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Agronomic and Economic Benefits of Pea/Maize Intercropping Systems in Relation to N Fertilizer and Maize Density

Caihong Yang [1,†], Zhilong Fan [2,†] and Qiang Chai [2,*]

1 College of Forestry, Gansu Agricultural University, Lanzhou 730070, China; yangch@gsau.edu.cn
2 Gansu Provincial Key Laboratory of Arid Land Crop Science/College of Agronomy, Gansu Agricultural University, Lanzhou 730070, China; fanzl@gsau.edu.cn
* Correspond: chaiq@gsau.edu.cn; Tel.: +86-931-7603-751
† These authors contributed equally to this work.

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Abstract: Intercropping has been shown to increase crop yields and improve land utilization in many cases but it is unknown how the interspecies relationship is enhanced with improved crop management schemes. In this study, we investigated the effect of different maize densities and N rates on the growth, crop yields and economic benefits of pea (*Pisum sativum* L.)/maize (*Zea mays* L.) intercropping. The results indicated that total yields of pea/maize intercropping were higher than the yield of maize alone, and that pea/maize intercropping improved land use efficiency significantly compared to sole crops, the partial land equivalent ratio (LER) of maize and pea with high planting density increased from 0.98% to 9.36% compared to low planting densities during 2012 and 2013. The pea strips provided significant compensatory effects on the growing maize after the earlier-sown, shorter-seasoned pea was harvested. The crop growth rate (CGR) of the intercropped maize was 18.5% to 216.9% greater than that of sole maize after pea harvest, the leaf area index (LAI) of pea/maize intercropping was 6.9% and 45.4% greater compared with the weighted average of sole maize and sole pea in 2012 and 2013, respectively. Net returns and benefit to cost ratios of pea/maize intercropping were increased with an increase of maize planting density. A low rate of N fertilizer was coupled with increased maize plant density, allowing interspecific facilitation to be fully expressed, thus improving the land utilization rate and increasing economic benefits. Overall, our findings show that a higher density of maize and lower N application can be used to increase grain production with no adverse effects on the growth components of either pea or maize crops. It could be considered an advanced farming system for agricultural sustainable development in the oasis region of northwest China.

Keywords: pea; maize; intercropping; plant-density; profitability

1. Introduction

Legume/cereal intercropping has been broadly practiced in many short-season areas, such as the northern Great Plains of Latin America, North America, northwest Eurasia and northwest China where the temperatures only permit one crop per year [1–3]. The advantages of legume/cereal intercrops are often assumed to arise from the complementary use of N sources by intercropping with legumes, because intercropped legumes can meet their N demand due to the complementarities between symbiotic N_2 fixation, soil N acquisition and intercropped cereals uptake of more N from the soil than they stand in sole cropping [4–6]. This is of particular interest for developing low-input and sustainable cropping systems. In addition, legume/maize (*Zea mays* L.) intercropping has higher land use efficiency, lower water consumption and more ecological and environmental benefits compared to a cereal-cereal intercropping [7,8]. For intercropping, interspecific interactions often occur, including interspecific facilitation (positive interaction) and interspecific competition (negative interaction) [9–11]. However, there is great yield advantage in intercropping compared with corresponding sole crops [12–14], this is largely because one component can enhance the survival, growth, or fitness of the other component [15]. Therefore, one component may influence the performance of the other components in the whole cropping system.

The Hexi Corridor of Gansu province in China is a typical oasis agricultural region with abundant sunlight and high temperatures and the traditional planting pattern is one crop per year [16]. In recent years, intercropping has been used to extend the growing season with a focus on producing more grains per year per unit land area. Pea/maize intercropping is one of the choices, as this system has high land use efficiency. More importantly, it is in harmony with ecological and environmental sustainability due to the benefits of N-fixation in pea crops [17]. Meanwhile, a substantial increase in grain yield and per capita food production in the last 50 years in China appeared mostly due to increased industrial energy inputs, especially nitrogen-based chemical fertilizer [18]. In this irrigation area, the amount of applied N fertilizer has risen to 450 kg ha^{-1} [19,20], yet N fertilizer in agricultural fields can be lost through many pathways, such as ammonia volatilization, nitrate leaching, and nitrous oxide (N_2O) emissions, which leads to ecosystem degradation and environmental pollution [21–23]. In addition, they use large quantities of locally available non-commercial and commercial energies in direct and indirect forms, therefore farmers want maximum return from a limited area using their scare resources [24,25]. The reasons for low yield and input include conventional planting methods, costly inputs, improper planting density and imbalanced fertilizer application over the past few years. The main objective of intercropping is to achieve higher productivity per unit area [13], increase resource use efficiency [14,26], and potentially reduce the negative impacts of cropping on the environment [27,28]. However, little has been studied with regard to N fertilizer management and planting density manipulation in legume/cereal intercropping systems.

Therefore, the aim of this study on pea/maize intercropping systems was to quantify the agronomic productivity of pea and maize mono-cropping and intercropping systems and to assess the profitability of pea/maize intercropping systems for smallholder farmers.

2. Materials and Methods

2.1. Site Description

The field experiment was conducted in 2012 and 2013 at the Wuwei Experimental Station of Gansu Agricultural University in an arid oasis region (37°52′20′′ N, 102°50′50′′ E, and 1776 m a.s.l). This station is in the temperate arid zone in the hinterland of the Eurasia Continent, and is located in the eastern part of the Hexi Corridor in northwestern China. Long-term (1950–2012) weather data shows that the average annual sunshine duration is more than 2968 h, mean temperature is 7.3 °C with an accumulated temperature above 10 °C more than 2985 °C, and the frost-free period is 156 days. Mean annual precipitation is less than 156 mm, which occurs mainly from June to September, and potential evaporation is greater than 2400 mm. The soil at the research station is classified as Aridisol, a kind of desert soil filled with calcareous particles. At the start of the experiment, some of the properties are shown in Tables 1 and 2. Daily rainfall and maximum and minimum temperature during the course of the experiment were recorded daily at the experimental site (Figure 1).

Table 1. Soil properties at the start of this experiment.

Layer	Bulk Density (g cm^{-3})	Wilting Point %	Field Capacity %	Soil Texture [a]	Particle Size % [b]		
					Sand	Silt	Clay
0–20 cm	1.42	6.6	20.5	Silt loam	27.9	66.2	5.9
20–40 cm	1.51	9.5	23.4	Silt loam	25.5	69.2	5.3
40–70 cm	1.55	10.4	26.1	Silt	17.1	78.6	4.3
70–110 cm	1.49	11.5	27.4	Silt loam	25.5	70.6	3.9

[a] Soil texture is determined using the soil particle percentage; [b] Soil particle fraction based on the USDA textural soil classification system.

Table 2. Soil properties at the experimental site, 2012–2013.

Year	Layer	Organic Matter ($g\ kg^{-1}$)	Total N ($g\ kg^{-1}$)	Available N ($mg\ kg^{-1}$)	Available P ($mg\ kg^{-1}$)	Available K ($mg\ kg^{-1}$)	pH
2012	0–20 cm	17.82	0.79	107.58	30.92	174.33	7.41
	20–40 cm	15.70	0.75	106.52	26.60	121.00	7.70
2013	0–20 cm	18.00	0.93	108.14	27.14	184.51	7.35
	20–40 cm	15.86	0.71	106.49	19.54	132.99	7.69

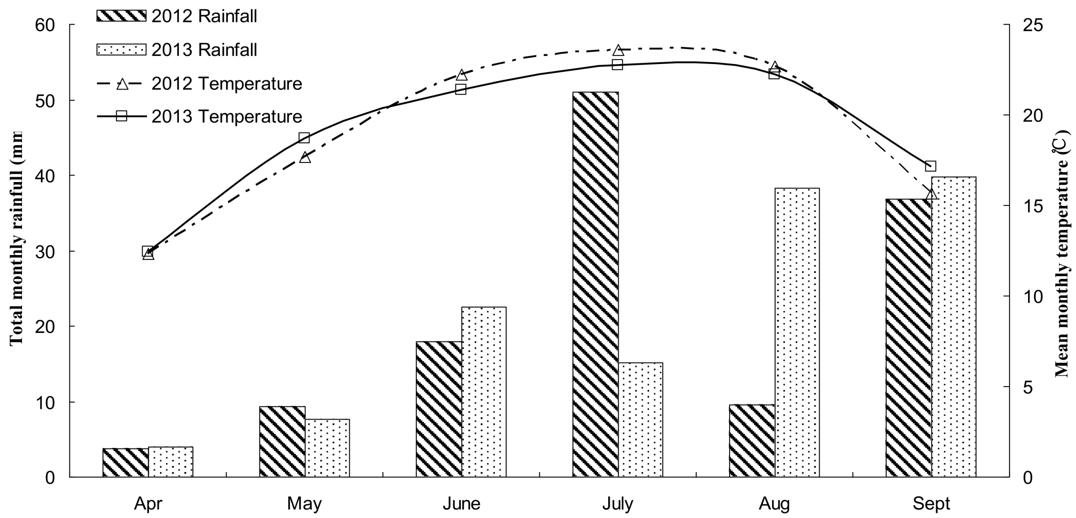

Figure 1. Monthly precipitation and mean air temperature of research station during growing seasons y in 2012 and 2013.

2.2. Experimental Design and Plot Management

The experiment was established with a randomized, incomplete block design and with three replicates. Three cropping systems, that is, sole pea (P), sole maize (M) and pea/maize intercropping (P/M), three planting density in maize, 73,500 plants ha^{-1} (D1), 85,900 plants ha^{-1} (D2), and 98,200 plants ha^{-1} (D3), two N fertilizer management systems, without nitrogen application (N0) and with nitrogen application and (N1), 0 and 450 kg N ha^{-1} for maize, 0 and 135 kg N ha^{-1} for pea respectively. The sole maize treatment received N fertilizer at 450 kg N ha^{-1} as urea (46-0-0 of N-P_2O_5-K_2O), with 20% of the total N (i.e., 90 kg N ha^{-1}) evenly spread and incorporated into the top 30 cm of soil using rotary tillage prior to seeding (as base fertilizer), and the remaining 80% (i.e., 360 kg N ha^{-1}) was divided into three portions as topdressing (implemented at typical maize growth stages, i.e., at jointing, pre-tasseling and 15 d post-flowering). The sole pea treatment received the same amount of N fertilizer as the sole maize with base fertilizer N (pre-seeding) plus topdressing N at maize jointing (pea flowering). Intercrops received the same area-based N fertilizer as the corresponding sole crops.

Selected pea and maize cultivars were "MZ-1" and "Xian-yu 335", respectively. Each plot size was 6.0 m × 9 m, with a 40 cm wide by 30 cm high ridge built between two neighboring plots to eliminate potential water movement. In the strip intercropping system, pea and maize were planted in a west-east row orientation in alternating 200 cm wide strips. In all years, pea/maize intercropping was planted in strips with four rows of pea (20-cm row space) alternated with three rows of maize (40-cm row space) in a set of 90:110 cm strips. There was a 30 cm wide gap between pea and maize strips (Figure 2). Planting density was 1,800,000 plants ha^{-1} for sole pea and 758,000 plants ha^{-1} for intercropped pea. Superphosphate (337.5 kg P_2O_5 ha^{-1}) was spread and then incorporated into the soil prior to seeding in all plots.

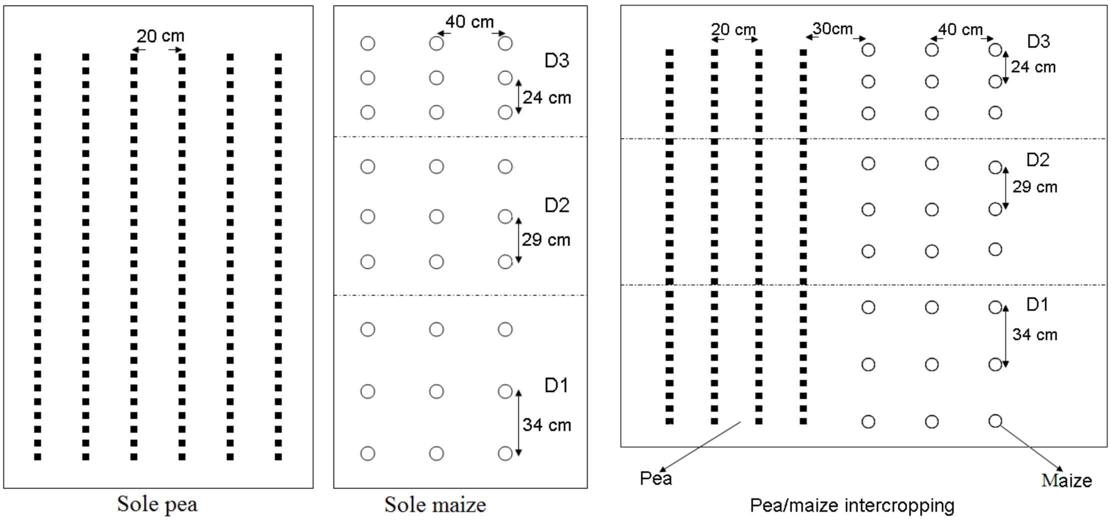

Figure 2. Planting pattern in pea/maize intercropping system.

Supplemental irrigation was applied because of low precipitation in the experimental area (less than 150 mm annually). We employed the irrigation schedule as locally practiced—all plots received an amount of 120 mm of irrigation in the previous fall just before soil freezing. During the growing season, five irrigations were applied to maize (90 mm at seedling, 120 mm at booting, 120 mm at pre-heading, and 120 mm at flowering and 90 mm at filling), and 210 mm of water was irrigated to sole pea (90 mm at maize seedling, 120 mm at maize booting). A hydrant low pressure pipe system was used for irrigation and a flow meter was installed at the discharging end of the pipe to measure and record the irrigation amounts entering each plot. The cultivar, fertilizing, insect control and strip form in all plots were the same for each year.

Pea (cv. MZ-1) was planted on 2 April and 1 April in 2012 and 2013 respectively and the maize (cv. Xian-yu 335) was planted 20 days after pea planting. Pea emerged on 16 April and 13 April, maize emerged on 30 April and 29 April in 2012 and 2013, respectively. Harvesting dates for pea were 8 July in both 2012 and 2013, while maize was harvested on 28 September and 30 September respectively for the two years. There were about 67–70 d of maize-pea co-growth.

2.3. Data Collection and Statistical Analysis

2.3.1. Grain Yield and Land Equivalent Ratio (LER)

At maturity, all plots were harvested by hand and the harvested grains were air-dried, cleaned, and weighed for grain yield. Land equivalent ratio (LER) was used to evaluate the success of intercropping using a concept proposed by Willey (1979) [29]—the total LER is defined as the total land area required under monoculture to give the yields obtained in the intercropping mixture. It is expressed as:

$$\text{LER} = (\text{LERpea} + \text{LERmaize}) = \left(\left(\frac{\text{Yip}}{\text{Ysp}}\right) + \left(\frac{\text{Yim}}{\text{Ysm}}\right)\right) \quad (1)$$

where Ysp and Yip are grain yields of pea in monoculture and intercropping (kg ha^{-1}), respectively; Ysm and Yim are grain yields of maize in monoculture and intercropping (kg ha^{-1}), respectively. LERpea and LERmaize are the partial LER of intercropped pea and intercropped maize, respectively. LERpea and LERmaize indicates the efficiency of intercropping for using land resources compared with sole cropping [30]. A total LER greater than 1.0 indicates the presence of positive interferences among the crop components of the mixture [31].

2.3.2. Crop Growth Rate

A sample of 20 pea plants and 10 maize plants were randomly selected from each plot at ground level at different stages of crop growth. All plant samples were oven dried at 80 °C in an air forced oven until at a constant weight. Dry matter (DM) was determined based on the fresh weight of sample plants and the moisture content of the subsamples.

Crop growth rate [32] (CGR), viz., the increase in dry weight of crop per unit area per unit time was calculated using the following equation:

$$\mathrm{CGR} = \frac{\mathrm{DM2} - \mathrm{DM1}}{\mathrm{d}} \quad (2)$$

where DM1 is the DM measured at an earlier sampling time, DM2 is the DM measured at a later sampling time, and d is the number of days between the two sampling dates.

2.3.3. Leaf Area Index

Leaf area index (LAI) [33] was calculated as leaf area per plant/ground area per plant. For pea, 20 plants were randomly taken from each plot and the leaf area was measured using a leaf area meter (Model Li-3000, LI-COR, Lincoln, NE, USA). For maize, 10 plants were randomly taken from each plot, leaf length and the greatest leaf width were measured with a ruler, and leaf area was determined by following the formula: leaf area = leaf length × the greatest leaf width × 0.78. For intercropping systems, the LAI of pea and maize was measured separately, and total LAI for the intercropping system was set as the means of the LAIs for pea and maize.

2.3.4. Economic Efficiency

The economic performance of different treatments was assessed to determine which treatment was sufficient to convince farmers for practicing. Economic inputs include seed, chemical fertilizers, irrigation water, labors, fuel, and so forth. The economic outputs included the seed yield plus the by-product yield. The primary data on various inputs and management practices were used for the computation of economic output. For estimation of economic inputs and outputs, economy equivalents (Table 3) were utilized. The economic efficiency was calculated as [34]:

$$\text{Net returns} = \text{Total output} - \text{Total input} \quad (3)$$

$$\text{Benefit Cost ratio} = \text{Net returns}/\text{Total input} \quad (4)$$

2.3.5. Statistical Analysis

Data on yield, LER, CGR, LAI and economic outcome were analyzed using the analysis of variance (ANOVA) procedure of the Statistical Analysis Software (SPSS software, 16.0, SPSS Institute Ltd., Chicago, IL, USA). The comparisons among different treatments were made with the Least Significant Differences Test. Because of significant treatment × year interaction for most of the variables in this study, the treatment effect was assessed for each year separately. Significances were declared at the probability level of 0.05, unless otherwise stated.

Table 3. Inputs and outputs of the production of pea and maize in an oasis region, northwest China, 2012–2013.

Item Description	Units	Value in Chinese Yuan (¥) [c]
(B) Inputs		
1. Human labor		
(a) Adult man	Man-hour	15.00
(b) Woman	Woman-hour	12.00
2. Diesel [a]	L	13.60
3. Petrol	L	15.20
4. Irrigation water	m^3	0.10
5. Electricity	kWh	0.55
6. Chemical fertilizer		
(a) Nitrogen	kg	1.70
(b) Phosphate(P_2O_5)	kg	1.80
(c) Potash(K_2O)	kg	15.00
7. Seed		
(a) Pea	kg	9.80
(b) Maize	kg	17.6
(A) Outputs [b]		
I. Main product		
1. Pea	kg	3.60
2. Maize	kg	2.40
II. By product		
1. Straw	kg	0.30
2. Stover	kg	0.20

[a] Includes lubricants; [b] Outputs are based on dry mass; [c] Averages of 2012 and 2013.

3. Results

3.1. Yield Advantage

Total grain yields (mixed yields) of the pea/maize intercropping were similar to that of sole maize in 2012 and 2013, but they were significantly increased compared with sole pea (Table 4). It was consistent that total grain yields of pea/maize intercropping were significantly improved with the use of nitrogen in each of the two study years. Grain yield of intercropped maize with nitrogen applied (N1) was increased by 17.03% and 11.07% compared with the maize without nitrogen fertilization (N0) during the two years. Plant density also had a significant impact on grain yield of intercropped maize, the maize with medium plant-density (D2) increased grain yield by 15.20% and 11.83% relative to the low plant-density (D1), and the maize at high plant-density level (D3) increased yield by 27.43% and 22.89% than maize at medium plant-density in 2012 and 2013, respectively.

Similarly, the grain yields of intercropped pea were increased with nitrogen fertilization (Table 4). Yields of intercropped pea with fertilization were increased by 13.65% to 14.41% compared with the pea without nitrogen applied. Planting density of maize had a significant effect on grain yields of intercropped pea in 2013. On average, the yield of intercropped pea with high planting density of maize was decreased by 2.47% and 17.38% more than that of low planting density in 2012 and 2013, respectively. Overall, application of nitrogen fertilizer enhanced the grain yields of intercropped pea and intercropped maize. Grain yield of maize was significantly increased with increasing planting density, but slightly decreased the yield of intercropped pea.

Total land equivalent ratio (LER) for pea/maize intercropping was greater than 1 (Table 5), which indicating that there is an advantage of utilizing land resources by pea/maize intercropping systems relative to the corresponding sole crops. Partial LER for maize with application of nitrogen fertilizer was increased by 7.17% than that of maize without nitrogen fertilization in 2012. The treatment with high planting density of maize gave the maximum partial LER for maize. Partial LER for maize with the high planting density increased by 4.26%, 3.31% and 7.08%, 7.19% more than that of low and medium planting densities in 2012 and 2013, respectively.

Table 4. Grain yields of pea and maize crops in intercrop- and sole-cropping systems with two rates of nitrogen and at three maize plant-density levels at an Oasis region, 2012–2013.

Treatment		2012			2013		
		Component Yield		Mixed Yields [a]	Component Yield		Mixed Yields [a]
		Pea	Maize		Pea	Maize	
		(kg ha^{-1})					
Inter-cropping		Rate of nitrogen effect					
	N0	1707	8458	10,165	2133	8345	10,478
	N1	1977	10,194	12,171	2492	9384	11,876
	N	NS [b]	*	*	*	**	*
		Planting density effect					
	D1	1868	7865	9734	2418	7751	10,169
	D2	1835	9275	11,110	2459	8791	11,249
	D3	1823	10,838	12,661	2060	10,052	12,112
	D	NS	*	*	*	*	*
	N × D (*p*-value)	NS	*	*	NS	*	NS
Sole-cropping		Rate of nitrogen effect					
	N0	3146	10,652	—	3380	9835	—
	N1	4603	11,983	—	4753	11,339	—
	N	*	*	—	NS	*	—
		Planting density effect					
	D1	—	9677	—	—	8850	—
	D2	—	11,443	—	—	10,561	—
	D3	—	12,832	—	—	12,349	—
	D	—	*	—	—	*	—
	N × D (*p*-value)	—	*	—	—	NS	—

[a] Mixed yields are the sum of the yields produced by the two component crops; [b] NS refers to no significant differences between treatments at the 0.05 level; * Significant difference between treatments at 0.05 levels. ** Significant difference between treatments at 0.01 levels.

Table 5. Partial land equivalent ratio (LER) for grain yields of intercropped pea and intercropped maize, total LER for grain yields of intercropping at an Oasis region, 2012–2013.

Treatment	Partial LER				Total LER	
	Pea		Maize			
	2012	2013	2012	2013	2012	2013
	Rate of nitrogen effect					
N0	0.699	0.611	0.795	0.839	1.634	1.466
N1	0.683	0.696	0.852	0.830	1.694	1.226
N	NS	*	*	NS	*	NS
	Planting density effect					
D1	0.692	0.497	0.809	0.814	1.635	1.373
D2	0.725	0.509	0.817	0.813	1.638	1.347
D3	0.764	0.502	0.845	0.876	1.719	1.317
D	*	NS [a]	NS	NS	*	NS
N × D	NS	NS	NS	NS	NS	NS

[a] NS refers to no significant differences between treatments at the 0.05 level, * Significant difference between treatments at 0.05 levels.

The partial LER of pea without nitrogen fertilization decreased by 12.21% more than that of pea with nitrogen fertilization in 2013, but no significant difference was found in 2012. Compared to low maize planting density, high and medium maize planting density increased partial LER of pea by 9.38% and 4.55% in 2012, 2.36% and 0.98% in 2013, respectively. Total LER of the two component crops with application of nitrogen fertilizer was significantly reduced by 16.4% compared to the treatments without nitrogen fertilization in 2013, no significant difference was found in 2012.

3.2. Crop Growth Rates

There were some compensatory effects between the two intercrops, as revealed by the change of the crop growth rates (CGR) in intercropped maize and sole maize (Figures 3 and 4). The CGR of sole maize was always greater than intercropped maize, and it increased by 3.2% to 93.6% during the period of 15 to 95 d after pea emergence in 2012 and 2013. However, the growth of maize plants increased rapidly after pea harvest (at 95 d after pea emergence) in pea/maize intercropping, the CGR of the intercropped maize was 18.5% to 216.9% greater than that of sole maize. The intercropped pea strips provided a significant compensatory effect on the growth of maize plants after the pea was harvested.

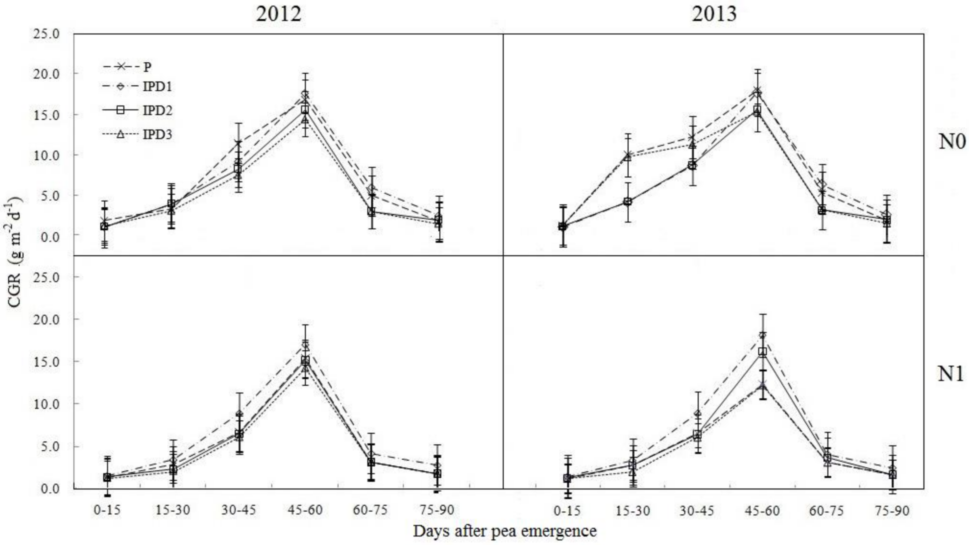

Figure 3. Crop growth rate (CGR) of sole pea (P) and intercropped pea (IP) grown under two nitrogen (N0 and N1) levels with three maize planting densities (D1, D2, and D3) throughout the 2012–2013 growing seasons, where error bars represent standard errors. The vertical bars represent ± SE.

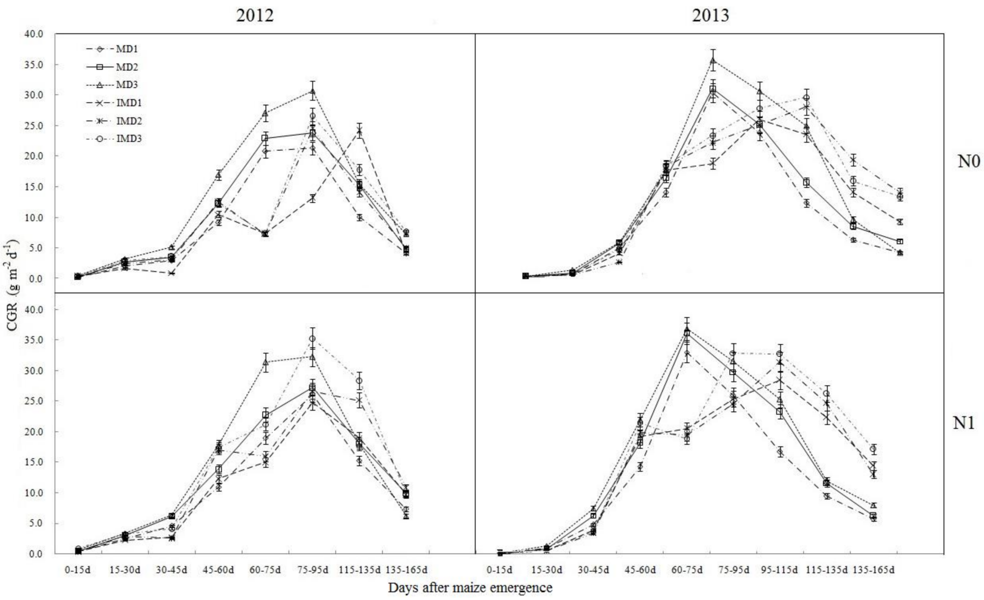

Figure 4. Crop growth rate (CGR) of sole maize (M) and intercropped maize (IM) grown under two nitrogen (N0 and N1) levels with three plant-densities (D1, D2, and D3) throughout the 2012 and 2013 growing seasons, where error bars represent standard errors. The vertical bars represent ± SE.

3.3. Leaf Area Index

Averaged over the four (for pea) and eight (for maize) measurements were conducted during the whole growth period, leaf area index (LAI) of pea/maize intercropping was 6.9% greater in 2012 and 45.4% greater in 2013 compared with the weighted average of sole maize and sole pea (Figure 5). The leaf area index was 11.0% to 19.3% higher for intercropping with N fertilization than that without use of N fertilizer, and 6.7% to 10.2% higher for sole maize and 21.0% to 24.1% higher for sole pea on average. Furthermore, LAI of pea/maize intercropping was increased on average by 17.2% in 2012 and 9.1% in 2013 with increased maize plant density from low to medium; the LAI increased by 15.1% in 2012 and 13.4% in 2013 as the maize density increased from medium to high.

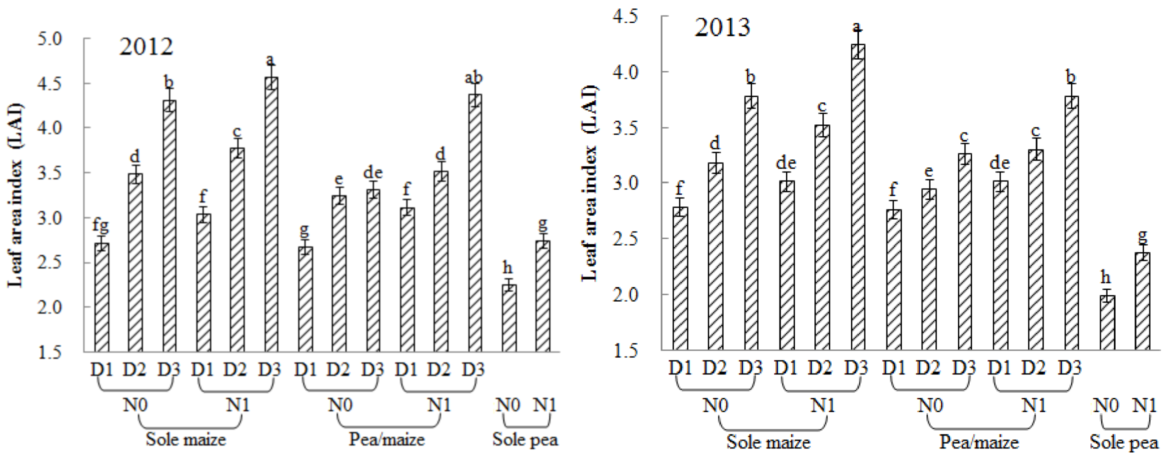

Figure 5. Leaf area index (LAI) of crops in different treatments. The letters above histogram indicate statistical significances within the same year at the 0.05 level using LSD tests. The vertical bars represent ± SE.

3.4. Economic Outcome

We made an effort to assess the economic outcome of the pea/maize intercropping under different crop management schemes. Labor, net return and benefit-cost ratio were calculated for each treatment (Table 6). Pea/maize intercropping had the highest labor input (1696–1768 man-hours ha^{-1}), which was 55.9% to 64.7% higher than sole maize, and 17.7% to 30.1% higher than sole pea. Net returns were improved by the use of nitrogen fertilizer regardless of intercropping or sole cropping. Pea/maize intercropping had a similar net return compared to corresponding sole maize with medium and high plant densities. However, the net returns of pea/maize intercropping were significantly higher than that of sole pea. In the treatment with zero N fertilization, both pea/maize intercropping and sole maize increased the net returns with increasing maize plant density. In the treatment with 450 kg ha^{-1} nitrogen fertilization, there was no significant difference in the net returns of pea/maize intercropping between medium and high plant densities of maize. In sole cropping systems with 450 kg ha^{-1} nitrogen fertilization, sole maize with medium plant density gave the maximum net returns of ¥2671 and ¥2772; it was significantly higher than that of sole maize at low and high planting densities. Large amounts of N fertilizer input reduced net returns with the increasing of maize planting density.

Table 6. Economic contributions of sole pea (P), sole maize (M) and pea/maize intercropping (P/M) under various treatments in an Oasis region of northwest China, 2012–2013.

Treatment			Labor (Man-Hours ha^{-1})	Total Input [a] (¥ ha^{-1})	Total Output [a] (¥ ha^{-1})	Net Returns [b] (¥ ha^{-1})	Benefit-Cost Ratio [c]
P	N0		1396	1288	1891	603	0.47
	N1			1341	2515	1175	0.88
M	N0	D1	1076	2164	3867	1703	0.79
		D2		2275	4380	2105	0.93
		D3		2468	4943	2475	1.01
	N1	D1		2309	4429	2120	0.92
		D2		2418	5140	2722	1.13
		D3		2593	5229	2635	1.02
P/M	N0	D1	1724	2225	3909	1685	0.76
		D2		2379	4526	2146	0.90
		D3		2513	4886	2374	0.94
	N1	D1		2370	4748	2379	1.01
		D2		2527	5187	2660	1.06
		D3		2618	5580	2963	1.14
Significant test (*p*-value)							
P: N0 vs. N1			NS [d]	NS	*	**	*
M: N0 vs. N1			NS	*	**	*	NS
P/M: N0 vs. N1			NS	**	*	*	*
P vs. M (N0, N1 average)			*	**	**	**	*
M: among D1, D2, D3			NS	*	*	*	NS
P/M: among D1, D2, D3			NS	*	*	*	NS

Economic contributions in 2012 and 2013 had the same varying tendency, all parameters are average value. [a] All the items listed in Table 2. [b] Net return is total outputs—total inputs. [c] Benefit ratio is net return divided by total input cost. [d] NS refers to no significant differences between treatments at the 0.05 level, * Significant difference between treatments at 0.05 levels, ** Significant difference between treatments at 0.01 levels.

The benefit-cost ratio was improved by the use of N fertilizer. The benefit to cost ratio was lower than 1 in the treatments with 0 kg ha^{-1} N applied either in pea/maize intercropping or sole cropping systems. In the corresponding density treatment, no significant difference was found between intercropped maize and sole maize, but they were significantly higher than that in corresponding sole pea. In pea/maize intercropping systems with 450 kg ha^{-1} N applied, the benefit to cost ratio of intercropping increased with increasing planting density. Pea/maize intercropping with high maize planting density provided the maximum benefit to cost ratios, from 1.13 to 1.29, which was increased by 11.8% to 14.4% more than that of the low maize planting density.

4. Discussion

In pea/maize intercropping, the increase of planting density of intercropped maize could improve the yield of intercropped maize but decrease the grain yield of intercropped pea. This was probably due to increased competition between the two species [35]. Although total grain yields of pea/maize intercropping were higher than that of sole maize, it had a yield advantage of up to 72% compared to the corresponding sole crops, and the land equivalent ratio (LER) of pea/maize intercropping ranged from 1.03 to 1.72. The yield advantages of intercropping over sole cropping may arise from the complementary use of growth resources [36,37], such as N and light in space and time [38,39]. However, we found that the total LER of pea/maize intercropping with N fertilizer application was reduced by 3.9% to 16.4% compared with no fertilizer application. Our results suggest that lower N fertilization levels should be considered for legume/cereal intercropping as the low-N soil environment allows the interspecies to have a complementary effect with the advantages of cropping mixture. Our study showed that higher maize planting density can change the use of land resources—this was supported by the fact that the partial LER for pea was reduced by 8.4% at a high maize density compared to the low maize density. In contrast, partial LER for maize was significantly increased with the increase of maize plant density.

Interspecies interaction determines the balance and outcome of the competitiveness between the two intercrops and the dynamics of the outcome can be evaluated using the crop growth rates [40]. In the present study, we found significant compensatory effects between the two intercrops, as is shown by the change of the crop growth rates (CGR) of intercropped maize compared to sole maize, where the growth rate of intercropped maize was 18.5% to 216.9% greater than sole maize after pea was harvested, and the leaf area index (LAI) of pea/maize intercropping was greatly increased in both years, compared with the weighted average of sole maize and sole pea. Larger spaces left by early-harvested pea provide excellent aeration and light conditions that facilitate aboveground biomass accumulation of intercropped maize. Also, unused water and nutrients that were left by intercropped pea are available for intercropped maize in the mid-filling period. Increased biomass of maize during the later part of the growth period plays a key role in maize yield and in the total productivity of pea/maize intercropping.

Another important aspect for pea/maize intercropping is the efficient use of light because of complementary use of space between the shorter pea plants and the taller maize plants. The complementary effect is also shown for the length of the growth period because their life cycles are different, with the maturity of intercropped pea was about 30 to 50 days earlier than the intercropped maize. This claim is supported by the consistent results on leaf photosynthetic rate (Pn) in this study that have not been published. During the co-growth period, the Pn of intercropped maize was significantly lower compared to that of sole maize. However, after pea was harvested, the Pn of intercropped maize became 13.2% to 19.6% higher than that of the sole maize. Our result disagrees with the findings on cowpea and sorghum (*sorghum bicolor* L.) mixed culture that monoculture had higher photosynthetic rates in the leaves of plants relative to those in mixed culture [41]. These results suggest that proper coordination of the two intercrops plays a large role in enhancing plant growth and improving crop productivity. Detailed studies are required to establish the best-matching intercrop partners for full utilization of resources in the production advantages of intercropping.

The pea/maize intercropping achieved higher yields but required more labor in their production than sole cropping in the present study. Consequently, the pea/maize intercropping had a similar net return as the corresponding sole maize, but the net returns of intercropping were higher than sole pea. In all cases, the net returns were improved by the use of nitrogen fertilizer regardless of intercropping or sole cropping. Although the grain yield, net returns and benefit to cost ratios of pea/maize intercropping were similar or even lower than sole maize, the grain composition and quality from this cereal-legume intercropping is more valid for animal or human consumption compared to the sole maize because of the higher protein in pea [42]. Furthermore, the inclusion of annual legumes in cropping systems via either legume-cereal intercropping or cereal-legume rotations can significantly reduce the use of synthetic N fertilizer [43,44], as the legumes fix N_2O from the atmosphere [45]. Such a legume-cereal system can provide significant ecological and environmental benefits by reducing carbon emissions [27,46], lowering the environmental footprint [47,48] and enhancing soil and ecological sustainability [49,50].

Furthermore, the pea/maize intercropping has more ecological benefits than sole maize, as the legume can fix N from the atmosphere and thus reduce the requirement for inorganic nitrogen in crop production [51].

5. Conclusions

Grain yield of pea/maize was increased, on average, by up to 71.9% compared to monoculture maize and monoculture pea on a per hectare basis. The increased yield with the intercropping was largely due to improved interspecies interaction and facilitation. Earlier sowing and faster growing of the intercropped pea allowed for greater dry matter accumulation before maize plants became large enough for a compatible competitiveness with the pea. Also, a strong compensatory effect occurred between the two intercrops after the early-sown, short-season pea was harvested, when the crop growth rate of the intercropped maize was increased by 18.53% to 216.89% over the sole maize. The use of nitrogen fertilizer decreased the total land equivalent ratio of the pea/maize intercropping significantly although the use of N improved the grain yield of intercropped maize. Furthermore, the interspecies facilitation and complementary effects were expressed better under the low fertility conditions. This suggests that relatively low N fertilization should be considered for pea/maize intercropping in order to improve land use efficiency, take advantage of intercropping facilitation and improve economic benefits. Also, linked with the higher yield, the associated higher amount of cereal-legume by-product is preferred for animal feed or human consumption. Therefore, pea/maize intercropping can be considered as an advanced farming system for agricultural development and environmental sustainability.

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