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INCREASING THE PRODUCTIVITY OF INTERCROPPING CORN AND PEANUTS BY INOCULATION WITH *Azotobacter chroococcum*

Siavash Pourjani, Hashem Aminpanah*, Mohamad Naghi Safarzad Vishkaei

Department of Agronomy and Plant Breeding, Rasht Branch, Islamic Azad University, Rasht, Iran
*Corresponding author. E-mail: aminpanah@iaurasht.ac.ir; haminpanah@yahoo.com

ABSTRACT

Intercropping and bio-fertilizer application play important roles in sustainable agro-ecosystems. A two-year field experiment was conducted at Astaneh-ye Ashrafiyeh, Northern Iran, to evaluate the effect of Azotobacter (*Azotobacter chroococcum)* inoculation on the growth and yield of a peanut/maize intercropping system. The experimental design was a randomized complete block in a factorial arrangement with three replicates. Factors were *Azotobacter* application [control (non-inoculated) and inoculation (with *Azotobacter chroococcum*) and different maize (*Zea mays* L.)/peanut (*Arachis hypogaea* L.) intercropping pattern (100% peanut + 100% maize, 100% peanut + 50% maize, 50% peanut + 100% maize, 50% peanut + 50% maize, 67% peanut + 33% maize, and 33% peanut + 67% maize). Sole cropping of peanut and maize were also used. Results showed that averaged across years and intercropping patterns, grain yields of peanut and maize were significantly increased by 10% and 16%, respectively, in inoculated plots compared to non-inoculated ones. Azotobacter also had a positive significant effect on nitrogen concentration of grain, while it had no significant effect on oil concentration of peanut grain and significantly decreased the oil concentration of maize grain. Land equivalent ratio (LER) ranged from 1.05 to 1.70, indicating more efficient and productive use of environmental resources by intercrops. Results also showed that inoculated intercropped plots had 12-16% grater LER that non-inoculated ones. The highest LER was observed for inoculated plot with 100% peanut + 50% maize intercropping pattern (1.70), while the lowest one was recorded for non-inoculated plot with 50% peanut + 50% maize intercropping pattern (1.05). Based on the result of this experiment, intercropping pattern of 100% peanut + 50% maize along with Azotobacter application is recommended to obtain the highest productivity in maize/peanut intercropping system.

Keywords: land equivalent ratio, legume-cereal intercropping, plant growth-promoting rhizobacteria, sustainable agriculture.
Abbreviations: land equivalent ratio (LER), plant growth-promoting rhizobacteria (PGPR).

INTRODUCTION

The current global human population is estimated to reach 9.8 billion by the middle of this century and, therefore, there has been a continuous increase in the demand for food. Agricultural production will have to rise by 70% to sustain all these people (FAO, 2019). On the other hand, the need for producing greater yield by mono-cropping and applying intensive agronomic practices such as application of more chemical fertilizers has negative effects on the soil productivity, biodiversity, environmental health, and agro-ecosystem sustainability. These negative effects of conventional agriculture have led to an increase in the desire for sustainable agriculture throughout the world.

Intercropping and biofertilizer application are among the most common techniques for increasing crop production and agro-ecosystem sustainability. Intercropping is defined as the growing of two or more crops simultaneously in the same land during a growing season (Sarkar et al., 2000). Intercropping can increase yield potential (Himmelstein et al., 2017) and biodiversity, and also can provide many ecosystem services such as reducing the needs for chemical fertilizers (Latati et al., 2016), herbicides (Liebman and Dyck, 1993) and fungicides (Boudreau, 2013). At the same time, intercropping reduces greenhouse gas emissions that are linked to industrial N_2-fixation (Crews and Peoples, 2004). The advantages of intercropping are mainly related to the complementary use of environmental resources, including water, nutrients, and solar

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energy by the component crops. Legume/cereal intercropping is widely practiced as a sustainable food production system throughout the world which improves use of renewable nitrogen sources and minimizes dependence on chemical N fertilizers by increasing biological N_2 fixation (Corre-Hellou et al., 2006). This intercropping system also results in increased crop yield, effective utilization of resources, and enhanced productivity of cultivation system. Chu et al. (2004) claimed that peanut (*Arachis hypogaea* L.)/rice (*Oryza sativa* L.) intercropping increases the proportion of N derived from air by intercropped peanut by 20%. At the same time, reports show that N- and P-nutrition of cereals were significantly improved when intercropped with legumes. Inal et al. (2007) reported that shoot N, P, and K concentrations of peanut and maize increased by intercropping the crops. Wasaki et al. (2003) claimed that inter-specific root interactions enhance nutrient mobilization in the rhizosphere and contribute efficiently to nutrient uptake by intercrop components.

Plant growth-promoting rhizobacteria (PGPR) are free-living beneficial soil microbes that colonize onto the plant roots and offers broad spectrum of beneficial functions to crops, by fixing N_2, mobilizing phosphate, producing plant growth regulators, alleviating biotic and abiotic stresses (Rahimzadeh and Pirzad, 2017) which helps improving crop nutrient uptake (Bender et al., 2016) and grain yield (Schutz et al., 2018). Among PGPRs, azotobacter is a non-symbiotic, free living, aerobic nitrogen fixing bacteria which colonize in the rhizosphere of crops (Kazi et al., 2016), significantly increases their growth and grain yield by enhancing the uptake of different nutrients (Inal et al., 2007). This microorganism also secrets vitamins and amino acids, and also produces siderophores and phytohormones (Aasfar et al., 2021) which are among the direct mechanisms of increasing root development and plant growth.

A survey of the literature showed some reports on the effects of maize-peanut intercropping patterns on growth and grain yield of the intercrop components, as well as on the effect of Azotobacter on maize and peanut yields in monoculture cropping system, while little information is available on the effect of Azotobacter on growth and grain yields of maize and peanut in intercropping system. Therefore, the objectives of this experiment were to clarify the effect of Azotobacter inoculation on grain, protein and oil yields of maize and peanut, and also to identify the effect of Azotobacter inoculation on land equivalent ratio.

MATERIAL AND METHODS

Experimental site and design, and plant growth conditions

Field experiments were conducted at Astaneh-ye Ashrafiyeh, Guilan province, northern Iran, during two consecutive years (2018 and 2019) in a field which had a history of growing peanut for over 30 years. The experimental farm is located at latitude 36°54' N, at longitude 40°50' E, and altitude of -10 m. The soil physico-chemical properties were 2.08% organic matter, 6% clay, 68% silt, 26% sand, 7.32 pH, total N 0.11%, available phosphorous 12.0 mg kg^{-1}, available potassium 195 mg kg^{-1}, and EC 0.6 dS m^{-1}. The amount of precipitation from April to September was 529.2 mm in 2018 and 447.6 mm in 2019. Although, the amount of precipitation was higher in 2018, their monthly distribution was deficient, in July being recorded only 2.9 mm precipitation.

The experimental design was a randomized complete block in a factorial arrangement with three replicates. Factors were Azotobacter inoculation [non-inoculated (control), and inoculated with *Azotobacter chroococcum*] and different maize/peanut intercropping patterns including: additive series (100% peanut + 100% maize, 100% peanut + 50% maize, and 50% peanut + 100% maize), replacement series (50% peanut + 50% maize, 67% peanut + 33% maize, and 33% peanut + 67% maize), peanut sole cropping, and maize sole cropping. In sole cropping, inter-row spacing between maize-maize and peanut-peanut was 70 cm. Intra-row spacing for the both crops was 25 cm. Azotobacter bacteria (*Azotobacter chroococcum*) were obtained from the biological laboratory of Soil and Water

Research Institute, Karaj, Iran. In inoculated plots, seeds of peanut and maize were inoculated with *Azotobacter chroococcum* and dried in sunshade for five hours and then were planted. Before final land preparation, the recommendation rates of nitrogen (100 kg ha^{-1} as urea), Phosphorus (75 kg ha^{-1}), and potassium (100 kg ha^{-1} as KCl) were applied to the plots. Furthermore, 50 kg N ha^{-1} was applied as topdressing at 30 days after planting. Maize and peanut were planted manually on 9 April in both years and were harvested on 10 August and 9 September 2018 and on 13 August and 11 September 2019, respectively. Weeds were controlled manually during the experiment. Moreover, no pesticides were applied to the experiment.

Plant sampling

At maturity stage, 25 randomly selected plants were harvested from each plot at ground level for measuring grain yields. Grain yields for peanut and maize were adjusted to 12% and 14% seed moisture content, respectively (Kermah et al., 2017).

Nitrogen (N) concentration in maize and peanut grains were determined using micro-kjeldahl method as described by Pregl (1945) and then protein concentration of maize and peanut grains were calculated by multiplying with 6.25.

Protein yield were calculated as following:

Protein yield of maize (kg ha^{-1}) = maize grain dry weight (kg ha^{-1}) × grain protein of maize (%) (1)

Protein yield of peanut (kg ha^{-1}) = peanut grain dry weight (kg ha^{-1}) × grain protein of peanut (%) (2)

The oil concentration of the maize and peanut grains was determined by Soxhlet extraction method and absolute ether was used as a solvent (Akbari et al., 2019), and then oil yields of maize and peanut were calculated as following:

Oil yield of maize (kg ha^{-1}) = maize grain dry weight (kg ha^{-1}) × grain oil concentration of maize (%) (3)

Oil yield of peanut (kg ha^{-1}) = peanut grain dry weight (kg ha^{-1}) × grain oil concentration of peanut (%) (4)

Land equivalent ratio (LER)

LER compares the yields from growing two crops in intercropping with yields from growing the same crops in monocultures and is an agronomically sound index to evaluate yield advantage derived from intercropping practice compared to monoculture. LER was calculated according following equation (Dhima et al., 2007):

$$\text{LER} = \frac{Yip}{Ysp} + \frac{Yim}{Ysm} \qquad (5)$$

where Y_{ip} and Y_{sp} are the grain yields of intercropped and sole peanut, and Y_{im} and Y_{sm} are the grain yields of intercropped and sole maize, respectively.

Statistical analyses

A combined analyses of variance over two years was conducted using SAS procedures (SAS Institute, 2004). For traits that interaction between year (Y) and factors (Y × Azotobacter application, Y × intercropping pattern, or Y × Azotobacter application × intercropping pattern) were significant at the 0.05 probability level, analyses of variance were computed separately for each year to determine the main effect of each factor, as well as interactions among them on the corresponding traits. Means separations were conducted using fisher's protected LSD at the 5% probability level.

RESULTS AND DISCUSSION

Analysis of variance indicated that the main effects of Azotobacter inoculation (A) and intercropping pattern (I) were significant ($P \leq 0.01$) for grain yields of peanut and maize. Moreover, the interaction between year (Y) and intercropping pattern (I) was significant ($P \leq 0.01$) only for peanut grain yield (data not shown).

On the other hand, the interaction effects of Y×A, A×I, and Y×A×I were not significant for grain yield of the both crops (data not shown). Grain N concentration, grain protein concentration and protein yield of peanut were significantly affected by Azotobacter inoculation (A), intercropping patterns (I), and Y×I. other 2- and 3-way interactions were not significant (data not shown). For maize, only Azotobacter inoculation (A) and intercropping patterns (I) had significant effect on grain N concentration, grain protein concentration, and protein yield (data not shown). Peanut grain oil concentration was significantly affected only by intercropping pattern (I), while peanut oil yield was significantly affected by Azotobacter inoculation (A), I, and Y×I (data not shown). Grain oil concentration of maize significantly affected by A, I, and Y×I, while maize oil yield was significantly affected by A and I (data not shown).

Mean comparison showed that in peanut, no significant difference in grain oil concentration was observed between inoculated and non-inoculated plants as averaged across years and intercropping patterns (Table 1). At the same time, regardless of year and intercropping pattern, oil yield of peanut was significantly increased by 9% in plants inoculated with Azotobacter compared to non-inoculated control plants (Table 1). The significant increase in oil yield of peanut in inoculated plots was mainly due to the positive effect of Azotobacter on peanut grain yield, because the oil yield depended greatly on grain yield of the crop.

Table 1. Effect of Azotobacter inoculation on peanut grain yield (PY), peanut grain N concentration (PGNC), peanut grain protein concentration (PGPC), peanut protein yield (PPY), peanut grain oil concentration (PGOC), and peanut oil yield (POY) as averaged across intercropping patterns and years

Traits / Azotobacter	PY (kg ha^{-1})	PGNC (%)	PGPC (%)	PPY (kg ha^{-1})	PGOC (%)	PGOC (kg ha^{-1})
Inoculation	1614.2a	4.53a	24.75a	401.3a	48.3a	776.8a
Non-inoculation	1467.5b	4.43b	24.23b	358.9b	49.0a	715.5b
LSD (0.05)	122.5	0.07	0.37	30.9	0.8	57.8

Grain oil concentration of maize was significantly lower in inoculated plants compared to non-inoculated plants (Table 2). It seems that enhanced N supply for inoculated plants reduced oil concentration in inoculated plants. Contrary to this result, oil content and oil yield of fennel (*Foeniculum vulgare* L.) intercropped with common bean (*Phaseolus vulgaris* L.) significantly increased under PGPR application compared to control treatment (Rezaei-Chiyaneha et al., 2020). Although Azotobacter inoculation decreased grain oil concentration in maize, it significantly increased the yield of oil by 12% in maize (Table 2). This was mainly due to increased grain yield in inoculated plants, which resulted in greater oil production per unit of land area. Results also showed that grain oil concentration was inversely related to grain protein concentration. This result is consistent with the findings of Ray et al. (2019) who claimed that there was an inverse relationship between grain protein and oil content of the maize hybrids.

Averaged across years and intercropping patterns, grain yields of peanut and maize were significantly increased by 10% and 16%, respectively for inoculated plants compared to uninoculated control plants (Tables 1 and 2). Besides biological N_2 fixation (El-Sawah et al., 2018), the positive role of Azotobacter inoculation on plant growth and grain yield could be attributed to its ability to influence directly plant growth by synthesizing plant growth regulators such as auxin (Gao et al., 2020), gibberellins, and cytokinins (Aasfar et al., 2021). The growth regulators can increase nutrient uptake, plant growth, and grain yield; protect host plants from phytopathogens; and also can stimulate other beneficial rhizosphere microorganisms (Sahoo et al., 2014; Arora et al., 2018). Furthermore, they also produce significant amount of exopolysaccharides, which are able to solubilize tricalcium phosphate and, therefore, increase phosphorus ability to plants (Yi et al., 2008). At the same time, Rotaru (2015) observed that the application of *Azotobacter chroococcum* increased the activity of acid phosphatase in the soil rhizosphere of soybean plants. The increase in grain yield of several economically important cereal and pulse crops due to *Azotobacter* inoculation are reported in previous experiments (Ritika and Utpal, 2014; Abdiev et al., 2019). Our results also revealed that grain yield of maize increased more than that of peanut due to Azotobacter inoculation. Consistent with this result, Díaz-Zorita et al. (2015) found that the increase in grain yield due to Azospirillum application was different among winter cereals (14.0%), summer cereals (9.5%), and legumes (6.6%).

Table 2. Effect of Azotobacter inoculation on maize grain yield (MY), maize grain N concentration (MGNC), maize grain protein concentration (MGPC), maize protein yield (MPY), maize grain oil concentration (MGOC), and maize oil yield (MOY) as averaged across intercropping patterns and years

Traits / Azotobacter	MY (kg ha^{-1})	MGNC (%)	MGPC (%)	MPY (kg ha^{-1})	MGOC (%)	MOY (kg ha^{-1})
Inoculation	5388.5	1.70	10.65	573.5	4.70	248.6
Non-inoculation	4629.5	1.59	9.95	460.1	4.84	222.2
LSD (0.05)	421.9	0.04	0.24	46.9	0.13	19.8

Mean comparison showed that for the both crops, grain N concentration, grain protein concentration, and protein yield were significantly higher in plants inoculated with Azotobacter compared to non-inoculated plants (Tables 1 and 2). In peanut, Azotobacter application increased grain N concentration, grain protein concentration, and protein yield by 2%, 2%, and 12%, respectively as averaged across years and intercropping patterns (Table 1). At the same time, inoculation with Azotobacter increased grain N concentration, grain protein concentration, and protein yield of maize by 7%, 7%, and 25%, respectively (Table 2). It has been reported that Azotobacter inoculation resulted in enhanced nutrients uptake specifically N, which could contribute to increasing amino acids content in plants and thereby increasing the plant protein content. Free-living bacteria such as Azotobacter species are able to interact with plant roots and the nitrogen fixed by these bacteria can be easily absorbed by plants (dos Santos et al., 2020). Besides biological N_2 fixation, the beneficial effects of Azotobacter on plant protein content are also attributed to an improvement in root development results in increase the rate of mineral N uptake by roots which in turn improves nitrogen status in plants. Abdiev et al. (2019) found that seed inoculation of different chickpea cultivars with *Azotobacter chroococcum* resulted in 7-8% increase in the grain protein content.

Mean comparison showed that the highest grain yields of peanut were observed in sole cropping and 100% peanut + 50% maize intercropped plots (2513.8 and 2505.0 kg ha^{-1}, respectively) in 2018, while the highest grain yield of peanut in 2019 was observed in sole cropping (3039.3 kg ha^{-1}) (Table 3).

Among intercropped plots, plots with 100% peanut + 50% maize intercropping pattern produced the highest grain yields (2505.0 and 2757.3 kg ha^{-1} in 2018 and 2019, respectively), followed by 67% peanut + 33% maize intercropping pattern (1979 and 1862.6 kg ha^{-1} in 2018 and 2019, respectively). The lowest grain yield of peanut was recorded for plots with 50% peanut + 100% maize intercropping pattern (560.8 and 368.0 kg ha^{-1} in 2018 and 2019, respectively) in both years as averaged across Azotobacter inoculations (Table 3). Result also showed that peanut produced more grain yield in the second season, while there was no significant difference in maize grain yield between years. Averaged across years and Azotobacter inoculations, the highest grain yield of maize was recorded for sole cropping (6896.7 kg ha^{-1}), with a value statistically similar to 50% peanut + 100% maize intercropped plots (6449.5 kg ha^{-1}), followed by 33% peanut + 67% maize intercropped plots (5588.2 kg ha^{-1}) with a value statistically similar to 100% peanut + 100% maize intercropped plots (5561.3 kg ha^{-1}); the lowest grain yield of maize was observed in 67% peanut + 33% maize intercropped plots (2903.7 kg ha^{-1}) (Table 4). Similarly, Kermah et al. (2017) and Gao et al. (2020) reported that sole cropping of maize and peanut produced greater grain yields than the associated intercrops.

Averaged across years and Azotobacter applications, the highest value for peanut grain N concentration was recorded for sole cropping (4.66%), 50% peanut + 50% maize (4.61%) and 67% peanut + 33% peanut (4.60%) intercropping patterns in 2018, while in 2019 sole cropping of peanut (4.74%) had the highest grain N concentration. Similar trends were also observed for protein grain concentration of peanut (Table 3). These results showed that grain N and protein concentrations of peanut in intercropped plots were statistically similar or significantly lower than those in sole cropping. This may be due to competition between peanut and maize for nitrogen, which in turn resulted in reduced N uptake by peanut plants in intercropped plots compared to those in sole cropping. In a greenhouse study, Inal et al. (2007) reported that the nitrogen concentration of peanut in response to intercropping with maize was not significantly changed compared to peanut sole cropping. Vlachostergios et al. (2015) found that red pea monocrop showed the highest crude protein concentration followed by its intercrops with barely (*Hordeum vulgare* L.), and triticale (×*Triticosecale* Wittmack).

Table 3. Mean comparison for the main effect of intercropping pattern on peanut grain oil concentration (PGOC), and for the interaction effect between intercropping pattern and year on peanut grain yield (PY), peanut grain N concentration (PGNC), peanut grain protein concentration (PGPC), peanut protein yield (PPY), and peanut oil yield (POY)

Intercropping patterns	PY (kg ha^{-1})		PGNC (%)		PGPC (%)		PPY (kg ha^{-1})		PGOC (%)	POY (kg ha^{-1})	
	2018	2019	2018	2019	2018	2019	2018	2019	-	2018	2019
Peanut sole cropping	2513.8a	3039.3a	4.66a	4.74a	25.4a	25.8a	642.1a	789.3a	46.6b	1154.5a	1433.0a
100%P:100%M	1008.8d	593.1f	4.18e	4.50bc	22.8e	24.5bc	230.1d	146.1f	48.6a	489.6d	289.1e
100%P:50%M	2505.0a	2757.3b	4.38dc	4.28d	23.9cd	24.1c	598.6a	645.3b	49.3a	1237.5a	1357.1a
50%P:100%M	560.8e	368.0g	4.26de	4.42c	23.2de	23.4d	130.6e	89.1g	49.5a	278.1e	182.1f
50%P:50%M	1358.5c	1190.3d	4.61ab	4.52b	25.2ab	24.6bc	343.3c	294.0d	48.7a	661.8c	582.5c
67%P:33%M	1979.5b	1862.6c	4.60ab	4.56b	25.1ab	24.9b	497.1b	462.3c	49.2a	969.5b	918.1b
33%P:67%M	932.0d	903.0e	4.52bc	4.54bc	24.6bc	24.8b	229.8d	224.1e	48.6a	454.8d	438.0d
LSD (0.05)	260.3	189.5	0.14	0.13	0.8	0.7	55.0	48.4	1.4	120.9	83.4

P: Peanut; M: Maize.

Results of the current study also showed that in 2018, the highest protein yields were observed for sole cropping and 100% peanut + 50% maize intercropped plot with the values of 642.1 and 598.6 kg ha^{-1}, respectively. At the same time, the lowest protein yield for peanut (130.6 kg ha^{-1}) was recorded for 50% peanut + 100% maize intercropping plot. In 2019, the highest and the lowest protein yields were observed for sole cropping and 50% peanut + 100% maize intercropped plot with the values of 789.3 and 89.1 kg ha^{-1}, respectively. These results show that protein yield for 50% peanut + 100% maize intercropped plots reduced by 80 and 89% (in 2018 and 2019, respectively) compared to those of peanut sole cropping. With regard to formula 2, this was mainly due to remarkable reduction in peanut grain yield in the 50% peanut + 100% maize intercropped plots, and to some extent was due to reduction in protein concentration in aforementioned plots compared to sole cropping.

Regardless of year and Azotobacter application, the highest grain N concentration and grain protein concentration of maize were recorded for all additive intercropped plots (100% peanut + 50% maize (1.72% and 10.79%, respectively), 100% peanut + 100% maize (1.71% and 10.73%, respectively), and 50% peanut + 100% maize (1.69% and 10.57%, respectively), which were significantly higher than those in other intercropping patterns and maize sole cropping. Similarly, Kadžiulienė et al. (2011) reported the protein grain content and protein yields of cereals [spring wheat (*Triticum aestivum* L.), barley, oat (*Avena sativa* L.), and triticale] grown in intercrops were positively affected by pea intercrops. Result also revealed that there were no significant differences in maize grain N and protein concentrations among replacement intercropping pattern and sole cropping. In a previous study, Inal et al. (2007) reported that nitrogen concentration of maize intercropped with peanut was statistically similar to that of sole cropping. Results of the current study also showed that the highest protein yield of maize was recorded for 50% peanut + 100% maize intercropped plots (684.7 kg ha^{-1}), with a value statistically similar to sole cropping (677.2 kg ha^{-1}) and 100% peanut + 100% maize (598.3 kg ha^{-1}), followed by 33% peanut + 67% maize intercropped plots (558.2 kg ha^{-1}), 100% peanut + 50% maize intercropped plots (407.3 kg ha^{-1}), with a value statistically similar to 50% peanut + 50% maize (396.8 kg ha^{-1}); the lowest was observed in 67% peanut + 33% maize intercropping plots (294.8 kg ha^{-1}) (Table 4).

Table 4. Mean comparison for the main effect of intercropping pattern on maize grain yield (MY), maize grain N concentration (MGNC), maize grain protein concentration (MGPC), maize protein yield (MPY), and maize oil yield (POY), and for the interaction effect between intercropping pattern and year on maize grain oil percent (MGOP)

Intercropping patterns	MY (kg ha^{-1})	MGNC (%)	MGPC (%)	MPY (kg ha^{-1})	MGOP (%)		MOY (kg ha^{-1})
					2018	2019	
Maize sole cropping	6896.7a	1.56c	9.78c	677.2a	5.12a	5.57a	366.2a
100%P:100%M	5561.3b	1.71a	10.73a	598.3ab	3.55c	3.54c	196.9d
100%P:50%M	3773.3c	1.72a	10.79a	407.3c	4.37b	5.29ab	181.6de
50%P:100%M	6449.5a	1.69ab	10.57ab	684.7a	3.92bc	3.82c	249.4c
50%P:50%M	3890.4c	1.62bc	10.17bc	396.8c	5.11a	5.55a	207.3d
67%P:33%M	2903.7d	1.61c	10.10c	294.8d	5.42a	5.02b	151.1e
33%P:67%M	5588.2b	1.591c	9.96c	558.2b	5.51a	5.03b	295.2b
LSD (0.05)	789.3	0.07	0.46	87.7	0.52	0.37	37.1

P: Peanut; M: Maize.

As we know, the protein yield depended greatly on grain yield of crop. Therefore, significant reduction in maize protein yield of the 67% peanut + 33% maize intercropping pattern compared to sole cropping was mainly due to lower maize grain yield in aforementioned intercropping pattern compared to that of sole cropping.

Averaged across years and Azotobacter applications, significantly higher grain oil concentration of peanut was recorded for all intercropping patterns compared to sole cropping. As a rule, there is a negative correlation between oil and protein concentrations. Result of the current experiment also confirmed this fact, as the intercropping plots with the higher grain oil concentration showed the lower protein concentration (Table 3). In both years, the highest oil yield of peanut were recorded for sole cropping and 100% peanut + 50% maize intercropping pattern, while the lowest one was recorded for 50% peanut + 100% maize intercropping pattern.

For maize, in both years, grain oil concentration of some intercropping patterns was statistically equal with that of sole cropping, while the other intercropping patterns showed significantly lower grain oil concentration than sole cropping (Table 4). Moreover, sole cropping of maize produced the highest oil yield (366.2 kg ha^{-1}) (Table 4). Among intercropping plots, the highest grain oil yield was recorded for 67% maize + 33% peanut (295.2 kg ha^{-1}), while the lowest one was recorded for 50% maize + 100 peanut (181.6 kg ha^{-1}) and 33% maize + 67% peanut (151.1 kg ha^{-1}) (Table 4). Klimek-Kopyra et al. (2017) reported that oil yield of linseed (*Linum usitatissimum* L.) was significantly greater in sole cropping than linseed-pea or linseed-common vetch intercropping systems, while the greatest oil content of linseed was found when intercropped with pea. Rezvani Moghaddam et al. (2014) reported that *Azotobacter chroococcum* inoculation significantly increased essential oil percent of cumin (*Cuminum cyminum* L.) when intercropped with fenugreek (*Trigonella foenum-graecum* L.), but had no significant effect on oil yield of cumin. In contrast, they found that intercropping pattern significantly increased oil yield of cumin, but had no significant effect on essential oil percentage of cumin.

Land equivalent ratio ranged from 1.05 to 1.70 among years, intercropping patterns, and Azotobacter application (Table 5), indicating the benefit of intercropping system compared to sole cropping. In other words, more land area in sole cropping is required to produce the equal amount of grain yield recorded under intercropping systems. Moreover, inoculated plots showed 12-16% grater LER that non-inoculated plots. The highest LER was observed for inoculated plots with 100% peanut + 50% maize intercropping pattern (1.70), followed by non-inoculated plots with 100% peanut + 50% maize intercropping pattern (1.52), inoculated plots with 33% peanut + 67% maize intercropping pattern (1.33), and inoculated plots with 67% peanut + 33% maize intercropping pattern (1.30); the lowest LER was recorded for non-inoculated plots with 50% peanut + 50% maize intercropping pattern (1.05) (Table 5).

Table 5. LER values of different intercropping patterns of peanut and maize affected by Azotobacter inoculation

	Year	Intercropping patterns					
		100%P:100%M	100%P:50%M	50%P:100%M	50%P:50%M	67%P:33%M	33%P:67%M
Non-inoculation	2018	1.27	1.53	1.15	1.10	1.17	1.19
	2019	0.95	1.51	1.06	1.00	1.09	1.15
Two years' average		**1.11**	**1.52**	**1.11**	**1.05**	**1.13**	**1.17**
Inoculation	2018	1.49	1.75	1.30	1.25	1.33	1.33
	2019	1.10	1.65	1.27	1.14	1.26	1.33
Two years' average		**1.30**	**1.70**	**1.29**	**1.20**	**1.30**	**1.33**

This result showed that all intercropping patterns had LERs greater than unity, indicating a more efficient and productive use of environmental resources by intercrops. Maize and peanut are morphologically different in above- and below ground structures. Also, their time of peak demand and requirement of light, nutrients and water are different. Thus, the complementary effect between maize and peanut is very common in intercropping systems. Jiao et al. (2008) found that in maize-peanut intercropping system, maize used strong light while peanut preferred weak light under maize canopy, resulted in yield advantage. Similarly, Kermah et al. (2017) reported that LERs of all maize-legume intercrops were greater than one. At the same time, results also showed that additive intercropping patterns, in most cases, showed greater LER than replacement intercropping patterns, indicating more benefit of additive intercropping patterns compared to replacement intercropping patterns. Consistent with our result, Maitra et al. (2021) revealed that the LER in additive series of intercropping exhibits the combined value of base crop with 100% plant density and the additional value of intercrops which ultimately results in the combined LER value with more than one.

CONCLUSIONS

The experiment illustrated that inoculation with *Azotobacter chroococcum* had significant positive effect on grain yield of maize and peanut both in monoculture and intercropping system. However, maize grain yield increased more than that of peanut (16% vs. 10%). The advantages of all intercropping patterns were verified by LER values greater than one. Among intercropping patterns, the greatest LER was recorded for inoculated plots with 100% peanut + 50% maize intercropping pattern. Therefore, this intercropping pattern along with *Azotobacter chroococcum* inoculation is recommended to obtain the highest productivity in maize/peanut intercropping system in the region.

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