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ROW CONFIGURATION AFFECTS YIELD AND SYSTEM PRODUCTIVITY OF MAIZE-BEAN INTERCROPPING UNDER VARIED NITROGEN LEVELS IN KASHMIR TEMPERATE CONDITIONS

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ABSTRACT

Cereal legume intercropping is considered as promising cropping system to surge crop productivity. A field trial was conducted during summer 2023 in a randomized block design with three replications to evaluate maize-bean intercropping under different nitrogen levels. The experiment comprised of 10 treatments involving sole maize, sole beans, maize-bean intercropping in 1:1 (IC-I) and 1:2 (IC- II) row ratios, each supplied with 0, 60 and 120 kg N ha^{-1}, along with sole bean at the recommended NPK dose. Maize growth, yield, nitrogen use efficiency and system productivity were significantly influenced by row arrangement and nitrogen level. The 1:1 intercropping arrangement with 120 kg N ha^{-1}, though statistically comparable with IC-II, recorded highest maize yield of 8.78 t ha^{-1}, while bean seed yield was highest under IC-II at the same N level. Maize equivalent yield (MEY) and land equivalent ratio (LER > 1) confirmed a consistent advantage of intercropping over sole cropping. These results indicate that maize-bean intercropping in 1: 2 row arrangement with 120 kg N ha^{-1} (IC-II + N_2) is an optimum treatment for enhancing system productivity and land use efficiency, while IC-I + N2 is the best treatment for maize yield under temperate agro-ecosystems.

Keywords: Intercropping, land equivalent ratio, maize-equivalent yield, nitrogen management, nutrient use efficiency, system productivity

INTRODUCTION

World agriculture is facing tough challenge of meeting the food demand of an ever-increasing population. This challenge is further complicated by the growing environmental concerns associated with the intensive use of chemical fertilizers. Maize (*Zea mays* L.), an important cereal crop, accounts for 19% of calorie intake capita^{-1} day^{-1} (Santpoort, 2020) and is world-wide a major target of food security programs. The wider adaptability, high yield potential, and diverse uses make maize an important crop of temperate regions (Sharma *et al*., 2020). Owing to its exhaustive and rapid growing nature, the demand for nutrients particularly nitrogen is more. Additionally, wider geometry followed in its establishment owing to its robust growing nature, leaves vacant space in between crop rows, primarily at earlier stage, which creates an opportunity for inclusion of legume crop in between wider crop rows. Integrating cereals with legumes in intercropping systems has been recognized as an efficient way to improve productivity while maintaining sustainability.

Common bean (*Phaseolus vulgaris* L.), an important legume, is valued both for its role in human diet as a protein source and for its contribution to soil fertility through biological nitrogen fixation (Herrera *et al.*, 2019). Inclusion of beans in widely spaced maize rows may create favourable conditions for complementary use of both above and below ground resources. Such intercropping systems have been accredited for enhanced resource complementarity, yield stability and land-use efficiency (Lithourgidis *et al*., 2011; Li *et al*., 2020). Nitrogen plays a vital role in maize production due to its high demand for this nutrient (Li *et al.*, 2020), while beans can partially meet their nitrogen requirement through symbiotic associations with rhizobia (Peoples *et al*., 2015). Consequently, appropriate nitrogen management in maize + bean intercropping remains critical for maximizing the benefits of complementarity while minimizing the nutrient losses and associated environmental impacts (Hauggaard-Nielsen *et al*., 2001).

Row configuration strongly influences the canopy growth and resource utilization consequently, benefits the intercropping system combining tall and short crops (Stomph *et al.*, 2020; Raza *et al.*, 2023). Although maize-legume intercropping has been evaluated under Kashmir conditions, particularly with respect to crop productivity and resource use efficiency (Bhat *et al.*, 2019a), the response of maize + beans intercropping to distinct row arrangements under varying nitrogen levels is inadequate. Kashmir valley experiences short growing seasons, fluctuating temperatures and uneven rainfall, which may further restrict crop growth, resource utilization and nitrogen dynamics. Hence, identifying appropriate row arrangement and nitrogen levels is vital for improving the productivity of maize + bean intercropping. We hypothesized that an appropriate combination of row configuration and nitrogen supply would improve maize yield and nitrogen use efficiency while enhancing system productivity. Therefore, the present study was aimed to evaluate the effect of distinct maize-bean row arrangements and nitrogen regimes on crop growth, yield, nitrogen use efficiency and overall system productivity.

MATERIALS AND METHODS

Field experiment was laid out in summer 2023 at Agronomy Research Farm, SKUAST Kashmir, Wadura, Sopore (Kashmir) [1590 m amsl] having a typical temperate climate. The soil of the site at 0-20 cm depth was clay loam in texture with pH 6.9, organic carbon 0.72% and available nitrogen, phosphorus, and potassium of 278.7, 19.1 and 205.7 kg ha^{-1}, respectively. The crop was sown on residual moisture, and meteorological data with respect to the total rainfall received during cropping period, and the mean maximum and minimum temperature of location at weekly intervals were noted. Maize and common bean crops were intercropped with different row ratios in a randomized complete block design (RCBD) with three replications. The treatments comprised of sole maize with 0 (N_0), 60 (N_1) and 120 (N_2) kg N ha^{-1}, maize + bean intercropping in 1:1 (IC-I) and 1: 2 (IC-II) row ratio at N_0, N_1 and N_2, respectively, and sole beans at recommended fertilizer dose (30:60:30, N: P_2O_5: K_2O kg ha^{-1}, respectively). Urea, single super phosphate (SSP) and muriate of potash (MOP) were used as source for N, P and K, respectively. The nitrogen was applied, as per treatment, in the form of urea in three equal splits [basal, knee high stage and tasselling]. Urea, single super phosphate (SSP) and muriate of potash (MOP) were used as source for N, P and K, respectively. The nitrogen was applied as per treatment in three equal splits as basal, knee high and tasselling stages; whereas, phosphorus and potassium were applied in a single dose at the time of sowing. Each experimental plot was 4.2 × 2.4 m (10.08 m^2) in size, two border rows were excluded, leaving a net plot area of 6.72 m^2 for observation and yield estimation. Maize and bean seeds for experimental study were procured from Dryland Agriculture Research Station (DARS), Budgam, SKUAST-Kashmir. Maize seed cv. 'Shalimar Maize Hybrid-1' with genetic purity of 95%, was sown manually in rows 70 cm apart and 20 cm within row, whereas beans (Local landrace) were included as single or double row arrangement in between maize rows following an additive series arrangement. In sole bean, seeds were sown at 60 cm × 20 cm. The treatments were designed to evaluate the effects of nitrogen levels and intercropping system on growth, yield, and system productivity of maize and common beans.

Data collection

Plant growth parameters including plant height, leaf area index and plant dry matter accumulation were assessed at harvest. From each plot five randomly tagged plants within net area were selected for measurements. For maize same five tagged plants were used for measuring the yield attributes like number of cobs plant^{-1}, cob length (cm), number of grains row^{-1} and number of rows cob^{-1}. After harvest, cobs were separated and threshed to measure seed weight in kg plot^{-1}. The values obtained were converted to t ha^{-1}. The measurement data followed in beans was on similar lines to that of maize. For assessing leaf area, green leaves from the sampled plants were excised and total leaf area measured using a Systronics leaf area meter (Model 211). Leaf area index (LAI) was calculated as:

$$\mathrm{LAI} = \frac{\text{Leaf area}}{\text{Ground area}}$$

Assessment of intercropping system

Maize and bean plants sampled from each treatment were cut off at the soil surface and subjected to shade drying for 48 h followed by oven drying at 65ºC to a constant weight. To compare the productivity of intercropping system with sole cropping system, maize equivalent yield (MEY) and land equivalent ratio (LER) were calculated to determine the efficiency of intercropping relative to sole cropping. MEY was calculated for both the crops and the same was added to give system productivity as follows (Menia *et al.*, 2021):

$$\mathrm{MEY} = (\mathrm{Ymi}) + \frac{\mathrm{Yim} \times \mathrm{pi}}{\mathrm{Pm}}$$

Where, Ymi = Yield of maize in intercropping system, Yim = Yield of beans in intercropping system, Pi = Price of beans, Pm = Price of maize.

Land equivalent ratio was used to assess the resource utilization under intercropping compared to sole cropping using following formula (Willey and Rao, 1980):

$$\mathrm{LER} = \frac{\mathrm{ymb}}{\mathrm{ymm}} + \frac{\mathrm{ybm}}{\mathrm{ybb}}$$

Where, ymb denotes yield of maize in intercropping system; ymm denotes yield of maize as sole crop, ybm denotes yield of bean in intercropping, and ybb denotes yield of beans as sole crop.

Aggressivity was used assess the competitiveness of component crops in an intercropping system using following formula (Mc Gilchrist, 1965):

$$\text{Aggressivity (Amb)} = \left(\frac{\mathrm{Ymb}}{\mathrm{Ymm} \times \mathrm{Zmb}}\right) - \left(\frac{\mathrm{Ymb}}{\mathrm{Ybb} \times \mathrm{Zbm}}\right)$$

Where, ‘Zmb’ denotes proportion of maize in intercropping and ‘Zbm’ denotes proportion of beans in intercropping system.

Nitrogen content uptake and nitrogen use efficiency

After harvest grain and stover samples were analysed for nitrogen content using Kjeldhal method after wet digestion by H_2SO_4 and K_2SO_4-$CuSO_4$ catalyst mixture ((Bremner and Mulvaney, 1982). Nitrogen uptake and different components of NUE were calculated using the formulae of Ladha *et al.* (2005) and Baral *et al.* (2020), respectively;

$$\text{N uptake in grain} = \frac{\mathrm{GY} \times \mathrm{NC}}{100} \quad (1)$$

$$\text{Agronomic nitrogen use efficiency AEN} = \frac{\mathrm{GYN} - \mathrm{GY0}}{\mathrm{FN}} \quad (2)$$

$$\text{Partial factor productivity PPFN} = \frac{\mathrm{GYN}}{\mathrm{FN}} \quad (3)$$

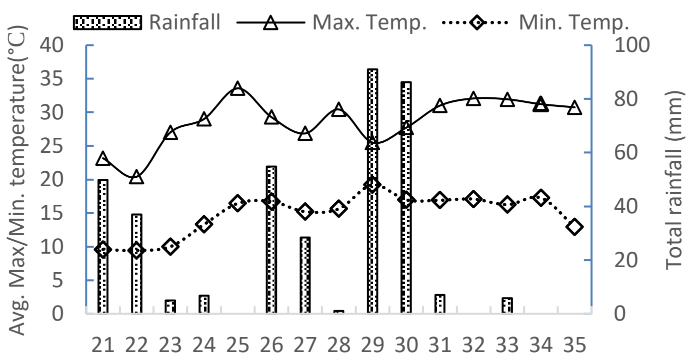
Where, GY- Yield of the respective plant component (Grain or stover) (kg ha^{-1}); NC- N content in grain (%); GY_N- Grain yield in nitrogen applied treatment (kg ha^{-1}), GY_0- Grain yield in N control treatment (kg ha^{-1}); F_N- Fertilizer nitrogen applied (kg N ha^{-1})

Statistical analysis

The data recorded during the study was analysed by analysis of variance (ANOVA) technique for randomized block design using OPSTAT® statistical software (Beta version; Sheoran *et al.*, 1998). Prior to ANOVA, the assumptions of independence of observations, normality of residuals and homogeneity of variance were considered. Treatment means were compared using Duncan's multiple range test (DMRT) at $p \leq 0.05$ to identify the significant difference among the treatments.

RESULTS AND DISCUSSION

The maize crop was sown on residual moisture with total rainfall amounting to 428 mm, received during cropping period of summer 2023. The mean maximum and minimum temperature of location were 28.5 & 14.0°C, respectively (Fig. 1).



Standard metereological weeks

Fig. 1: Weather parameters (mean maximum/ minimum temperatures and total rainfall) prevailing during the cropping period of 2023

Maize growth attributes

Vegetative developmental response of maize in terms of plant height (PH), leaf area index (LAI) and dry matter accumulation (DMA) was significantly affected by nitrogen application (N0-N2). Compared to sole planting, maize intercropped with beans in 1:1 (IC-I) and 1:2 (IC-II) arrangement, showed improvement in growth parameters. However, IC-II recorded numerically higher values than IC-I (Table 1). At N_2 (120 kg N ha^{-1}), IC-I recorded an increment of 14.18 and 34.21% in plant height, 79.0 and 56.7% in LAI, and 20.6 and 46.4% in DMA over N_1 and N_0, respectively. At elevated level of N application, increased nitrogen availability likely promoted the synthesis of growth

Table 1: Growth attributes of maize and beans as influenced by intercropping pattern and nitrogen levels

Treatments		Growth parameters					
		Maize			Beans		
Cropping pattern	N application rate (kg ha^{-1})	Plant height (cm)	Leaf areas index	Dry matter accumulation (g plant^{-1})	Plant height (cm)	Leaf areas index	Dry matter accumulation (g plant^{-1})
Sole maize	N_0	218^c	1.25d	104^d	-	-	-
	N_1	238^c	1.91^c	131^b	-	-	-
	N_2	287^{ab}	2.87^a	146^b	-	-	-
Intercropping IC-I	N_0	228^c	1.85^c	112^d	170 ^{c}	0.97^e	78^c
	N_1	268^b	1.62^c	136^{bc}	185^a	1.27^c	112^b
	N_2	306^a	2.90^a	164^a	195^a	1.29^c	129^a
Intercropping IC- II	N_0	235^c	2.35^b	128^c	165^c	1.14^d	68^d
	N_1	273^b	1.99^{bc}	145^b	175^{bc}	1.74^a	88^c
	N_2	315^a	3.08^a	164^a	172^{bc}	1.95^a	116^b
Sole beans	RDF	-	-	-	188^{ab}	1.53^b	122^{ab}
	$LSD_{0.05}$	28.33	0.42	14.06	17.71	0.18	13.27

IC-I - maize-bean 1:1 row ratio; IC-II - maize bean 1: 2 row ratio; N_0 - 0 kg N ha^{-1}; N_1 - 60 kg N ha^{-1}; N_2 - 120 kg N ha^{-1}; RDF - Recommended dose of fertilizers.
Different values followed by same letter within the same column do not differ significantly at $p \leq 0.05$.

regulators such as auxins, facilitating rapid cell division and elongation thus reflecting in overall growth enhancement (Wei *et al*., 2022). Advantage attributed to maize under intercropping might be due to greater light interception (Liu *et al.*, 2018), water use efficiency (Rahman *et al.*, 2017) and nutrient acquisition (Ahmed *et al.*, 2018). However, the present results differed with the earlier findings of Bhat *et al.* (2019b) and Meena *et al.* (2025) who reported superior values for maize growth under sole cropping attributing this to unrestricted access to essential resources such as light, nutrients and moisture with no competition from component crops. These contrasting responses may be attributed to differences in the agro-morphological traits and growth habits of maize and bean genotypes, along with variations in environmental conditions. Difference in plant stature, canopy architecture and competing ability of component crops may have influenced the resource acquisition and interspecific interactions, thereby resulting in contrasting responses of maize under sole and intercropping system.

Table 2: Yield components of maize and beans as influenced by intercropping pattern under varied nitrogen levels

Treatments		Yield attributes							
		Maize					Beans		
Cropping pattern	N application rate (kg ha^{-1})	No. of rows cob^{-1}	Cob length (cm)	No. of grains row-^{1}	No. of grains cob-^{1}	100 grain weight (g)	No. of pods plant$_{-1}$	No. of seeds pod$_{-1}$	Seed index
Sole maize	N_0	13.7^{a}	15.5^{e}	25.5^{d}	349.3^{e}	19.5^{b}			
	N_1	13.4^{a}	19.7^{cd}	36.6^{b}	490.4^{c}	23.8^{ab}			
	N_2	14.1^{a}	20.9^{bcd}	37.7^{b}	531.5^{bc}	26.2^{a}			
Intercropping	N_0	13.5^{a}	17.4^{de}	29.7^{c}	400.9^{d}	22.8^{ab}	10.8^{de}	4.3^{c}	23.1^{b}
IC-I	N_1	13.7^{a}	20.9^{bcd}	37.1^{b}	508.2^{bc}	22.9^{ab}	13.0^{b}	5.8^{a}	29.5^{a}
	N_2	13.9^{a}	27.2^{a}	42.5^{a}	590.7^{a}	26.7^{a}	13.4^{ab}	5.9^{a}	30.8^{a}
Intercropping	N_0	13.7^{a}	18.7^{cde}	36.8^{b}	505.2^{c}	22.5^{ab}	9.8^{e}	4.4^{bc}	24.1^{b}
IC-II	N_1	14.0^{a}	22.6^{bc}	37.1^{b}	521.9^{bc}	24.0^{a}	10.3^{de}	5.6^{ab}	30.6^{a}
	N_2	13.8^{a}	23.1^{b}	39.8^{ab}	549.2^{ab}	25.1^{a}	11.4^{cd}	5.8^{a}	30.0^{a}
Sole beans	RDF	-	-	-	-	-	15.2a	6.1^{a}	31.2^{a}
$LSD_{0.05}$		ns	3.98	4.35	43.32	4.41	1.84	1.16	5.17

IC-I, Maize-bean 1:1 row ratio; IC-II, Maize bean 1: 2 row ratio; N_0, 0 kg N ha^{-1}; N_1, 60 kg N ha^{-1}; N_2, 120 kg N ha^{-1}; RDF, Recommended dose of fertilizers; ns, non -significant

Different values followed by same letter within the same column do not differ significantly at $p \leq 0.05$.

Maize yield attributes and yield

Yield attributes of maize like cob length, number of grains row^{-1} and number of grains cob^{-1} improved significantly ($p \leq 0.05$) with higher N application rate under IC-I intercropping system. Maize in IC-I recorded significantly larger cob length (27.2 cm), number of grains row^{-1} (42.5), number of grains cob^{-1} (590) and 100 grain weight of 26.7 g (Table 2). Furthermore, the magnitude of superiority at N_2 in IC-I for yield attributes of maize ranged from 17.73 and 30.14% for cob length, 6.7 and 12.73% for number of grains row^{-1}, 7.5 and 11.13% for number of grains cob^{-1} and 6.3 and 1.9% for 100 seed weight compared to IC-II and sole maize, respectively. This increase in the key yield parameters was consistent with the improvement in growth parameters under intercropping and may be attributed to complimentary effect of beans favouring proper source sink relation.

The highest grain yield (8.78 t ha^{-1}) was obtained in maize + bean IC-I at N_2 though remaining statistically similar with IC-II under same nitrogen rate of application. Furthermore, same treatment echoed an increment of 5.27 and 10.02% in grain yield over IC-II and sole maize at same nitrogen level, respectively. Legume based intercropping affects the maize growth, yield attributes and yield through improved nutrient acquisition associated with the symbiotic relationship with *Rhizobium*. Our results align with the findings of Zhang *et al.* (2017) and Hu *et al.* (2020), who attributed yield gain in intercropping to complementary interaction among the component crops for better resource capture and utilization compared to monoculture. Such yield enhancement under intercropping may arise from interspecific facilitation through enhanced resource acquisition, which can offset inter-specific competition between the component crops (Li *et al*., 2010). IC-I at N_2 indicates the potential for achieving higher maize yield, while obtaining an additional bean harvest from same land.

Bean growth attributes

On contrary to maize, beans demonstrated higher values for growth parameters such as PH and DA plant^{-1} under IC-I at each level of nitrogen compared to IC-II. Significantly taller plants were recorded in beans at higher level of N_2 under IC-1 though remaining statistically indifferent from IC-I at N_1 and sole beans at recommended rate of fertilizers (Table 1). This better growth under IC-I might have occurred due to effective spatial differentiation between the two intercrops. Furthermore, the climbing habit of pole type beans allowed them to avoid shading by maize, facilitating better light interception and overall improvement in growth. Unlike PH and DA, higher LAI values for beans were registered in IC-II compared to IC-I at same N level. Compared to sole beans at the recommended fertilizer dose, IC-II at N_2 recorded higher LAI (1.95), though remaining statistically indifferent from IC-II at N_1 (1.74), but significantly superior than sole beans (1.53). This increase in LAI in IC-II can be attributed to higher nitrogen availability, supporting cell division, chlorophyll production, and meristematic activity. Additionally, the presence of beans contributed to moisture conservation, nitrogen fixation and complementary root interactions, all of which further improved canopy development (Dawadi *et al*., 2012; Raza *et al*., 2022; Gaikwad *et al*., 2022).

Bean yield attributes and yield

Intercropping of beans with maize, well supplied with 120 kg N ha^{-1} significantly affected the yield attributes of bean ($p \leq 0.05$). Though sole beans at recommended rate of N application exhibited higher values for pods plant^{-1}, seeds pod^{-1} (6.1) and seed index (31.2), but were statistically at par with intercropping in IC-I at higher level of N (N_2) for pods plant^{-1} (Table 2). Grain yield of intercropped bean increased between 0.42 to 1.03 and 0.88 to 1.24 t ha^{-1} with the increase in N application from N_0-N_2 under IC-I and IC-II, respectively Fig. 2). Furthermore, intercropped beans in

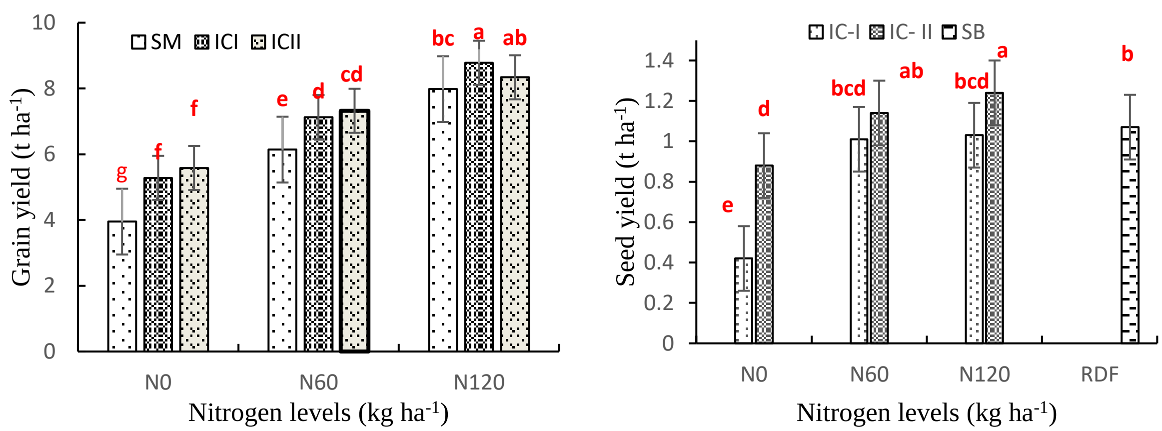


Fig. 2: Yield of maize (left side) and beans (right side) as affected by intercropping at varied nitrogen levels

IC-II at N_2 produced significantly highest grains with 20.38 and 15.88% superiority over IC-I at N_2 and sole bean supplied with recommended fertilizer dose, respectively. This increase in yield under IC-II at N_2 can largely be explained on account of additive nature of beans in intercropping system as well as the physical support provided by the maize plants, which enhances the growth performance of climbing bean varieties. Additionally, this arrangement of IC-II with 120 Kg N ha^{-1} could be advantageous for farmers seeking higher bean yield in maize + beans intercropping.

Nitrogen content, uptake and nitrogen use efficiency

Irrespective of the cropping pattern, maize crop accumulated more nitrogen in terms of the content and uptake both in grain and stover with increase in nitrogen levels (Table 3). In IC-I maize crop recorded significantly highest numerical N content and uptake both in grain and stover at N_2, though remaining statistically similar to IC-II and sole crop of maize at same N level. Higher N accumulation of 4.16% in IC-I with N_2 over sole maize crop indicates enhanced N transfer from the component crop, unlike IC-II, where grain N content was lower by 4.76% compared to sole maize at the same level of N, on account of severe intraspecific competition due to higher legume population. Our results align with the findings of Hu *et al.* (2020) who found 31% increment in N accumulation of

Table 3: Nitrogen content, uptake and nitrogen use efficiency as affected by intercropping pattern under varied nitrogen levels

Treatments		Nitrogen content (%)		Nitrogen uptake (kg ha^{-1})		Nutrient use efficiency in maize (kg kg^{-1})	
Cropping pattern	N application rate (kg ha^{-1})	Grains	Stover	Grains	Stover	PFP_N	AE_N
Sole maize	N_0	1.33^c	0.51^c	52.5^e	31.2^e	-	-
	N_1	1.37^c	0.63^c	84.1^{bcd}	54.6^c	102.3^b	39.37^a
	N_2	1.68^{ab}	1.07^a	134.1^a	117.2^a	66.5^c	35.03^a
Intercropping IC-I	N_0	1.34^c	0.59^c	70.8^{de}	42.8^{cd}	-	-
	N_1	1.49^{bc}	0.87^b	106.2^b	84.0^b	118.8^a	33.13^a
	N_2	1.75^a	1.11^a	153.7^a	127.4^a	73.2^c	30.3a
Intercropping IC- II	N_0	1.33^c	0.61^c	74.2^{de}	50.4^{cd}	-	-
	N_1	1.34^c	0.91^b	98.1^{bc}	88.8^b	122.0^a	31.50^a
	N_2	1.60^{ab}	1.14^a	133.4^a	128.3^a	69.5^c	24.36^a
$LSD_{0.05}$		0.19	0.15	22.41	14.43	12.96	ns

IC-I, Maize-bean 1:1 row ratio; IC-II, Maize bean 1: 2 row ratio; N_0, 0 kg N ha^{-1}; N_1, 60 kg N ha^{-1}; N_2, 120 kg N ha^{-1}; ns, non-significant.
Different values followed by same letter within the same column do not differ significantly at $p \leq 0.05$.

intercropped maize due to indirect N transfer from legume crop compared to sole maize. However, contrarily Meena *et al.* (2025) observed significantly higher N uptake in mono-cropped maize and attributed it to the absence of nutrient sharing. The contrasting response may be due to differences in crop combination, spatial arrangement and N availability, which can strongly influence the balance between nutrient competition and complementarity.

Partial factor productivity of fertilizer nitrogen (PFP_N) varied from 102.3 to 122.0 and 66.5 to 73.2 for N_1 and N_2, respectively. Irrespective of the cropping pattern, PFP_N generally decreased with increase in N application rate due to lesser yield increase relative to the applied nitrogen supply. Decrease in NUE at higher N application rates was also reported in brassica and cereals (Jehangir *et al*., 2024). Overall intercropping increased NUE compared to sole crop. Additionally, NUE assessed in terms of PFP_N, though remaining at par between IC-I and IC-II, differed significantly from sole maize at lower level of N_1 (Table 3). An increase of 16.12, 19.25% at N_2 and 10.07, 4.51% at N_1 ha^{-1} in PPF_N was recorded in IC-I and IC-II, respectively, compared to sole maize. Similar increased NUE in intercropped maize have been attributed to the N compensation from legume component forcing greater N acquisition from applied N fertilizer (Hu *et al*., 2020).

Agronomic efficiency (AE_N), which is the yield increase unit^{-1} N applied, varied between 31.5 to 39.37 kg kg^{-1} at N_1 and 24.36 to 35.03 kg kg^{-1} at N_2 and was found to decrease with increase in N, irrespective of the cropping pattern (Table 3). In contrast to PFP_N, AE_N exhibited a numerical decrease compared to sole maize. The probable reason might be due to difference in yield response to applied nitrogen between sole and intercropped maize. Similar observations have reported AE_N varying between 10 to 30 kg kg^{-1} in well managed soils (Dobermann *et al*., 2007).

Intercropping indices

The land equivalent ratio (LER) values were used to derive the land benefits associated with intercropping. This additive intercropping consistently resulted in LER values above one, varying from 1.7 to 2.3 across the systems, with highest value recorded in IC-II supplied with N_1, followed by the same row ratio at N_2 (Table 4). These results indicate higher land productivity representing a 70-130% yield advantage in land use efficiency over mono-cropped maize. This higher LER reflects the sizeable land saving potential of maize + bean intercropping in temperate agroecology. Across the globe, the LER values for intercropping have been observed to stagger from 1.22 to 1.30 (Yu *et al.*, 2015; Martin-Guay *et al.*, 2018). Our results are consistent with Xua *et al.* (2020), who noted 30% increase in land productivity in maize soybean intercropping.

Table 4: Land equivalent ratio (LER), aggressivity (AI) and maize equivalent yield (MEY) as affected by intercropping pattern under varied nitrogen levels

Cropping pattern	N application rate (kg ha^{-1})	LER	AI	MEY (t ha^{-1})
Sole crop	N_0	-	-	3.95
	N_1	-	-	6.14
	N_2	-	-	7.98
Intercropping IC-I	N_0	1.7	1.9	9.06
	N_1	2.1	0.4	16.22
	N_2	2.1	0.3	18.05
Intercropping IC-II	N_0	2.2	3.0	13.50
	N_1	2.3	2.0	17.60
	N_2	2.2	1.4	19.50

IC-I, Maize-bean 1:1 row ratio; IC-II, Maize bean 1:2 row ratio; N_0, 0 kg N ha^{-1}; N_1, 60 kg N ha^{-1}; and N_2, 120 kg N ha^{-1}

Aggressivity, the measure of competitive strength among component crops, was positive for maize in all treatments. Irrespective of row arrangement and nitrogen application, maize was more competitive compared to beans particularly in treatments without nitrogen application (Table 4). This is likely due to maize's root system extensively explores both shallow and deeper soil layers, whereas bean roots remain mostly confined to the upper soil layer (Carruthers *et al*., 2000; Huggaard-Nielsen *et al*., 2001). These results are consistent with earlier studies of Li *et al*. (2001), reporting the dominant competitive ability of maize in intercropping systems.

Maize + bean intercropping IC-II at N_2 gave highest maize equivalent yield (MEY) of 19.5 t ha^{-1}, followed by IC-I (18.05 t ha^{-1}) at same level of N, with lowest MEY observed in sole maize without N application (Table 4). This indicates that varying the row ratio significantly influences overall system productivity. The superior MEY in IC-II was likely due to higher maize yield combined with relatively high market price of beans, corroborating the results of Chaudhary and Choudhary (2018).

The present study revealed that maize + bean intercropping in temperate Kashmir is strongly responsive to the spatial arrangement and N fertilization. Among the tested intercropping systems at 120 kg N ha^{-1}, IC-I produced highest maize grain yield while IC-II gave higher land use efficiency and maize equivalent yield. Overall, integrating pole type beans with maize in 1:2 row ratio with 120 kg N ha^{-1} offers a sustainable land saving and productive strategy for temperate agro-ecosystems, with the potential to improve total returns. However, as these findings are based on single year study, multi-year and multi-location trials are necessary to validate the performance of tested intercropping and N management across diverse environmental conditions before making recommendation.

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REFERENCES

Ahmed, S., Raza, M.A., Zhou, T., Hussain, S., Khalid, M.H.B., Feng, L., *et al.,* 2018. Responses of soybean dry matter production, phosphorus accumulation, and seed yield to sowing time under relay intercropping with maize. *Agronomy,* **8**: 1-18.

Baral, B.R., Pande, K.R., Gaihre, Y.K., Baral, K.R., Sah, S.K., Thapa, Y.B., *et al.*, 2020. Increasing nitrogen use efficiency in rice through fertilizer application method under rainfed drought conditions in Nepal. *Nutrient Cycling in Agroecosystems*, **118**: 103-114.

Bhat, S.F., Saad, A.A., Masood, A., Nazir, A. and Rasool, K. 2019a. Yield and yield attributes of maize and bean as influenced by intercropping under various tillage and fertilizer management practices in Kashmir valley. *Research Journal of Agricultural Sciences*, **10**(3): 552-557.

Bhat, S.F., Saad, A.A., Masood, A., Nazir, A., Maqbool, S. and Siddiqui, S. 2019b. Effect of intercropping of maize with bean under various tillage and fertilizer management practices on crop growth under the temperate conditions of Kashmir valley. *Research Journal of Agricultural Sciences*, **10**(3): 628-632.

Bremner, J.M. and Mulvaney, C.S. 1982. Nitrogen — Total. **In**: *Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties* (2nd edn.). Agronomy Monograph 9. American Society of Agronomy and Soil Science Society of America, Madison, WI, USA, pp. 595-624.

Carruthers, K., Prithiviraj, B., Fe, Q., Cloutier, D., Martin, R.C. and Smith, D.L. 2000. Intercropping corn with soybean, lupin and forages: Yield component responses. *European Journal of Agronomy*, **12**: 103-115.

Choudhary, V.K. and Choudhury, B.U. 2018. A staggered maize–legume intercrop arrangement influences yield, weed smothering and nutrient balance in the eastern Himalayan region of India. *Experimental Agriculture*, **54**: 181-200.

Dawadi, K.P. and Sah, S.K. 2012. Growth and yield of hybrid maize as influenced by planting density and nitrogen levels in Chitwan valley, Nepal. *Nepal Journal of Science and Technology*, **13**: 1-6.

Dobermann, A. 2007. Nutrient use efficiency — Measurement and management. pp. 1-28. **In**: *Fertilizer Best Management Practices: General Principles, Strategy for Their Adoption and Voluntary Initiatives Versus Regulations* (eds. A. Krauss, K. Isherwood, K. and P. Heffer). International Fertilizer Industry Association, Paris, France.

Gaikwad, D.D., Pankhaniya, R.M., Singh, B., Patel, K.G. and Viridia, H.M. 2022. Studies on growth and productivity of maize-cowpea intercropping system under different spatial arrangements and nutrient levels. *Pharma Innovation*, **12**: 2506-2512.

Hauggaard-Nielsen, H., Ambus, P. and Jensen, E.S. 2001. Temporal and spatial distribution of roots and competition for nitrogen in pea-barley intercrops – A field study employing ^{32}P technique. *Plant and Soil*, **236**: 63-74.

Herrera, A., Carmona, A. and García, P. 2019. Legume contributions to nitrogen cycling in cereal-based cropping systems. *Soil Biology and Biochemistry*, **135**: 45-55.

Hu, F., Yu, A., Zhao, C., Fan, Z., Yin, W., Chai, Q., *et al.*, 2020. Strip width ratio expansion with lowered N fertilizer rate enhances N complementary use between intercropped pea and maize. *Scientific Reports*, **10**: 19969. [*https://doi.org/10.1038/s41598-020-76815-7*].

Jehangir, I.A., Jan, B., Al-Tawaha, A, R.M., Hussain, A., Nazir, A., Bhat, M.A., *et al.*, 2024. Assessing the impact of nutrient omissions on growth, yield, and nutrient use efficiency in winter rape (*Brassica napus* L.) under rainfed ecology. *Journal of Plant Nutrition*, **47**: 1-12.

Ladha, J.K., Pathak, H., Krupnik, T.J.J., Six, J. and van Kessel, C. 2005. Efficiency of fertilizer nitrogen in cereal production: Retrospects and prospects. *Advances in Agronomy*, **87**: 85-156.

Li, G., Zhao, B., Dong, S., Zhang, J., Liu, P. and Lu, W. 2020. Controlled-release urea combining with optimal irrigation improved grain yield, nitrogen uptake, and growth of maize. *Agricultural Water Management*, **227**: 105834. [*https://doi.org/10.1016/j.agwat.2019.105834*].

Li, L., Sun, J., Zhang, F., Li, X., Yang, S. and Rengel, Z. 2001. Wheat/maize or wheat/soybean strip intercropping: I. Yield advantage and interspecific interactions on nutrients. *Field crops research*, **71**: 123-137.

Li, Q., Sun, J., Wei, X., Christie, P., Zhang, F., Li, L., 2010. Over yielding and interspecific interactions mediated by nitrogen fertilization in strip intercropping of maize with faba bean, wheat and barley. *Plant Soil*, **339**: 147-161.

Lithourgidis, A.S., Dordas, C.A., Damalas, C.A. and Vlachostergios, D.N. 2011. Annual intercrops: An alternative pathway for sustainable agriculture. *Australian Journal of Crop Science*, **5**: 396-410.

Liu, X., Rahman, T., Song, C., Yang, F., Su, B., Cui, L., *et al.*, 2018. Relationships among light distribution, radiation use efficiency and land equivalent ratio in maize soybean strip intercropping. *Field Crops Research*, **224**: 91-101.

Martin-Guay, M.O., Paquette, A., Dupras, J. and Rivest, D. 2018. The new Green Revolution: Sustainable intensification of agriculture by intercropping. *Science of the Total Environment*, **615**: 767-772.

Mc Gilchrist, C.A. 1965. Analysis of competition experiments. *Biometrics*, **21**: 975-985.

Meena, H., Patra, P.S., Adhikary, P., Ahmed, A.S., Kheroar, S., Deb, S., *et al.*, 2025. Optimizing resources for sustainable maize production under different intercrop association in eastern sub Himalayan region of India. *Frontiers in Sustainable Food Systems*, **9**: 1584085. [*doi: 10.3389/fsufs.2025.1584085*].

Menia, M., Saad. A.A., Sharma, J., Bochalya, S.R. and Bhagat, S. 2021, Resource-use efficiency in sweet corn based intercropping system under irrigated conditions of Kashmir valley, *Agriculture Mechanization in India*, **51**: 1407-1415.

Peoples, M.B., Brockwell, J., Herridge, D.F., Rochester, I.J., Alves, B.J.R., Urquiaga, S., *et al.*, 2015. The contributions of nitrogen-fixing crop legumes to the productivity of agricultural systems. *Symbiosis*, **57**: 1-17.

Rahman, T., Liu, X., Hussain, S., Ahmed, S., Chen, G., Yang, F., *et al.*, 2017. Water use efficiency and evapotranspiration in maize-soybean relay strip intercrop systems as affected by planting geometries. *PloS One* **12**: e0178332. [*https://doi.org/10.1371/journal.pone.0178332*].

Raza, M.A., Yasin, H.S., Gul, H., Qin, R., Mohi Ud Din, A., Khalid, M.H.B., *et al.*, 2022. Maize/soybean strip intercropping produces higher crop yields and saves water under semi-arid conditions *Frontiers in Plant Science*, **13**: 1006720. [*https://doi.org/10.3389/fpls.2022.1006720*].

Santpoort, R. 2020. The drivers of maize area expansion in Sub-Saharan Africa. How policies to boost maize production overlook the interests of smallholder farmers. *Land*, **9**: 68-81.

Sharma, S., Kumar, R. and Singh, P. 2020. Maize production in temperate regions: Constraints and opportunities. *Indian Journal of Agricultural Sciences*, **90**(5): 887-895.

Sheoran, O.P., Tonk, D.S., Kaushik, L.S., Hasija, R.C. and Pannu, R.S. 1998. *Statistical Software Package for Agricultural Research Workers. Recent Advances in Information Theory, Statistics & Computer Applications* (pp. 139-143). Department of Mathematics Statistics, CCS HAU, Hisar, Haryana, India.

Stomph, T., Dordas, C., Baranger, A., de Rijk, J., Dong, B., Evers, J., *et al.*, 2020. Designing intercrops for high yield, yield stability and efficient use of resources: Are there principles? *Advances in Agronomy*, **160**: 1-50.

Wei, W., Liu, T., Shen, L., Wang, X., Zhang, S. and Zhang, W. 2022. Effect of maize (*Zea mays* L.) and soybean (*Glycine max*) Intercropping on yield and root development in Xinjiang, China. *Agriculture,* **12**: 996. [*https://doi.org/10.3390/agriculture12070996*].

Willey, R.W. and Rao, M.R. 1980. A competitive ratio for quantifying competition between intercrops. *Experimental Agriculture*, **16**: 117-125.

Xua., Z., Lia, C., Zhanga, C., Yub, Y. and Werfb, W. 2020. Intercropping maize and soybean increases efficiency of land and fertilizer nitrogen use: A meta-analysis. *Field Crops Research,* **246**: 107661. [*https://doi.org/10.1016/j.fcr.2019.107661*].

Yu, Y., Stomph, T.J. and van der Werf, W. 2015. Temporal niche differentiation increase the land equivalent ratio of annual intercrops: A meta-analysis. *Field Crops Research*, **184**: 133-144.

Zhang, W.P., Liu, G.C., Sun, J.H., Fornara, D, Zhang, L.Z., Zhang, F.F., *et al.*, 2017. Temporal dynamics of nutrient uptake by neighbouring plant species: Evidence from intercropping. *Functional Ecology,* **31**: 469-479.