A Sustainable Step in Food Security: Impact of Legume Intercropping on the Soil Environment and Agronomic Performance of Maize (*Zea mays*)

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ABSTRACT

Background: Intercropping facilitates the exchange of nutrients between crops such as cowpea, maizeand mung bean. Soil nutrients are very limited as they are being consumed by the crops and weeds to complete their life cycle. Intercropping is a strategy against the overuse of inorganic fertilizer and to suppress the weed growth to avoid any harmful chemical application.
Methods: This research has been conducted in the field during *Kharif* season 2022 as well as in lab for post evaluation of soil and plant samples to analyze the available nutrients. The plant sample was determined based on agronomic parameters. After assuming homogeneity of variance, the data was put through an ANOVA and the results were reported as means and standard deviations.
Result: The present experiment conducted with intercropping the main crop maize with cowpea and mung bean has offered an interesting result by providing better production and enhanced nutrient use efficiency, which is believed to be due to biological nitrogen fixation (BNF), the leguminous crops can supplement the maize crop with additional nutrients. Therefore, maize-cowpea intercrop (1:2) is recommended for higher yield for farmers in comparison to sole cropping of maize or cowpea in Punjab.

Key words: Biological nitrogen fixation, Legumes, Overused fertilizer, Responsible crop production, Weed growth.

INTRODUCTION

The Punjab region cultivates *Kharif* maize because of the crop's strong yield potential, tolerance of high temperatures and general environmental versatility. India's rice-wheat planting pattern has caused serious problems and low productivity, especially in the country's northern regions. Intercropping has been shown to be a vital practice for agricultural intensification, enhancing land use efficiency, productivity, economic value and resilience against the effects of climate change. Cereal-legume intercropping is a generally permitted approach for building a sustainable food and forage production system with minimal outside input and dispersed land distribution (Singh *et al.,* 2023). Growing numerous crops at once can reduce the yields of the primary crop and the intercrop due to competition for resources like water, nutrientsand light. The physiological and morphological differences between the component crops allow them to complement one another in their use of the environment's resources, leading to a greater yield and more efficient use of the land. N fixation by legumes, for instance, can be transferred to surrounding cereals in cereal/legume intercropping systems, so enhancing their growth and development. It keeps soil alive and productive by modifying its physical, chemical and biological properties. Furthermore, it protects soil from erosion and adds a substantial amount of organic matter through root biomass. Punjab Pollution Control Board only tracks farm fires by satellite until November 30, thus after that date there were about 30% fewer cases of stubble burning in the state compared to last year. Meanwhile, official statistics showed that the area subject to stubble burning could be cut to just 1.4%, significantly less than the incidences. The nitrogen gas can be fixed by legumes in the soil *via* nodules and then dispersed by microorganisms for it to be accessible to all vegetation (Rajeshkumar *et al.,* 2018).

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Key objectives of the study

1. To evaluate the maize- cowpea performance and moong bean intercrop as influenced by different row proportions.
2. To study the effect of cowpea and moong bean as intercropping on the growth and yield components of maize.

MATERIALS AND METHODS

An experiment was carried out on a sandy loam soil at Lovely Professional University in *Kharif* season of 2022.

The experiment design was randomized block design (RBD) with three replicates comprised with different row proportions of sole and intercrops *viz*. sole maize, sole cowpea, sole mung bean, maize+cowpea (1:1), maize+cowpea (1:2), maize+cowpea (1:3), maize+mung bean (1:1), maize+mung bean (1:2) and maize+mung bean (2:1) as represented in Fig 1, 2. The farm is located at an elevation of 250 m from mean sea level, near the

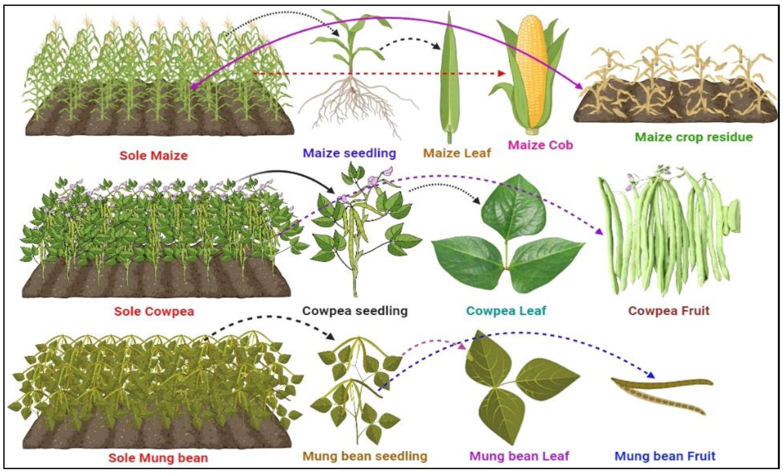
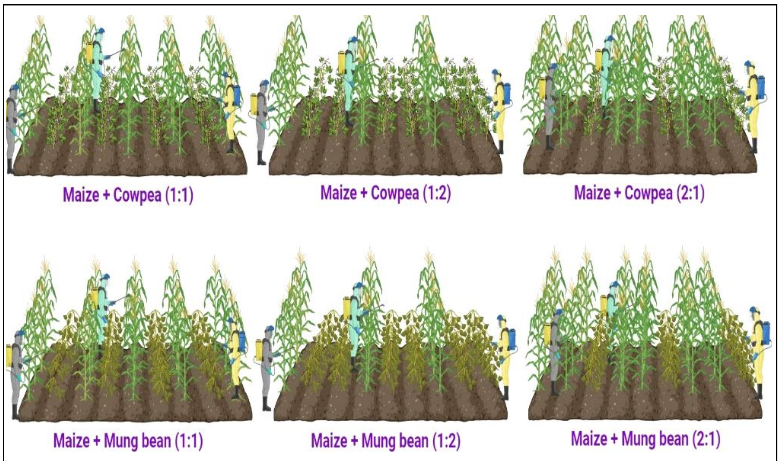


Fig 1: Schematic representation of monocropping *i.e.* sole maize, sole cowpea and sole mung bean in field along with morphology of plants and economic products.



1:1 proportion indicating 1 line of main crop and 1 line of intercrop, 1:2 indicating 1 row of maize and 2 rows of intercrop whereas 2:1 indicating 2 rows of maize and 1 row of mung bean.

Fig 2: Schematic diagram of layout of intercropping of maize with cowpea and mung bean in different proportions in field.

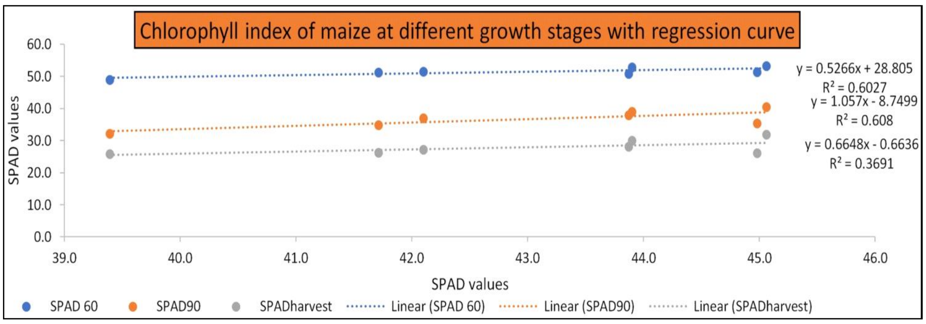


Fig 3: SPAD value variation as per the growth stages of maize represented by the regression curve and equation which indicated SPAD value maximum at 60 DAS and it reduced at maturity.

intersection of latitude 310°22′ 31.81″ North and longitude 750°23′ 03.02″ East and 20 Km away from Jalandhar city in Punjab, India. The average annual precipitation received by the region is 628 mm rest required water given by irrigation. The soil contained 0.152% organic carbon, 300 kg ha^{-1} available nitrogen, 16 kg ha^{-1} available. phosphorus, 125 kg ha^{-1} available potassium with 0.370 dSm^{-1} electrical conductivity and 7.9 pH.

Agronomic practices, the field was cultivated twice with the disc harrow to incorporate all the stubbles of previous crop and later leveled once. The RDF is applied as per the PAU package and practices. The dibbling method was used to sow the seeds of all crops on the ridges by maintaining row to row and plant to plant distance.

Parameters of the study

Leaf area (cm^2) was estimated using a leaf area meter. The stem girth and chlorophyll index were measured with a Vernier caliper and a SPAD meter. No. of cobs $plant^{-1}$, rows cob^{-1}, grains $row^{-1}$and grains cob^{-1} were all measured at harvesting time. Crop growth rate (CGR) was measured by formulae suggested by Watson and Wilson (1956), net assimilation rate (NAR) and relative growth rate (RGR) was also calculated by formulae given by Williams (1946). The average weight of 100 grains was recorded as the "Seed index". Grain yield (kg ha^{-1}) was calculated by weighing cobs after they had been dried to a moisture level of 12-14%. The remaining plant material and husks were mixed and weighed to determine the Stover yield (q ha^{-1}). The harvest index (%) was calculated by formulae given by Donald, (1962) and the Maize equivalent yield (kg ha^{-1}) was computed by equation given by Verma and Modgel (1983).

$$\text{Harvest index} = \frac{\text{Economical yield kg ha}^{-1}}{\text{Biological yield kg ha}^{-1}} \times 100$$

Statistical analysis

SPSS (version 22) was used for the data analysis. Duncan's multiple range test (DMRT) mean separation method was utilized at a significant level of P=0.05 to select the most beneficial intervention. The relationship between growth parameters among themselves and with yield was found by Pearson's correlation at 1% and 5% level of significance (to check the significant and non-significant parameters).

RESULTS AND DISCUSSION

Effect of legume crops on the maize growth attributes

The plant height of maize measured at different stages of crop growth as influenced significantly by different proportions of row arrangement are given in Table 1. Results indicated that significantly maximum (197.69 cm) plant height was recorded in maize+cowpea (1:2), which was at par with maize + cowpea (2:1) with (194.28 cm) plant height. The minimum plant height (185.04 cm) was observed in the sole maize.

The number of green leaves $plant^{-1}$ is a quantum of photosynthetic unit. There was a significant variation recorded in the number of leaves per plant at all periodical

Table 1: Effect of legume on maize growth parameters.

Treatments	Plant height (cm)	No. of leaves $plant^{-1}$	Leaf area cm^2	Chlorophyll index (SPAD)	Stem girth (cm)	Dry matter accumulation (g)
T1- Sole maize	$185.04^{d}\pm2.48$	$9.11^{c}\pm0.37$	$702.07^{e}\pm1.39$	$25.91^{c}\pm1.33$	$11.50^{c}\pm1.64$	$113.25^{d}\pm1.54$
T4- Maize+ Cowpea (1:1)	$192.06^{bc}\pm2.64$	$11.00^{bc}\pm0.86$	$710.35^{c}\pm0.65$	$30.00^{ab}\pm1.11$	$13.96^{bc}\pm1.41$	$118.93^{ab}\pm1.29$
T5- Maize+ Cowpea (1:2)	$197.69^{a}\pm2.64$	$12.97^{a}\pm0.83$	$725.14^{a}\pm0.98$	$31.83^{a}\pm1.22$	$15.35^{a}\pm1.06$	$121.03^{a}\pm1.59$
T6- Maize+ Cowpea (2:1)	$194.28^{ab}\pm1.68$	$11.6^{ab}\pm0.73$	$712.78^{b}\pm1.51$	$28.14^{bc}\pm0.88$	$14.56^{ab}\pm1.39$	$116.43^{bc}\pm1.52$
T7- Maize+ Moong bean (1:1)	$190.16^{bc}\pm1.68$	$10.85^{bc}\pm0.71$	$700.60^{e}\pm1.55$	$26.17^{c}\pm1.78$	$13.02^{bc}\pm2.16$	$115.18^{cd}\pm1.02$
T8- Maize+ Moong bean (1:2)	$191.15^{bc}\pm1.56$	$10.17^{bc}\pm0.87$	$708.93^{c}\pm1.29$	$27.13^{c}\pm1.78$	$12.59^{c}\pm2.09$	$115.71^{cd}\pm1.85$
T9- Maize+ Moong bean (2:1)	$188.38^{cd}\pm0.83$	$09.17^{bc}\pm9.71$	$705.25^{d}\pm1.30$	$26.25^{c}\pm1.25$	$13.93^{bc}\pm2.19$	$113.90^{cd}\pm1.77$

intervals between all treatments are shown in Table 1. The highest no. of green leaves (12.97) was noted in Maize+Cowpea (1:2), which was at par with Maize+Cowpea (2:1) with 11.6 leaves and lowest (9.11) was recorded in Sole maize.

Notably, compared to other configurations, the 1:2 row design for both crops significantly had the highest leaf area. The higher leaf area (725.14 cm^2) was recorded in the Maize+Cowpea (1:2) which was closely followed by Maize+Cowpea (2:1) with (712.78 cm^2) and lower (702.07 cm^2) was recorded in the sole maize (Table 1).

There was significant variation recorded in SPAD value. The maximum chlorophyll index (31.83 SPAD) was observed in Maize+Cowpea (1:2) which was at par with Maize+Cowpea (1:1) with (30.0 SPAD) and minimum (25.91 SPAD) was recorded in Sole maize (Table 1).

As illustrated in Fig 3, there was a statistically significant difference noticed in SPAD value at 60 DAS, 90 DAS and at harvest. In 60 DAS, a higher SPAD value illustrates the highly substantial fluctuation of the SPAD value at different ages of the reproductive stage. The value of SPAD increased over a period of 4-5 weeks and then it fell after the crop was harvested. Regression curves with R^2 value represented in the figure.

The stem girth was found to be linear at early stage and grows wider at middle and slightly increased towards maturity and harvest stages. Stem girth was significantly differed at all growth stages. The maximum stem girth (15.35 cm) was measured in Maize+Cowpea (1:2) that was at par with Maize+Cowpea (2:1) with (14.56 cm) girth and lowest stem girth was recorded in Sole maize (11.50 cm) (Table 1).

Dry matter production is an important index for the enhancing photosynthetic efficiency in plants. During advancement of crop growth, steady and steep increase in DMP was noticed from vegetative to flowering phases and slightly increased towards maturity (90 DAS) and harvest stages. Significantly highest dry matter accumulation (12.03 g) was recorded in Maize+Cowpea (1:2) which was at par (118.93 g) with Maize+Cowpea (1:1) and the lowest was recorded in Sole maize (113.25 g) (Table 1).

One important component of agricultural physiology is CGR. Growth rate, which is determined by several factors like light absorption, photosynthetic efficiency and nutrient availability, is the rate at which a crop builds up biomass. Dry matter accumulation, a gauge of plant biomass production and CGR are tightly associated. Growth throughout the reproductive phase and intercropping has an impact on relative growth rate levels. Maximum CGR and RGR (2.71 $gm^{-1}day^{-1}$ and 0.193 $gg^{-1}day^{-1}$) was recorded in Maize+Cowpea (1:2) and minimum (2.13 $gm^{-1}day^{-1}$, 0.134 $gg^{-1}day^{-1}$) observed under sole maize (Table 2) while there was significant differences observed in other treatments in case of CGR as well as RGR.

Effect of legume crops on the maize yield attributes

Number of cobs $plant^{-1}$, cob length, number of grains cob^{-1} and number of rows cob^{-1} are the main yield contributing attributes which were significantly varied with the different row proportions. All intercropped treatments statistically perform better as compared to sole crop. Number of cobs $plant^{-1}$ was the main yield attribute. Statistically, higher no. of cobs (2.87) $plant^{-1}$ was observed in Maize+Cowpea (1:2), which was at par (2.03) with Maize + Mung bean (1:2) and lower (1.76) was recorded in Sole Maize (Table 3). Significantly highest cob length (22 cm) was recorded in maize+cowpea (1:2) and minimum (13.98 cm) recorded in Sole Maize. The maximum cob diameter (8.5 cm) has been recorded in Maize+Cowpea (1:2) and lowest was recorded in Sole Maize (7.98 cm). In Maize+Cowpea (1:2), the highest number of rows cob^{-1} (35) was reported, while the lowest number (22.98) was found in Sole Maize. The highest number of grains row^{-1} (17.98) was found in Maize+Cowpea (1:2), which was equal to Maize+Cowpea (1:1) at (17.01), while the lowest number of grains row^{-1} (14.7) was found in Sole Maize. In Maize+Cowpea (1:2), the highest number of grains row^{-1} (580.52) was recorded, while the lowest number (432.01) was found in Sole maize. According to Table 4, the longest tassels were measured in Maize+Cowpea (1:2) at 44.05 cm, while the shortest ones were measured in Sole maize at 30.98 cm.

The test weights for the Maize+Cowpea (1:2) significantly had the highest weight (44.05 g) and the lowest (38.88 g) in the Sole maize significantly. Legume intercropping makes extensive use of the nutrients that are available, as demonstrated by the highest test weight in Maize+Cowpea (1:2) as compared to maize grown alone. Table 4 shows that Maize+Cowpea (1:2) recorded significantly highest grain yield of 6003 kg ha^{-1}, while Sole maize recorded the lowest grain yield 5402.19 kg ha^{-1}. Sole maize (6690.7 kg ha^{-1}) had the lowest stover production and maize+cowpea (1:2) had the highest (7701.2 kg ha^{-1}). Growing cowpea in 1:1 and 2:1 row arrangement resulted

Table 2: Effect of rotating legume crops on maize CGR and RGR.

Treatments	CGR (gm^{-1} day^{-1})	RGR (gg^{-1} day^{-1})
T1- Sole maize	2.13b±0.083	0.134d±0.05
T4- Maize+Cowpea (1:1)	2.59ab±0.029	0.176b±0.09
T5- Maize+Cowpea (1:2)	2.71a±0.016	0.193a±0.02
T6- Maize+Cowpea (2:1)	2.53ab±0.043	0.160bc±0.04
T7- Maize+Moong bean (1:1)	2.35ab±0.056	0.150c±0.05
T8- Maize+Moong bean (1:2)	2.37ab±0.06	0.163bc±0.01
T9- Maize+Moong bean (2:1)	2.27ab±0.036	0.159c±0.06

Table 3: Effect of legume crops on maize yield attributing characters.

Treatments	No. of cobs plant^{-1}	Length of cobs (cm)	Cob diameter (cm)	No. of rows cob^{-1}	Grains row^{-1}	Grains cob^{-1}
T1- Sole maize	$1.76^{b}\pm0.45$	$13.98^{e}\pm0.44$	$7.98^{b}\pm0.12$	$22.98^{c}\pm0.26$	$14.7^{b}\pm0.46$	$432.01^{e}\pm2.58$
T4- Maize+Cowpea (1:1)	$2.56^{b}\pm0.19$	$20.12^{ab}\pm1.48$	$8.32^{ab}\pm0.10$	$30.91^{ab}\pm1.13$	$17.01^{ab}\pm0.73$	$529.09^{b}\pm2.01$
T5- Maize+Cowpea (1:2)	$2.87^{a}\pm0.26$	$22.00^{a}\pm0.29$	$8.5^{a}\pm0.06$	$35.02^{a}\pm0.89$	$17.98^{a}\pm0.13$	$580.52^{a}\pm2.61$
T6- Maize+Cowpea (2:1)	$1.84^{b}\pm0.19$	$20.73^{abc}\pm0.72$	$8.22^{ab}\pm0.23$	$31.70^{bc}\pm1.10$	$16.10^{abc}\pm0.90$	$505.61^{c}\pm2.01$
T7- Maize+Moong bean (1:1)	$1.71^{b}\pm0.17$	$16.99^{cd}\pm0.50$	$8.20^{ab}\pm0.19$	$29.98^{bc}\pm1.29$	$15.3^{bcd}\pm0.71$	$450.98^{d}\pm2.98$
T8- Maize+Moong bean (1:2)	$2.03^{ab}\pm0.31$	$19.01^{bcd}\pm1.23$	$8.26^{ab}\pm0.10$	$31.00^{bc}\pm0.90$	$15.98^{abc}\pm0.20$	$451.92^{d}\pm3.01$
T9- Maize+Moong bean (2:1)	$1.97^{b}\pm0.35$	$17.01^{de}\pm0.71$	$8.19^{ab}\pm0.12$	$27.72^{bc}\pm0.80$	$15.01^{cd}\pm0.52$	$434.01^{e}\pm2.91$

*Data is in the form of mean ± SDM at $p\leq0.05$. The mean followed by different letters was significantly different at $p\leq0.05$, according to DMRT for separation of means.

Table 4: Effect of legume crops on maize yield attributing characteristics.

Treatments	Tassel length (cm)	Test weight (g)	Stover yield (Kg ha^{-1})	Grain yield (kg ha^{-1})	MEY (q ha^{-1})	Harvest index (%)
T1- Sole maize	$30.98^{d}\pm0.44$	$38.88^{c}\pm0.40$	$6690.7^{f}\pm34.01$	$5428.19^{f}\pm27.13$	-	$42.97^{b}\pm0.07$
T4- Maize+Cowpea (1:1)	$41.01^{b}\pm0.44$	$41.01^{b}\pm0.44$	$7589.01^{b}\pm32.98$	$5799^{b}\pm19.13$	$75.44^{c}\pm15.65$	$43.12^{b}\pm0.15$
T5- Maize+Cowpea (1:2)	$44.05^{a}\pm0.60$	$44.05^{a}\pm0.60$	$7701.12^{a}\pm35.68$	$6003^{a}\pm32.19$	$81.91^{a}\pm17.63$	$46.01^{a}\pm0.70$
T6- Maize+Cowpea (2:1)	$41.10^{b}\pm0.53$	$41.10^{b}\pm0.53$	$7470.76^{c}\pm22.13$	$5778.53^{bc}\pm16.01$	$79.31^{b}\pm25.63$	$44.78^{b}\pm0.35$
T7- Maize+Moong bean (1:1)	$40.79^{bc}\pm0.43$	$40.79^{bc}\pm0.43$	$7268.68^{de}\pm40.80$	$5642.37^{d}\pm36.91$	$74.11^{c}\pm28.87$	$44.06^{b}\pm0.44$
T8- Maize+Moong bean (1:2)	$39.96^{bc}\pm0.90$	$39.96^{bc}\pm0.90$	$7355.17^{cd}\pm20.90$	$5732^{cd}\pm10.23$	$80.30^{ab}\pm31.2$	$44.10^{b}\pm0.31$
T9- Maize+Moong bean (2:1)	$39.7^{bc}\pm0.47$	$39.7^{bc}\pm0.47$	$7099.24^{e}\pm21.01$	$5531.12^{e}\pm37.18$	$77.63^{bc}\pm12.43$	$44.01^{b}\pm0.10$

*Data is in the form of mean ± SDM at $p\leq0.05$. The mean followed by different letters was significantly different at $p \leq0.05$, according to DMRT for separation of means.

Table 5: Simple correlation between different growth parameters.

Variable	r
Plant height with SPAD	0.84*
Plant height with leaf area	0.873**
Plant height with dry matter	0.880*
Plant height with grain yield	0.972**
Plant height with straw yield	0.946**

*Indicates significant at 5% level of significance, **Indicates significant at 1% level of significance.

in a substantially lower maize equivalent yield (MEY) of 75.44 q ha^{-1}; in contrast, growing maize with cowpea in a 1:2 row arrangement produced a significantly higher MEY of 81.91 q ha^{-1} significantly. The biological and economic yields have a direct relationship with the harvest index percentage. The mixture of maize and cowpea (1:2) had the greatest HI (46.01%) and the lowest (42.97%) percentages, respectively.

Plant height was highly positively correlated with leaf area, grain yield and straw yield (0.873**, 0.972**, 0.946**), which showed highly significant correlation. Whereas plant height with chlorophyll index and dry matter are correlated at 5 % level of significance as shown in Table 5.

Impact of legume crops on the maize growth attributes

The highest plant height recorded in intercropped plots might be due to better land cover due to more plant population which inhibited the weed seed germination (Burgess *et al.,* 2023). A higher number of functional leaves $plant^{-1}$ may result from less cereal-legume competition, optimal light availability, optimal temperature, sufficient spaceand improvements in physiological and morphological characteristics (Uher *et al.,* 2019). The maize plant chlorophyll index was measured by SPAD (Soil Plant Analysis Development) (KONICA MINOLTA) (Kandel 2020). Due to the symbiotic relationship between cereals and legumes and increased nitrogen fixation by legumes, intercropping may have produced the highest chlorophyll index ever measured (Hossain *et al.,* 2022). The brace/stilt roots ratio was more on the stem which was helpful to provide the extra support to plant and absorbed the more nutrient significantly showed in (Table 1) (Gogna *et al.,* 2022). Maize+Cowpea (1:2) had the highest dry matter, which was mostly explained by significantly more plant height, more leavesand increased light absorption (Li *et al.,* 2022). These factors enable greater solar radiation utilization and higher dry matter accumulation. Crop biomass boosted per unit ground area per unit time is shown by CGR. Significantly, since there was greater nitrogen uptake and less weed infestation, the highest CGR may have been caused by maize plants' improved ability to use CO_2 and sun radiation (Khedwal *et al.,* 2023).

Impact of legume crops on the maize yield attributes

The metabolic activity of maize plants is significantly influenced by nitrogen fixation in conjunction with legumes, resulting in an increase in the number of cobs produced in intercrop combinations (Pinto *et al.,* 2023). The presence of synthetic and fixed atmospheric nitrogen in the silk length caused the legumes to have a considerable impact, resulting in an automatic increase in maize yield of 80-95% (Di Bene *et al.,* 2022). Generally, no. of rows cob^{-1} were mainly dependent on plant genetics, rather than on environmental factors like humidity, temperature, rainfall *etc.* (Kumar *et al.,* 2023).

Harvest index % increased that might be due to the grain yield and stover yield both were recorded highest because of better utilization of the resources by intercropping, cropping intensity was more which led to more dry accumulation of the plants. In sole maize wider space and more weed population was the maize reason to reduce the harvest index % (Ksiezak *et al.,* 2023).

CONCLUSION

In conclusion, intercropping increases a unit land area's production more than a single crop. The findings showed that intercropping was significantly more advantageous than sole cropping in case of growth and yield parameters. The present study found that by enhancing leaf functional characteristics and dry matter partition, intercropped maize yielded more. Therefore, maize-cowpea intercrop at 1:2 recommended for higher yield for farmers in comparison to sole maize.

Conflict of interest

The authors declared that they have no conflict of interest with respect to this work.

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