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Optimizing soybean integration in maize-dominated cropping systems for enhanced yield and resource efficiency

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Abstract

Maize holds paramount significance in Pakistan's agricultural landscape but traditional maize farming faces challenges due to inefficient resource management and soil fertility depletion, this study delves into the transformative benefits of intercropping maize with soybeans. A field experiment employed a factorial arrangement. It evaluated maize planting geometries (MPG) - P_1: Alternate single row on 75 cm apart ridges, P_2: Alternate double rows on 75 cm apart ridges, and control (CK) treatments without soybean intercropping. Intercropping techniques (SIT) for soybeans included S_1: Soybean for brown manuring at 30 days after sowing (DAS), S_2: Soybean as fodder at 60 days after sowing (DAS), and S_3: Soybean as a grain crop at maturity. Standard methods were employed to record soil health, growth, and yield parameters. Results indicate that the P_1 geometry optimizes both maize and soybean production, significantly impacting various parameters. The most favorable outcomes, such as 217.33 cm plant height, 22.24 cm cob length, 4.63 cm cob diameter, 496.13 total grains per cob, 372.97 g 1000-grain weight, 19.10 t ha^{-1} maize yield, 10.76 t ha^{-1} soybean yield, and 2.9% harvest index (HI), are observed with soybean-maize treatments on alternate single rows at 75 cm apart ridges with no intercropping. Additionally, the highest Benefit-Cost Ratio (BCR) of 1.19 is achieved when intercropping in alternate single rows at 75 cm apart with soybean as a grain crop. The adoption of the P_1S_3 approach emerges as economically viable for Faisalabad's farming community, offering a sustainable remedy to labor-intensive practices and soil fertility concerns in Pakistan.

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Introduction

After wheat and rice, maize ranks third in the world (Bawa, 2021). In developing countries, maize is consumed directly and serves as staple diet for some 200 million people (Erenstein *et al.,* 2022). Maize possesses significant nutritional benefits for both humans and animals (Poole *et al.,* 2021). Maize grain had 8% fats, 68.5% carbohydrates, 16.5% protein, 3% crude fiber and 4% ash (Jocelyne *et al.,* 2020). Maize production is continuously decreasing because of exhaustive cropping systems depleting the soil fertility badly triggering towards high input requirements (Maitra *et al.,* 2021).

The traditional agricultural practices in Pakistan are significantly draining and exhausting the soil resources. The existing cropping systems fail to meet the needs and requirements of farmers (Yang *et al.,* 2020). There's a need to develop such a cropping system which can sustain the production and soil fertility. Intercropping of the leguminous crop with maize could be a feasible approach for tackling the above-mentioned problems (Yang *et al.,* 2020).

Soybean has multiple uses which can be grown for fodder, oilseed and as manure crop (Shea *et al.,* 2020). Soybeans, being a leguminous plant that can harness atmospheric nitrogen (N) with root nodules in their roots. This ability not only enhances the nutritional value of fodder but also helps alleviate nutrient depletion issues (Kebede, 2021). Additionally, soybeans have been recently employed as biofuels (Voora, 2020). Introducing soybean in maize intercropping proved to be a practical method for bridging the substantial gap between oilseed production and demand (OSIEYO, 2022).

Cropping system continuously depletes the soil fertility badly ensuring more use of synthetic fertilizers along with lowering the yield potential (Aleminew *et al.,* 2020). Organic matter is less than 1 % along with problematic soils increasing day by day (Zahid *et al.,* 2020). Continuously depleting soil fertility demands massive use of fertilizer to attain a better yield (Aleminew *et al.,* 2020). To guarantee global food security for the following generations, there's an urgent need of current situation to modernize conventional cropping systems to potentially productive systems and to conserve soil fertility.

Maize-soybean intercropping for brown manuring can address the soil problems on small farms by sustaining soil fertility (Jena *et al.,* 2022). The leguminous crops fix atmospheric nitrogen (N) via nodule establishment (Lyu *et al.,* 2020). Brown manuring provides the N through the N2-fixation, leads to enhanced moisture retention as well as acts as mulch during the summer (Das *et al.,* 2020). The leguminous nature of soybean crop does not only helps fix the atmospheric nitrogen with the help of nodules which is present on its roots but also enhance the soil fertility by adding the organic matter (Yuvaraj *et al.,* 2020).

In addition to this atmospheric nitrogen fixation by legumes, the nutritive worth of the fodder can be improved by legume-cereal intercropping (Uher *et al.,* 2020). Legume and maize intercropping for fodder is a feasible strategy for silage (Soe Htet et al., 2022). Introducing intercropping into a maize-based monocropping system holds the potential to enhance yield per unit area, offering a contrast to the traditional practice of monocropping (Zhang *et al.,* 2022). The intercropping system exhibited higher levels of dry matter, nutrients, and Photosynthetically Active Radiation (PAR) interception compared to the sole cropping system. This heightened resource utilization contributes to a substantial advantage in yield (Raza *et al.,* 2021). Cereal-legume intercropping stands out as the optimal choice for achieving both increased herbage yield and balanced nutrition for livestock.

Pakistan continues to grapple with a shortage of edible oil, with edible oil and oilseeds ranking among the country's most substantial food and feed imports. The projections for edible oil imports in the year 2020/21 were estimated to reach a record 3.55 million metric tons (USDA, 2020).

The domestic production is only projected at 0.374 million tonnes. Total consumption of edible oil from all resources is estimated at 3.291 million tonnes. The import bill is Rs. 574.199 billion (Pakistan Bearu of statistics, 2020). There is a widespread breach among national production and requirements. Farmers are hesitated to grow soybeans due to the lack of interest in oilseed production, adaptation problems, planting geometry, crop establishment and low-yielding varieties (Asad *et al.,* 2020).

One significant challenge confronting farmer in soybean cultivation is the integration of soybean into well-established and widely accepted monocropping conventional patterns (Bybee-Finley, 2021). Utilizing specific planting geometries in maize-soybean intercropping offers a potential solution to overcome these challenges. Additionally, it has the capacity to meet the demand for oilseed.

The study aims to provide a comprehensive solution to the challenges faced by conventional cropping systems, contributing to the overall improvement of agricultural practices and food security.

Materials and methods

During the autumn season of 2019, the experiment was conducted at the Agronomic Research Area of the University of Agriculture in Faisalabad, Pakistan. The soil used for the investigation was sandy clay loam with a fine texture, and contained homogenous particles. Using an auger, soil samples were obtained before and after from each experimental plot between 0 and 30 cm deep to evaluate the physiochemical characteristics of the soil (Fu *et al.,* 2019). A manual dibbling technique was used for sowing on ridges, with a seed rate of 25 kg per hectare for maize and 75 kg per hectare for soybeans. Pioneer-DK8148 hybrid maize and Faisal-soy variety of soybean were employed in the experiment. Fertilizers were administered to meet the recommended levels of Phosphorous (P), Potassium (K) and Nitrogen (N) at rates of 125, 125, and 250 kg ha^{-1}, respectively. All of the P, K, were broadcasted in their entirety at the sowing time, while N was applied in three stages: at sowing, knee height, and flowering.

The environmental conditions of the region and the crop's water needs were taken into consideration when scheduling irrigations. A total of seven irrigations were applied over the course of the whole growth cycle, from seeding to the crop's physiological maturity. Ten days after sowing, the first irrigation was performed, and additional irrigations were done as necessary. To maintain the desired plant-to-plant distance, thinning of maize and soybean plants was conducted prior to the first irrigation, as dictated by the specific treatment requirements. Weed control was achieved through regular tillage operations to mitigate competition between crops and weeds. Furdan (granular insecticide) was administered when the crop had six leaves, at a dosage of 20 kg per hectare, to protect it from maize borers and shoot flies.

Experimental design and analysis

Maize was sown by using recommended production technology in each experimental plot while soybean was intercropped with maize by using different set of treatments. The experiment was set up using a factorial arrangement and three replications in a randomized complete block design (RCBD). Treatments included in the experiment included Factor A: maize planting geometries (MPG)- P_1: Alternate single row on 75 cm apart ridges, P_2: Alternate double rows on 75 cm apart ridges, and control (CK) treatments with no soybean intercropping. Factor B: Soybean intercropping techniques (SIT) include S_1: Soybean for brown manuring at 30 DAS, S_2: Soybean as fodder at 60 DAS, and S3: Soybean as a grain crop at maturity.

The experiment was replicated three times with net plot size of 2.25 m × 6.0 m. for all treatments in maize soybean intercropping. On ridges 75 cm apart, maize and soybeans were intercropped in alternate single and double rows. The field was prepared by planking after each of the three times the dirt was dug up to a deepness of 10 to 15 cm with a tractor-mounted cultivator. The data collected underwent statistical analysis using Fisher's analysis of variance to conduct a rigorous statistical assessment (Steel *et al.,* 1997).

To assess mean differences between treatments, the least significant difference (LSD) test was employed at a significance level of 5%. Graphical presentation was carried out using GraphPad Prism 8 software, developed by GraphPad Software in San Diego, CA, USA.

Study parameters

Maize and soybeans were both manually harvested in the last week of November 2019. Subsequently, the maize plants were left on the ground for four days for drying under sun, followed by bundling. After bundling, the cobs were detached from the stems and left to dry in the sunlight for an additional five days before the shelling process. Data on the relevant parameters of the component crops per treatment were then gathered using standard methods. To ascertain the quantity of pods per soybean plant and the number of seeds per pod, data was collected from ten randomly selected tagged plants, and the results were subsequently averaged. Similarly, for maize plants, ten cobs were randomly chosen from each treatment, and parameters such as cob length, diameter, and total number of grains per cob were measured and then averaged (Undie *et al.,* 2012).

The weight of 1000 seeds for both crops was determined by extracting three representative samples, each comprising 1000 seeds from every treatment. These samples were then weighed using an electronic balance, and the results were converted to the average weight of 1000 seeds in grams (Ehsanullah *et al.,* 2011). The biological yield for both crops, measured on a dry weight basis, was calculated. The obtained biological yield from each plot was logged in kilograms and subsequently transformed into tons per hectare.

To ascertain the grain yield at maturity for both maize and soybean, plants from each plot were harvested, sun-dried, and manually threshed. The resulting seed yield was recorded in kilograms per plot and then converted into tons per hectare (Matusso *et al.,* 2013). Additionally, the benefit-cost ratio (BCR) was computed by subtracting the total expenditure from the total income, as per the methodology outlined by Raza *et al.,* 2018. The harvest index (HI) for both maize and soybean was calculated by taking the ratio of grain yield to biological yield and expressing it as a percentage.

$$\text{Harvest index (HI)} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

Results and discussion

Parameters of main crop (Maize)

Plant height (cm)

The results display that P_1CK recorded the maximum plant height (217.33 cm), while P_2CK recorded the minimum plant height was recorded at P_2S_3 (172 cm) (Fig. 1A). The treatments were found to differ significantly. Their interaction, however, was not determined to be substantial. It could be due to presence maize-legume of competition. These results were also backed by the findings of Ehsanullah *et al.,* (2011) who determined that plant height was significantly altered in legume-maize intercropping. However, results presented by Arshad (2000) were in contrast with the results of parameter under study who stated that plant height was not significantly affected by different planting geometries.

Cob length (cm)

Data concerning the cob length (cm) of autumn planted maize as altered by different treatments is presented in Fig. 1B, which displays that both the factors had significant impact on cob length and effect of their interaction was found significant. Maximum cob length was recorded with P_1CK (22.24 cm) while minimum cob length was measured at P_2S_3 (13.97 cm). The length of maize cobs can be significantly influenced by intercropping practices. Intercropping introduces a dynamic where neighboring plants compete for essential resources like sunlight, nutrients, and water. The results were matched with those reported by Arshad (2000) who reported that cob length was diminished in intercropping treatments as comparation to sole plantation of maize. Santalla *et al.,* (2001) also carried out a similar experiment in which it was concluded that cob length is significantly affected by the various maize planting geometries of intercropping due variation of soil fertility as well as the genetic potential of crop.

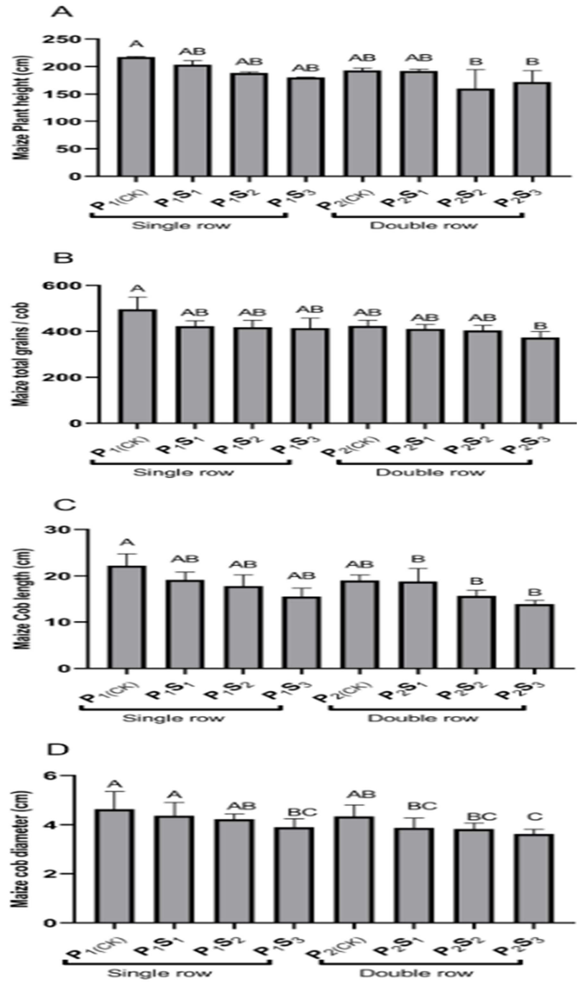

Fig. 1A-D. Plant height (A), maize cob length (B), cob diameter (C) and total grains per cob (D). The letters A, B, C above the bars signify statistical significance; distinct letters denote significant differences between two samples, while identical letters suggest no significant difference between the compared samples

Cob diameter

Data concerning cob diameter (cm) of autumn planted maize as affected by various maize planting geometries and soybean intercropping techniques are offered in Fig. 1C. Comparison between treatments shows that maximum cob diameter was recorded with P_1CK (4.63 cm) while minimum value (3.63 cm) of cob diameter was recorded with P_2S_3. Both the factors had a substantial impact on cob diameter and the effect of their interaction was found significant. In certain planting geometries, where plants are spaced too closely or arranged in a way that leads to increased competition among them, the cobs may experience limitations in terms of available resources which can result in smaller cobs in diameter. These results relate to the results of Arshad (2000), who concluded that various intercropping techniques significantly affected the cob diameter.

Total grains per cob

Data concerning number of grains per cob of autumn planted maize as altered by treatments are presented in the Fig. 1D, that both the factors had significant impact on total grains per cob at harvest however, effect of their interaction was found non-significant. Maximum number of total grains per cob was recorded with P_1CK (496.13) while least number of grains per cob was measured at P_2S_3 (373.06). The variation in the number of grains per maize cob can be attributed to the differing intercropping intensities of soybean within the maize, leading to competition among the component crops. This competition ultimately influenced the yield of grains per maize cob. These results were match with Meena *et al.,* (2006) reported that various planting arrangements significantly affect the number of grains per cob in maize. Conversely, Arshad (2000) investigated that various planting arrangements has non-significant effect on number of grains per cob.

1000-grain weight (g)

Significant differences in the 1000-grain weight of maize under the treatments were revealed in Fig. 2E. P_1CK, recorded the highest 1000-grain weight (280.30 g), which was statistically comparable to P_2CK (253.84 g). While P_2S_3 recorded the lowest 1000-grain weight (209.03 g). The 1000-grain weight serves as a crucial indicator of both seed development and seed quality, holding significant importance in the overall grain yield of maize. This characteristic is influenced not only by genetic factors but also by the specific environmental conditions of a given area. Disparities in 1000-grain weight arise due to diverse competitions experienced in varying planting geometries. These findings align with the conclusions of previous studies conducted by Ullah *et al.,* 2007 and Ehsanullah *et al.,* 2011, which emphasized the considerable impact of intercropping systems on the 1000-grain weight of maize. Conversely, Panhwar *et al.*, 2005 reported a non-significant effect of intercropping on the 1000-grain weight of maize within intercropping treatments.

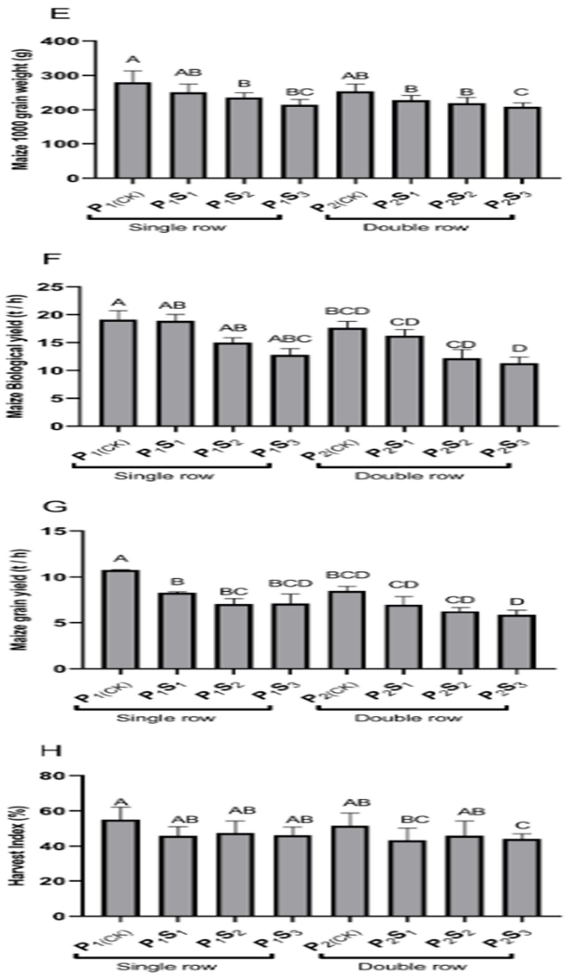

Fig. 2E-H. 1000 grain weight (E), biological yield (F), grain yield (G), and harvest index (H) of maize crop

Biological yield (t ha^{-1})

The biological yield of maize was strongly impacted by the treatments under study, according to the results shown in Fig. 2F. P_1CK reported the highest biological yield (19.10 t ha^{-1}), which was statistically comparable to P_2CK (18.99 t ha^{-1}). P_2S_3 showed the lowest biological yield (11.29 t ha^{-1}) nevertheless. Biological yield serves as an indicator of the total dry matter generated throughout the entire growth period of a crop. Significant reduction was observed in the production of maize biomass with different soybean intercropping techniques and maize planting geometries as associated to sole maize this might be due to presence of competition for growth resources (Khan *et al.,* 2007). The findings are consistent with *Matusso et al.,* 2013, who similarly observed a reduction in the biological yield of maize when intercropped compared to sole maize cultivation. Similar study was carried out by Mandal *et al.,* (2013) who observed the decrease in biomass yield base crop due to presence of diverse intercrops.

Grain yield (t ha^{-1})

The parameter being researched was considerably impacted by each parameter is represented in Fig. 2G. The P_1CK recorded the highest grain yield 10.76 t ha^{-1}, While P_2S_3 documented the bottommost grain yield of 5.86 t ha^{-1}. It is an important factor that combines different yield components. In comparison to sole maize cropping, there was a significant decrease in the grain yield of the maize crop when soybeans and maize were intercropped. This could be because of increased intra and inter-specific competition between the two crops, which in turn affected yield-contributing factors like the number of 1000-grain weight and grains per cob (Khan *et al.,* 2005).

Harvest index (%)

The harvest index data demonstrated that while the value of their interaction was judged to be non-significant and but all parameters had substantial differences. Maximum harvest index at 55.12 % was recorded with P_1CK. While, minimum 43.39 % value was recorded with P_2S_1 as displayed in Fig. 2H. It. The harvest index is indicative of a crop's ability to efficiently convert total dry matter into economically valuable yield, serving as a measure of the crop's physiological efficiency. These results were backed by Ehsanullah *et al.,* (2011), Matusso *et al.,* (2013) and Khan *et al.,* (2007) they reported that there was non-significant difference in harvest index of maize in different planting geometries in maize-soybean intercropping.

Parameters of Intercrop (Soybean)

At soybean maturity

Plant height (cm)

We present data on soybean plant height within the context of maize-soybean intercropping in Fig. 3A. The maximum soybean plant height, reaching 95 cm, was observed in P_2S_3, whereas the minimum height of 87.33 cm was noted in P_1S_3. The variation in plant height can be attributed to different harvesting times for soybean and the dominant effect of maize on soybean. It is essential to recognize that plant height is a multifaceted trait influenced by factors such as genetics and environmental conditions. These findings align with the study by Aziz *et al.,* (2012), who concluded that varied planting configurations in intercropping systems significantly altered the height of both crops. The observed variations in soybean plant height underscore the complex interactions within maize-soybean intercropping systems, emphasizing the need for a comprehensive understanding of the contributing factors.

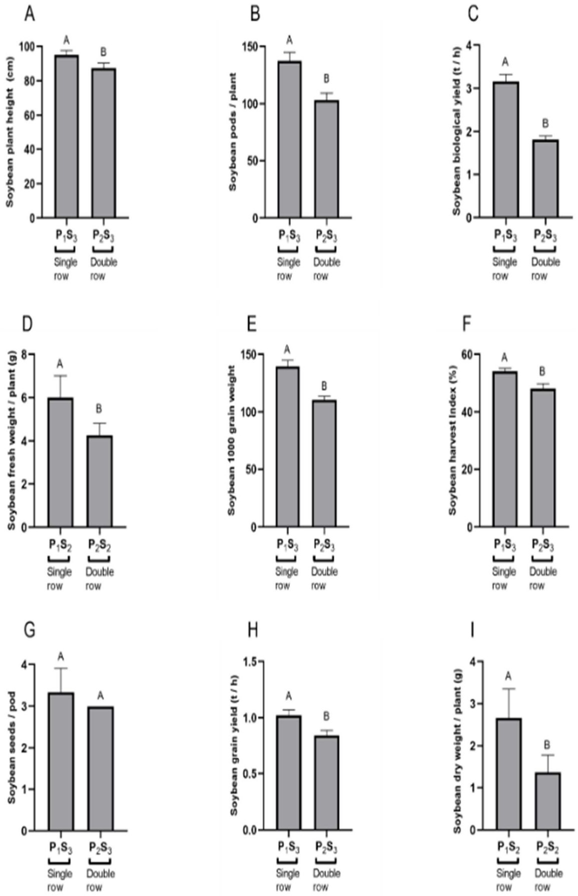

Fig. 3A-I. Soybean plant height (A), soybean pods per plant (B), soybean seeds per plant (C), soybean 1000 grain weight (D), soybean biological yield (E), soybean grain yield (F), soybean harvest index (G), soybean fresh weight per plant (H), and soybean dry weight per plant (I).

Number of pods per plant

The data highlights that the number of pods per plant was significantly influenced by various maize planting geometries in intercropping (Fig. 3B). The highest number of pods per plant (137.33) was observed in the P_1S_3 row, statistically comparable to P_2S_3 (103.33). The observed variation in the number of pods per plant is attributed to the competitive dynamics among crop plants and the dominant effect of maize. This finding is consistent with studies by Aziz *et al.* (2012) and Kebebew *et al.* (2014), indicating that dissimilar planting arrangements have a noteworthy impact on the number of pods per plant. These results underscore the importance of considering planting configurations to optimize pod production in maize-soybean intercropping systems.

Number of seeds per pod

The maximum number of seed pods (4) was observed in P_1S_3, while the minimum number of seeds (3) was recorded in P_2S_3. No significant difference was noted between the higher and lower values of the number of seeds per pod (Fig. 3C). The number of seeds per pod is a crucial factor contributing to overall yield. Our investigation indicated that various maize planting geometries did not have a significant effect on the number of seeds per pod. This lack of impact can be attributed to the genetic nature of this trait, which is less influenced by environmental factors. These findings align with the conclusions of Kebebew *et al.,* (2014), further supporting that the number of seeds per pod is a genetically regulated characteristic relatively unaffected by planting arrangements.

1000-grain weight (g)

The results shows that the highest 1000-grain weight (139.66 g) was found in P_1S_3, where soybean was intercropped with maize as a grain crop on alternate double rows, and the lowest 1000-grain weight (110.66 g) was found in P_2S_3 (Fig. 3D), where soybean was intercropped with maize on alternate single rows. The outcomes align with the conclusions of *Aziz et al.* (2012), indicating that varying planting arrangements exerted a notable influence on the 1000-grain weight of soybeans in intercropping scenarios, support the hypothesis that the difference in 1000-grain weight was possibly caused by the presence of various types of competition, such as shading effect and less availability of growth resources among the maize and soybean.

Biological yield (ton per hectare)

The data illustrates the biological yield (tons per hectare) in soybean-maize intercropping scenarios. Notably, the intercropping of soybean at P_1S_3 resulted in the highest biological yield at 3.16 t h^{-1}, while the intercropping at P_2S_3 produced the lowest yield at 1.81 h^{-1} (Fig. 3E). This outcome could be attributed to the faster growth rate, height advantage, and wider root system of cereal components in cereal-legume intercropping, influencing competitive dynamics and subsequently impacting biological yield. These observations align with Ghaffarzaeh *et al.,* (1994) findings, which indicate that in intercropping systems combining soybeans and maize, soybean yields typically decrease while maize yields tend to increase.

Grain yield (ton per hectare)

The data presents soybean grain yield data in maize-soybean intercropping. The highest grain yield (1.02 h^{-1}) was observed in P_1S_3, while the lowest yield (0.84 h^{-1}) occurred in P_2S_3 (Fig. 3F), where soybean was intercropped with maize in alternate single rows. These results align with Egbe *et al.,* (2010) findings, attributing variances with grain production within different maize planting geometries to the existence of diverse plant competition. Intercropping, as emphasized by Matusso *et al.,* (2014) has a substantial impact on grain yield, underlining the importance of considering planting configurations for optimizing crop production.

Harvest index (%)

The results displayed revels that highest harvest index value (54.17%) was recorded in P_1S_3 and lowest value of harvest index (48.15%) was measured in P_2S_3 (Fig. 3G). The difference in harvest value with various maize planting geometries could be consequence of the shading effect of maize on soybean. Matusso *et al.,* (2014) who came to the conclusion that the harvest index of soybean in intercropping was significantly impacted by different maize planting geometries. The economic gain will be greater the drier matter is turned into economic produce.

Soybean fodder production

Fresh weight per plant (g)

In our examination of maize planting geometries within soybean intercropping, we observed significant variations in fresh weight, ranging from a maximum of 6.0 g in P_1S_2 to a minimum of 4.26 g in P_2S_2. The results are displayed in Fig. 3H. As fresh weight is a crucial parameter for fodder, directly impacting fodder yield, our findings highlight the practical implications for forage production. These results are consistent with Htet *et al.* (2016) conclusion that variations in fresh weight across different maize planting geometries are influenced by various types of competitions within the intercropping system. This underscores the importance of considering spatial arrangements to optimize fodder production in agricultural systems. The observed variations in fresh weight provide valuable insights into the dynamic interplays between maize and soybean in intercropping scenarios, informing strategies to enhance forage yield.

Dry weight per plant (g)

In our investigation of maize planting geometries within soybean intercropping, we found significant variations in dry weight represented in Fig. 3I that ranging from a maximum of 2.6 g in P_1S_2 to a minimum of 1.36 g in P_2S_2. Dry weight, a crucial parameter for fodder and indicative of fodder yield, was notably influenced by different maize planting configurations. These findings align with Htet *et al.,* (2016) conclusion that the variations in dry weight across various maize planting geometries can be attributed to diverse competition dynamics within the intercropping system. This emphasizes the importance of optimizing spatial arrangements for enhanced forage production in agricultural systems. The observed variations in dry weight provide valuable insights into the dynamic interactions between maize and soybean in intercropping scenarios, guiding strategies to maximize forage yield.

Soybean brown manuring

The study investigated the impact of brown manuring on soil nutrient dynamics, examining total nitrogen, available phosphorous, available potassium, and organic matter levels before and after the process. Before brown manuring, P_1S_1 showed the highest total nitrogen content at 0.5%, whereas P_2S_1 exhibited a lower value of 0.04%. Post-brown manuring, P_1S_1

experienced an increase to 0.09%, while P_2S_1 concurrently decreased to 0.07%. In terms of available phosphorous, P_1S_1 demonstrated the maximum content before brown manuring at 7.57 ppm, slightly surpassing P_2S_1 at 7.62 ppm. Post-brown manuring, P_1S_1 saw a significant increase to 9.13 ppm, while P_2S_1 decreased to the same level. Before brown manuring, P_1S_1 displayed higher available potassium levels (173 ppm) compared to P_2S_1 (172 ppm). After brown manuring, P_1S_1 experienced a notable rise to 205.33 ppm, whereas P_2S_1 showed a decline to 189.33 ppm. Before sowing, P_1S_1 had the maximum organic matter content at 0.85%, and P_2S_1 closely followed at 0.86%. Following brown manuring, P_1S_1 exhibited a further increase to 1.09%, while P_2S_1 decreased to a minimum of 0.94%. The detailed results are comprehensively presented in Table 2, highlighting the dynamic changes induced by the brown manuring process on soil nutrient levels.

In our study of maize-soybean intercropping, total nitrogen variations were influenced by soybean rows, plant numbers, and maize dominance (Fu *et al.,* 2019). Surprisingly, different maize planting geometries did not significantly affect total nitrogen, aligning with Matusso *et al.* (2014) conclusions, highlighting the intricate interactions in this intercropping system. For total available phosphorus, significant variations were observed with different planting configurations, reflecting the complex relationship between spatial arrangements and soil phosphorus dynamics (Fan *et al.,* 2020). Similarly, available phosphorus and potassium were significantly influenced by planting geometries, emphasizing the interconnectedness of nutrient dynamics in intercropping (Ariel *et al.,* 2023). Regarding organic matter, its contents were significantly affected by maize planting arrangements, both before and after brown manuring, underlining its crucial role in soil fertility. However, intriguingly, organic matter contents remained non-significantly influenced by various maize planting geometries, suggesting a nuanced interplay that warrants further exploration (Te *et al.,* 2022).

Moving on to total available phosphorous, a crucial macronutrient, we observed significant variations based on different maize planting geometries in soybean intercropping, both before sowing and after brown manuring (Fan *et al.,* 2020). This nutrient, known for its essential role in promoting root and grain formation in crop plants, showcased a dynamic response to different planting arrangements. These findings underscore the intricate relationship between soil phosphorous dynamics and the spatial arrangement of crops in intercropping systems.

Similarly, available phosphorous contents were significantly influenced by various maize planting geometries in soybean intercropping, and the variations in available potassium were linked to variations in the number of soybean rows and the dominant effect of maize on soybean (Ariel *et al.,* 2023). This emphasizes the importance of considering the spatial arrangement of crops in intercropping systems, as it not only affects individual nutrient dynamics but also interplays with other nutrients.

Shifting focus to organic matter, our investigation concluded that its contents were significantly affected by various maize planting geometries in soybean intercropping, both before sowing and after brown manuring (Te *et al.,* 2022). Organic matter, recognized as a key component of soil fertility, demonstrated its impact on aeration, water holding capacity, microbial activity, and the water and nutrient uptake of plants. However, intriguingly, organic matter contents were found to be non-significantly affected by various maize planting geometries in soybean intercropping. These findings underscore the complexity of the interplay between crop arrangement and organic matter dynamics, urging further exploration into the underlying mechanisms.

Conclusion

In conclusion, our research highlights the effectiveness of intercropping maize with soybean in the agro-ecological conditions of Faisalabad, Pakistan. While the intercropping system led to a reduction in maize grain yield, the accompanying economic advantages from soybean cultivation more than compensated for this loss. The recommended approach of planting maize and soybean in alternate single rows at a ridge separation of 75 cm with soybean as grain crop proved to be both feasible and economically beneficial for the local farming community. This method not only yielded high net benefits but also showcased superior resource utilization. Overall, our findings suggest that this intercropping strategy holds promise for enhancing the economic and agricultural sustainability of farmers in the region.

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