frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 03 April 2023
DOI 10.3389/fsufs.2023.1052392

OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to Climate-Smart Food Systems, a section of the journal Frontiers in Sustainable Food Systems

RECEIVED 23 September 2022
ACCEPTED 13 March 2023
PUBLISHED 03 April 2023

CITATION
El-Mehy AA, Shehata MA, Mohamed AS, Saleh SA and Suliman AA (2023) Relay intercropping of maize with common dry beans to rationalize nitrogen fertilizer. *Front. Sustain. Food Syst.* 7:1052392. doi: 10.3389/fsufs.2023.1052392

Relay intercropping of maize with common dry beans to rationalize nitrogen fertilizer

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Maize (*Zea mays* L.) and dry beans (*Phaseolus vulgaris* L.) are important staple food and cash crops worldwide. Common bean in an intercrop with maize contributes to biological nitrogen fixation, which stabilize productivity of cropping systems and reduce negative environmental impacts and loss of biodiversity for sustainable agriculture. A field experiments was performed during the years of 2020 and 2021 at Sers El-Layian Station, northern Egypt. The current study aiming to study the effect of three sowing dates of maize, represent 3 co-growth duration [T1: at flowering stage (FS) of common beans (60 days co-growth duration), T2: 15 days after FS (45 days co-growth duration), and T3: 30 days after FS (30 days co-growth duration with beans)] and three *N* fertilizer levels (N1: 190.4, N2: 238.0, and N3: 285.6 kg N/ha of maize) on productivity, profitability and *N* fertilizer rationalization. The longest co-growth duration of maize intercropping with common beans (T1) significantly ($P \leq 0.05$) decreased common beans and maize yields compared with T2 and T3. Performance of common beans did not show ($P \leq 0.05$) any variation under different *N* fertilizer levels of maize. Significant ($P \leq 0.05$) increase in maize yield and its components with raising *N* fertilizer level up to N3. Although there was no significant variation in maize yield when applied N2 and N3, however, nitrogen use efficiency (NUE) was significant ($P \leq 0.05$) higher in N2 than N3 by 18.34%. Regardless of planting time and *N* fertilizer level of maize, combined productivity of common beans and maize increased in the intercropped system as cleared by higher total land equivalent ratios (LER) and area time equivalent ratios (ATER). Highest LER value 1.99 was observed at the shortest co-growth period T3 under N3 followed by 1.97 with N2. Positive values in the actual yield loss index (AYL) indicated intercropping advantage. Different competition indices showed a greater dominance of maize over common beans (aggressivity, Ag; competitive ratio, CR; actual yield losses, AYL). However, the intercropping systems increased the economic advantage (intercropping advantage index, IAI and monetary advantage index MAI) over monoculture. These results imply that shortening the period of co-growth maize with common beans (T3) and applying 238.0 kg N/ha in the relay intercropping system reduced mineral N fertilizer use by 16.67% compared to the advised level 285.6 kg N/ha along with increased productivity per unit area and economic advantages for small-farmer.

KEYWORDS
sowing date, *N* use efficiency, sustainability, competitive index, economic advantage

Introduction

Maize (*Zea mays L.*) is one of the most important staple food and a target of most food security programs and accounts for 19% of the average calorie intake per person per day (Santpoort, 2020). It is also grown for poultry and livestock feed and as industrial raw material (Badu-Apraku and Fakorede, 2017). In Egypt, there is an estimated 45% disparity between maize output and consumption and the area must fulfill the population's food requirements (FAOSTAT, 2019). In Egypt, increasing food security is a challenge under the prevailing situation of lack of arable land, climatic change and water deficiency. Common dry beans (*Phaseolus vulgaris* L.) is an important vegetable crop widely used as a cheaper protein source and for other nutrients in many developing countries including Egypt (Saleh et al., 2018).

Conventional agriculture relied heavily on high inputs of synthetic fertilizers and other agrochemicals, intensive tillage, and mono/limited rotation systems. These practices have led to soil degradation, both physically and biologically, depleting a significant amount of soil organic carbon (SOC) resulting in negative impacts on soil biodiversity (Rosati et al., 2020). In this context, sustainable agriculture aims to remove all deficiencies and not cause more damage to the environment. It also aims to design crop systems using ecological principles and ecosystem services to enhance agro-ecosystem sustainability and production efficiency, reducing chemical inputs and non-renewable energy (Otieno et al., 2019). According to ecological agriculture guidelines, a wide range of practices have been developed to improve the environmental performance of cropping systems including intercropping, crop rotation, cover cultivation, green manure, reduce tillage, and agroforestry (Wezel et al., 2014; Girip et al., 2020).

Intercropping maize with common beans would present an alternative to monoculture of maize as part of sustainable systems intensification in smallholder farms (Kermah et al., 2017; Sheha et al., 2022). Common bean can improve soil fertility through the fixation of atmospheric nitrogen (N2) in symbiosis with rhizobia and decomposition of its residues (Kermah et al., 2019). Biological fixation of atmospheric-*N* can replace *N*-fertilizer wholly or in part (Dwivedi et al., 2015; Massawe et al., 2016), increased cereal yield and NUF (Latati et al., 2016; Chen et al., 2017). Intercropping maize with common beans rendered higher yields in intercropping system than the sole crop (Nkhata et al., 2021). Intercrops produced 33% more gross incomes, whilst using 23% less land by increased land equivalent ratios (LER) (Alemayehu et al., 2017, 2018; Nassary et al., 2020; Bitew et al., 2021).

Co-growth duration between intercrop components in the intercropping system and fertilizer availability are influence yield of crops by regulate competition between intercrop components on growth factors, especially N (Ahmed et al., 2020; Coelho et al., 2022). Competition can be reduced by staggering the sowing dates of the companion crops in the intercropping system (Nyi et al., 2014). In intercropping system, if the difference in sowing date between species is larger, a larger size difference occurs between earlier and later emerging plants, resulting in unequal resource capture of soil and light (Huang et al., 2018). Sowing date of maize in relay intercropping systems affects the growth mostly through its determination of the shading duration, where two crop species in the early sown maize system suffer from shading for a longer period of time (Ahmed et al., 2018, 2020). Laub et al. (2021) stated that maize and grain legumes experienced strong crop yield losses even at low RSR (reduction in solar radiation) levels.

Complementarity between intercropped cereals and legumes strongly depends on the availability of *N* and thus on *N* fertilization. Fixed-*N* by common beans supplemented the inorganic nitrogen-added enhanced maize production (Massawe et al., 2016; Kermah et al., 2017). Increased *N*-application in early growth stages of legume will result in reduced the amount of fixed-*N*, legume yield and a corresponding increased cereal yield (Naudin et al., 2010; Abera et al., 2017). Jensen et al. (2020) found that the intercropped legume derives more of its N from the atmosphere, comparing with when it is grown as sole crop. Fertilizer recommendation studies for maize have focused mainly on pure maize stands. Dhakal et al. (2021) reported that application of *N* above 120 kg ha^{-1} did not have any significant effects on yield and yield components of maize and a *N* level of 120 kg ha^{-1} was optimal for agronomic, economic and NUE factors. However, the management of nitrogen fertilization in intercrops is still indefinite. Likewise, the relative sowing date of maize to optimize co-growth period of both crops in intercropping system has not been widely studied and not well-documented in the maize/common beans cropping systems in Egypt. The hypothesis is that legumes can provide an amount of nitrogen required by cereal crops, this amount depends on the planting date of the cereal crop, soil available nitrogen content, and the cropping system.

Therefore, this study aimed to investigate the appropriate sowing date (co-growth period) of intercropping maize with beans and the optimum inorganic *N*-fertilizer level to increase the productivity of maize and common beans, land usage and profitability per the unit area along with rationalization *N*-fertilization.

Materials and methods

Site description

During the cultivated years of 2020 and 2021, Two field trials were set up in Sers El-Layin Agriculture Research Station, Agricultural Research Center (ARC), Minufiya governorate (30°25′ 60 N; 30°58′ 0E), northern Egypt. Soil texture description and chemical properties of the experimental site were done by central laboratory, Faculty of Agriculture, Ain Shams Univ., according to Jackson (1973) as shown in Table 1.

The meteorological data for the study area, as monthly interval means in the two growing seasons are presented in Table 2.

Experimental setup

The experimental setup included three sowing date, which represented three period of co-growth duration between maize and beans (60, 45, and 30 days co-growth) and three doses from *N* fertilization of maize. Treatments were repeated three times. In addition intercropping culture, the recommended sole culture

TABLE 1 Mechanical and chemical soil properties of experimental site before sowing beans.

Mechanical properties	Value	Soluble cations (meq l^{-1})	Value	Soluble anions (meq l^{-1})	Value
Sand %	30.6	Na^{+}	5.12	Cl^{-}	6.63
Silt %	25.9	K^{+}	0.72	CO_3^{2-}	0
Clay %	43.5	Ca^{2+}	2.22	HCO_3^{-}	1.94
Soil texture	Clay	Mg^{2+}	2.84	SO_4^{-}	2.34
pH	8.1	Available NPK (mg/kg)	N	P	K
EC (dS.m^{-1})	1.09		39.19	16.44	231.3

TABLE 2 Monthly meteorological data of the experimental site in 2020 and 2021 seasons.

Month	Max. T °C	RH %	WS m/s	Rainfall kg/m^2	Max. T °C	RH %	WS m/s	Rainfall kg/m^2
	2020 season				2021 season			
February	12.40	66.64	2.39	11.62	14.66	59.43	1.12	3.93
March	13.77	63.04	2.33	6.18	14.59	58.93	1.85	8.74
April	16.44	56.23	1.71	8.66	15.89	57.69	2.23	1.40
May	19.22	53.32	1.95	2.62	20.18	44.23	2.16	0.80
June	23.67	47.61	2.72	1.59	27.05	33.66	2.97	0.39
July	27.70	38.67	2.86	1.34	28.12	39.07	3.76	0.59
August	29.95	40.83	3.76	1.05	30.86	39.35	3.58	0.34
September	30.22	43.28	3.60	0.74	31.20	40.70	3.49	1.16
October	29.62	46.71	3.30	0.86	28.26	46.79	3.48	1.17

Max. T, maximum temperature; RH, relative humidity; WS, wind speed.
Source: https://power.larc.nasa.gov/data-access-viewer/.

of both crops were grown and used to calculate the competitive relationships and economic performance of intercropping. Plot area was 4 × 3 m, comprising five ridges spaced 0.80 m apart. Diagram of experimental area with each treatment of intercropping system is presented in Figure 1. A completely randomized block design in split-plot was established. Three sowing dates of maize were arranged in main plots, whereas sub-plots allocated with *N* fertilizer levels of maize (190.4, 238.0, and 285.6 kg/ha). Maize sowing dates were chosen so that the shading and adverse competition resulting from the co-growth period of companion crops long, medium and short durations.

Crop management

The crop management of intercropped maize and beans was similar among the two experimental years. The dry beans cultivar (Nebraska) and maize (Yellow hybrid SC 168) were used. Sowing and harvesting dates of in sole and intercropping culture are presented in Table 3.

The land preparation process started with plowing by chisel plow, leveling, and division into ridges, that was 80 cm wide and 3 m long. Sorghum was the preceding crop in both growing seasons. Maize and common bean were planted manually by hand. In sole and intercropping culture, dry beans seeds were sowing on one side of the ridge at 80 cm, two plants/hill at spacing 15 cm apart (166,667 plants/ha). Common beans seeds were inoculated with *Rhizobium leguminosarum* before sowing using Arabic gum as a sticking agent in solid and intercropping cultures. Maize seeds were sown on the other side of beans ridge (0.80 m) at 0.25 m between hills with leave one plant/hill (49,980 plants/ha), in intercropping culture. Planting distance of sole maize implements as intercropping culture 0.80 × 0.25 m between ridges and hills, respectively, which gave 50,000 plants/ha. In this study, an additive intercropping system was used, where plant densities of both crops were (100% common beans: 100% maize).

Furrow irrigation was the irrigation system in this study, and irrigation was done at intervals, ranged from 20 to 12 days according to temperature degree. Fertilizer was applied at the rate of 119.0 kg P_2O_5/ha, as calcium superphosphate (15.5% P_2O_5) and 119.0 kg K_2O/ha as potassium sulfate (50% K_2O) were applied during soil preparation. While mineral *N* fertilizer as ammonium sulfate (20.6% *N*), was applied at 35.7 kg N/ha for common beans as booster dose at sowing, in sole and intercropping culture. Three mineral N fertilizer levels (190.4, 238.0, and 285.6 kg/ha) for intercropping maize and 285.6 kg N/ha for sole maize, which were added in to equal doses, at first and second irrigations. The hoeing method was used to control weeds for both crops. Other agricultural practices were done as recommended of both crops.

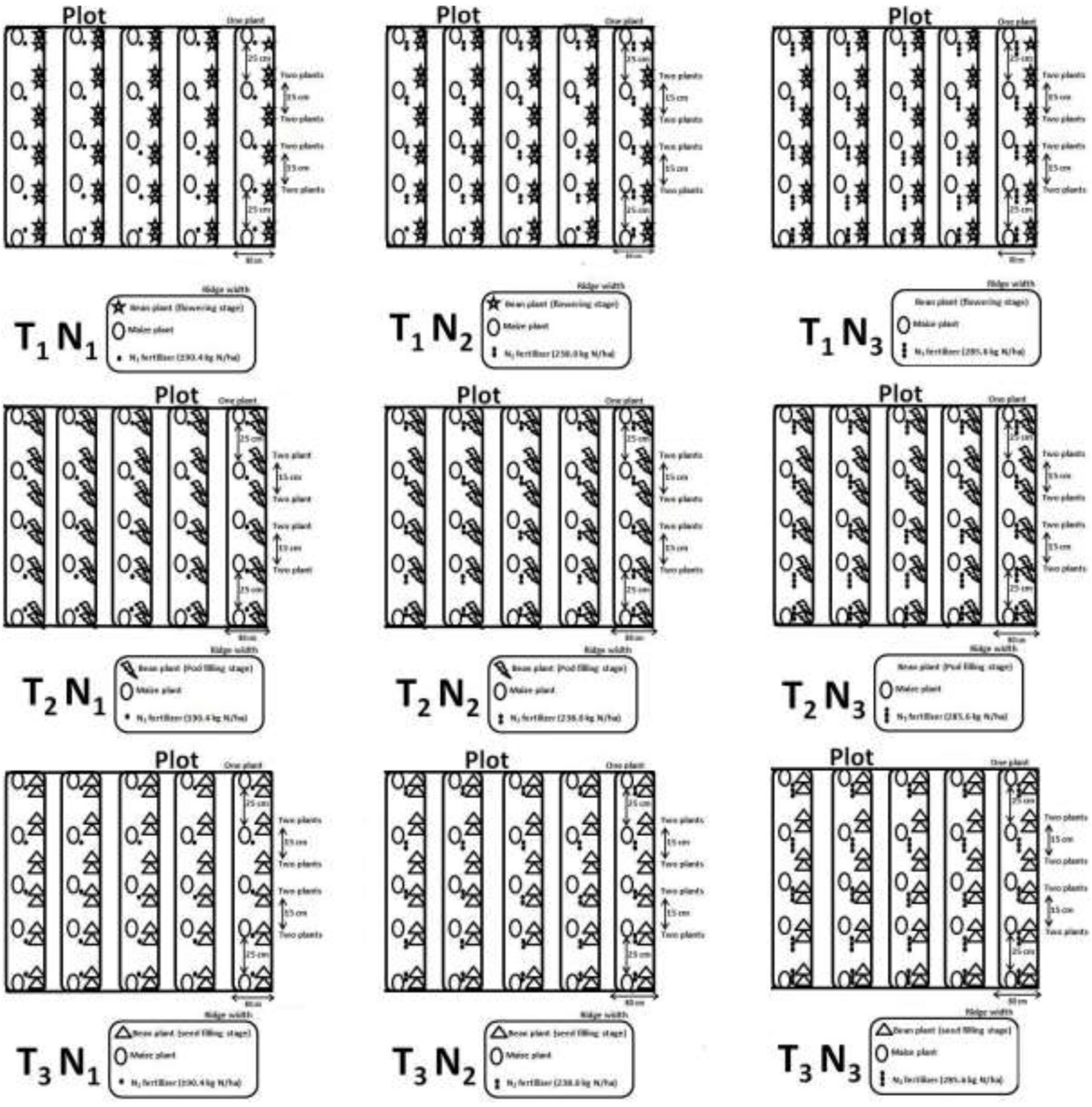

FIGURE 1
Diagram of experimental area with each treatment of intercropping system.

TABLE 3 Sowing and harvesting dates of common beans and maize in both seasons.

	Common beans		Maize in two growing seasons		
	2020 season	2021 season	T1	T2	T3
Sowing date	February 26th	February 25th	April 15th	May 1st	May 15th
Harvesting date	June 14th after 110 days		August 10th	August 26th	September 10th
Co-growth duration between maize and beans at different sowing dates			60 days long co-growth	45 days medium co-growth	30 days short co-growth

Data collection

Crop parameters

Data were collected from middle rows of each sub-plot. Characters for common beans were branches number/plant, dry weight/plant (g), pods number/plant, seed weight/plant (g), 100-seed weight (g), and seed yield kg/ha. Corresponding maize: plant height (cm), green leaves number/plant at harvest, ears number/plant, ear weight (g), grains weight/ear (g), ear diameter (cm), grains number/ear, 100-grain weight (g), and grain yield ton/ha were estimated.

Nitrogen use efficiency of maize

The *N* use efficiency of maize was calculated by this equation, according to Moll et al. (1982).

$$\text{Nitrogen use efficiency (NUE)} = \text{YN/FN (kg grain/kg N} - \text{fertilizer)}$$

Where FN: amount of *N* fertilizer applied (kg/ha), YN: crop yield with applied *N* fertilizer (kg/ha).

Competitive relationships and yield advantages

1. Land equivalent ratio was calculated as follows (Willey, 1979)

$$\text{LER} = (\text{LERa} + \text{LERb}) = (\text{Yab/Yaa} + \text{Yba/Ybb})$$

Where LERa and LERb are the partial LER of crop beans and maize, respectively.

2. Area Time Equivalent Ratio (ATER) estimated according to Hiebsch (1980) as follows:

$$\text{ATER} = (\text{LERa} \times \text{DCa} + \text{LERb} \times \text{DCb})/\text{Dt}$$

Where LER is land equivalent ratio of crop, DC is duration (days) taken by crop, Dt is days to intercropping system from planting to harvest.

3. Aggressivity (A) It mean a comparison of how much relative yield increase for the intercropped crop (a) on crop (b) with the expected crop to find out which of the two crops dominated in yield according to Mc-Gilchrist (1965).

$$\text{Aab} = \text{Yab/yaa X zab} - \text{Yba/ybb X zba.}$$

Where Yaa and Ybb = pure stand yield of a (dry beans) and b (maize). Yab and Yba = intercropping yield of a and b. zab and zba = the area ratio of the crop beans and maize when intercropping, respectively.

4. Competitive ratio was calculated by following the formula as advocated by Willey and Rao (1980). CR = CRa + CRb

$$\text{CRa} = (\text{LERa/LERb}) \times (\text{Zba/Zab}), \text{CRb} = (\text{LERb/LERa}) \times (\text{Zab/Zba})$$

Where CRa and CRb are the competitive ratio for intercrop maize and dry beans, respectively. When CR = 1, it indicates situations where both species have equal grain yield. CR > 1 reflects yield dominance and vice versa when CR < 1.

5. Actual yield loss (AYL) is the proportionate yield loss of intercrops compared to sole crop as indicated by Banik (1996).

$$\text{AYL} = \text{AYLa} + \text{AYLb} = [\{(\text{Yab/Zab})/(\text{Yaa/Zaa})\} - 1] + [\{(\text{Yba/Zba})/\text{Ybb/Zbb})\} - 1]$$

Where AYLa and AYLb are the partial yield loss of intercrop dry beans and maize, respectively.

Economic evaluation

1. Intercropping advantage index (IAI) was calculated using the following formula (Banik et al., 2000). IAI = IAB + IAM

$$\text{IAB} = \text{AYLB} \times \text{PB and IAM} = \text{AYLM} \times \text{PM}$$

Where P_{beans} and P_{maize} are the prevailing market prices of common beans (the current price of common beans is 1,364.76 and 1,273.88 U$ per ton), and maize (the current price is 301.31 and 307.10 per ton) in first and second season, respectively. The IAI shows the economic losses (– values) or gains (+ values) for each species and crop.

2. Monetary advantage index MAI as suggested by Willey (1979)

MAI = [(value of combined intercropping) × (LER – 1)]/LER.

The statistical analysis

Data were analyzed according to Gomez and Gomez (1984). Treatment means were compared using least significant differences (LSD) test at 0.05 level of probability. Statistical analysis was performed using analysis of variance technique of STAT-C statistical package (Freed, 1991).

Results and discussion

Soil content of available nitrogen

Interaction between sowing date and nitrogen doses, showed that T3 × N2 level significantly ($P \leq 0.05$) increased soil content of available *N* (Table 4). These results probably due to short co-growth duration of maize with common beans along with optimum *N* level enhanced shoot and root growth of beans, consequently increased fixing *N* in the intercropping plots. Advantage of maize-legume combination of intercropping system is fixation of biological nitrogen by legumes and transfer of *N* to associated maize (Maitra et al., 2020).

Further, soil content of available *N* varied by sole crop, where sole maize reduce initial *N* compared to common beans, which as legume crop increased available *N* (Table 4). However, intercropping maize with common beans increased soil content of available *N* from 49.33 to 50.13 mg/kg (as general average). Jensen et al. (2020) found that the intercropped legume derives more *N* from the atmosphere compared with when it is grown as sole crop.

TABLE 4 Response of soil content of available nitrogen (mg/kg) to interaction effect of sowing date and N levels in intercropping and sole plots.

	Available *N* content in intercropping plots (mg/kg)			Increase % of available N content in intercropping plots over sole maize		
	T1	T2	T3	T1	T2	T3
N1	47.60	49.30	50.50	35.23	40.06	43.47
N2	49.50	51.00	52.20	40.63	44.89	48.30
N3	50.10	51.00	50.00	42.33	44.89	42.05
LSD at 5%	0.93			Initial *N*	Sole maize	Sole beans
				39.19	35.20	49.33

N1 = 190.4 kg N/ha, N2 = 238.0 kg N/ha, N3 = 285.6 kg N/ha.

TABLE 5 Response of common beans characters to sowing date (co-growth duration) in 2020 and 2021 seasons.

Sowing date	Branches no./Pl	Dry wt/ plant (g)	Pods/Pl. (no.)	Seed wt./Pl (g)	100-seed wt. (g)	Seed yield (kg/ha)
2020 season						
T1	4.17	13.53	8.44	7.15	29.44	1,370.06
T2	4.25	16.35	9.88	10.08	33.37	1,473.99
T3	4.25	19.57	12.69	11.98	33.79	1,866.65
LSD at 5%	N.S	4.04	0.86	0.49	2.19	57.27
2021 season						
T1	4.24	14.21	9.26	7.65	30.45	1,549.33
T2	4.30	17.01	11.26	10.31	33.56	1,698.61
T3	4.29	20.26	12.64	12.23	34.09	1,952.03
LSD at 5%	N.S	4.17	0.44	0.89	2.80	70.43

N.S, not significant.

Common beans yield and yield component

Sowing date of maize (co-growth duration)

As illustrated by Table 5, sowing date (co-growth duration) of maize affected significantly ($P \leq 0.05$) for all studied parameters of common beans plants except the number of branches/plant. Number of branches/plant not affected by sowing date and remained between 4.17 to 4.25 in 1st season and 4.24 to 4.30 in 2nd season, this may be attributed to that maize was planted after common beans reached the branching stage. These results were in line with Nyi et al. (2014) and Ahmed et al. (2020), they found the optimum planting date is one of the most critical factors in the maize/soybean relay intercropping system. Postponement maize intercropped with common beans at T3, short co-growth period, significantly ($P \leq 0.05$) increased dry matter /plant, number of pods/plant, seed weight per plant and 100-seed weight of common beans, which may be attributed to maize was planted when common beans plants reached full pod stage. Meanwhile, early sowing date of maize at T1 (flowering stage) resulted in longer co-growth duration and the stiff competition encountered by beans plants from maize plants, which caused a significant reduction in yield components of common beans (No. of pods/plant and seed weight/plant). Sowing time, with 50 days overlap between soybean and maize, had more pronounced and significant effect on photosynthetic rate, dry matter accumulation and partitioning to reproductive parts over 90 days coexistence duration (Ahmed et al., 2018). The results are in line with Zemede et al. (2018) found that dry matter accumulation differ from early to late time of intercropping.

Similarly, seed yield/ha increased progressively and significantly ($P \leq 0.05$) as reduced overlap period between dry beans and maize at T3 (30 days) compared to T1 (60 days) and T2 (45 days co-growth period) by 36.25 and 26.64% in 2020 season and 25.99 and 14.92% in 2021 season, respectively. This increase may be attributed to high dry matter accumulation that produce many pods/plant as this had an implication on the seeds formed and the resultant grain yield. This is likely, common beans pods were formed at T3 before maize plants had the ability to compete with common beans on growth factors, light and nutrient. Results are in line with Nyi et al. (2014) and Huang et al. (2018). Reduce duration of co-growth in relay-intercropping encouraged plants to achieve higher crop growth rates and biomass accumulation (Zemede et al., 2018; Ahmed et al., 2020).

N fertilizer levels of maize

At both seasons, the results of the experiment show that all studied traits of common beans were not significantly ($P \leq 0.05$) affected by *N* levels (Table 6). It's obvious, there was no relationship between *N* levels of maize and the studied traits of common beans, where common beans reached reproductive phase before *N* levels for maize were used. Similar results were observed by Cardoso et al. (2007) confirm that *N* levels did not affect yield in either common beans cultivar with any of the intercropping treatments.

TABLE 6 Response of common beans characters to N fertilizer levels of maize in 2020 and 2021 seasons.

Fertilizer effect	Branches no./Pl	Dry wt./pl (g)	Pods no./Pl.	Seed wt./Pl (g)	100-seed wt. (g)	Seed yield (kg/ha)
2020 season						
N1	4.19	16.12	9.81	9.41	31.96	1,560.16
N2	4.26	16.42	10.62	9.75	31.99	1,591.54
N3	4.22	16.91	10.58	10.05	32.64	1,559.00
LSD at 5%	N.S	N.S	N.S	N.S	N.S	N.S
2021 season						
N1	4.28	17.08	11.01	9.68	32.57	1,711.03
N2	4.31	17.14	11.07	10.19	33.14	1,738.58
N3	4.25	17.26	11.08	10.32	32.38	1,750.37
LSD at 5%	N.S	N.S	N.S	N.S	N.S	N.S

N.S, not significant.

TABLE 7 Response of common beans characters to interaction effect of sowing date and N levels of maize in 2020 and 2021 seasons.

Interaction		Branches no./plant	Dry wt./plant (g)	Pods no./plant	Seed wt./Pl (g)	100-seed wt. (g)	Seed yield (kg/ha)
		2020	2020	2020	2020	2020	2020
T1	N1	4.25	12.99	7.20	6.97	28.57	1,334.32
	N2	4.17	15.05	9.23	7.48	29.35	1,433.06
	N3	4.08	12.56	8.90	7.01	30.40	1,342.80
T2	N1	4.17	16.95	10.23	9.66	33.40	1,476.99
	N2	4.18	14.42	9.73	10.09	32.80	1,484.98
	N3	4.40	17.69	9.67	10.47	33.90	1,460.00
T3	N1	4.15	18.43	12.00	11.61	33.90	1,869.17
	N2	4.42	19.80	12.90	11.67	33.83	1,856.59
	N3	4.18	20.49	13.17	12.67	33.63	1,874.20
LSD at 5%		N.S	N.S	N.S	N.S	N.S	N.S
Sole beans		4.15	17.93	12.11	11.85	40.62	1,900.00
		2021	2021	2021	2021	2021	2021
T1	N1	4.30	14.50	9.27	7.45	31.31	1,535.62
	N2	4.29	15.83	9.43	7.93	30.43	1,522.97
	N3	4.13	12.30	9.07	7.57	29.60	1,589.40
T2	N1	4.27	17.57	11.23	9.77	32.97	1,645.73
	N2	4.17	15.07	11.10	10.47	33.80	1,730.60
	N3	4.46	18.40	11.43	10.70	33.90	1,719.50
T3	N1	4.25	19.17	12.53	11.83	33.43	1,951.73
	N2	4.47	20.53	12.67	12.17	35.20	1,962.17
	N3	4.16	21.07	12.73	12.70	33.63	1,942.20
LSD at 5%		N.S	N.S	N.S	N.S	N.S	N.S
Sole beans		4.20	18.38	12.57	12.20	41.10	2,005.50

N.S, not significant.

The response of beans to *N* fertilizer was lower than the response of maize. Since, beans is a legume and can fix *N via* symbiotic nitrifying bacteria in its roots, there is less necessity for *N* fertilizer for this crop (Chen et al., 2017; Jensen et al., 2020).

Interaction

The non-significant ($P \leq 0.05$) effect of the interaction on the yield components and grain yield of common beans could be due to these factors act independently on all the studied traits of common beans as shown in Table 7. Furthermore, the higher yield and yield components of common beans under sole cropping system may be related to the absence of shading effect of maize, and then plants can intercept light to their potential and grow vigorously opposite to intercropped beans. The results corroborate previous maize–beans intercrop studies (Alemayehu et al., 2018; Nassary et al., 2020; Laub et al., 2021).

Maize yield and yield components

Sowing date of maize (co-growth duration)

Sowing dates of maize had significant ($P \leq 0.05$) effect on growth traits of maize i.e., plant height (in the second season) and number of green leaves/plant in both seasons (Table 8). Maximum plant height of 271.76 cm was recorded at T1 and the minimum plant height of 254.86 cm was recorded at T3 in 2nd season. This implies that early sowing date of maize with longer co-growth period with beans allows it to good growth and increase of plant height. This result accordance with the findings of Hegab et al. (2019) which reported higher height of maize were observed with early planting date of maize. While, the highest values of active leaves 7.64 and 6.87 and the lowest values being 2.97 and 5.04 were recorded with T2 and T3 in 1st and 2nd seasons, respectively. Delay leaf senescence of maize at T2 could be due to increase the co-growth period with bean and high soil content of available *N* compared to T3 (Table 3). Also, result suggested that number of green leaves were associated with sowing date, due to changes in climate (Table 2). According to Hegab et al. (2019) late planting of maize terminated vegetative growth and resulted in shorter plant with fewer and smaller leaves.

The influence of sowing date on yield and yield components of maize were significant ($P \leq 0.05$) with exception of ear weight in in 2nd season and ear length in 1st season. The increase in number of ears/plant was inconsistent in the both growing seasons and the highest values 1.04 (in 2020 season) and 1.07 (in 2021 season) was obtained by T1 and T2, respectively, without significant differences between them. The highest values of ear characters, 100-grain weight and grain yield/ha were attained by rely-intercropping maize at T2, while the lowest values were recorded with T3 in both seasons. These results could be due to sowing date T2 having the highest number of active leaves at harvest, which increases photosynthesis processing and consequently raise grain yield. Leaf senescence is a natural process, which occurs during the lifecycle of crops. However, leaf senescence of maize plants was delayed, which in turn significantly enhanced the photosynthetic rate of maize leaves and significantly increased maize yield, in legume-maize

TABLE 8 Response of maize characters to sowing date (co-growth duration with maize) in 2020 and 2021 seasons.

Sowing date	Plant height (cm)	Green leaves/Pl at harvest (No.)	Ears/plant (No.)	Ear weight (g)	Grain ear weight (g)	Ear length (cm)	Ear diameter (cm)	Grains/row (No.)	100-grain wt. (g)	Grain yield (ton/ha)
2020 season										
T1	270.33	6.10	1.04	175.91	142.96	21.59	4.80	42.02	30.95	6.90
T2	267.33	7.64	1.02	188.00	156.89	22.58	4.80	41.39	31.98	7.53
T3	257.72	2.97	0.91	153.42	125.97	20.93	4.34	39.33	28.69	6.39
LSD at 5%	N.S	0.81	0.06	15.92	9.37	N.S	0.18	1.06	0.50	0.53
2021 season										
T1	271.76	6.72	1.01	226.78	190.07	23.44	4.80	44.29	33.96	7.44
T2	264.82	6.87	1.07	238.03	200.42	23.98	5.02	45.29	34.70	7.79
T3	254.87	5.04	0.99	203.98	168.02	20.73	4.62	34.15	29.57	7.13
LSD at 5%	5.52	1.60	0.03	N.S	12.70	0.49	0.14	1.62	3.36	0.15

N.S, not significant.

relay intercropping (Feng et al., 2020). Also, these increment in the yield and yield components of maize in T2 might be due to the high available *N* concentration in the soil (Table 4) compared to T1, and the favorable growing conditions (Table 2) compared to T3. Hegab et al. (2019) the relationships between planting date and climate for maize can be useful for estimating planting dates in regions. Where, less number of grains/row was found in the third sowing date because of serious heat stress at anthesis silk interval. At the flowering stage, high temperatures inhibited pollen germination and delay in the anthesis-silking interval, which caused maize yield reduction (Wang et al., 2019, 2021). Additionally, medium co-growth period (T2) reduce shading effect of common beans in compared with longer co-growth period (T1). Longer co-growth duration resulted in intense interspecific competition between the intercropped specie and intensive shading negatively affected the maize yield (Ahmed et al., 2018, 2020; Huang et al., 2018; Zemede et al., 2018).

N fertilizer levels of maize

The result showed that plant height and number of green leaves/plant were significantly ($P \leq 0.05$) affected by *N* fertilizer level as shown in Table 9. Increasing *N* level from N1 (190.4 kg/ha) up to N3 (285.6 kg/ha) gradually increased plant height of 259.06–269.94 cm in 2020 season and of 256.96–271.82 cm in 2021 season. This implies that mineral *N* fertilizer vial to cell division and elongation. This finding was in agreement with the findings reported by Takele et al. (2017) maize attained maximum plant height with full level of *N* (92 Kg ha^{-1}). Moreover, green leaves number/plant increased by increasing *N* level from N1 up to N2. The results are in line with previous findings in maize by Dhakal et al. (2021) the lowest percentage leaf senescence was obtained at and up 120 kg N/ha at all the sampled periods compared to the levels below 120 kg/ha. The highest *N* level (N3) did not improve number of green leaves/plant of intercropped maize compared to N2. This indicated that maize plants maybe had more nitrogen available to absorb when intercropped with common beans at N2. Nitrogen fixed by common beans supplemented the inorganic nitrogen-added enhanced maize production (Massawe et al., 2016; Kermah et al., 2017).

Yield and yield components of maize significantly ($P \leq 0.05$) affected by *N* fertilizer levels as shown in Table 9. Maize plants that received the full mineral N fertilizer level N3 (285.6 kg N/ha) had the highest values of ears number per plant, ear characteristics, 100-grain weight and grain yield per ha in both seasons, with some exception. Meanwhile, the lowest values of these characters were recorded in plots with N1 (190.4 kgN/ha). Those higher N levels will have more green leaves and higher photosynthetic capacity than the lower N levels. Results are in line with Hegab et al. (2019) who reported that increase number of green leaves/plant resulting in good photosynthetic accumulated in leaves and their transfer to economic parts like grains and ears. Besides, it is obvious from the results there were no significant differences in grain yield and its attributes especially, ear weight, grain ear weight, ear length and grains No. of rows, between N2 and N3 in both seasons. This indicated that N2 increases productivity as it takes advantage of the biological *N* fixation by the common beans, thereby reducing

TABLE 9 Response of maize characters to N fertilizer level of maize in 2020 and 2021 seasons.

N fert. Level	Plant height (cm)	Green leaves/Pl at harvest (No.)	Ears/plant (No.)	Ear weight (g)	Grain ear weight (g)	Ear length (cm)	Ear diameter (cm)	Grains/row (No.)	100-grain wt. (g)	Grain yield (ton/ha)
2020 season										
N1	259.06	4.57	0.95	162.47	133.49	20.57	4.55	38.71	28.75	6.46
N2	266.39	6.08	1.01	175.09	144.96	21.92	4.66	41.54	31.33	7.17
N3	269.94	6.07	1.01	179.78	147.37	22.61	4.72	42.49	33.53	7.20
LSD at 5%	6.08	0.50	0.06	4.83	5.92	0.69	0.08	1.53	1.10	0.47
2021 season										
N1	256.96	5.40	0.98	207.68	173.33	21.62	4.69	39.10	30.78	6.80
N2	262.67	6.69	1.03	225.40	192.14	23.16	4.78	42.30	33.33	7.69
N3	271.81	6.54	1.04	235.71	193.01	23.38	4.98	42.06	34.11	7.88
LSD at 5%	4.39	0.88	0.04	10.42	8.51	1.11	0.09	1.20	2.05	0.17

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TABLE 10 Response of maize characters to interaction effect of sowing date and N levels of maize in 2020 and 2021 seasons.

		Plant height (cm)	Green leaves/Pl at harvest (No.)	Ears/plant (No.)	Ear weight (g)	Grain ear weight (g)	Ear length (cm)	Ear diameter (cm)	Grains/row (No.)	100-grain wt. (g)	Grain yield (ton/ha)
2020 season											
T1	N1	261.33	5.07	1.01	171.00	138.97	20.43	4.70	38.60	29.45	6.28
	N2	272.67	6.37	1.03	174.90	143.97	21.67	4.83	43.27	32.00	7.37
	N3	277.00	6.87	1.07	181.83	145.93	22.67	4.87	44.20	32.40	7.06
T2	N1	262.67	6.03	1.00	174.63	148.47	21.43	4.73	40.47	30.47	7.12
	N2	267.83	8.67	1.03	190.93	160.53	22.90	4.83	41.63	33.07	7.57
	N3	271.50	8.23	1.03	198.43	161.67	23.40	4.83	42.07	32.40	7.90
T3	N1	253.17	2.60	0.83	141.77	113.03	19.83	4.23	37.07	27.33	5.98
	N2	258.67	3.20	0.97	159.43	130.37	21.20	4.33	39.73	28.93	6.56
	N3	261.33	3.10	0.93	159.07	134.50	21.77	4.47	41.20	29.80	6.64
LSD at 5%		N.S	0.86	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S
Grain yield of sole maize at: T1 = 7.48 ton/ha, T2 = 7.24 ton/ha, T3 = 6.58 ton/ha											
2021 season											
T1	N1	266.22	6.07	0.99	207.37	174.63	22.60	4.73	42.37	32.30	6.83
	N2	273.72	7.13	1.00	232.17	194.43	23.60	4.77	45.13	34.20	7.67
	N3	275.33	6.97	1.03	240.80	201.13	24.13	4.90	45.37	35.37	7.83
T2	N1	256.56	6.73	1.03	222.57	185.83	23.27	4.80	43.03	33.27	7.17
	N2	261.95	7.33	1.07	241.33	201.53	24.27	4.90	46.20	35.23	7.97
	N3	275.95	6.53	1.10	250.20	213.90	24.40	5.37	45.83	35.60	8.23
T3	N1	248.11	3.40c	0.91	193.10	159.53	19.00	4.53	31.90	26.77	6.40
	N2	252.33	5.60	1.03	202.70	180.47	21.60	4.67	35.57	30.57	7.43
	N3	264.17	6.13	1.00	216.13	164.07	21.60	4.67	34.97	31.37	7.57
LSD at 5%		N.S	1.53	0.08	N.S	14.73	N.S	0.16	N.S	N.S	0.82
Grain yield of sole maize at: T1 = 8.20 ton/ha, T2 = 7.81 ton/ha, T3 = 7.45 ton/ha											

N.S, not significant.

the demand for mineral *N* fertilizer. This finding was supported by Dwivedi et al. (2015) and Massawe et al. (2016). Jensen et al. (2020) found the biological N2 fixed by the intercropped cereal with legume may also diminish the requirement for fertilizer *N* in the cereal.

Interaction

Results in Table 10 confirm that number of green leaves/plant (in both seasons), ears number/plant, grain weight/ear, ear diameter and grain yield/ha (in 2021 season) were affected significantly ($P \leq 0.05$) by maize sowing dates × mineral *N* fertilizer levels. The lowest number of green leaves/plant (2.60 and 3.40), ears number/plant (0.91), grain weight/ear (159.53 g), ear diameter (4.53), and grain yield/ha (6.40 ton/ha) were attained by delaying maize sowing date at T3 with N1 (190.4 kgN/ha). While, planting maize in association with medium overlap duration (T2) had the highest values of number of green leaves (8.67 and 7.33) that received 238.0 kg N/ha (N2), in both season. In 2021 season, raising N level up to 285.6 kg N/ha (N3) at the same sowing date of maize (T2) had the highest values of ears number/plant (1.10), grain weight/ear (213.90 g), and grain yield/ha (8.23 ton). Although there were no significant differences between 238.0 and 285.6 kg N ha in both season (Table 10). These results mainly due to reduced co-growth period of common beans with maize at T2 interacted positively with applying *N* levels at N2 (238.0 kg/ha) to improve green leaves number, consequently improved yield and its components. Especially, nodulation and *N* fixation by legumes is adversely affected by higher levels of fertilizer *N* as shown in Table 3. Similar results were observed by Naudin et al. (2010). Alemayehu et al. (2018) who demonstrated that intercropping maize with common beans with appropriate nutrient level significantly increased yield of crops. Chen et al. (2017) noting that maize grain yield of reduced nitrogen (RN) was greater than that in conventional nitrogen (CN) in intercropping system compared sole system.

In both years, the grain yield of sole maize had low variation as compared to intercropped maize, where intercropping maize increase yield at T2 and T3 with the availability of *N* fertilizer under N2 and/or N3 (Table 10). High soil content of available *N* in intercropping maize compared to sole crop (Table 4), probably was the reason for these increases in yield of intercropped maize. Maize-legume combination of intercropping system produce higher yield and greater utilization of available resources, fixation of biological nitrogen by legumes and transfer of *N* to associated maize (Kermah et al., 2019; Maitra et al., 2020) and increased N use efficiency (Zheng et al., 2021). Intercropping increase maize yield by more than 12.5% (Latati et al., 2016). Optimized planting time of common beans reduce the yield difference between intercropped and sole maize by enhancing maize resilience toward asymmetric competition (Bitew et al., 2021).

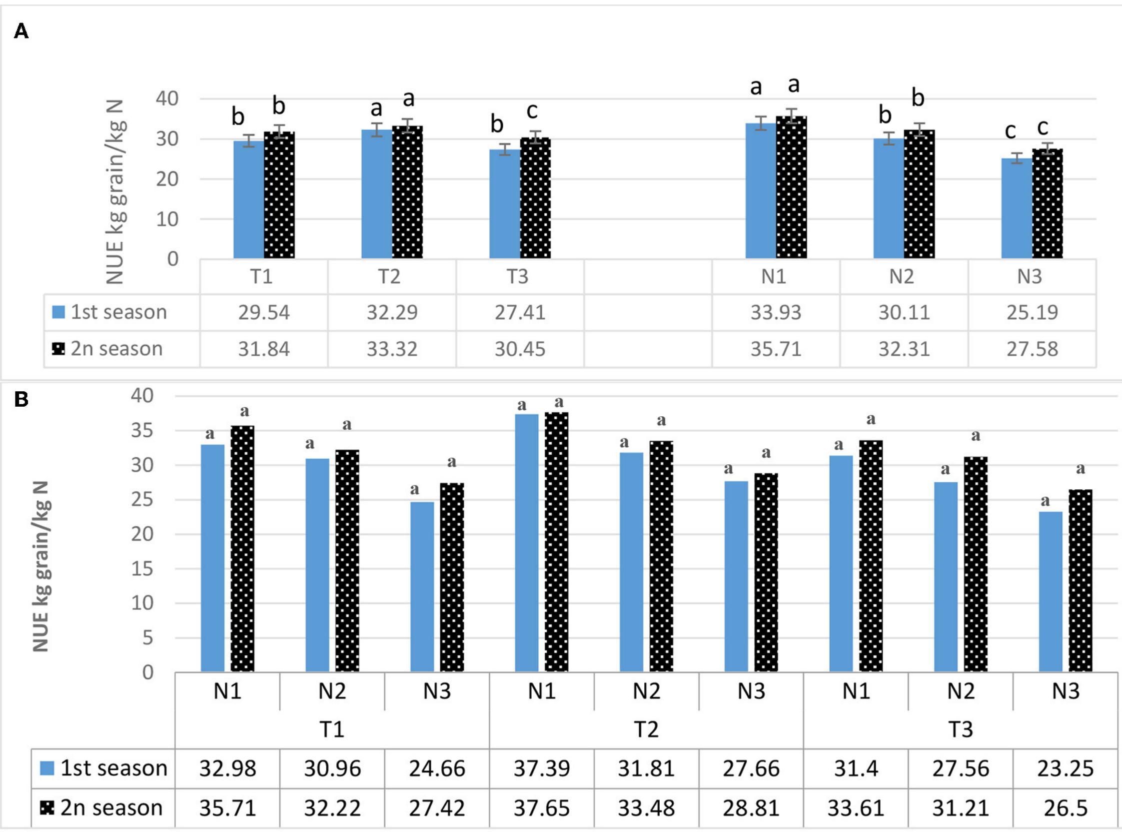

FIGURE 2
Response of NUF to sowing date **(A)**, N fertilizer level **(A)** and their interaction **(B)** in both seasons. Different letters between columns indicate significant differences according to Duncan test at ($P \leq 0.05$).

TABLE 11 Response of LER and ATER to interaction effect of sowing date and N levels of maize in 2020 and 2021 seasons.

		2020 season				2021 season			
		LER			ATER	LER			ATER
		L beans	L maize	LER		L beans	L maize	LER	
T1	N1	0.70	0.84	1.54	1.05	0.77	0.83	1.60	1.09
	N2	0.75	0.99	1.74	1.19	0.76	0.94	1.70	1.15
	N3	0.70	0.94	1.65	1.12	0.79	0.95	1.74	1.19
Mean		0.72	0.92	1.64	1.12	0.77	0.91	1.68	1.14
T2	N1	0.78	0.98	1.76	1.10	0.82	0.92	1.74	1.08
	N2	0.78	1.05	1.83	1.14	0.86	1.02	1.88	1.18
	N3	0.77	1.09	1.86	1.17	0.86	1.05	1.91	1.19
Mean		0.77	1.04	1.82	1.14	0.85	1.00	1.84	1.15
T3	N1	0.98	0.91	1.89	1.09	0.97	0.86	1.83	1.05
	N2	0.97	1.00	1.97	1.13	0.98	1.00	1.97	1.14
	N3	0.98	1.01	1.99	1.15	0.97	1.02	1.99	1.14
Mean		0.98	0.97	1.95	1.12	0.97	0.96	1.93	1.11
N1		0.82	0.91	1.73	1.08	0.85	0.87	1.72	1.07
N2		0.84	1.01	1.85	1.15	0.87	0.98	1.85	1.16
N3		0.82	1.01	1.84	1.15	0.87	1.01	1.88	1.17
LSD *T*		0.03	0.08	0.02	N.S	0.04	0.02	0.01	0.02
LSD *N*		N.S	0.07	0.02	0.05	N.S	0.02	0.01	0.07
LSD $T \times N$		0.03	N.S	N.S	N.S	N.S	N.S	N.S	N.S

N.S, not significant.

Nitrogen use efficiency of maize

Results in Figure 2 show that sowing date and N fertilizer levels were significantly ($P \leq 0.05$) affected NUE in both season. The highest values of NUF, 32.29 and 33.32 kg grains/kg *N* applied to the soil, were produce with T2 in 1st and 2nd season, respectively. Whereas, the lowest values 27.41 and 30.45 were achieved by T3 (Figure 2A). These results indicated that the optimum planting date for maize T2 coupled with the high concentration of available *N*, 51 mg/kg (Table 4), in intercropping treatments in T2 improved growth, grain yield and NUF of maize. Results confirmed that maize-legume intercropping could enhance root activity and increase the *N* uptake of maize roots and *N* use efficiency compared with monoculture maize (Zheng et al., 2021). The delay of maize sowing date from early to late maize reduced 10% the number of kernels per ear, grain yield and NUF (Coelho et al., 2022).

Increase *N* fertilizer levels from 190.4 (N1) to 285.6 kg N/ha (N2) significantly decreased NUF of grain maize in both seasons. However, the highest grain yield/ha was obtained by N2 and N3 without significant differences between them. Where, the NUE was higher in N2 over N3 by 19.53 and 17.15% in 2020 and 2021 seasons, respectively, as shown in Figure 1. Therefore, the optimum nitrogen level was N2, which increased yield and NUF. These results supported by Chen et al. (2017) found the NUE of maize in intercropping system increased by 103.7% under reduced *N* compared with that under conventional *N*. Nitrogen use efficiency (NUE) of maize decreased with increasing *N* levels (Dhakal et al., 2021). Regardless of the sowing date of maize, the *N* use efficiency decreased 0.08 for each kg ha^{-1} *N* rate increase (Coelho et al., 2022).

Interaction effect between sowing dates and *N* fertilization levels did not had any significant ($P \leq 0.05$) effect in nitrogen use efficiency of maize NUE in both seasons (Figure 2B). This result could be due to these factors act independently on all the studied traits of common beans.

Competitive relationships and yield advantages

Land equivalent ratio

The results showed that there was significant ($P \leq 0.05$) difference in the effect of sowing date and *N* fertilizer levels on land equivalent ratio (LER) and area time equivalent ratio (ATER), while interaction did not show ($P \leq 0.05$) any difference as indicated in Table 11. Results showed that maize partial land equivalent ratio (L_{maize}) were higher than common beans (L_{beans}) for all intercrops which indicates that there was an advantage for maize, except sowing date T3 with N1 (190.4 kgN/ha). LER values were all >1, implying a significant yield advantage for the intercropping system. Relay intercropping maize-common beans at T3 the greatest with

10.3389/fsufs.2023.1052392

TABLE 12 Response of aggressivity Ag, competitive ratio CR and actual yield losses AYL to interaction effect of sowing date and N levels of maize in 2020 and 2021 seasons.

		2020 season							2021 season						
		Ag_{beans}	Ag_{maize}	CR_{beans}	CR_{maize}	AYL_{beans}	AYL_{maize}	AYL_{total}	Ag_{beans}	Ag_{maize}	CR_{beans}	CR_{maize}	AYL_{beans}	AYL_{maize}	AYL_{total}
T1	N1	−0.28	0.28	0.84	1.20	0.40	0.68	1.08	−0.13	0.13	0.92	1.09	0.53	0.67	1.20
	N2	−0.47	0.47	0.76	1.32	0.50	0.97	1.47	−0.35	0.35	0.81	1.24	0.52	0.87	1.39
	N3	−0.48	0.48	0.75	1.35	0.41	0.89	1.30	−0.32	0.32	0.83	1.21	0.59	0.91	1.49
Mean		−0.41	0.41	0.78	1.29	0.44	0.85	1.28	−0.27	0.27	0.85	1.18	0.55	0.81	1.36
T2	N1	−0.42	0.42	0.79	1.27	0.55	0.97	1.52	−0.19	0.19	0.89	1.13	0.64	0.83	1.48
	N2	−0.53	0.53	0.75	1.34	0.56	1.09	1.65	−0.31	0.31	0.85	1.19	0.73	1.04	1.76
	N3	−0.65	0.65	0.70	1.43	0.53	1.18	1.71	−0.40	0.40	0.81	1.23	0.72	1.11	1.82
Mean		−0.53	0.53	0.75	1.35	0.55	1.08	1.63	−0.30	0.30	0.85	1.18	0.70	0.99	1.69
T3	N1	0.14	−0.14	1.09	0.93	0.96	0.82	1.78	0.23	−0.23	1.13	0.89	0.95	0.72	1.67
	N2	−0.04	0.04	0.98	1.03	0.95	0.99	1.95	−0.04	0.04	0.98	1.02	0.96	1.0	1.95
	N3	−0.05	0.05	0.97	1.03	0.97	1.02	1.99	−0.10	0.10	0.95	1.05	0.94	1.03	1.97
Mean		0.02	−0.02	1.01	1.00	0.96	0.94	1.90	0.03	−0.03	1.02	0.99	0.95	0.92	1.86
Average of *N*															
N1		−0.18	0.18	0.90	1.14	0.64	0.82	1.46	−0.03	0.03	0.98	1.03	0.71	0.74	1.45
N2		−0.35	0.35	0.83	1.23	0.67	1.02	1.69	−0.24	0.24	0.88	1.15	0.74	0.97	1.70
N3		−0.39	0.39	0.81	1.27	0.64	1.03	1.67	−0.27	0.27	0.87	1.17	0.75	1.02	1.76
LSD *T*		0.14	0.14	0.06	0.08	0.06	0.14	0.18	0.09	0.09	0.04	0.07	0.07	0.04	0.06
LSD *N*		0.14	0.14	0.05	0.09	N.S	0.13	0.13	0.03	0.03	0.03	0.05	N.S	0.05	0.06
LSD $T \times N$		N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	0.06	N.S	N.S	N.S	N.S

N.S, not significant.

N3 (1.99) followed by 1.97 with N2. This indicates that 99% (0.99 ha) more area would be required by a sole cropping system to equal the yield of intercropping system. This is attributed to short coexistence period between intercrops components (T3) under available *N* fertilizer application that generated a favorable environment for the development of both crops, maize, and beans (Alemayehu et al., 2017; Ahmed et al., 2020). These results indicate that efficiency of land usage of the maize and beans intercropping is greater compared to monocultures. This result is in line with Alemayehu et al. (2018), Nkhata et al. (2021), and Suárez et al. (2022).

Area time equivalent ratio

ATER provides more realistic comparison of the yield advantage of intercropping over sole cropping in terms of variation in time taken by the component crops of different intercropping systems (Khonde et al., 2018). In all intercropping systems, the ATER values were lesser than LER values indicating the over estimation of resource utilization perhaps due to the wide variations in the maturity periods of the crops (Table 11). ATER values showed an advantage of 19% at T1 × N2 in 2020 season, and 19% at T1 × N3 and T2 × N3 in 2021 season. This could be due to the reason of a significant effect of sowing date of maize on reducing competition and increasing productivity of both crops (Khonde et al., 2018; Ahmed et al., 2020).

Aggressivity

The Ag values show significant ($P \leq 0.05$) difference by the two evaluated factors, but interaction no significantly ($P \leq 0.05$) differences (Table 12). In general, maize has a greater grain yield per ha in relation to dry beans. This information is reflected in the results of the previous indicators and the positive values of aggressivity index that maize showed. A_{maize} was positive, while A_{beans} was negative, demonstrating the dominance of maize over beans, a situation that has also been reported from different studies (Khonde et al., 2018; Suárez et al., 2022). Changes in the maize planting date improvement in the aggressivity (Huang et al., 2018).

Competition ratio

Competition ratio was affected significantly ($P \leq 0.05$) by sowing dates and *N* fertilization levels, but interaction did not show significant differences (Table 12). Maize presented the highest values in the competitive ratio (CR_{maize}) for three sowing dates, except T3 under N1 fertilizer application rate, where maize more competitive than beans. The CR_{beans} values were higher those of maize for sowing date T3 with N1 fertilizer application, showing a high level of competition and benefit for common beans crop species. The trends for CR indicated a positive interspecific interaction between component crops in the maize- soybean relay intercropping system, and *N* application was advantageous and improved the CR (Chen et al., 2017; Khonde et al., 2018). AYL shows the yield loss or gain by its sign and as well as its value (Table 12).

TABLE 13 Response of economic advantage (IAI and MAI) to interaction effect of sowing date and *N* levels of maize as average of both seasons.

		IAI beans	IAI m	IAI total	MAI
T1	N1	611.8	204.5	816.4	1,409.9
	N2	674.0	279.9	953.9	1,766.3
	N3	652.1	273.4	925.5	1,726.1
Mean		646.0	252.6	898.6c	1,634.1
T2	N1	667.4	274.0	1,058.1	1,810.7
	N2	843.6	324.2	1,167.8	2,064.5
	N3	578.4	348.2	1,116.7	2,133.7
Mean		696.5	315.5	1,130.9	2,003.0
T3	N1	1,259.3	166.8	1,492.7	2,012.3
	N2	1,257.0	302.5	1,559.4	2,292.0
	N3	1,256.9	311.9	1,568.8	2,326.0
Mean		1,257.7	260.4	1,540.3	2,210.1
N1		846.2	215.1	1,122.4	1,744.3
N2		924.9	302.2	1,227.1	2,040.9
N3		829.1	311.1	1,220.3	2,061.9
LSD *T*		206.4	66.14	74.19	129.27
LSD *N*		N.S	46.77	55.45	97.63
LSD *T* × *N*		N.S	N.S	N.S	N.S

N.S, not significant.

Actual yield losses

The estimated actual yield loss (AYL) value reflects that the most benefit for both crop species (AYL_{maize} and AYL_{beans}) with intercropping, since its positive values indicate a higher yield per plant compared to the monoculture. The AYL values affected significantly ($P \leq 0.05$) by sowing dates and *N* fertilization levels of maize, but interaction had no significant effect (Table 12). The beans crop was the least benefited compared to maize, but it is important to note that under all intercropping treatments beans yielded better in comparison to monoculture. According to Banik et al. (2000) the AYL index can give more precise information than the other indices on the inter- and intra-specific competition of the component crops and the behavior of each species involved in the intercropping systems. The results are in line with Khonde et al. (2018) and Suárez et al. (2022).

Economic evaluation

The values of the intercropping advantage index (IAI) indicated the economic viability of intercropping when compared to monoculture (Table 13). This viability was reflected by the positive and different values of AYL for each crop (AYL_{maize} and AYL_{beans}). The most advantageous relay intercropping maize with beans was sowing date T3 with applying *N* levels at N3 (285.6 kg/ha); it showed the highest value. Similarly, the monetary advantage index (MAI) values showed that the intercrop presents a greater economic advantage. The highest values for the sowing date T3 under three *N* fertilizer level resulted mainly due to the greater production of beans and maize. Despite the reduction of maize yield in intercropping, this system was shown to be more economically viable (Cardoso et al., 2007). Among the different levels (0, 60, 120, 180, 240), 120 kg ha^{-1} *N* was found efficient with the highest net income (USD 500.43) in comparison to other N levels (Dhakal et al., 2021). In the same way, the intercropping maize at T3 under N2 fertilizer rate indicated a greatest economic advantage, mainly due to the higher production of both beans and maize. This system is profitable and therefore recommended for a resource-poor producer who wishes to increased income with reduced *N* fertilize cost. Similarly, Bitew et al. (2021) found that reduce competition between intercrops components by changes planting date had significant economic benefit expressed with higher MAI. The high economic advantage (IAI and MAI) for common beans/maize relay intercropping might be better utilization of growth resources between maize and common beans combinations (Alemayehu et al., 2017, 2018; Bitew et al., 2021; Suárez et al., 2022).

Conclusion

In light of the preceding discussion, we can conclude that reducing overlap duration (T3) between intercrop components along with applying adequate nitrogen levels, reduces competition and increase complementary resource use to yield sustainability. Therefore, maize relay intercropped with common beans at 30 days from beginning flowering stage of common beans reduces competition between both crops and seems to be a promising strategy to increase crop yield, and increased profitability by 35.2 and 10.3%, beside reduce mineral nitrogen fertilizer applying through N2- fixation by common beans, compared to T1 and T2.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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