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The effects of different seeding rates on nitrogen acquisition in pea–wheat intercropping

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Abstract: Intercropping may improve the use of environmental resources in low-input agricultural systems compared to sole crops and it is possible that risk may be reduced in intercropping, leading to more stable yields and weed control. The aim of the present study was to determine the effect of seeding rate of a normal leafed cultivar and a semileafless pea cultivar (*Pisum sativum* L.) grown as sole crops, cultivar mixture, and in double and triple intercrops with spring wheat (*Triticum aestivum* L.) on competitive dynamics, yield and use of nitrogen sources from soil, and symbiotic N_2 fixation. A randomized complete blocks experiment design was used. The differences between the treatments were not significant for total grain yield. Land equivalent ratios for grain yield varied between 1.04 (80P/20W) and 1.40 (80D/20W), which showed that plant growth factors are used more efficiently by the intercrops than by the sole crops for grain production. Nitrogen accumulation was higher in pea sole crops compared to pea component crops in the intercrops, due to the decreased pea density and decreased pea growth caused by interspecific competition from wheat. The amount of N_2 fixed in pea in the intercrops at the flowering harvest was less than the in the pea sole crop also due to competition from wheat for other growth factors than nitrogen, probably by shading. It was concluded that pea–wheat intercropping can use N resources more efficiently compared to sole crops in sustainable cropping systems

Key words: Intercropping, N concentration, N_2 fixation, pea cultivar mixture, wheat

1. Introduction

Legumes are very important in human and animal diets since they contain high amounts of protein, vitamins, and minerals. Legumes fix air nitrogen at high levels throughout rhizobia in their roots and this also increases the fertility of soil. Legumes can be grown in crop rotation as green manure providing nitrogen and carbon to the soil (Dawson et al., 2008). Intercropping is the growing of two or more crop species together in the same field at the same time for at least part of their growth cycles. Legumes are frequently intercropped with other species in arable cropping systems. Legume–cereal or other non-N_2 fixing crops in intercrops are the most applied in the intercropping systems around the world (Van Kessel and Hartley, 2000; Hauggaard-Nielsen et al., 2009; Monti et al., 2016, Jensen et al., 2020a; Ton, 2021). Intercropping has many benefits such as increased use of resources; greater yield than of sole crops; erosion control (Wall et al., 1991); disease, insect, and weed control; protection of soil fertility; improved product quality; and increased land use efficiency in low-input agricultural systems (Jensen and Hauggaard-Nielsen, 2003) and it is possible that risk may be reduced in intercropping, leading to more stable yields (Jensen, 1996; Hauggaard-Nielsen et al., 2008; Corre-Hellou et al., 2011; Carlsson and Huss-Danell, 2014; Dwivedi et al., 2015; Fletcher et al., 2016, Rodriguez et al., 2020). However, intercropping generally leads to yield reduction for both crops, due to lower production of each species per unit area as compared to sole cropping, but the combined grain yield of intercrops may be greater than that of the sole crops. The final yield of the pea sole crop was slightly higher than those of the highest yielding intercrops (Andersen et al., 2005). The total grain yields of intercropped pea with barley (*Hordeum vulgare* L.) were greater than those of the sole crops in Danish cropping systems (Hauggaard-Nielsen et al., 2001). On the other hand, Monti et al. (2016) reported that grain and straw nitrogen (N) concentration in an intercropped cereal was higher than in the sole cereal crop, but the N concentration of pea grain was reduced in the intercrop. Similarly, the protein concentration of cereal grain was higher in the intercrop than in sole crop wheat (Jensen et al., 2015).

Intercropping may often improve the use of environmental resources in an intercrop compared to sole crops, as evaluated by the land equivalent ratio (LER). LER val-

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ues >1 indicate that environmental resources for plant growth is used more efficiently by the intercrop than the sole crops (Hauggaard-Nielsen et al., 2008; Bedoussac et al., 2015). Jensen (1996) reported that pea and barley intercropped without N fertilization utilized environmental sources more efficiently for plant growth than sole crops did. The highest LER values were found in barley–pea intercrop for grain yield and straw nitrogen yields (Monti et al., 2016).

The final amount of N accumulation by pea without N fertilizer was less in intercrop than in sole crop pea (Ghaley et al., 2005), but there was no significant differences between the relative amount of N_2 fixed by pea in pea–barley intercrop or pea, barley, oilseed rape (*Brassica napus* L.) intercrops and sole cropped pea at the low nitrogen level (Andersen et al., 2005). On the other hand, the proportion of total N derived from fixation (Ndfa%) was higher in pea intercropped with barley or oat (*Avena sativa* L.) than sole crop pea (Izaurralde et al., 1992; Jensen, 1996; Geijersstam and Mårtensson, 2006).

Pea competition with weeds is often an important factor for its grain yield. Previous studies have shown that weed pressure was less in pea–barley intercrops and sole crop barley than in sole crop pea (Hauggaard-Nielsen et al., 2008, Corre-Hellou et al., 2011, Bedoussac et al., 2015). Hence, some workers revealed that the competition of leafed pea with wild oat (or animated oat) (*Avena sterilis* spp. *ludoviciana* (Durieu) Gill & Magne) and broad leaf weeds was better than that of semileafless pea (Vasilakoglou and Dhima, 2012; Harker et al., 2008). The seeding rate of semileafless pea can have an important effect on grain yield. Uzun and Açıkgöz (1998) indicated that the grain yield of pea increased with higher seeding rates, and the biomass yield and grain yield of semileafless cultivars were higher than those of normal leafed pea cultivars in both fall and spring sowings.

The aim of the present research was to determine the effects of seeding rate of normal leafed and a semileafless pea cultivars grown as sole crops, cultivar mixture, and in double and triple intercrops with wheat on the competitive dynamics, yield and use of nitrogen sources from soil, and symbiotic N_2 fixation. Intercropped wheat and pea cultivars were compared to sole crops in terms of weeds, N_2 fixation, biomass yield, and grain yield.

2. Materials and methods

The aim of the present study was to determine the effects of different seeding rates on nitrogen acquisition in pea–wheat intercropping.

The pea (*Pisum sativum* L.) cultivars Partner (semileafless pea) and Dukat (normal leafed pea) and wheat (*Triticum aestivum* L.) (Diskett) were used as plant material.

2.1. Site and soil

The field experiment was conducted between April 2017 and August 2017 at the field experimental station SITES Lönnstorp at the Swedish University of Agricultural Sciences in Alnarp in Sweden. The soil was a sandy loam (Tables 1 and 2; Figure 1).

2.2. Experimental design

A randomized complete blocks experiment design was used with 10 treatments in four replications. The size of the plots was 15 m × 2 m. Seeding density was 90 plants m^{-2} for both pea cultivars and 525 wheat plants m^{-2} in sole crops. The 10 treatments are given in Table 3.

Table 1. Soil characteristics.

Soil depth (cm)	Clay (%)	Silt (%)	Very fine– fine sand (%)	Medium-coarse sand (%)	Organic matter (%)	pH
0–20	20.5	14.0	39.8	25.7	2.05	7.26
40–60	17.2	19.2	38.1	25.6	0.25	8.11
60–90	16.7	21.4	37.3	24.6	0.20	8.35

Table 2. Long-term (1961–1990) weather characteristics.

Months	Precipitation (mm)	Temperature (°C) (mean)
April	40.3	6.0
May	44.5	11.5
June	55.5	15.4
July	69.7	16.8
August	64.2	16.5

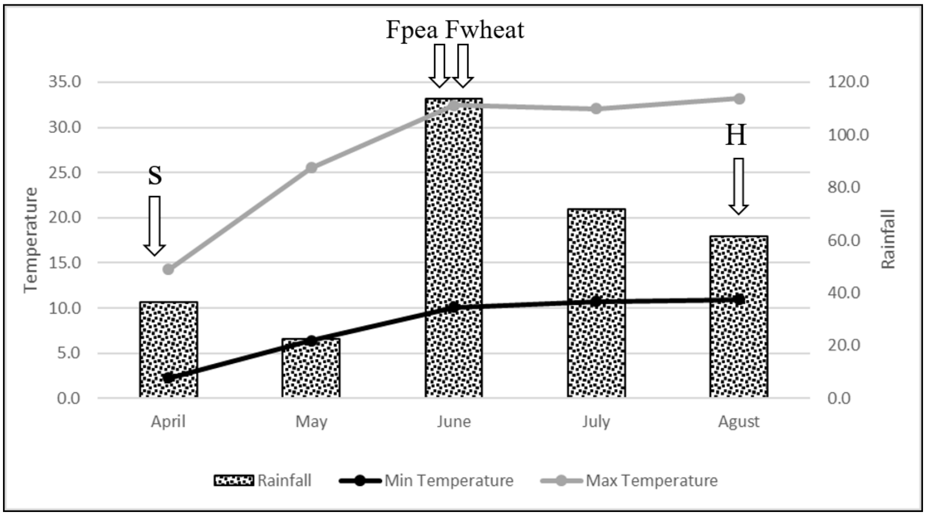

Figure 1. Monthly minimum and maximum temperatures (°C), monthly total rainfall (mm) during April 2017– August 2017. S = Sowing, F = Flowering, H = Harvest (maturity harvest).

Table 3. Experimental treatments: seeding rates in intercropping of semileafless and normal leafed pea cultivars with wheat.

Treatments	Species/cultivars	Seeding rate (% of sole crop)
100W	Wheat (Diskett)	100
100D	Normal leafed pea (Dukat)	100
100P	Semileafless pea (Partner) ((Partner)	100
50D/50P	Dukat/Partner	50/50
50D/50W	Dukat/Diskett	50/50
50P/50W	Partner/Diskett	50/50
25D/25P/50W	Dukat/Partner/Diskett	25/25/50
80D/20W	Dukat/Diskett	80/20
80P/20W	Partner/Diskett	80/20
40D/40P/20W	Dukat/Partner/Diskett	40/40/20

D: Dukat (normal leafed pea), P: Partner (semileafless pea), W: Wheat (Diskett)

The row spacing was 12.5 cm. Crops were sown on 22 April 2017. The experiment was carried out under rainfall conditions and the previous crop was barley. There was no control of weeds, to determine the effect of crop diversification on weeds.

2.3. Measurements and observations

The date of 50% flowering was 16.06.2017 for Dukat and Partner. The date of 50% spiking was 18.06.2017 for wheat. The date of 50% podding was 02.07.2017 for Dukat and Partner in both sole crops and intercrops. Lodging was observed in some plots, but only at the maturity stage.

The traits investigated and the methods used are given below.

Dry matter (DM) yield of above ground biomass and grain of components (t ha^{-1}): The crops were harvested manually of 0.5 m^2 at the flowering time (19.06.2017) and maturity date (16.08.2017) and separated in Dukat (normal leaf), Partner (semileafless), Diskett (spring wheat), and weeds. After separation of the crops' components the samples were dried at 60°C for at least 24 h followed by determination of the dry weight of biomass, straw, and grain of each component.

LER: It was calculated according to a formula (Willey and Osiru, 1972).

Depending on the number of components in the intercrop the LER was calculated as follows (De wit and Van den Bergh 1965):

$$LER = \frac{Pea\ yield\ in\ IC}{Pea\ yield\ in\ SC} + \frac{Wheat\ yield\ in\ IC}{Wheat\ yield\ in\ SC}$$

Nitrogen yield in the biomass (kg ha^{-1}): The samples of dried biomass of each component harvested at the flowering stage were milled for N analysis.

Nitrogen yield in straw and grain (kg ha^{-1}): The samples of grain of each component were milled for N analysis. N% and ^{15}N natural abundance content in the milled samples were determined.

$$N\ yield = N\% \times DM\ yield/100$$

Nitrogen concentration and ^{15}N analysis: The total N concentration and isotopic ratios of $^{15}N/^{14}N$ in the sample of biomass and grain were measured by Dumas combustion on an elemental analyzer (Flash 2000, Thermo Scientific, Bremen, Germany) coupled in continuous flow mode to a Thermo Delta V Advantage isotope ratio mass spectrometer (Thermo Scientific, Bremen, Germany) at the University of Copenhagen, Denmark.

The percentage of N derived from symbiotic N_2 fixation (%Ndfa) was determined as follows:

$$\%\,Ndfa = 100 \times \frac{\delta^{15}\,N\ reference\ plant - \delta^{15}\,N\ legume}{\delta^{15}\,N\ reference\ plant - B}$$

The amount of N_2 fixed (kg ha^{-1}): N_2 fixed by pea was calculated according to the formula given below.

$$N_2 fixed = \left(\frac{\%\,Ndfa}{100}\right) \times DM \times \left(\frac{\%\,N}{100}\right)$$

Soil N accumulation (kg ha^{-1}) = Total N – N_2 fixation for each component and total soil N in intercrops is the sum of component crops.

2.4. Statistical analysis

The data were analyzed according to the randomized complete blocks experimental design using the data analysis software MSTAT-C. Comparisons between the means were made using the LSD multiple range test at 0.05 probability level. The bars represent mean values ± SEM on replications.

3. Results

3.1. Biomass dry matter yield

The differences between the treatments were not significant for total biomass DM yield at the flowering harvest (Table 4), but the biomass yield varied between 3.44 t ha^{-1} (50D/50P) and 4.28 t ha^{-1} (sole crop Partner). However, the biomass yield of sole crop wheat and sole crop Partner was slightly higher than that of 50D/50P, 80D/20W, and 80P/20W intercrops (Table 4). The highest proportion of biomass DM yield of Dukat and Partner in intercrops were obtained in intercrops with 80%/20% pea/wheat. The lowest biomass DM yields of Dukat and Partner were determined in the 25D/25P/50W intercrop. The proportion of wheat biomass DM yields was higher in the pea–wheat intercrop with 50% Dukat and 50% Partner and three component intercrop with 25D/25P/50W intercrop than in the other intercrops (Table 4).

Differences between the intercrop sowing rates were not significant for total biomass DM yield at the final harvest (maturity stage) (Table 5). The total biomass yield varied between 8.65 t ha^{-1} (sole crop Dukat) and 11.9 t ha^{-1}

Table 4. Biomass dry matter (DM) yield in sole crops and intercrops of pea and wheat (t ha^{-1}) at the flowering harvest.

Treatment	Dukat	Partner	Wheat	Total
100W			4.18a*	4.18
100D	3.50a			3.50
100P		4.28a		4.28
50D/50P	1.65c	1.79bc		3.44
50D/50W	1.19c		2.83b	4.02
50P/50W		1.12cd	3.04b	4.16
25D/25P/50W	0.68d	0.70d	2.85b	4.23
80D/20W	2.42b		1.43c	3.85
80P/20W		2.32b	1.53c	3.85
40D/40P/20W	1.49c	1.05d	1.69c	4.23
Mean	1.82	1.87	2.50	3.97
LSD (5%)	0.50	0.68	0.72	N.S.

D: Dukat (normal leafed pea), P: Partner (semileafless pea), W: Wheat (Diskett)
*Means with the same letters in a column are not significantly different from each other.

Table 5. Biomass dry matter yield in the sole crops and intercrops at the maturity harvest (t ha^{-1}).

Treatment	Dukat	Partner	Wheat	Total
100W			11.1a	11.1
100D	8.65a*			8.65
100P		10.0a		10.0
50D/50P	6.10b	4.07c		10.2
50D/50W	3.72c		8.13b	11.9
50P/50W		3.32cd	8.38b	11.7
25D/25P/50W	1.85d	1.28e	8.27b	11.4
80D/20W	6.88b		4.50c	11.4
80P/20W		5.69b	5.26c	10.9
40D/40P/20W	3.58c	2.25de	4.99c	10.8
Mean	5.13	4.44	7.24	10.8
LSD (5%)	1.27	1.44	1.99	N.S.

D: Dukat (normal leafed pea), P: Partner (semileafless pea), W: Wheat (Diskett)
*Means with the same letters in a column are not significantly different from each other.

(50 Dukat/50 Wheat) at the maturity harvest. The proportion of biomass DM yields of Dukat, Partner, and Diskett (wheat) at the maturity harvest was significantly influenced by seeding rates in intercrops. Partial biomass DM yields of wheat in the intercrops were higher in 50D/50W or 50P/50W and 25 D/25 P/50W intercrops compared to in other intercrops as biomass DM yield at the maturity harvest (Table 5).

3.2. Grain yield

The grain yields varied between 4.36 t ha^{-1} (Dukat sole crop) and 6.12 t ha^{-1} (50D/50W) (Table 6). The seed yield of the normal leafed Dukat in sole crop was 23% lower than that of semileafless Partner, but the difference was not significant. The differences between the treatments were not significant for total grain yield. However, the grain yields of pea–wheat intercrops were slightly greater than those of Partner, Dukat, and Diskett (wheat) sole crop yields (Table 6). The partial grain yields of wheat in the intercrops were significantly higher in 50D/50W, 50P/50W, and 25D/25P/50W intercrops compared to other crops at the maturity harvest.

3.3. Weed biomass

Weed above-ground DM production was significantly affected by the treatments (Table 7). Weed DM yield was greater in the Dukat and Partner and 50 Dukat/50 Partner seeding ratio compared to other intercrop and sole crop wheat. The lowest weed biomass was sole crop wheat. The weed pressure was less in intercrops than in sole crop pea. In the present study the weed biomass in Dukat was slightly less than that in Partner.

There were no significant differences between the treatments regarding the weed biomass DM at the maturity stage (Table 7). The lower weed biomass density was observed in wheat sole crop for both harvest stages. Weed suppression in intercropping Partner with wheat at both flowering and maturity decreased with increasing wheat rate in the intercrops.

3.4. Land equivalent ratio

The LER value for grain yield varied between 1.04 (80P/20W) and 1.40 (80D/20W) (Figure 2).

The partial LER for Dukat was higher in pea–wheat intercrop as compared to Partner for grain yield (Figure 2).

3.5. Biomass and grain N concentration

The average N concentration in pea sole crops Dukat and Partner and the sole crop wheat for biomass at the flowering harvest were 3.85%, 3.28%, and 1.59 %N, respectively (Figure 3). The nitrogen concentration in the intercropped wheat was higher than that in sole crop wheat (Figure 3). However, nitrogen concentrations in the intercropped pea, with the exception of the Partner/Dukat cultivar mixture, were less than in sole crop Dukat and sole crop Partner, probably, due to competition for light from wheat at the flowering harvest (Figure 3).

The average grain N concentration in sole crop Dukat, sole crop Partner, and sole crop wheat were 4.18%, 3.86%, and 1.60%, respectively. The nitrogen % in the intercropped wheat grain was greater than that in sole crop wheat (Figure 4).

3.6. Biomass N accumulation

There were significant differences between all the seeding ratios for N accumulation in Dukat, Partner, and wheat in intercrops for biomass (Table 8). Nitrogen yield for biomass was greater in sole crop Dukat and Partner as compared to pea component crops in the intercrops.

Table 6. Grain yield in sole crops and intercrops and component crops (t ha^{-1}).*

Treatment	Dukat	Partner	Wheat	Total
100W			5.44a*	5.44
100D	4.36a			4.36
100P		5.65a		5.65
50D/50P	3.20b	2.17c		5.37
50D/50W	2.14c		3.98b	6.12
50P/50W		1.76cd	4.14b	5.90
25D/25P/50W	1.10d	0.70e	4.11b	5.91
80D/20W	3.96ab		2.09c	6.05
80P/20W		3.29b	2.44c	5.72
40D/40P/20WW	2.04c	1.28de	2.22c	5.54
Mean	2.80	2.47	3.48	5.60
LSD (5%)	0.82	0.82	0.99	N.S.

D: Dukat (normal leafed pea), P: Partner (semileafless pea), W: Wheat (Diskett)
*Means with the same letters in a column are not significantly different from each other.

Table 7. The weed biomass dry matter yield in sole crops and intercrops at flowering and maturity harvests (kg ha^{-1}).

Treatment	Flowering Harvest	Maturity Harvest
100W	27d*	249
100D	194abc	925
100P	276ab	1220
50D/50P	299a	818
50D/50W	39d	375
50P/50W	72.5cd	491
25D/25P/50W	102cd	321
80D/20W	163abcd	439
80P/20W	158bcd	907
40D/40P/20W	120cd	572
Mean	145	633
LSD (5%)	141	N.S.

D: Dukat (normal leafed pea), P: Partner (semileafless pea), W: Wheat (Diskett)
*Means with the same letters in a column are not significantly different from each other.

The highest N yield in the proportion of Dukat and Partner in the cultivar mixture for biomass production was obtained in 50D/50P with 65.7 kg ha^{-1} and 59.5 kg ha^{-1}, respectively, while the lowest N yield of Dukat and Partner was found in 25 D/25P/50W with 22.2 and 19.8 kg/ha, respectively. The N yield of Dukat or Partner in the 50D/50P cultivar mixture was significantly greater than the N yield of Dukat 50% or Partner 50% in pea–wheat intercrops.

3.7. Grain N and biomass N accumulation

There were significant differences between the treatments for grain N accumulation in Dukat, Partner, and wheat of intercrops (Table 9). The grain N yield in Dukat varied between 44.5 (25D/25P/50 W) and 182 kg ha^{-1} (sole crop Dukat). The grain N yield in Partner varied similarly between 25.7 and 219 kg ha^{-1}. Grain N yield in the intercrops with 80% pea was significantly higher than in the

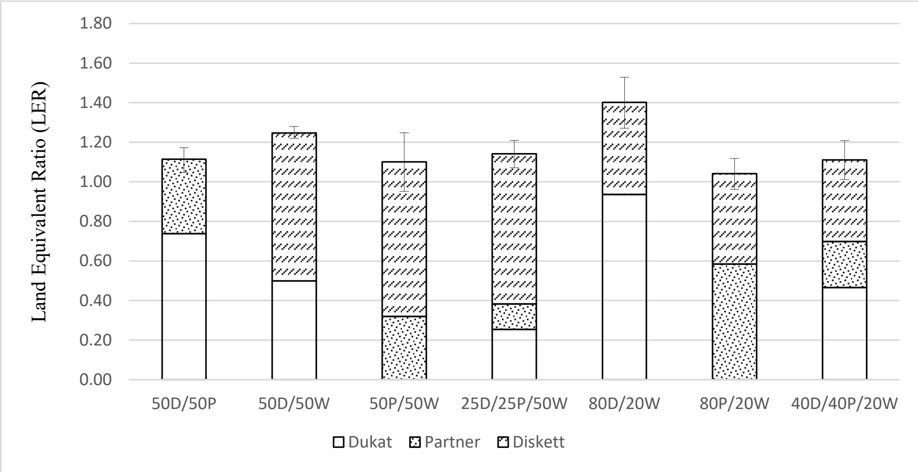

Figure 2. Land equivalent ratio (LER) for intercrops on the grain yield.
D: Dukat (normal leafed pea), P: Partner (semileafless pea), W: Wheat (Diskett).

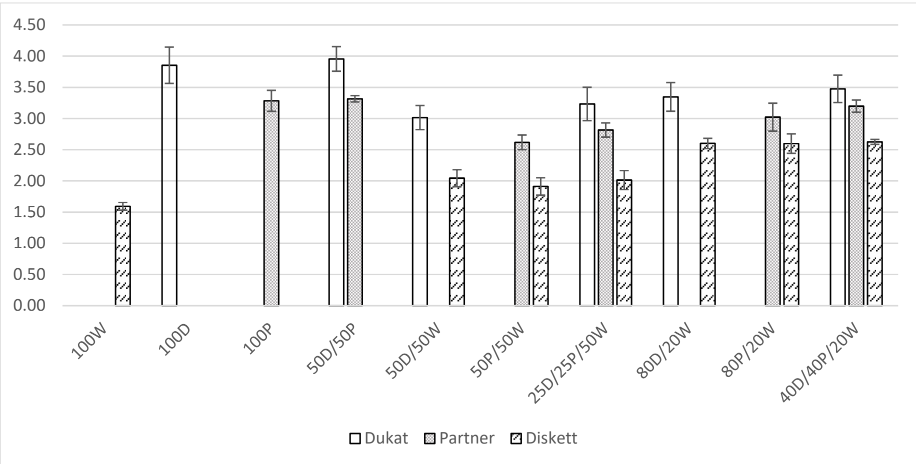

Figure 3. Nitrogen concentration in sole crops and intercrop component crop biomass at the flowering harvest (%).The bars represent mean values ± SEM of 4 replicates.
D: Dukat (normal leafed pea), P: Partner (semileafless pea), W: Wheat (Diskett).

other intercrops in both intercropped Partner and intercropped Dukat (Table 9).

The biomass N yield (straw + grain) in Dukat varied between 54.5 (25D/25P/50W) and 255 kg ha^{-1} (sole crop Dukat). The total biomass N yield in Partner varied between 33.9 in the same intercrop and 275 kg ha^{-1} in the sole crop Partner (Table 9).

3.8. Symbiotic N_2 fixation

Significant differences were found between the seeding ratios in Partner or Dukat for the amount of N_2 fixed by pea in the biomass at the flowering harvest (Table 10). The highest N_2 fixed by pea in biomass was found in the sole crop Dukat and sole crop Partner, whereas the lowest N_2 fixation for pea cultivars was found in the 25D/25P/50W intercrop. The amount of N_2 fixed by pea in pea–wheat intercrops was significantly higher than in those including Dukat or Partner 50% in the pea–wheat intercrops, but there were no significant differences between the 50D/50P cultivar mixture and 80 Dukat or Partner/20 wheat intercrops.

3.9. Soil N

Soil N accumulation in crops was greater in pea–wheat intercrops than in sole crop Dukat, sole crop Partner, and the 50D/50P cultivar mixture for flowering and maturity harvest (Figures 5 and 6). It was also higher in sole crop wheat than in sole crop Dukat, sole crop Partner, the 50D/50P cultivar mixture, and the other intercrops for flowering and maturity harvest.

4. Discussion

In the present study, the differences in total biomass DM yields between intercrops and sole crops were not sig-

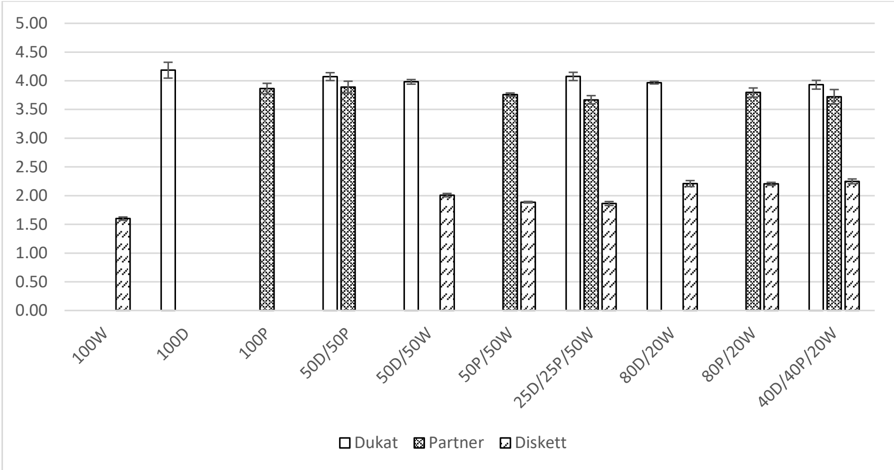

Figure 4. Nitrogen concentration in sole crops and component crops for grain (%). The bars represent mean values ± SEM of 4 replicates.
D: Dukat (normal leafed pea), P: Partner (semileafless pea), W: Wheat (Diskett).

Table 8. Nitrogen yield in sole crop and component crops for biomass (kg ha^{-1}).

Treatment	Dukat	Partner	Wheat
100W			66.4a*
100D	136a		
100P		139a	
50D/50P	65.7bc	59.5b	
50D/50W	35.9d		57.3ab
50P/50W		29.1c	57.6ab
25D/25P/50W	22.2d	19.8c	57.0ab
80D/20W	82.1b		36.7c
80P/20W		70.5b	39.2c
40D/40P/20W	51.1cd	33.4c	44.4bc
Mean	65.6	58.6	51.2
LSD(5%)	29.5	20.5	14.1

D: Dukat (normal leafed pea), P: Partner (semileafless pea), W: Wheat (Diskett)
*Means with the same letters in a column are not significantly different from each other.

nificant at flowering harvest and maturity harvest. There were no significant differences between the treatments for grain yield. The grain yields of pea–wheat intercrops were slightly greater than those of sole cropped Partner, Dukat, and wheat yields. In contrast to our findings, Andersen et al. (2005) reported that grain yields of pea sole crops only slightly exceeded those of the highest yielding pea–barley intercrop. Some workers reported that intercropping significantly increased grain yield compared to sole crops (Hauggaard-Nielsen et al., 2001; Justes et al., 2021). Conversely, total grain yields in oat–pea intercrops were generally less than in the sole crops, due to the competitive ability of oat (Neugschwandtner and Kaul, 2014, 2015). In the present study, the grain of the sole crop normal leafed cultivar (Dukat) was 23% lower than that of the sole crop semileafless cultivar (Partner). Similarly, Uzun and Açıkgöz (1998) reported that the biomass and grain yield of semileafless cultivars were also higher than those of normal leafed pea cultivars.

The weed biomass DM yield was greater in the sole crop Dukat and sole crop Partner compared to intercrops at the flowering harvest stage. Sole crop wheat had the

Table 9. Nitrogen yield in sole crop and component crops for grain and biomass (straw and grain) in the maturity harvest (kg ha^{-1}).

Treatment	Grain			Biomass (straw and grain)		
	Dukat	Partner	Wheat	Dukat	Partner	Wheat
100W			87.1a*			109a
100D	182a			255a		
100P		219a			275a	
50D/50P	130b	85.5c		178b	112bc	
50D/50W	85.4c		79.8a	108c		104a
50P/50W		66.3c	77.9a		88.2cd	97.9ab
25D/25P/50W	44.5d	25.7d	76.7a	54.5d	33.9e	98.5ab
80D/20W	157ab		46.0b	194b		65.7c
80P/20W		125b	53.8b		155b	75.7bc
40D/40P/20W	80.0	48.1cd	50.0b	102c	61.7de	72.2c
Mean	113.1	94.9	67.1	148.5	121.0	89.0
LSD (5%)	30.7	38.4	18.6	39.6	48.9	23.5

D: Dukat (normal leafed pea), P: Partner (semileafless pea), W: Wheat (Diskett)
*Means with the same letters in a column are not significantly different from each other.

Table 10. Amount of N_2 fixed by pea in sole crops and component crops in the intercrops for biomass (kg ha^{-1}) at flowering harvest.

Treatment	Dukat	Partner
100D	106a*	
100P		97.2a
50D/50P	47.5bc	42.9b
50D/50W	32.3c	
50P/50W		24.5c
25D/25P/50W	20.8c	17.2c
80D/20W	69.5b	
80P/20W		54.4b
40D/40P/20W	41.7bc	26.1c
Mean	53.0	43.8
LSD (5%)	27.9	12.8

D: Dukat (normal leafed pea), P: Partner (semileafless pea), W: Wheat (Diskett)
*Means with the same letters in a column are not significantly different from each other.

lowest weed biomass yield at the flowering stages. Similar to our findings, previous studies have reported that weed pressure was less in pea–cereal intercrops and sole crop cereal than in sole crop pea (Hauggaard-Nielsen et al., 2001, 2008; Corre-Hellou et al., 2011; Bedoussac et al., 2015, Stomph et al., 2020). The weed biomass in the intercrops with Partner and wheat intercrops decreased with increased wheat proportion at flowering. However, intercropping had lower weed pressure as compared to sole crop Dukat and Partner. Weed biomass in the sole crop Dukat (normal leafed pea) was also slightly less than that of the sole crop Partner (semileafless pea) at flowering stages. Some workers recorded that competition of normal leafed pea with weeds was better than that of semileafless pea (Harker et al., 2008; Vasilakoglou and Dhima, 2012). On the other hand, there were not significant differences between the treatments for weed biomass yield at the maturity stage.

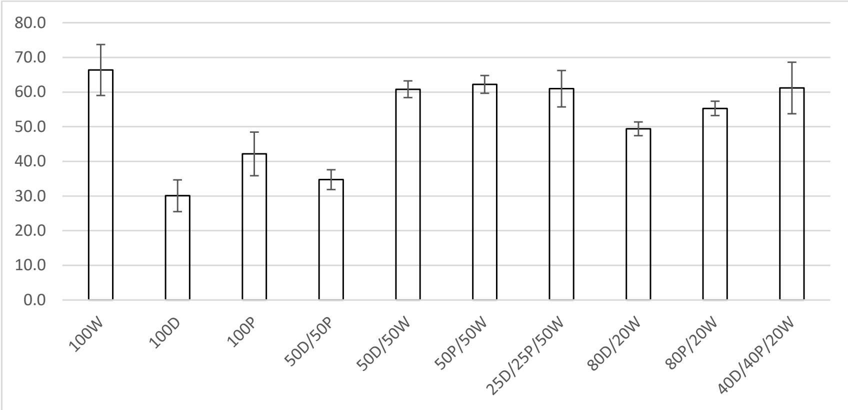

Figure 5. The soil N accumulation in sole crops and intercrops for total biomass production at the flowering harvest (kg ha^{-1}). The bars represent mean values ± SEM of 4 replicates.
Dukat (normal leafed pea), Partner (semileafless pea), Diskett (wheat).

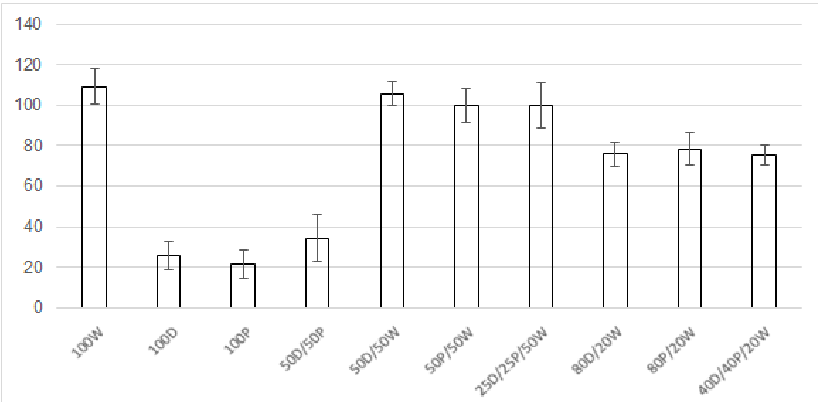

Figure 6. The soil N accumulation in sole crops and intercrops for total biomass production maturity harvest (kg ha^{-1}). The bars represent mean values ± SEM of 4 replicates.
Dukat (normal leafed pea), Partner (semileafless pea), Diskett (wheat).

The LER values for grain yield in all the intercrops were greater than 1 and up to 1.40 (80D/20W intercrop), indicating a yield advantage of intercropping of up to 40% compared to growing sole crops. Similar observations were found in other intercrop studies (Jensen, 1996; Hauggaard-Nielsen et al., 2008; Bedoussac et al., 2015; Jensen et al., 2020b). The LER values of pea–wheat intercrops with the normal leafed pea (Dukat) for grain yield were greater than those for intercrops with the semileafless pea (Partner).

Nitrogen concentration increased in the intercropped wheat compared to sole crop wheat for biomass and grain, but nitrogen concentrations in Dukat and Partner intercropped with wheat were lower than those of sole crop pea in accordance with Monti et al. (2016).

There were significant differences between all the treatments for N accumulation in Dukat and Partner in the intercrops for biomass and grain in accordance with Geijersstam and Mårtensson (2006). Nitrogen accumulation was higher in sole crop Partner and sole crop Dukat compared to in component crops in all intercrops, due to lower seed and pea growth caused by interspecific competition (Hauggaard-Nielsen et al., 2001; Andersen et al., 2005).

The amount of N_2 fixed in pea for intercrops in the biomass at the flowering was less than that in the sole crop Dukat and sole crop Partner due to competition with wheat in accordance with Jensen (1996), Hauggaard-Nielsen et al. (2001), and Ghaley et al. (2005). The N_2 fixation of intercropped pea was probably because of shading by wheat leading to competition for light.

Soil N accumulation was greater in pea–wheat intercrops than in sole crop Dukat, sole crop Partner, and the 50D/50P cultivar mixture for flowering and maturity harvest. Similar findings were reported by Jensen (1996), Hauggaard-Nielsen et al. (2006), and Rodriguez et al. (2020). Wheat was more competitive for soil N than pea. Unkovich and Pate (2000) also indicated that soil N accumulation in some legumes sole crops was less than in nonlegumes. On the other hand, in the present study, the soil N accumulation in the intercrops increased with increasing wheat seeding ratio for maturity harvest.

5. Conclusion

In the present study, differences between the intercrops and both the sole crops were not significant for total grain DM yield or biomass DM yield (flowering and maturity harvest). However, generally the grain yields of the pea–wheat intercrops were slightly greater than those of the sole crops. Sole crop Dukat and Partner and sole crop wheat grain yield were significantly higher than those of intercropped pea and intercropped wheat. The grain yields of pea–wheat intercrops containing 50% or 80% Dukat were slightly greater than those of sole crops. The seed yield of the normal leafed Dukat in sole crop was 23% lower than those of semileafless Partner. The LER value for grain in all intercrops was greater than 1, indicating that the use of plant growth factors was improved by intercropping compared to the sole crops for grain. The N accumulation was higher in both sole crop pea cultivars compared to the component crops in all intercrops due to decreased pea growth caused by interspecific competition. Soil N uptake was greater in pea–wheat intercrops than in sole crop pea and the 50D/50P cultivar mixture for flowering and maturity harvest. It is concluded that pea–wheat intercropping can use N resources more efficiently than sole crops in sustainable cropping systems. However, more studies focusing on optimization of intercrop component cultivars and the relative frequency of components are required.

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Conflict of interest

The authors declare they have no conflicts of interest.

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