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Assess the Sustainability of Intercropping Systems in the Transgangetic Plains of Punjab, Specially Focusing on the Intercropping of Maize (*Zea mays* L.) with Black Gram (*Vigna mungo*) and French Bean (*Phaseolus vulgaris*)

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Abstract

In order to enhance the legumes potential advantages on the cereal yield in intercropping system by nitrogen direct transfer from legume to cereal, an intercropping experiment was conducted during Kharif season 2022 at Lovely Professional University, Phagwara Punjab. The experimental design was randomized block design with three replications, nine treatments were applied. Evaluation of the soles plantings and intercropping's was performed on basis of several intercropping indices (Maize equivalent yield (MEY), Land equivalent ration (LER), land equivalent coefficient (LEC), area time equivalent ratio (ATER), aggressivity (A), and competitive ration (CR)), the monetary advantage (MA) and net returns. After data analysis, competitivity indices indicated that higher yields advantages of maize in intercropping in maize + black gram (1:2) (MEY = 11671.03 kgha^{-1}), LER is 2.23 and LEC (0.43) in maize + black gram (1:2) intercrops respectively. ATER showed highest value (1.70) in maize + black gram (1:2). Aggressivity showed dominance of legumes in all intercrops, against the CR showed that the competitivity was stronger (2.48) in black gram than French bean. MA of ₹ 14082.1 in maize + black gram (1:2) had determined that intercropping as an economic efficiency intercrop than other mixtures. Maize – black gram intercropping resulted in an additional net return gain of ₹ 189796.02 compared to just maize. These results suggest there is considerable potential for small farmers to increase their yields and profits by intercropping.

Keywords

Life on land, Responsible consumption and production, Food security, Competitive efficiencies, Monetary returns

Introduction

The concept of legume intercropping is not new, but its presence has always had a positive influence on crop productivity/unit area and time. Intercropping provides financial assistance in the event of crop failure due to land utilization, sources, resources, and labor inputs [1]. The broad leaves will cover most of the area, providing protection from heavy rainfall and evaporation. Due to excessive rainfall, splash erosion will occur, causing substantial soil erosion, and in the absence of clouds, there will be more bright days, causing higher evaporation and water loss. On the other side, more bright sunlight hours are always required to aid in photosynthesis. Intercropping with legumes provides shade and protection to the soil, as well as increased water availability. Because farmers in Punjab mostly use ground water for irrigation, the water board is being impacted [2] (Figure 1). Maize crops are typically grown solely on flats or ridges and furrow systems using broad casting, dibbling, and line sowing methods with wider row spacing (60 x 20 cm) [3], but intercropping can yield higher returns by reducing crop

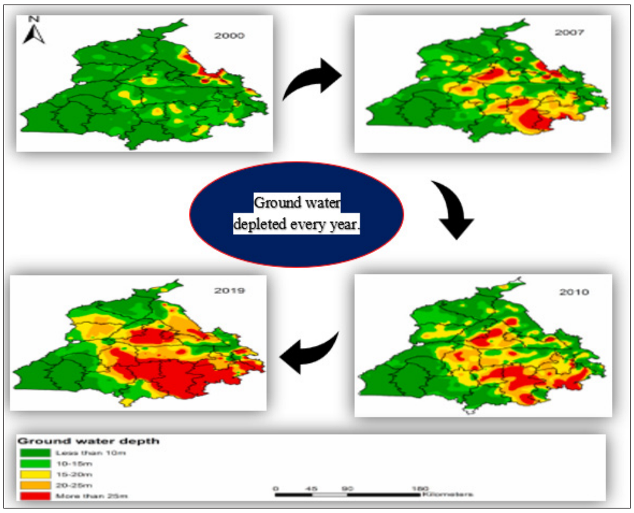

Figure 1: Ground water depth in different years.

failure and increasing crop yield. A single maize crop is adequate to provide good productivity per unit area and time, but when combined with legumes, atmospheric nitrogen will be incorporated in significant quantities into the soil, resulting in soil enrichment via nodules. Which is assisting in increasing maize dry matter accumulation, grain per row, row per plant, seed index, and so on. Legumes not only give nitrogen to the soil, but they also add humus in large quantities after being incorporated as plant waste. As a result, soil aeration is increased, as is soil porosity, which aids root penetration into the soil. The penetration of the root is always required for nutrient uptake. Humus increases soil surface area, which increases both micro and macro porosity. More water and nutrients will be stored for the crops in porosity for a longer period. The root system of legumes is a tap root system that grows deep into the soil and fixes nitrogen in an accessible form. Nitrogen availability in the environment is 78 %, it is 300 times warmer than carbon dioxide, and it will be active in the atmosphere for more than 100 years, so it is preferable to fix this atmospheric nitrogen into the soil rather than applying inorganic nitrogen, which causes greenhouse effect after volatilization, and take its greatest advantages to grow plants and get good crop yield with economic benefits and net returns. Nitrogen gas is a significant contribution to climate change [4].

Material and Methodology

Experimental site

During the 2022 kharif season, the trail was held at Lovely Professional University Phagwara in Punjab, India. The experimental site was at 31°22'31.81' North latitude and 75°23'03.02 East longitude, with a height of 252 m above mean sea level. The average precipitation is 1192 mm, with the majority (89%) falling between June and September due to the south-west monsoon. The soil history was typical haplustept with sandy-loan textured soil with 77% sand, 10.9% silt, and 12.1% clay with a bulk density of 1.8 gcm^{-3}. The total nitrogen was 147 $kgha^{-1}$, the available phosphorus was 15.71 $kgha^{-1}$, and the available potassium was 172 $kgha^{-1}$. The pH ranged from 6.5 to 7.5, the electrical conductivity was 0.18 dSm^{-1}, and the OC was 0.47%.

Experimental design

The experiment was designed using a randomized block design with three replications to decrease error. The trail consisted total of 9 treatments as a sole and in combination forms viz., T1-sole maize (*Zea mays* L.), T2-sole French bean (*Phaseolus vulgaris*), T3-sole black gram (*Vigna mungo*), T4-maize + French bean (1:1), T5-maize + French bean (1:2), T6-maize + French bean (1:3), T7-maize + black gram (1:1), T8-maize + black gram (1:2) and T9-maize + black gram (1:3) row proportions maize + legumes. The spacing was kept at 60 x 20 cm for the primary crop (maize) and altered with equal spacing between French bean and black gram. In one plot, 7 rows of maize crop were maintained. The percentage of maize crop was one row (line sowing) and (1:1), (1:2), (1:3) of French bean (L1) and black gram (L2) viz., maize + French bean (1:1), maize + French bean (1:2), maize + French bean (1:3) and maize + black gram (1:1), maize + black gram (1:2), maize + black gram (1:3).

Experiment management

The crops were seeded in 42 m^2 net plot area according to late maize (PMH-13) and early sowing legumes (French bean - RBL-6 and black gram - Mash-48) to sustain major crops 7 rows $plot^{-1}$ with north-south orientation. The plant development and yield parameters of maize (*Z. mays* L.) were tested. The required fertilizer dose was administered according to the Punjab Agricultural University package and practices for maize (120:60:40 $kgha^{-1}$), French bean (60:120:50 $kgha^{-1}$) and black gram (20:40:20 $kgha^{-1}$). Because maize crops can fix atmospheric nitrogen in soil via nodules and bacteria, the required nitrogen rate for maize crops is higher than for legumes. Bacteria are constantly assisting in the dispersion of nitrogen in soil, ensuring that nitrogen is available to all plants. Yield parameters of maize and pulses were recorded as per standard procedures and analyzed statistically.

Assessment of intercropping efficiency

A, CR, LER, LEC, MA, ATER, net return, gross return were all measured using different formulas. Standard process was closely followed for the calculations to measure and find the best treatment and combination from all 9 treatments using the following formulas.

Aggressivity

It is calculated by following formulae:

$$A_{maize} = \left[Yab/\left(Yaa \text{ x } Zab \right) - Yba/\left(Ybb - Zba \right) \right]$$

$$A_{legume} = \left[\left(Yba \text{ x } Zba \right) - Yab/\left(Yaa \text{ x } Zba \right) \right]$$

Whereas 'Yaa' and 'Ybb' represent sole crop yield or (maize) crop yield and intercrops, 'Yab' and 'Yba' represent mixed yield of sole or main crop (maize) and intercrops, and 'Zab' and 'Zba' represent their sowed proportion of maize crop (maize) crop. If the component species compete equally, the aggressivity is always zero. Otherwise, in the remaining circumstances, one species will give a negative ratio and will be dominant.

CR analysis

To quantify the degree to which one component crop is more competitive than the other, the CR has been developed to assess intercrop competition.

$$\text{Competition ratio}(CR) = [(Yab/Yaa)/(Yba/Ybb)] \times (Zba/Zab)$$

Whereas 'Yaa' and 'Ybb' represent sole crop yield or (maize) crop yield and intercrops, respectively, 'Yab' and 'Yba' represent mixed yield of single or main crop (maize) and intercrops, respectively, and 'Zab' and 'Zba' represent their sowed proportion of maize crop (maize) crop, respectively.

LER and LEC analysis

It was developed to assess the interaction and production potential of crop mixture.

$$LER = [(Yab/Yaa)+(Yba/Ybb)]$$

$$LEC = [(Yab/Yaa) \times (Yba/Ybb)]$$

Whereas "Yaa" and "Ybb" both stands for sole crop yield of main crop and intercrops, respectively, "Yab" and "Yba" stands for mixed yield of main crop and intercrops, respectively.

MA analysis

It can be calculated as per the formulae:

$$MA = \frac{(LER-1)}{LER} \text{ x value of combined yield}$$

Whereas "LER" stands for land equivalent ratio.

MEY analysis

(kgha^{-1}): The yield of a single crop was translated into an equivalent yield based on the crop's current market price MEY was given by [27]. It is expressed in qha^{-1}. The formula used to determine it is as follows:

$$MEY = \text{Grain yield of maize} + \frac{\text{Yield of intercrop x Price of intercrop}}{\text{Price of maize}}$$

ATER analysis

ATER is a variant of LER that gives crop duration information and daily yield assessments for the intercropping system

$$ATER = \frac{[(RYa \times ta)+(RYb \times tb)]}{T}$$

Whereas "RY" stands for relative yield of main crop or intercrop; "Rya" = Intercrop yield of maize with associated crop/pure stand maize yield; "RYb" = Intercrop yield of associated crop/pure stand yield of associated crop; "t" refers to duration (days) for main crop or intercrop, "T" refers to duration of intercropping system (days), "a" refers for the main crop and "b refers for intercrops.

Economics analysis

Gross returns (₹ ha^{-1})

The market prices of maize and intercrops were multiplied by the corresponding yields, and the price of the straw yield of maize and intercrop was also added, to determine the gross returns (₹ ha^{-1}).

Net returns (₹ ha^{-1})

By subtracting the total cost of cultivation from the gross returns, net returns (₹ ha^{-1}) were computed.

Benefit cost ratio (BCR)

The net returns were divided by the total cost of cultivation for each treatment to arrive at the benefit-cost ratio.

Statistical analysis

Analysis of variance was carried out on the data applying the function of Post hoc, Tukey and Duncan using SPSS 22 software. Homogeneity of variance was adapted, and results were expressed as means ± standard deviation. To find out the most efficient treatment Duncan's multiple range test a mean separation technique was applied with probability $p < 0.05$. Fisher's LSD test as post hoc test was used to test the significance of the variation components.

Results and Discussion

The effects of legume cereal intercropping interaction were significant on number of cobs per plant, length of cob, grain yield, stover yield, harvest index and intercrop yield, MEY, LER, CR, and MA. During the experiments, a higher yield was obtained with their respective row proportions in comparison to sole crop.

Effect of maize legume intercropping on yield and yield attributing characters of maize

The number of cobs plant^{-1} was recorded significantly highest (2) in maize + black gram (1:2) and maize + black gram (1:3) intercropping system followed by maize + French bean (1:2) with 1.73 cobs (Table 1). Because of the less competition, resources may be used more effectively, increasing production and the number of cobs plant^{-1} [5]. The canopies of legumes offer shade, lower soil temperature and better soil moisture retention. Legumes provide a shadowing effect that might inhibit weed growth, which could compete with maize for nutrients. These elements may help maize plants to grow and develop more successfully, which will enhance the quantity of cobs they produce [6]. The length of cob was maximum (19.33 cm) in maize + black gram (1:2) followed by maize + black gram (1:2) with 18.45 cm respectively which was almost like maize + French bean (1:2) (18.36 cm). This might be because of nitrogen fixation from legumes boosted yield metrics, which in turn appeared to have a good effect on photosynthesis, the production of metabolites and growth-regulating substances and ultimately better crop growth, leading to a rise in maize output. The intercropping system's enhanced resource efficiency and soil fertility were credited for the increase in cob length [7]. Sole maize (T_1) had less length of cob (16.70 cm). Cob diameter had the similar results i.e., it was maximum (8.37 cm) in maize + black gram (1:2) followed by maize + black gram (1:3), maize + French bean (1:2) *viz.* 8.10 cm, 8.03 cm. By fixing atmospheric nitrogen, legumes enable other plants to access it in the soil. This could improve the intercropped maize plants' access to nutrients, promoting better growth and wider cob diameter [8]. Sole maize had lesser cob diameter (7.37 cm). The number of rows cob^{-1} was found maximum (18.33) in maize + black gram (1:2) followed by maize + black gram (1:3) (17.27) and maize + French bean (1:2) (16.80). This is because longer corn cobs often have more rows, whereas shorter cobs typically have fewer rows. Legumes

Table 1: Effect of intercropping on yield and yield attributed of maize.

Treatments	Cob^{-1} plant	Cob length (cm)	Cob diameter (cm)	No. of rows cob^{-1}	No. of grains cob^{-1}	Grain yield (kgha^{-1})	Straw yield (kgha^{-1})	Harvest index (%)	Seed index (g)
T_1-sole maize	1.00^c ± 0.00	16.70^d ± 0.12	7.37^e ± 0.2	14.33^d ± 0.47	455.67^e ± 3.7	5434.5^e ± 37.16	6597.10^f ± 38.62	43.78^d ± 0.05	20.8^d ± 0.4
T_4-maize + French bean (1:1)	1.17^c ± 0.24	17.03^{cd} ± 0.17	7.67^d ± 0.1	15.33^c ± 0.47	465.33^d ± 3.4	5629.33^d ± 18.01	7150.40^e ± 16.51	43.93^{cd} ± 0.02	22.9^c ± 1.4
T_5-maize + French bean (1:2)	1.73^a ± 0.21	18.36^b ± 0.24	8.03^{bc} ± 0.1	16.80^b ± 0.43	476.67^{bc} ± 2.5	5776.33^b ± 22.40	7328.40^c ± 27.53	44.15^{bc} ± 0.04	26.1^b ± 0.6
T_6-maize + French bean (1:3)	1.67^{ab} ± 0.24	18.17^b ± 0.12	7.93^{bc} ± 0.0	16.30^{bc} ± 0.42	474.00^{bc} ± 0.8	5723.00^c ± 8.29	7274.33^{cd} ± 59.00	44.03^{bcd} ± 0.02	25.7^b ± 0.4
T_7-maize + black gram (1:1)	1.33^{bc} ± 0.24	17.5^c ± 0.23	7.82^{cd} ± 0.1	15.67^c ± 0.47	471.33^c ± 0.9	5696.33^c ± 12.71	7223.00^{de} ± 27.86	43.99^{cd} ± 0.05	23.3^c ± 0.9
T_8-maize + black gram (1:2)	2.00^a ± 0.00	19.33^a ± 0.39	8.37^a ± 0.1	18.33^a ± 0.47	484.33^a ± 1.7	5911.50^a ± 35.72	7519.00^a ± 43.23	45.17^a ± 0.31	28.4^a ± 1.0
T_9-maize + black gram (1:3)	2.00^a ± 0.00	18.45^b ± 0.19	8.10^b ± 0.1	17.27^b ± 0.25	479.00^b ± 2.2	5805.50^b ± 19.93	7414.67^b ± 17.00	44.30^b ± 0.10	27.3^{ab} ± 0.2

Note: *Data is in the form of mean ± SDM at p ≤ 0.05. the mean followed by different letters was significantly different at p ≤ 0.05, according to DMRT for separation of means.

improve the amount of photosynthesis in maize when they are present in intercropping systems. As a result, there are more rows of developing cobs, and more energy is produced and transferred to them [9]. Sole maize (T_1) had a smaller number of rows cob^{-1} (7.37 cm). The maximum number of grains row^{-1} cob^{-1} (484.33) was noticed in maize + black gram (1:2) intercropping system followed by maize + black gram (1:3) (479.00) and maize + French bean (1:2) (476.67). Raza et al. [10] resulted that compared to sole maize plants, intercropped maize plants had considerably more cobs plant^{-1} and larger cobs overall. Crusciol et al. [11] attributed this to resource competition between maize and legume plants, which boosted resource allocation to the maize plants' reproductive organs, resulting in larger and more developed cobs. The maximum seed index (28.40 g) was found in maize + black gram (1:2) followed by maize + black gram (1:3) (27.30) and maize + French bean (1:2) (26.10). Legume crops typically grow to a lower height in intercropping systems than maize plants. Because the taller maize plants intercept the higher portion of the light spectrum while the shorter legume plants do the opposite, this variation in plant height can lead to a more effective utilisation of the available sunshine. As a result of the improved use of light and photosynthesis made possible by this, there is more growth and yield [9]. The maximum grain yield (5911.50 kgha^{-1}) was recorded in maize + black gram (1:2) followed by maize + black gram (1:3) (5805.50 kgha^{-1}) and maize + French bean (1:2) (5776.33 kgha^{-1}). Stover yield was observed maximum (7519.00 kgha^{-1}) in maize + black gram (1:2) followed by maize + black gram (1:3) (7414.67 kgha^{-1}) and maize + French bean (1:2) (7328.40 kgha^{-1}). This is because intercropping raises the amount of biomass generated overall, leading to increased yields. The high stover yield may have been enhanced by this vigorous growth, which may have raised the leaf area index and encouraged the synthesis of photosynthate as well as deep roots to capture nutrients and water. Due to the coordinated delayed release of nutrients throughout the growing season and the legumes' ability to improve the soil, the higher stover yield seen in the legume intercropped condition might be explained [12, 13]. The highest harvest index (45.17 %) was recorded in maize + black gram (1:2) followed by maize + black gram (1:2) (44.30%) and maize + French bean (1:2) (44.15%). Numerous elements including planting density, nutrient availability, water availability and crop management techniques, might affect the Harvest index of an intercropping system.

Effect of intercropping on associated intercrop yield and yield attributing parameters

Among the associated intercrops sole black gram was recorded significantly maximum (32.17) number of pods plant^{-1} followed by sole French bean (29.00). Sole black gram and French bean can utilize all the resources, including sunlight, water, and nutrients, in a monocrop environment without interference from other crop species. This makes it easier for the plants to make better use of these resources, which promotes better growth and development and, eventually, higher pod production [14]. The number of seed pods $^{-1}$ recorded maximum in sole crops as compared to intercrops in case of pulses. Maximum number of seed pods $^{-1}$ (7.33, 6.73) in sole black gram and French bean followed by maize + black gram (1:2) (6.67) and maize + black gram (1:2) (6.33) (Table 2). The plant's ability to photosynthesize more light increases, which boosts the creation of carbohydrates. The extra carbohydrates can be used to make seeds, increasing the quantity of seeds pod^{-1} [15]. Because of competition, resources may be scarcer, which could reduce the amount of seeds pod^{-1} in intercropped black gram [16]. The seed yield was recorded maximum (2317.13 kgha^{-1}) in sole black gram followed by maize + black gram (1:2) and sole French bean (2148.70 kgha^{-1} and 2111.90 kgha^{-1}). This might be because of spatial arrangement. Legume sole cropping allows the best possible spacing to enhance airflow and sunlight exposure, fostering greater growth. Since

Table 2: Effect of intercropping on yield and yield attributing characters of associated legume crops.

Treatments	No. of pods plant^{-1}	Seeds pod^{-1}	Seed yield (kgha^{-1})	Test weight (g)	Stover yield (kgha^{-1})
T_1-sole maize	-	-	-	-	-
T_2-sole French bean	$29.00^{b} \pm 0.82$	$6.73^{ab} \pm 0.377$	$2216.27^{b} \pm 15.61$	$258.13^{a} \pm 3.34$	$1192.00^{e} \pm 4.32$
T_3-sole black gram	$32.17^{a} \pm 1.03$	$7.33^{a} \pm 0.471$	$2317.13^{a} \pm 28.38$	$36.17^{d} \pm 0.28$	$2661.67^{b} \pm 43.76$
T_4-maize + French bean (1:1)	$20.67^{d} \pm 0.47$	$5.67^{b} \pm 0.471$	$1851.83^{e} \pm 24.82$	$230.10^{c} \pm 1.39$	$906.00^{h} \pm 5.35$
T_5-maize + French bean (1:2)	$28.10^{c} \pm 1.25$	$6.67^{ab} \pm 0.471$	$2111.90^{c} \pm 17.45$	$257.90^{b} \pm 2.55$	$1132.67^{e} \pm 44.80$
T_6-maize + French bean (1:3)	$25.67^{b} \pm 0.94$	$6.33^{ab} \pm 0.471$	$2020.37^{d} \pm 41.55$	$245.13^{a} \pm 2.07$	$1031.33^{f} \pm 40.82$
T_7-maize + black gram (1:1)	$25.53^{c} \pm 0.34$	$5.97^{b} \pm 0.818$	$1984.97^{d} \pm 24.28$	$33.37^{d} \pm 0.66$	$2275.00^{d} \pm 16.51$
T_8-maize + black gram (1:2)	$28.13^{b} \pm 0.82$	$6.67^{ab} \pm 0.471$	$2148.70^{c} \pm 9.68$	$35.28^{d} \pm 0.31$	$2770.00^{a} \pm 4.08$
T_9-maize + black gram (1:3)	$28.00^{b} \pm 0.34$	$6.33^{ab} \pm 0.471$	$2028.80^{d} \pm 12.48$	$34.95^{d} \pm 0.09$	$2384.00^{c} \pm 11.34$

Note: *Data is in the form of mean ± SDM at $p \leq 0.05$. the mean followed by different letters was significantly different at $p \leq 0.05$, according to DMRT for separation of means.

they must be planted close together while intercropping, the spatial arrangement may not be as favourable for each crop. This may result in certain plants being shaded and having less access to sunshine, which could limit their total yield [17]. The test weight in French bean was recorded maximum (258.13 g) in sole French bean followed by maize + French bean (1:2) (257.90 g) and maize + black gram (1:2) (245.13 g). This might be due to improved nutrient availability. Since there is no rivalry from other crops like maize when French bean plants are grown as the sole crop, they have access to all the nutrients in the soil. Because of this, the French bean plants can use the resources at their disposal more effectively, which promotes better seed growth and higher seed weight [18]. The stover yield in black gram was recorded and was maximum (2770 kgha^{-1}) in sole black gram followed by maize + black gram (1:2) (2661 kgha^{-1}) and maize + black gram (1:2) (2384 kgha^{-1}). Black gram plants can obtain all the nutrients in the soil during sole cropping because there is no competition from other crops. This enables them to use nutrients for vegetative growth and stover production more effectively. An adequate supply of nutrients encourages the growth of a strong plant structure and raises the biomass of the stover [18].

Effect of intercropping-on-intercropping competitions and efficiency

LER

The LER indicates the efficiency of an intercropping system to use the limited available resources as against their pure stand. The maximum LER (2.23) is obtained from maize + black gram (1:2). Maize + French bean (1:2) and maize + French bean (1:3) had same LER (2.16) (Table 3). This indicates that sole maize crop would need more land to produce the same amount as an intercropping system. This can be attributed to the nutritive transfer's complementary action of legumes in intercropping systems. These results were in conformity with the findings of Thilakarathna et al. [17] and Khonde et al. [19] who resulted that both intercropping systems had higher LER because maize is sensitive to intercropping component crops' spatial arrangement, which accounts for the highest significant LER.

MEY (kgha^{-1})

The maize equivalent yield of sole maize was recorded minimum (5434.50 kgha^{-1}) and found maximum (11671.03 kgha^{-1}) in maize + black gram (1:2) followed by maize + black gram (1:3) (11165.18 kgha^{-1}). This might be due to the lower density and dry biomass of weeds in these treatments. The MEY in these treatments may also have been higher because of lower mining of N, P, and K by weeds. This was mainly due to the lower density and dry biomass of weeds, which resulted in lower nutrient mining and resulted in higher uptake of nutrients by crops. Two-row proportions of legumes can fix more atmospheric N than a single row proportion, and higher row proportions of legumes might transform and mobilize the inherent nutrients from the rhizosphere, which resulted in higher availability of nutrients for crop plants. Similar results were found in the studies of Kim et al. [20] and Salama et al. [21].

CR

Competition ratio term could be helpful in comparing the competitive ability of various crops, measuring competitive changes within a given combination, identifying which plant characters are associated with competitive ability and figuring out what competitive factors are most important. The maximum CR (3.46) is obtained from maize + black gram (1:3) followed by maize + French bean (1:3) (3.32). Sole plots of maize and French bean and black gram had the least competition between them. This might be attributed to the fact that in an additive intercropping pattern, maize reached the desired population and produced yield that was close to that of a pure stand. The paired row geometry of planting gave the legumes enough room to grow and produce in a manner that was satisfactory, likely because of a temporal and spatial complementary effect. Legumes were more competitive than maize, as evidenced by the CR of legumes being greater than unity. Similar results were found in the studies of Wei et al. [22]and Raza et al. [23].

ATER

The idea of area time equivalent ratio has been created considering the occupation of land by crops for specific periods to address the LER's constraint. Values of the ATER greater than unity, like the LER, indicate the benefit of intercropping. ATER showed the positive influences on growth and yield of maize and legumes intercropping. ATER of maize + black gram (1:3) was recorded maximum (1.70) which was statistically non-significant with maize + black gram (1:2) (1.69) and second highest (1.63) ATER recorded in maize + black gram (1:2). Therefore, compared to a single crop, the intercropping strategy was determined to be favourable. This was made pos-

Table 3: Effect of intercropping-on-intercropping competitions and efficiency.

Treatments	LER	MEY (kgha^{-1})	CR	ATER	Aggressivity		LEC
					A_{maize}	A_{legume}	
T_1-sole maize	1.00^e ± 0	5434^e ± 50	1.00^f ± 0.00	1.00^d ± 0.00			
T_2-sole French bean	1.00^e ± 0	-	1.00^f ± 0.00	1.00^d ± 0.00	-		
T_3-sole black gram	1.00^e ± 0	-	1.00^f ± 0.00	1.00^d ± 0.00	-		
T_4-maize + French bean (1:1)	2.11^d ± 0	7916.26^d ± 45.99	1.24^e ± 0.03	1.54^c ± 0.01	-1.99^c ± 0.033	1.99^a ± 0.033	0.41^a ± 0.0056
T_5-maize + French bean (1:2)	2.16^c ± 0.01	8536.81^c ± 104.58	2.33^d ± 0.02	1.62^b ± 0.01	-0.32^b ± 0.020	0.32^b ± 0.020	0.41^a ± 0.0056
T_6-maize + French bean (1:3)	2.16^c ± 0.03	8165.19^d ± 57.53	3.32^b ± 0.11	1.63^b ± 0.01	0.26^a ± 0.016	-0.26^c ± 0.016	0.41^a ± 0.0056
T_7-maize + black gram (1:1)	2.11^d ± 0.03	10969.55^b ± 134.18	1.22^e ± 0.04	1.63^b ± 0.01	-2.05^c ± 0.038	2.05^a ± 0.038	0.43^a ± 0.0070
T_8-maize + black gram (1:2)	2.23^a ± 0.01	11671.03^a ± 229.67	2.48^c ± 0.03	1.69^a ± 0.01	-0.33^b ± 0.023	0.33^b ± 0.023	0.43^a ± 0.0070
T_9-maize + black gram (1:3)	2.19^b ± 0.01	11165.18^b ± 96.44	3.46^a ± 0.09	1.70^a ± 0.01	0.26^a ± 0.018	-0.26^c ± 0.0185	0.43^a ± 0.0070

Note: *Data is in the form of mean ± SDM at p ≤ 0.05. the mean followed by different letters was significantly different at p ≤ 0.05, according to DMRT for separation of means.

sible by the advancement of complementary temporal and spatial theories. According to Maitra and Gitari [24], the LER and ATER were higher in maize + legume in a 1:2 ratio than in a 1:1 ratio. ATER gives a more accurate evaluation of the yield advantage of intercropping over monocropping.

Aggressivity

The competitive ability of the legumes and cereals was estimated through aggressivity. The results showed that the variation ($p < 0.05$) of aggressivity depended on the configuration of the intercropping system. Legumes was found to be the dominant crop (+ve) while the maize appeared as dominated crops (-ve). Highest aggressivity values (2.05 and 1.99 in 1:1 proportion of respectively) were calculated with maize + black gram and maize + French bean. In contrast, maize with legumes had positive values in association, this result indicated a yield advantage for maize crop. Gitari et al. [25] reported that the yield of an intercropping system is positively associated with the interspecific competition of the component crops.

LEC

LEC values were recorded to be greater than 0.25 which indicated yield advantages in maize + legume intercropping systems in both the proportions of intercropping (1:1, 1:2 and 1:3), however, maize + black gram proportion was found to be superior due to better spatial complementarity.

Production economics

MA

Different intercropping systems had significantly different MA. The reason for intercropping not only indicates higher yield than sole crop but also to get higher returns per unit area and greater monetary benefits. Higher monetary benefit (₹ 14082.11) was observed in maize + black gram (1:2). Second highest monetary advantage (₹ 13762.82) was recorded in maize + black gram (1:3). Lowest monetary advantage index (₹ 12215.36) recorded in maize + French bean (1:1) (Table 4). The above results indicate that higher plant density and minimal spacing leads to effective utilization of resources and available nutrients. It also shows the cost of production in intercrops is less compared to sole cropping as there was reduction in labor requirement for weeding. The results are like finding reported by Karunarathna and Maduwanthi [26] in which the row proportions of 1:3 ratio maize-based legume intercropping showed greater monetary benefits.

Gross returns, net returns, and B:C ratio

The gross return was maximum (₹ 290254.93) in maize + French bean (1:2) as MSP of French bean was more than the MSP of both black gram and maize. While minimum gross return (₹ 190629) was seen in sole maize. In case of B:C ratio maximum (2.18) ratio was found in maize + black gram (1:2) in maize + black gram intercropping system as it had less cost of cultivation and more benefit as compared to French bean and maize. The net return (₹ 189796.20) was maximum in maize + black gram (1:2) followed by maize + French bean (1:2) (₹ 187411.93) and maize + black gram (1:3) (₹ 178252.30). In maize + French bean intercropping system maize + French bean (1:2) had the maximum (1.82) B:C ratio as this treatment had a greater number of French bean rows

Table 4: Effect of intercropping on production economics.

Treatments	MA (₹ ha^{-1})	Gross returns (₹ ha^{-1})	Net returns (₹ ha^{-1})	B:C ratio
T_1-sole maize	-	190629.00	90666.00	0.91
T_2-sole French bean	-	196200.00	96608.00	0.97
T_3-sole black gram	-	192930.00	102576.00	1.14
T_4-maize + French bean (1:1)	12215.36^e ± 35.30085	266362.33	167390.33	1.69
T_5-maize + French bean (1:2)	13188.78^c ± 197.8308	290254.93	187411.93	1.82
T_6-maize + French bean (1:3)	13258.37^b ± 221.1059	281812.60	175582.60	1.65
T_7-maize + black gram (1:1)	12544.02^d ± 271.406	260555.80	166349.80	1.77
T_8-maize + black gram (1:2)	14082.11^a ± 137.6969	276699.20	189796.20	2.18
T_9-maize + black gram (1:3)	13762.82^b ± 63.69589	265960.30	178252.30	2.03

which was sold at high price. In sole cropping sole black gram had the maximum (1.14) B:C ratio because of less cost of cultivation as compared to other two sole crops. Sole maize had the minimum (0.91) B:C ratio in the whole experiment because of the higher cost of cultivation and less net return. This rise in economic returns can be attributed to the intercropping system's improved resource efficiency and lower input costs, as well as its higher yield, lower weed biomass, and higher nutrient uptake [27].

Conclusion

In contrast to solitary cropping of the same species, the present study finds that intercropping maize with black gram and French bean may have an impact on grain yield, seed yield, competition between maize and legumes, and the economics of mixtures. As compared to other intercropping methods, maize-black gram or maize-French bean intercropping had the yield benefits of intercropping and optimal utilization of the environmental resources. These 2 intercropping systems were also shown to be the most lucrative. Additionally, black gramme intercropped with maize outperformed French bean in terms of competition. In all mixes, maize was typically the dominating species. Even though legumes produced less in a mixture but cost more at the market, a single planting of them would not be as profitable as one of maize or the other cereals mentioned in the literature. However, as shown by the economic and land use efficiency estimates, mixes with maize and black gram produced significant intercropping benefits. A system like that is simple to use. Considering the foregoing information and conclusions, farmers might boost their revenue and production efficiency by engaging in intercropping, particularly if they used maize-black gram and maize-French bean intercropping systems.

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Conflict of Interest

None.

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