(±1.01)	4.56(±1.23)	30.23(±0.47)	14.5(±1.27)	-2.11(±0.66)	6.17(±0.86)
May	40.13(±0.37)	19.83(±1.02)	5.56(±0.79)	12.67(±0.78)	49.02(±0.58	19.89(±1.01)	4.39(±0.54)	12.11(±0.72
June	120.65(±1.67)	26.22(±1.04)	10.72(±0.55)	18.5(±0.71)	9.65(±0.15)	31.27(±0.77)	10.88(±0.59)	21.06(±0.62)
July	26.67(±0.53)	30.83(±0.56)	11.78(±0.52)	21.33(±0.50)	3.3(±0.06)	34.89(±0.64)	13.94(±0.57)	24.44(±0.52)
August	18.29(±0.36)	32.06(±1.18)	11.67(±0.59)	21.89(±0.85)	37.85(±0.56)	29.05(±1.12)	10.89(±0.57)	19.94(±0.77)
September	13.97(±0.42)	25.72(±1.43)	5.67(±0.49)	15.72(±0.90)	1.78(±0.05)	27.05(±0.95)	5.78(±0.72)	16.44(±0.75)
Total	239.78				131.83			

2.3.1 Grain yield, protein, and oil concentration

Chickpea and flax were harvested on August 25th, 2020 and August 16th, 2021 in Sidney, and August 24th, 2020, and August 31st, 2021 in Huntley using a plot combine harvester (Wintersteiger, Salt Lake City, Utah). After harvesting, the total grain weight was determined from each plot. The intercropped flax and chickpea were separated using a 3.5 mm round screen to determine the yield of each. The chickpea and flax yield data are reported on dry mass basis.

Fifty grams of chickpea and five grams of flax seed samples were homogenized into a fine powder (<6 mm) using a UDY cyclone sample mill (UDY Corporation, Fort Collins, CO). The moisture content of the ground sample was measured by weighing 1.5 g samples prior to and following a 48-hr oven-drying at 65 °C (Jones Jr. & Case, 1990). Seed nitrogen (N) concentrations of chickpea and flax were determined by the Pregl-Dumas method on a Perkin Elmer 2400 Series II CHNS/O Elemental Analyzer (PerkinElmer Inc., Waltham, MA). Seed protein concentration was calculated by multiplying the total grain N concentration to a N-to-protein conversion factor of 6.25. The protein concentration reported in this paper is on dry mass basis.

Flax oil content was measured by a nuclear magnetic resonance analyzer (NMR) (Oxford Instruments Industrial Analysis Group, Abingdon, Oxon.). Four grams of flax seed were calibrated from pure flaxseed oil. The readings are expressed as the percentage oil content on dry mass basis.

2.3.2 Disease evaluation

Ten plants were randomly selected from each plot to evaluate disease severity (DS) and disease incidence (DI) when symptoms were observed in the field. DS was determined by a percentage scale developed by Gowen et al. (1989) (Table 3). The infected plants were counted to calculate DI by the following formula.

$$DI(\%) = \frac{number\ of\ infected\ plants}{10}\ X100\%$$

Table 3. Rating scale for disease severity applied to each plant

% Infection	Symptoms
0-10	No infection - small lesions
11-20	Some stem lesions - minor stem breakage in upper foliage
21-30	1-2 branches broken - several girdling stem lesions low down on some branches
31-40	Large basal stem lesions or several branches broken near to main stem
41-50	Half foliage dead or partly severed
51-60	> Half foliage dead or dying, young shoots still actively growing from base
61-70	Most foliage dead - some healthy stem tissue with lateral buds
71-80	Most foliage dead, no healthy lateral buds in leaf axils
81-99	Most foliage dead, decreasing areas of living stem tissue
100	Plants completely dead

2.4. Data Analysis

LER was calculated to compare the yields of companion crops obtained from chickpea-flax intercropping to the yields obtained from monocultured crops. The LER was calculated (Mead & Willey, 1980) as follows:

$$LER = LERc + LERf = \frac{intercrop\ yield_{chickpea}}{monocrop\ yield_{chickpea}} + \frac{intercrop\ yield_{flax}}{monocrop\ yield_{flax}}$$

where LER, LERc, and LERf represent the land equivalent ratios of intercrop, chickpea, and flax, respectively. ‘Intercrop $yield_{chickpea}$’ and ‘monocrop $yield_{chickpea}$’ represent the chickpea yields in the intercropping and monocropping, respectively. ‘Intercrop $yield_{flax}$’ and ‘monocrop $yield_{flax}$’ are the flax yield in the intercropping and monocropping, respectively.

Combined analysis of variance (ANOVA) showed great interactions between location and treatment due to environmental impacts and equipment-driven differences in row spacing among locations. Therefore, data were analyzed separately by location. Yield, LER, protein, oil, DI, and DS were analyzed using R studio (Version 4.0.3, R Studio Team, 2020). The beta regression model was used to analyze the disease severity and disease incidence by the *betareg* package because they are nature bound at 0 and 1, and not normally distributed or homoscedastic. (Cribari-Neto & Zeileis, 2010, Kieschnick & McCullough, 2003). An ANOVA-like table for factor terms was produced with the *joint_tests* function in the *emmeans* package, which was based on linear functions of predictors in a beta regression model (Lenth et al., 2019). ANOVA was performed on yield, LER, protein content, and oil content for data from Sidney and Huntley. The effects were considered statistically significant at $p < 0.05$. Tukey’s HSD test was conducted for mean comparisons with 5% significance levels.

3. RESULTS

3.1. Seed yield

Sidney Site

The ANOVA results showed that chickpea yield was significantly affected by year, cultivar, configuration, and configuration x year interactions in Sidney (Table 4). Averaged across cultivars and treatments chickpea yielded greater in 2021 (2006 kg ha^{-1}) than 2020 (985 kg ha^{-1}) due to irrigation. Averaged across years and intercropping treatments, Royal produced a higher yield (1450 kg ha^{-1}) than CDC Leader (1272 kg ha^{-1}). Although ANOVA analysis showed significant year x configuration interactions (Table 4), the separated means showed a similar trend of the configuration effects in 2020 and 2021 (Figure 2A). The highest chickpea yield was observed for monocrop chickpea, and chickpea yield decreased with reduced chickpea and increased flax seeding rates in the mixed rows intercrop treatments. Configurations with 50C/50F in alternate rows produced chickpea yield similar to 70C/30F in mixed rows, and significantly higher than 50C/50F in mixed rows (Figure 2A).

Flax yield was significantly affected by year, configuration, and configuration × year interaction (Table 4). Like chickpea yield, averaged across treatments flax produced a higher grain yield in 2021 (987 kg ha^{-1}) than in 2020 (527 kg ha^{-1}). Monocrop flax had the highest yield for both years (Figure 2B). Flax yield decreased with increased chickpea proportion in the mixed row intercrop treatments for both years. However, the significant decrease in flax yield in intercrop was only observed for mixed rows of 70C/30F in 2020. The alternate rows configuration with 50C/50F displayed a significantly lower flax yield than that in the mixed rows for 2021, but not in 2020 (Figure 2B).

Significant differences among years, cultivars, and configurations were observed in chickpea and flax combined yield. Effect of configuration × year interaction also was detected for combined yield. Similar to individual crop yields, the combined yield of Royal and flax was significant higher than the combined yield of CDC Leader and flax; and the combined yield was greater in 2021 than in 2020. The combined yield demonstrated a similar trend in both years, i.e., the yield decreased with the increased flax proportion in the mixed intercrops, ranging from 939 to 1228 kg ha^{-1} in 2020 and 1885 to 2584 kg ha^{-1} in 2021

(Figure 2C). The alternate rows configuration with 50C/50F yielded higher than 50C/50F in mixed rows in 2021. However, there was no significant difference of combined yield between 70C/30F in mixed rows 50C/50F ratio in mixed rows, and 50C/50F in alternate rows in 2020.

Table 4. Analysis of variance (ANOVA) table showing the effects of year, cultivar, and configuration on chickpea yield, flax yield, and combined yield of chickpea and flax in Sidney.

Source of Variance	df	Chickpea Yield	df	Flax Yield	df	Combined Yield
		P>F		*P>F*		*P>F*
		kg ha^{-1}				
Year	1	**<0.01**	1	**<0.01**	1	**<0.01**
Cultivar	1	**<0.01**	1	0.56	1	**0.01**
Configuration	4	**<0.01**	4	**<0.01**	5	**<0.01**
Cultivar × Year	1	0.18	1	0.54	1	0.14
Configuration × Year	4	**<0.01**	4	**<0.01**	5	**<0.01**
Cultivar × Configuration	4	0.2	4	0.92	5	0.18
Cultivar × Configuration × Year	4	0.29	4	0.91	5	0.41

Huntley Site

In Huntley, chickpea yield was significantly affected by cultivar and configuration (Table 5). There were significant cultivar x configuration interactions (Table 5). Two chickpea cultivars yielded differently among configurations. The yield of CDC Leader varied among five configurations, ranging from 1534 to 3941 kg ha^{-1}. The yield decreased with increased flax proportion in the intercrop. In contrast, there was no significant difference between monocrop and other intercropping configurations in chickpea yield of Royal except for 30C/70F. Royal chickpea yield in 30C/70F was lower compared to monocrop chickpea and other intercropping treatments. Averaged across the years and intercropping treatments, Royal produced significantly lower yield (1543 kg ha^{-1}) than CDC Leader (2883 kg ha^{-1}) in

Huntley (Figure 3A), which was contrary to the Sidney site and likely due to the Ascochyta disease infection (to be reported in Section 3.4). The chickpea yield of Royal ranged from 788 to 1729 kg ha^{-1}.

There were significant configuration and configurations × year interactive effects on flax yield (Table 5). The mixed rows with 30C/70F and 50C/50F seeding rates produced similar flax yield to monocrop flax in 2020 (Figure 3B). However, monocrop flax demonstrated the highest flax yield compared to all intercropping configurations in 2021.

There were significant cultivar, configuration, and cultivar x configuration effects on chickpea and flax combined yield (Table 5). CDC Leader monocrop produced the highest yield, which was not significantly different from combined yield of CDC Leader and flax in 70C/30F mixed rows (Figure 3C). Other intercropping configurations for CDC Leader and flax showed lower combined yields than the CDC Leader monocrop. There were no differences in the combined yield between 50C/50F mixed rows, 70C/30F mixed rows, and 50C/50F alternate rows. The combined yield for CDC Leader and flax ranged from 2456 to 3477 kg ha^{-1}. However, the combined yield of Royal and flax intercrop was similar to that of monocrop chickpea (Figure 3C). The combined yield of Royal and flax ranged from 1745 to 1969 kg ha^{-1}.

Table 5. ANOVA table showing the effects of year, cultivar, and configuration on chickpea yield, flax yield, and combined yield of chickpea and flax in Huntley.

Source of Variance	df	Chickpea Yield	df	Flax Yield	df	Combined Yield
		P>F		*P>F*		*P>F*
		kg ha^{-1}				
Year	1	0.09	1	0.18	1	0.09
Cultivar	1	**<0.01**	1	0.36	1	**<0.01**
Configuration	4	**<0.01**	4	**<0.01**	5	**<0.01**
Cultivar × Year	1	0.57	1	0.99	1	0.75
Configuration × Year	4	0.08	4	**<0.01**	5	0.14

Cultivar × Configuration	4	**<0.01**	4	0.9	5	**<0.01**
Cultivar × Configuration × Year	4	0.55	4	0.95	5	0.72

3.2. Land equivalent ratio

Sidney Site

The ANOVA for combined data from the Sidney site across years showed significant effects of year, cultivar, and configuration on LER and LERc (Table 6). LERc is higher in 2021 (0.55) than in 2020 (0.51). LERc of Royal was higher (0.55) than that of CDC Leader (0.52). The LERc value of chickpea-flax intercropping ranged from 0.24 to 0.52 and decreased as the flax proportion increased in the mixed rows configurations (Figure 4A). The LERc of alternate rows with a 50C/50F seeding rate was higher (0.52) than in the mixed rows (0.38).

LERf affected by configurations (Table 6). It ranged from 0.54 to 0.78 in different chickpea-flax intercropping treatments (Figure 4B). LERf of 50C/50F in mixed rows (0.71) was similar to the 30C/70F mixed rows (0.78), but higher than 50C/50F in alternate rows (0.56).

LER was not affected by cultivar but was significantly affected by configurations (Table 6). Alternate rows with a 50C/50F seeding rate had the highest LER (1.13), improving productivity by 13% when compared with the monocrop (Figure 4C).

Table 6. ANOVA table showing the effects of year, cultivar, and configuration on land equivalent ratio of chickpea (LERc), land equivalent ratio of flax (LERf), and land equivalent ratio (LER) in Sidney.

Source of Variance	df	LERc	df	LERf	df	LER
		P>F		*P>F*		*P>F*
Year	1	**<0.01**	1	0.3	1	0.84

Cultivar	1	**0.047**	1	0.06	1	0.92
Configuration	4	**<0.01**	4	**<0.01**	5	**<0.01**
Cultivar × Year	1	0.14	1	0.71	1	0.69
Configuration × Year	4	0.33	4	0.06	5	0.33
Cultivar × Configuration	4	0.15	4	0.48	5	0.95
Cultivar × Configuration × Year	4	0.55	4	0.59	5	1

Huntley Site

In Huntley, cultivar and planting configurations had significant effects on LERc. The LERc of each cultivar under different configurations were presented in Figure 5A. Like chickpea yield, LERc of Royal was not significantly decreased by intercropping compared to monocropping, excluding the 30C/70F in the mixed rows, which was decreased by 54%. In contrast, all intercropping configurations reduced the LERc of CDC Leader compared to monocropping (Figure 5A). For both cultivars, the value of LERc was greater than 0.5 except for 30C/70F in the mixed rows intercropping. The value of LERc in the 30C/70F configuration was 0.46 and 0.40 for Royal and CDC Leader, respectively.

Configurations of 50C/50F and 30C/70F in the mixed rows showed similar levels of LERf to monocrop flax in 2020. The lowest LERf (0.62) was observed in the 50C/50F in alternate rows configuration in 2020 (Figure 5B). In 2021, however, the value of LERf decreased with increased chickpea proportion in the mixed rows treatments, ranging from 0.34 to 0.63 (Figure 5B).

The value of LER was affected by year and configurations. In 2020, all intercropping treatments significantly improved LER by 30% to 67% (Figure 5C). Alternate rows configuration with 50C/50F seeding rate demonstrated lower LER (1.30) than the mixed rows with the same seeding rate (1.58). In 2021, the value of LER in the 50C/50F mixed rows was 1.23 compared to 1.07 in the 50C/50F alternate rows.

3.3. Chickpea protein content, flax protein content, and flax oil content

Sidney Site

In Sidney, chickpea protein content was affected by year, cultivar, and row configuration. The cultivar × year and configuration × year effects on chickpea protein content were also detected. Royal displayed a higher protein content than CDC Leader in 2020, but not in 2021 (Figure 6A). There was no significant difference in chickpea protein between monocrop and intercrop in 2020 (Figure 6B). In 2021, however, the chickpea protein content under five configurations ranged from 16.9 to 18.6%, and the protein content in 50C/50F mixed rows and 30C/70F mixed rows were lower than in the 50C/50F alternate rows (Figure 6B).

Flax protein content varied among configurations in Sidney. There were also interactions between configuration and year. Flax protein was significantly higher in the 50C/50F mixed rows than in the monoculture flax in 2020 (Figure 6C). In 2021, however, intercropping showed similar flax protein content to the monocrop flax. The flax protein in the intercrop with Royal chickpea in the 50C/50F mixed rows and in the 50C/50F alternate rows was higher than in the other treatments, including the monocrop flax (Figure 6D).

The oil content of flax was affected by year and row configuration. The highest flax oil content was observed in the monocrop flax (45.2%) and all intercropping configurations produced a lower oil content than the monocropping flax (Figure 6E).

Huntley Site

Chickpea protein content was affected by year and cultivar in Huntley. Chickpea produced higher protein in 2021(25.4%) than 2020 (21.5%) (Figure 7A). Averaged over years and treatments, Royal demonstrated higher protein content than CDC Leader in Huntley (Figure 7B). Year had significant effects on flax protein content in Huntley. In contrast to chickpea protein, average flax protein across the treatments was higher in 2020 than 2021(Figure 7C). Flax oil content varied among configurations, ranging from 39.9 to 44.1%. Flax oil in 70C/30F mixed rows and 50C/50F alternate rows was higher than in other treatments (Figure 7D).

3.4. Disease assessment

Sidney Site

In Sidney, the DS and DI were analyzed separately for each year due to the cultivar × configuration × year interactions (Table 7). Effect of cultivar on DS and DI was only observed in 2020. DS and DI were significantly affected by configuration and variety × configuration interactions in both years. DS of Royal was higher than CDC Leader in 2020, ranging from 2.2 to 5.5% (Figure 8A). For Royal, all intercropping configurations showed similar DS to monocrop chickpea in 2020 except for 50C/50F in mixed rows. CDC Leader in 70C/30F mixed rows and 30C/70F mixed rows significantly reduced DS compared to monocrop, but the DS were generally very low in all treatments. Like DS, Royal had significant higher DI than CDC Leader, ranging from 34 to 87% (Figure 8B). For Royal, the lowest DI in 50C/50F mixed rows, and all other intercropping configurations showed a similar level of DI to monocrop in 2020. For CDC Leader, a significant reduction in DI was observed in 2020 in the 70C/30F and 30C/70F mixed rows than in monocropping, and much lower DI was found in comparison to Royal (Figure 8B).

In 2021, intercropping decreased DS of chickpea in all intercropping configurations compared to monocropping (Figure 8C). All intercropping configurations had similar effects on DS reduction in Royal. In contrast, CDC Leader in the 30C/70F and 50C/50F in mixed rows had a significantly greater reduction in DS than that in the 70C/30F mixed rows and 50C/50F in alternate rows. The DS of Royal ranged from 4.8 to 10.2%; and the DS of CDC Leader ranged from 2.4 to 12.7%. The DI showed a similar trend to DS (Figure 8D). The comparable reduction of DI from monocropping to intercropping was also observed in Royal; all intercropping configurations had similar effects on DI reduction of Royal. The reduction of DI was not observed for CDC Leader in 50C/50F alternate rows (Figure 8D). Although intercropping chickpea-flax in mixed rows decreased DI of CDC Leader, there is no difference in DI reduction among the three mixed rows intercropping configurations.

Table 7. ANOVA table showing the effects of year, cultivar, and configuration on disease severity (DS) and disease incidence (DI) in Sidney.

Source of Variance	df	Disease Severity (%)	Disease Incidence (%)
		P>F	*P>F*
Year	1	**<0.01**	**<0.01**
Cultivar	1	**<0.01**	**<0.01**
Configuration	4	**<0.01**	**<0.01**
Cultivar × Year	1	**<0.01**	**<0.01**
Configuration × Year	4	**<0.01**	0.23
Cultivar × Configuration	4	0.06	**<0.01**
Cultivar × Configuration × Year	4	**<0.01**	**<0.01**

Huntley Site

Only DS was evaluated in Huntley in 2020. DS was significantly affected by cultivar and configurations. CDC Leader had significantly lower DS than Royal (Figure 9). The DS of CDC Leader did not differ between the monocrop and intercrop. In contrast, all intercropping configurations in mixed rows decreased the DS of Royal, but the DS of Royal in 50C/50F alternate rows did not differ from the monocrop chickpea (Figure 9).

4. DISCUSSION

4.1. Effectiveness of intercropping chickpea-flax in managing Ascochyta blight

The advantage of intercropping in controlling crop diseases has been reported in numerous intercropping systems (Cao et al., 2015; Fernández-Aparicio et al., 2010; Fininsa & Yuen, 2002; Schoeny et al., 2010). The results of our study suggested that intercropping chickpea-flax can be an effective strategy to reduce Ascochyta blight in chickpea. Meanwhile, cultivar selection and intercropping configurations are also critical for disease management. In Sidney, for example, resistant cultivar CDC Leader had lower Ascochyta blight than susceptible cultivar Royal in 2020. Although not all intercropping configurations significantly reduced disease in 2020, integration of resistant cultivars (CDC Leader) with 70C/30F and 30C/70F in mixed rows was most efficient for disease suppression. All intercropping configurations reduced Ascochyta blight severity in 2021 (Figure 8C). While the cultivar effect was not detected, the efficiency of integrated resistant cultivar and appropriate configurations in Ascochyta management was also observed in 2021. The reason of intercropping configurations demonstrating different control abilities in 2020 and 2021 was likely due to diverse environmental conditions generating distinct disease pressure. Although the precipitation in 2020 and 2021 was similar, the research site in the valley surrounded by irrigated lands in 2021 created a more favorable environment for Ascochyta development and promoted the dispersion of secondary inoculum in 2021 as indicated by the increased disease incidence on resistant cultivar CDC Leader. This is similar to what has been observed in other studies (Kaiser, 1997). Therefore, the disease pressure is slightly higher in 2021 than in 2020, even though the disease pressure was generally low in both years.

In Huntley, the disease severity of mono-cropped CDC Leader was significantly lower than that of Royal. CDC Leader is considered moderately resistant to Ascochyta blight, whereas Royal is considered susceptible. When the susceptible cultivars combined with considerably higher humidity in Huntley relatively higher disease pressure was observed, the mixed row intercrop treatments were highly effective in disease management on Royal. These results are consistent with previous research conducted by Schoeny et al. (2010), where a 50% pea - 50% cereal reduced disease severity of pea Ascochyta blight in mixture under moderate and severe epidemics, but not under slight epidemic pressure. Planting resistant cultivars is another efficient strategy in disease management, which is supported by the results of this study. In Sidney, the integration of CDC Leader and flax intercrop provided the most efficient Ascochyta blight management for both years. Although the DS of intercropped CDC Leader was not significantly lower than the monocrop, it showed a lower DS than Royal in intercrop treatments. Previous studies suggested that integrating several strategies is the key in Ascochyta blight management of chickpea (Gan et al., 2006; Pande et al., 2005).

The mechanism of intercropping for disease management has been investigated which includes the reduced density of host plants, barrier effects of non-host plants to spore dispersion, alteration of microclimate, and morphological and physiological changes in the host (Schoeny et al., 2010; Villegas-Fernández et al., 2021). In this study, the disease severity of intercrop did not decrease with increasing flax proportion. However, intercrop in mixed rows with a lower host plant density showed lower disease severity in higher disease pressure environments. Although, it was not consistent at each location in each year, the dilution effects can still be observed. Moreover, Royal in 50C/50F mixture was more effective in limiting Ascochyta blight than in alternate rows in most cases. Fininsa and Yuen (2002) reported that crop arrangement in separate rows was less effective than in mixed rows in controlling common bacterial blight in bean-cereal intercropping system. These results may derive from a barrier effect provided by the non-host plants and/or an alteration of microclimate of the intercropping system. In this study, the chickpea was grown next to flax in the mixed rows configuration, the dispersal interference and modification of microclimate effects were higher in the mixed rows than in the alternate rows configuration.

The results of the disease assessment corresponded to chickpea yield. In Huntley, CDC Leader yielded much higher than Royal, which is opposite to the results from Sidney. The better performance of CDC Leader in Huntley was attributed to higher Ascochyta blight resistance than Royal, and the disease pressure of the trial in Huntley was much higher than in Sidney. Light disease pressure did not cause damage to the yield in Sidney. That could explain why 50C/50F in mixed rows produced the same or slightly higher chickpea yield than in alternate rows at Huntley, but not at Sidney. Higher disease dispersal interference and microclimate modification effects in mixed rows led to more effective yield protection than the alternate row arrangement. These results demonstrated that intercropping can effectively reduce chickpea Ascochyta blight and protect yield, and this protection is more obvious for the susceptible cultivar.

This conclusion is supported by evidence in other intercropping systems (Cao et al., 2015; Guo et al., 2021; Lithourgidis et al., 2011; Villegas-Fernández et al., 2021). Cao et al.

(2015) reported that intercropping wheat-maize reduced wheat stripe rust by 16.7-45.7%, and wheat powdery mildew by 14.7-27.0% with 4:4 and 4:2 seeding ratio of wheat and maize, compared to the wheat monocrop. The yield was increased by 52.4-140.0%. Similarly, Guo et al. (2021) found that faba bean rust occurrence was decreased in faba bean-wheat intercropping by 22.3-54.7% and was regulated by canopy microclimate and nitrogen nutrition. Intercropping was most effective in disease control with a 40-90 kg ha $^{-1}$ application of nitrogen fertilizer and contributed to a 34.4-40.7% yield increase.

4.2. Competition of component crop in intercropping

In Sidney, the proportion of flax was the critical variable for yield in the intercrop. Chickpea yield and LERc decreased while flax proportion is increasing in the mixed rows intercrop. Similar results were also observed in sunflower-soybean intercrops, where increased sunflower density results in decreased soybean yield (Echarte et al., 2011). Competitiveness of one companion crop increased as the proportion of that crop increased, resulting in a yield increase of this crop. The competition could be more intense due to limited environmental resources since flax and chickpea share similar root zone and root growth rates as monocrop (Liu et al., 2011). The LERc value ranged only from 0.24 to 0.52 in Sidney. In Huntley, the value of LERc in other intercropping configurations was greater than 0.5 except for 30C/70F mixture. This is largely due to less water availability in Sidney than in Huntley. Andrade et al. (2012) found that intercropped sunflower with soybean was as productive as sole sunflower in an extremely dry cropping season due to its higher ability to capture water and radiation. Soybean became more competitive for light with less limiting water due to better vegetative growth (Dowling et al., 2021; Gan et al., 2009). As observed in the field, flax (average 43 cm) grew taller than chickpea (average 33 cm) in Sidney, but chickpea (average 56 cm) had similar plant height as flax (average 57 cm) in Huntley (data not shown). Thus, sufficient environmental resources may be critical for stable yield production in chickpea-flax intercrop.

The alternate rows configuration with 50C/50F demonstrated a higher chickpea yield and LERc in Sidney for 2020 than in the mixed rows. Although they were planted with the same seeding rate, chickpea and flax were placed closer than in alternate rows in the mixed rows configuration. For a less competitive species, it performed better when planted in alternate rows. In a pea-barley intercropping system, the suppression of barley on pea biomass production was greater in mixed rows than separated arrangement (Chen et al., 2004). Similar results were reported by Chalmers (2014), who described that pea produced 21% higher yield in alternate rows than in mixture in a pea-canola intercrop, while canola yielded 49% higher in mixed rows than in alternate rows. These results indicate that the alternate rows arrangement has less interspecies competition than the mixed rows at the same seeing rate. The alternate row configuration might be able to improve competition of subordinate plants (e.g., chickpea, pea) with dominant plants (e.g., flax, canola, barely) (Dowling et al., 2021). For example, the 50C/50F in alternate row design showed similar or lower productivity as compared to chickpea in 50C/50F mixed rows in Huntley. One of the main reasons could be that the closer row spacing between alternate rows in Huntley than in Sidney reduced the benefits of alternate rows on chickpea (subordinate plants). This result is in accordant with Dedio (1994), who described that the LER of pea in a sunflower-pea intercrop decreased with increased row spacing between alternate rows. However, there are other benefits of the mixed-row configuration, such as diluting the host plant density and providing more barriers to protect host plants from foliar disease infection.

4.3. Intercropping effect on land productivity

Although the yield of chickpea and flax decreased in intercrop, the combined land productivity improved based on the LER in this study. When the value of LER is higher than one in the intercrop, intercropping produces a yield advantage and increased land productivity compared to the monocrop. The improved efficiency of land utilization in a legume-oilseed intercropping system has been reported (Andersen et al., 2005; Jo et al., 2022; Roberts et al., 2019). A study conducted in South Australia found that legumes (pea, vetch, lentil) intercropped with canola at 2:1 ratio over-yielded by 12-80% (Roberts et al., 2019). Jo et al. (2022) reported that soybean and flax planted in ridge-furrow intercropping systems increased land productivity by 103.5%.

In this study, 50C/50F displayed the highest LER in most cases at both locations, which indicates that a 50%-50% seeding rate of chickpea and flax might be most efficient in improving land productivity. Previous work has found that the crop component ratio can be critical to improve intercropping advantage. In a sunflower-soybean intercrop, LER increased as the ratio of sunflower to soybean decreased from 8/30 to 3/30 (Echarte et al., 2011). Further reductions in sunflower plant ratio did not increase LER. These results suggest that the intercrop component ratio can be manipulated to improve land productivity and interspecific competition in the intercrop. The seeding rates may be manipulated to increase the LER for individual crops based on the market values of the individual crops. From an economic point, if chickpea is more valuable, the chickpea seeding rate may be increased and the flax rate reduced to maximize income while retaining some reduction in disease pressure.

In Huntley, the LER of the 50C/50F mixture was higher or similar to 50C/50F alternate rows. However, the 50C/50F alternate rows were more effective in improving land productivity than the mixed rows in Sidney. Different environmental conditions and row spacing could explain these results among locations. With higher water availability and higher disease pressure in Huntley, the mixed rows treatments demonstrated the advantage of disease suppression (more dilution to host plants within the row), and enhanced yield over the alternate rows. In contrast, light disease pressure and higher competition between species for water under dryer conditions in Sidney resulted in a lower chickpea yield in mixed rows treatment than in the alternate rows.

4.4. Nutrient content in intercropping chickpea-flax

Chickpea protein content slightly decreased in mixed intercrop under low-N soil conditions which is opposite to flax protein, suggesting flax might be more vigorous and competitive than chickpea in N uptake. Andersen et al. (2005) reported that the uptake of soil N by pea was suppressed by canola and barley when pea was intercropped with canola and/or barley. Flax protein was improved by intercrop, which indicates that the nitrogen assimilation in flax may have benefited from the nitrogen fixation of chickpea (Gan et al., 2010). Xie et al. (2020) has reported that flax oil content was increased by higher soil phosphorus. The effects of intercrop varied among different locations. Intercrop reduced the flax oil content in Sidney. However, the oil content of intercropped flax was similar to monocrop in Huntley and even increased in 70C/30F mixture and 50C/50F alternate rows. These results could be attributed to the interaction of environment and intercropping configuration. Further studies need to be conducted to investigate the effects of interaction between environment and intercrop on flax oil content.

5. CONCLUSIONS

In this study, the yield of chickpea increased with the decreased proportion of flax in the mixed intercrop. Chickpea yielded better in the alternate row configuration than in the mixed rows at the same seeding rate due to less interspecies competition in alternate rows. Intercropping improved land productivity by 2% to 23%, depending on the seeding rates and row configurations. Chickpea-flax at 50%-50% of the individual sole crop seeding rates had the highest LER value at both locations (1.13 in Sidney, 1.23 in Huntley), suggesting it might be a target seeding ratio for improving land productivity. Flax displayed higher competitiveness than chickpea, resulting in decreased yield and protein concentration in chickpea but increased yield and protein content in flax. The 50% chickpea – 50% flax and 30% chickpea – 70% flax intercropping configurations could decrease disease severity to 50% (in Huntley) and 67% (in Sidney) that in the monocropping chickpea. Under relatively higher disease pressure, CDC Leader yielded higher than Royal, and 50% chickpea – 50% flax in the mixed rows was more effective in suppressing Ascochyta blight than in the alternate rows. Intercropping configuration in conjunction with resistant chickpea cultivar selection reduced Ascochyta blight on chickpea.

6. CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The seed treatment and commercial cultivars we used in this study is solely for the purpose of providing specific information and does not imply recommendation or endorsement.

7. ACKNOWLEDGEMENT

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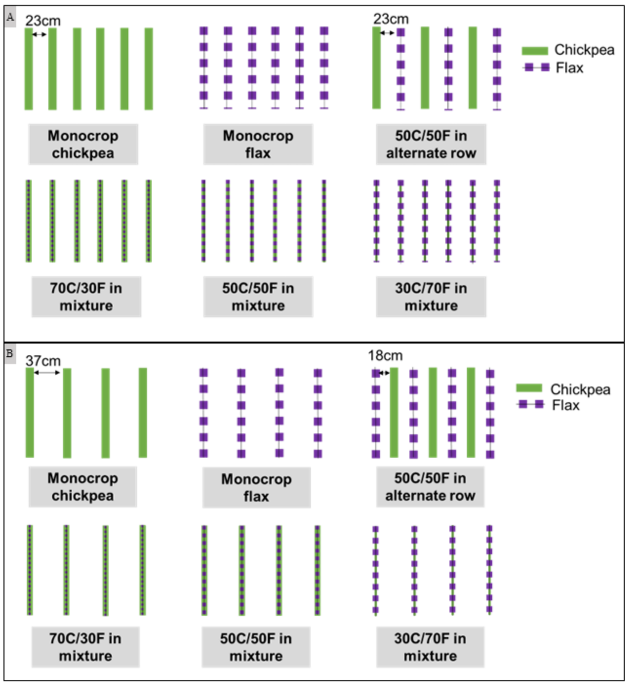


Figure 1. Diagrams of monocrop and intercrops row configurations in Sidney (A) and in Huntley (B). Continuous lines represent chickpea rows and dash lines correspond to flax rows. 70C/30F represents 70% chickpea and 30% flax. 50C/50F represents 50% chickpea and 50% flax. 30C/70F represents 30% chickpea and 70% flax.

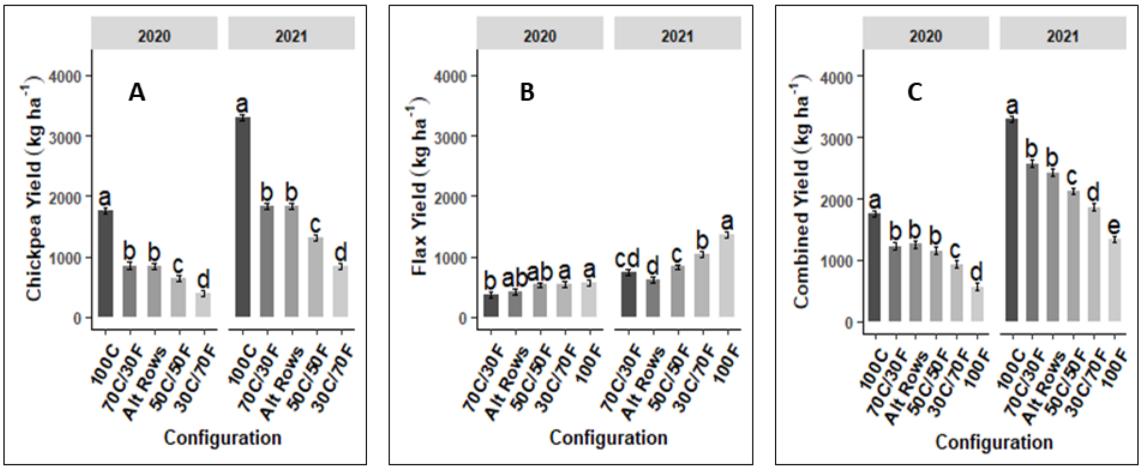


Figure 2.

Figure 2. Interactive effects of configuration and year on chickpea yield (A), flax yield (B), and chickpea and flax combined yield in Sidney (C). 100C represents monocrop chickpea. 70C/30F represents 70% chickpea and 30% flax in mixture. Alt Rows represents 50% chickpea and 50% flax in alternate rows. 50C/50F represents 50% chickpea and 50% flax in mixture. 30C/70F represents 30% chickpea and 70% flax in mixture. 100F represents monocrop flax. Different letters at top each bar within a crop component represent a significant difference at the 0.05 probability level according to the Tukey's HSD test. Vertical bars represent the standard error (SE).

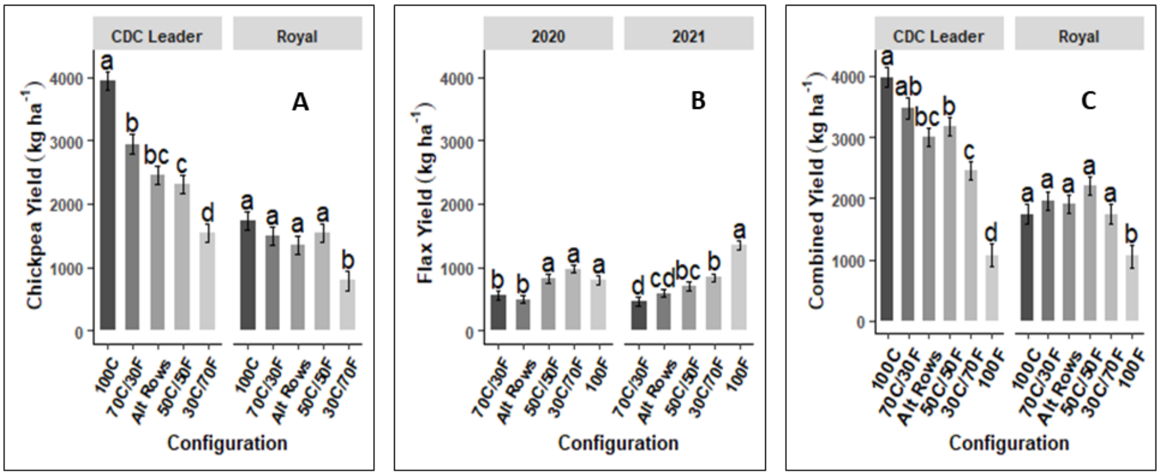


Figure 3

Figure 3. Interactive effects of (A) cultivar x configuration on chickpea yield, (B) configuration x year on flax yield, and (C) cultivar x configuration on chickpea and flax combined yield in Huntley. 100C represents monocrop chickpea. 70C/30F represents 70% chickpea and 30% flax in mixture. Alt Rows represents 50% chickpea and 50% flax in alternate rows. 50C/50F represents 50% chickpea and 50% flax in mixture. 30C/70F represents 30% chickpea and 70% flax in mixture. 100F represents monocrop flax. Different letters at top each bar within a crop component represent a significant difference at the 0.05 probability level according to the Tukey's HSD test. Vertical bars represent the standard error (SE).

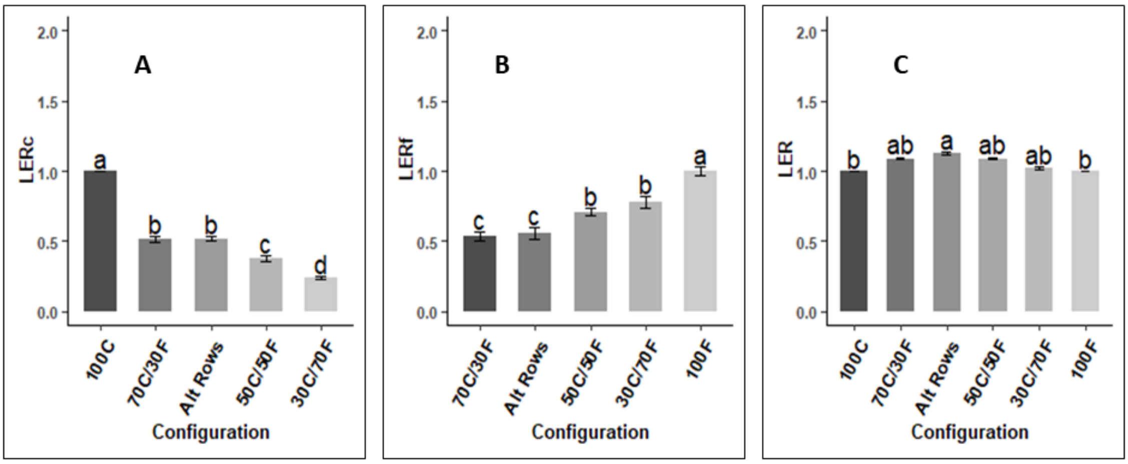


Figure 4

Figure 4. Effect of planting configurations (on the land equivalent ratio of (A) chickpea (LERc), (B) flax (LERf) (D), and (C) chickpea and flax intercrop (LER) in Sidney. 100C represents monocrop chickpea. 70C/30F represents 70% chickpea and 30% flax in mixture. Alt Rows represents 50% chickpea and 50% flax in alternate rows. 50C/50F represents 50% chickpea and 50% flax in mixture. 30C/70F represents 30% chickpea and 70% flax in mixture. 100F represents monocrop flax. Different letters at top each bar within a crop component represent a significant difference at the 0.05 probability level according to the Tukey's HSD test. Vertical bars represent the standard error (SE).

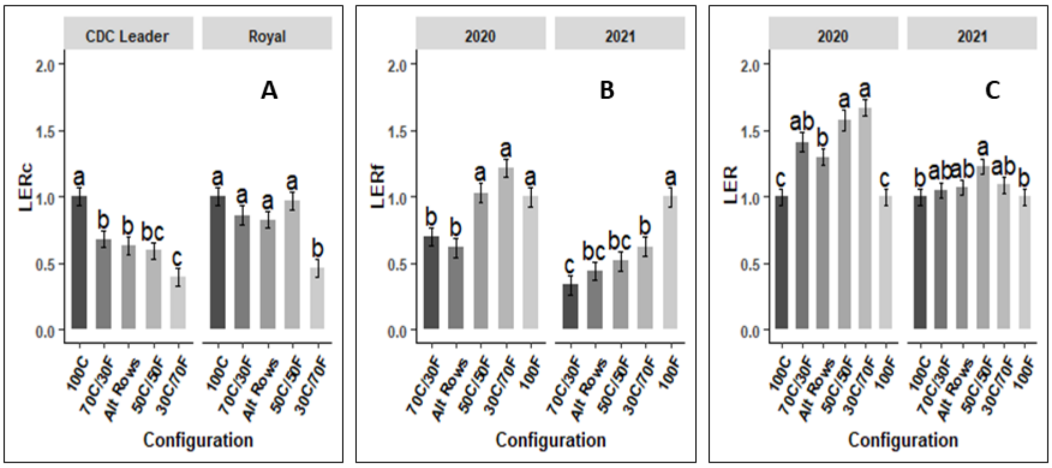


Figure 5

Figure 5. Interactive effects of cultivar × configuration on land equivalent ratio of chickpea (LERc) (A) and interactive effects of year × configuration on land equivalent ratio of flax (LERf) (B) and chickpea and flax intercrop (LER) in Huntley (C). 100C represents monocrop chickpea. 70C/30F represents 70% chickpea and 30% flax in mixture. Alt Rows represents 50% chickpea and 50% flax in alternate rows. 50C/50F represents 50% chickpea and 50% flax in mixture. 30C/70F represents 30% chickpea and 70% flax in mixture. 100F represents monocrop flax. Different letters at top each bar within a crop component represent a significant difference at the 0.05 probability level according to the Tukey's HSD test. Vertical bars represent the standard error (SE).

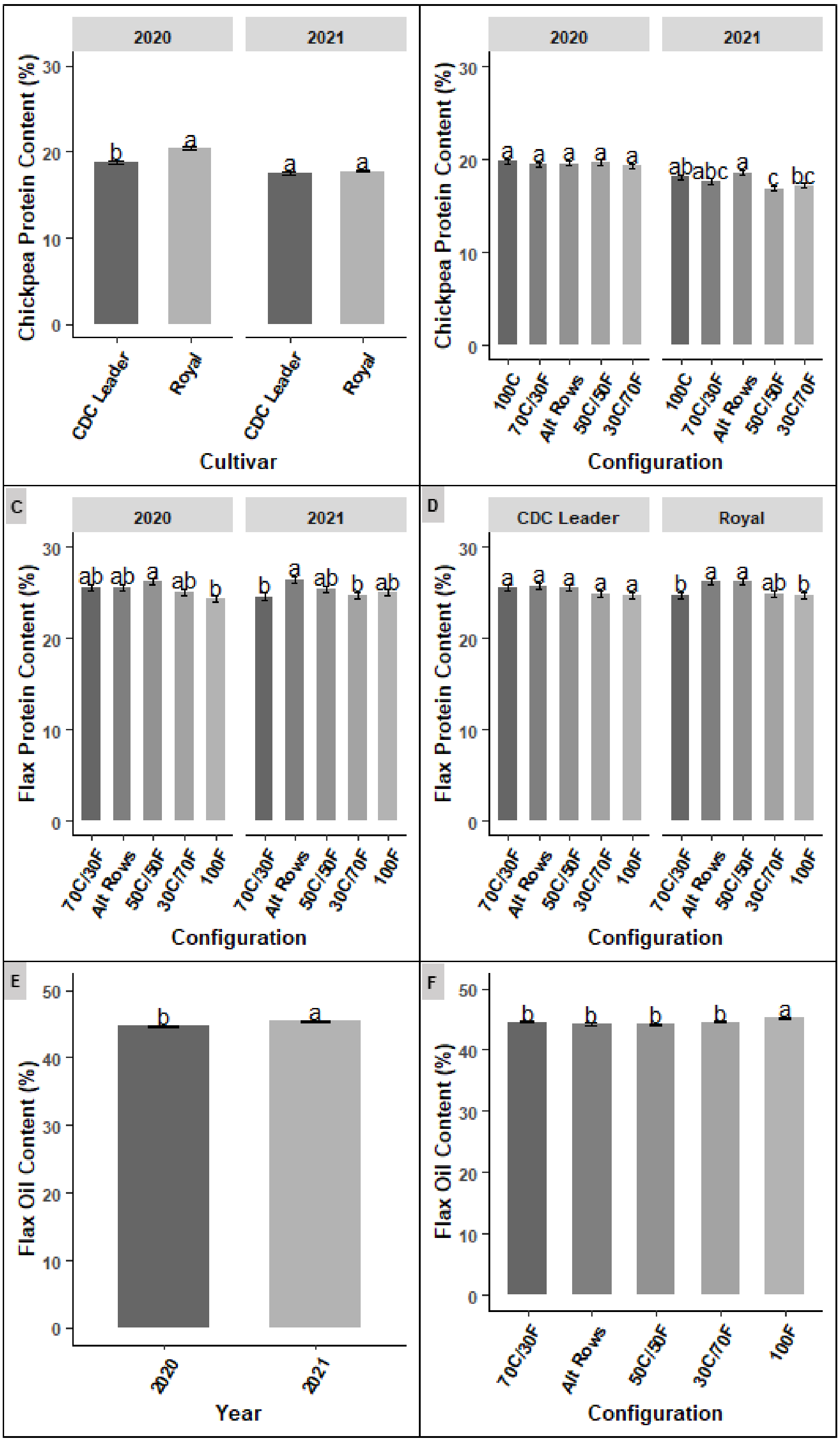

2020
2021
Chickpea Protein Content (%)
CDC Leader
Royal
Cultivar
100C
70C/30F
Alt Rows
50C/50F
30C/70F
Configuration
C
D
CDC Leader
Royal
Flax Protein Content (%)
100F
E
F
Flax Oil Content (%)
Year

Figure 6. Interactive effects of cultivar x year (A) and configuration x year (B) on chickpea protein content, interactive effects of configuration x year (C) and configuration x cultivar (D) on chickpea protein content, and effects of cultivar (E) and configuration (F) on flax protein content in Sidney.100C represents monocrop chickpea. 70C/30F represents 70% chickpea and 30% flax in mixture. Alt Rows represents 50% chickpea and 50% flax in alternate rows. 50C/50F represents 50% chickpea and 50% flax in mixture. 30C/70F represents 30% chickpea and 70% flax in mixture.100F represents monocrop flax. Different letters at top each bar within a crop component represent a significant difference at the 0.05 probability level according to the Tukey's HSD test. Vertical bars represent the standard error (SE).

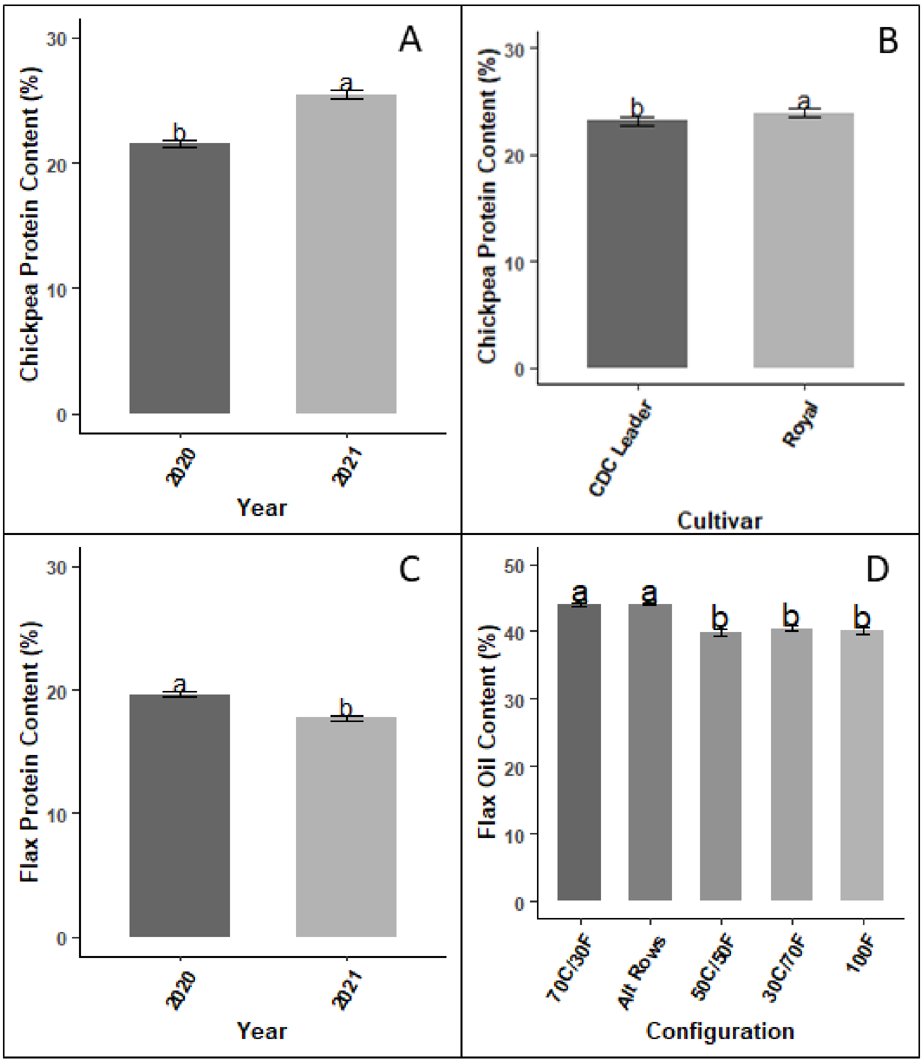

A
Chickpea Protein Content (%)
0
10
20
30
b
a
2020
2021
Year
B
Chickpea Protein Content (%)
b
a
CDC Leader
Royal
Cultivar
C
Flax Protein Content (%)
a
b
2020
2021
Year
D
Flax Oil Content (%)
0
10
20
30
40
50
a
a
b
b
b
70C/30F
Alt Rows
50C/50F
30C/70F
100F
Configuration

Figure 7

Figure 7. Effects of year (A) and cultivar (B) on chickpea protein content, effects of year on flax protein content (C), and effects of configuration on flax oil content in Huntley (D). 100C represents monocrop chickpea. 70C/30F represents 70% chickpea and 30% flax in mixture. Alt Rows represents 50% chickpea and 50% flax in alternate rows. 50C/50F represents 50% chickpea and 50% flax in mixture. 30C/70F represents 30% chickpea and 70% flax in mixture. 100F represents monocrop flax. Different letters at top each bar within a crop component represent a significant difference at the 0.05 probability level according to the Tukey's HSD test. Vertical bars represent the standard error (SE).

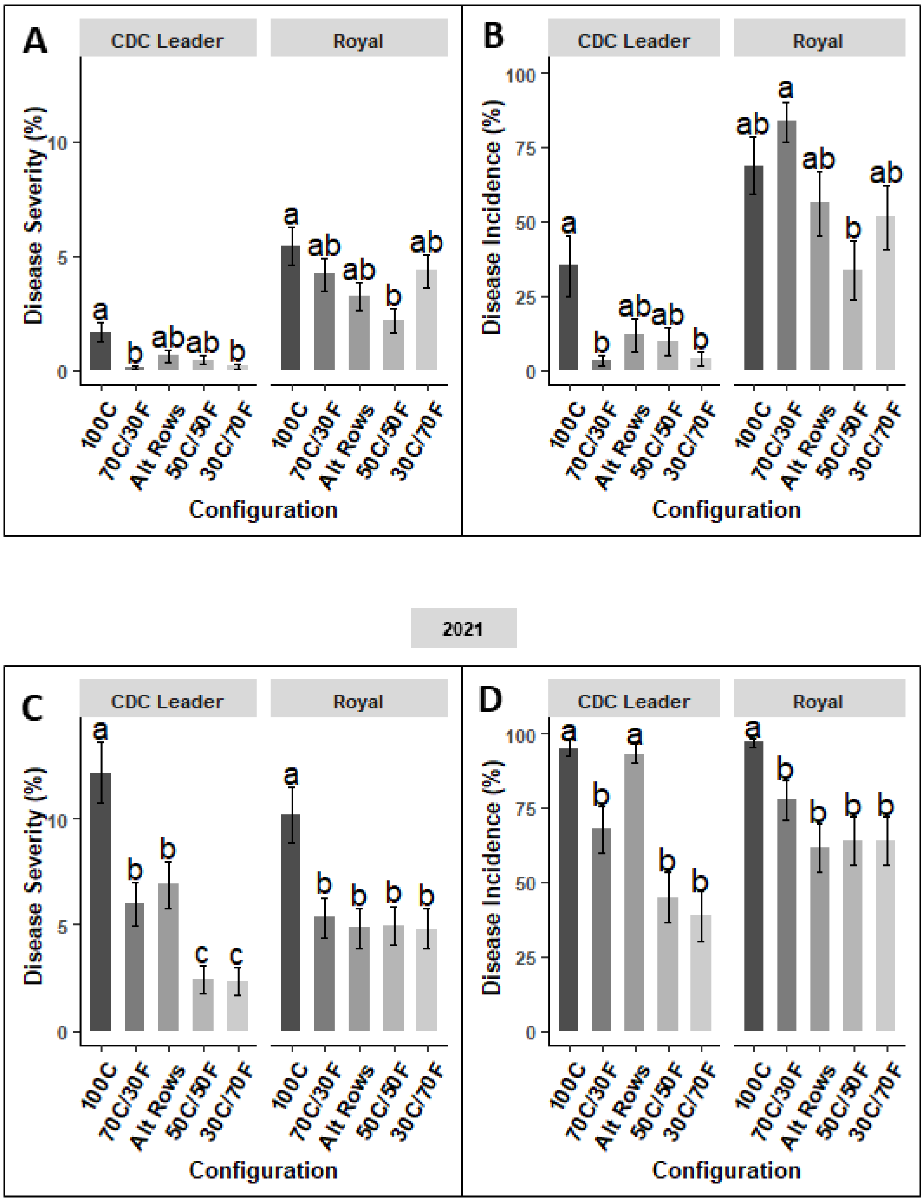
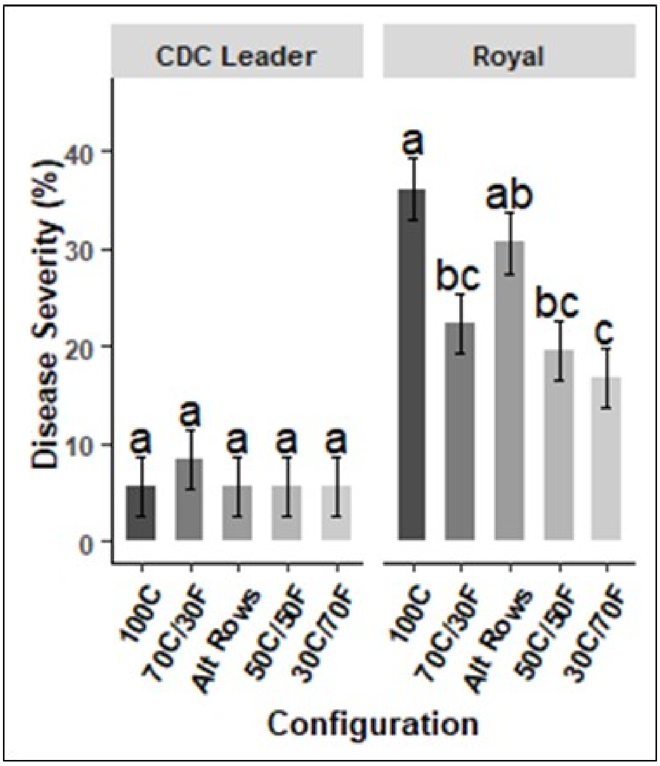

A
CDC Leader
Royal
Disease Severity (%)
0
5
10
100C
70C/30F
Alt Rows
50C/50F
30C/70F
Configuration
B
Disease Incidence (%)
0
25
50
75
100
2021
C
D

Figure 8

Figure 8. Disease severity and incidence of chickpea affected by cultivar and configuration in 2020 (A and B) and 2021 (Cand D) in Sidney. 100C represents monocrop chickpea. 70C/30F represents 70% chickpea and 30% flax in mixture. Alt Rows represents 50% chickpea and 50% flax in alternate rows. 50C/50F represents 50% chickpea and 50% flax in mixture. 30C/70F represents 30% chickpea and 70% flax in mixture. Different letters at top each bar within a crop component represent a significant difference at the 0.05 probability level according to the Tukey's HSD test. Vertical bars represent the standard error (SE).



CDC Leader
Royal
Disease Severity (%)
0
10
20
30
40
a
a
a
a
a
a
bc
ab
bc
c
100C
70C/30F
Alt Rows
50C/50F
30C/70F
Configuration

Figure 9

Figure 9. Interactive effects of cultivar and configuration on disease severity in Huntley in 2020. 100C represents monocrop chickpea. 70C/30F represents 70% chickpea and 30% flax in mixture. Alt Rows represents 50% chickpea and 50% flax in alternate rows. 50C/50F represents 50% chickpea and 50% flax in mixture. 30C/70F represents 30% chickpea and 70% flax in mixture. Different letters at top each bar within a crop component represent a significant difference at the 0.05 probability level according to the Tukey's HSD test. Vertical bars represent the standard error (SE).

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