

Available on <https://www.joarps.org>
 Journal of Applied Research in Plant Sciences
 (JOARPS)
 ISSN: 2708-3004 (Online), 2708-2997 (Print)



Evaluation of Maize and Soybean as A Sole and Intercrop Under Various Planting Geometries

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Article Received 10-10-2025, Article Revised 25-11-2025, Article Accepted 18-12-2025

ABSTRACT

Soil fertility and sustainability is intensively affected by monocropping system of maize in Pakistan. The maize-legume intercropping with suitable planting geometry can be an appropriate strategy that can improve sustainable soil fertility. Keeping in view the above facts, a field experiment was conducted at Agronomic Research Area, University of Agriculture Faisalabad during Autumn season 2023-24 under the following treatments i.e. two Planting Geometries: G_1 = 60 cm apart ridge plantation, G_2 = 75 cm apart ridge plantation with three Planting Techniques: T_1 = Sole maize, T_2 = Sole soybean, T_3 = Maize-soybean Intercropping. Randomized complete block design with split plot arrangements was used with three replications. All the agro-physiological parameters of both crops were assessed by adopting approved/standard procedures. Recorded data was analyzed statistically by using Fisher's analysis of variance techniques and treatments means' were compared by Least Significant Difference (LSD) test at 5% probability level. Results revealed that in case of maize, maximum grain yield, biological yield and Benefit Cost Ratio (BCR) were reported with T_1 (Sole maize plantation), however minimum values for above mentioned parameters were reported with T_3 (Maize soybean intercropping). Similarly, in case of soybean, maximum grain yield, biological yield and BCR were reported with T_2 (Sole soybean plantation), however minimum values for these above mentioned parameters were reported with T_3 (Maize soybean intercropping). Intercropping systems were assessed by Land Equivalent Ratio (LER). Results revealed that maximum value of LER (1.18) was recorded with G_1T_3 (60 cm apart ridge plantation of maize soybean intercropping), it was concluded that 75 cm apart sole maize plantation and 75cm apart ridge plantation of maize-soybean intercropping would be a feasible approach under the agro-ecological conditions of Faisalabad, Pakistan.

Keywords: Maize, Soybeans, Intercropping, Planting geometries, Land equivalent ratio, Benefit cost ratio.

INTRODUCTION

Maize plays a diverse and dynamic role in global agriculture food systems and food security (Grote *et al.*, 2021). It is dispersed across the world and has become the leading staple cereal in terms of annual production surpassing 1 billion metric tons (Madhukar *et al.*, 2020). After wheat and rice, maize ranks third in the world. Maize grains constitute of 68.5% carbohydrate, 8% lipid, 4% ashes, 3% crude fibers and 16.5% protein (Mut *et al.*, 2022), therefore, it is widely used in poultry and animal feed, making it important industrial crop (Patra, 2021). In Pakistan, maize is grown as a multipurpose food and forage crop with greatest average yield across cereals cultivated in the country. It is the second-largest grain crop after wheat in Pakistan (Hussain *et al.*, 2023). The major maize growing areas of Pakistan are KPK and Punjab, providing 99% of the total maize production of the country. During 2022-23, maize was cultivated on area of 1720 thousand hectares with total output of 10.18 million tones (Govt. of Pakistan, 2023).

Soybean is one of the most important oilseed crop, accounting 28% of global oil production and 64% of

oilseed meals in the world (El-Hamidi and Zaher, 2018), it is also rich in protein content. As a leguminous crop, it can fix the atmospheric nitrogen through root nodules in its roots. Therefore, when grown in intercropping, it can increase the nutritional value of subsequent crop, it can also address the nutrient depletion problem and shortage of biofuel. Soybean and maize intercropping can be a viable technique for the fulfilment of a huge gap between the production and demand of oilseed (Wilton, 2019). In Pakistan soybean was introduced as an oilseed crop like other oilseed crops but it was reported that it has poor adaptability in the field. Among various problems associated with growing soybean in Pakistan are low yield, poor germination, deterioration of seed viability, climatic hazards and marketing problems (Asad *et al.*, 2020). Globally, soybeans are currently growing in more than 50 countries. This crop can grow in the world's temperate, tropical and subtropical regions, the leading soybean growing countries and exporters are Brazil, the USA and Argentina. While China is the biggest importer of soybean importing 166.33 million metric tons (Qiao, 2023). It is also a multipurpose crop

that is not only grown for its edible oil and nutrients enriched fodder but also significantly contributes to poultry feed and industrial raw material such as paints, cooking, inks, biofuels, textiles and gums. It is also used to treat chronic illnesses including cancer and heart attack. In Pakistan, soybean (*Glycine max* L.) was introduced in Sindh in the 1960s and the Punjab rain-fed regions.

Crop intensification, high yielding hybrids and exhaustive conventional cropping systems of Pakistan are depleting the soil badly. Cultivable land is decreasing due to urbanization and industrialization, similarly due to the lack of interest of the farming community in minor crops our country is facing an acute shortage of edible oil. Pakistan is still facing a scarcity of edible oil. The domestic production is only 0.446 million tons while the oilseed import bill is Rs.152.514 billion. There is a wide gap between domestic production and requirements. The low oilseed status of Pakistan is due to conventional fixed cropping patterns which do not permit the cultivation of oilseed on a large area. Traditional oilseed cultivars have become unable to fulfil the demand for edible oil. There is an urgent need to develop such a type of pattern which facilitates intercropping. The current system of mono-cropping cannot keep pace with the increasing demands of a farmer. Multiple cropping could be efficient and economically viable because it increases production, saves time and ensures judicious resources use with increased farmers' economy. Polyculture especially intercropping, is a beneficial approach around the world. It is beneficial for the farmer as it provides sustainable yields.

Maize-soybean intercropping can fulfil space between oilseed productions and demand (Iqbal *et al.*, 2019). However, there are some issues associated with maize-soybean intercropping, such as soybean being a broad leaves crop, its adjustment with narrow leaves crop maize create a problem in weeds control and shading effect of maize on soybean reduces the photosynthesis rate resulting in less production of chlorophyll content. Due to shading more inappropriate management of water, disturbing planting geometries and indeterminate behavior of soybean creates difficulties at the time of harvesting. Nevertheless, it is reported if soybeans intercropped with maize in dryland-upland areas, it can boost land intensity, and income. Intercropping systems have been widely used around the world because of their ability to improve land-use efficiency and Radiation Use Efficiency (RUE) (Siamabele, 2021). It is predicted that intercropping soybean with maize will increase the system's net profit and Benefit Cost Ratio (BCR) and

help to overcome the shortage of oilseeds in Pakistan (Ahmad *et al.*, 2016).

Maize is a C4 plant, uses all input very efficiently while on the other hand soybean has completely different input requirement than maize. Furthermore, the advantage may be obtained by selecting appropriate planting geometry. In Pakistan, farmers mostly adopt bed plantation for maize soybean intercropping but not with restricted input application technique. In intercropping, it is difficult to do using traditional crop planting geometry. It is an urgent necessity to develop such type of pattern which facilitates intercropping (Maitra *et al.*, 2021). Therefore, this research was conducted to compare the production of maize and soybean under different cropping systems and geometries.

MATERIAL & METHODS

Experimental site: A field experiment was conducted during Autumn, 2023-24 under the agro-ecological conditions of Faisalabad (31.25 North latitude and 73.09° East longitudes) at 184 m height from the sea level.

Soil analysis and agro metrological data: Prior to the experiment, chemical and physical analysis (Table.1) of selected area was conducted. The Soil samples were gathered with the use of an auger from the depth of 0-30 cm. A soil extract was collected from saturated soil and measured electrical conductivity of soil extract by using an EC meter (Rhoades *et al.*, 1996). Soil pH was measured according to Thomas *et al.*, 1996. The nitrogen content was calculated using the Kjeldahl method (Kirk 1950). Available Phosphorus (Kuo, 1996), Available potassium (Helmke and Sparks, 1996), Organic matter (Helmke and Sparks, 1996) were measured. Samples were analyzed in the laboratory of Ayub Agricultural Research Institute, (AARI) Faisalabad. The metrological data (Figure 1) during the crop growth period was obtained from meteorological observatory cell, Department of Agronomy, University of Agriculture, Faisalabad

Treatments: The experiment consisted of the following treatments.

Factor A: Planting Geometries

G₁ = 60 cm apart ridge plantation

G₂ = 75 cm apart ridge plantation

Factor B: Planting techniques

T₁ = Sole maize

T₂ = Sole soybean

T₃ = Maize-soybean Intercropping

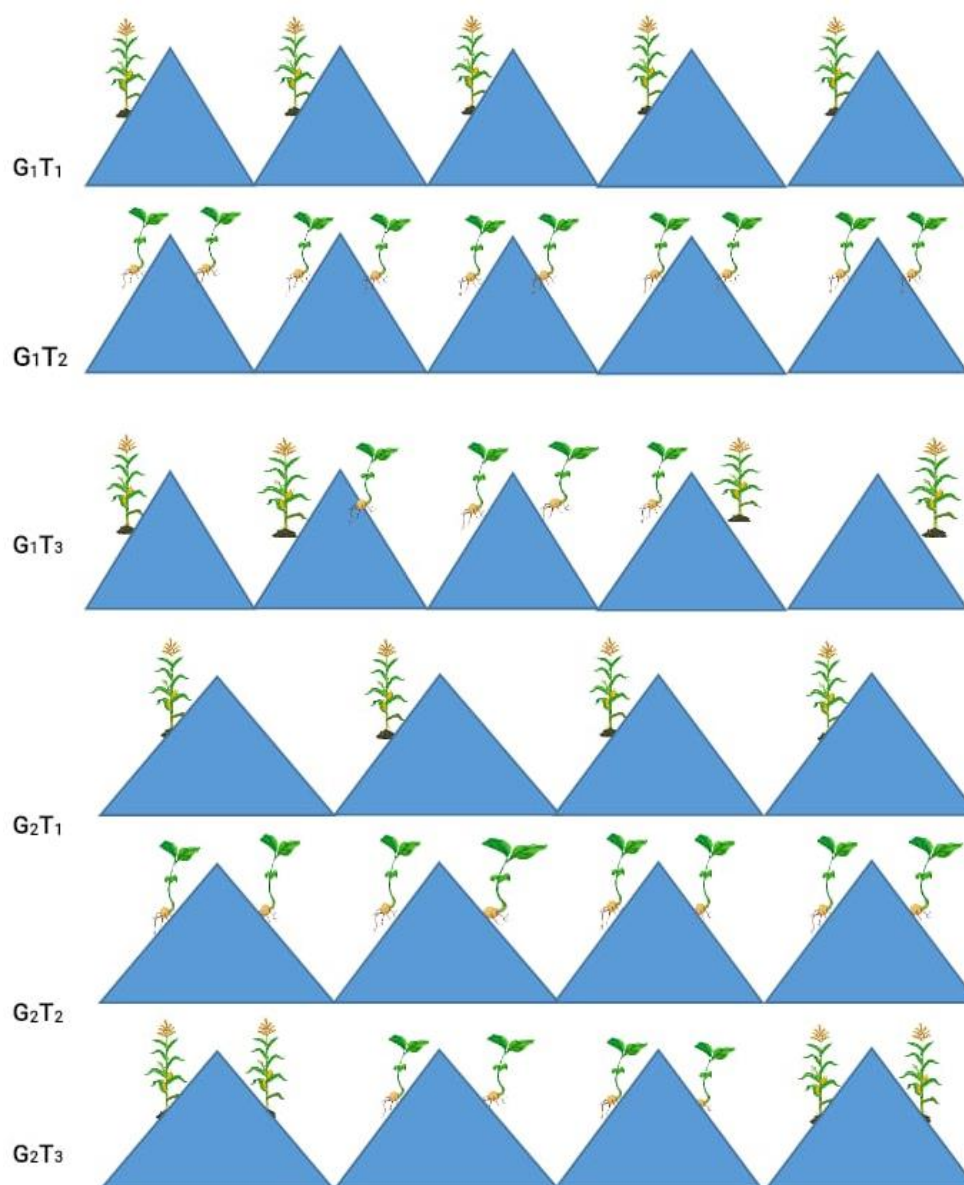


Table 1. Analysis of soil (physio-chemical) before and after sowing of crops

Determination	Before	After
Soil texture	Loamy	Loamy
Electrical Conductivity (EC) (dS m ⁻¹)	1.71	5.88
pH	8.4	8.1
Organic matter (%)	1.40	1.08
Total Nitrogen (%)	0.055	0.07
Available phosphorus (ppm)	23.9	20.3
Available potassium (ppm)	217	118
Soil saturation (%)	34	40

Crop Arrangements: Experiment was performed in a Randomized Complete Block Design (RCBD) with split plot arrangement having three replications. Total plot size of 3m × 7m was used for all the treatments. A soybean genotype “UAF-Soya” and a single cross maize hybrid “P-4040” were used in this experimentation. Pre-sowing irrigation (Rauni) was applied in the field, and when moisture was at the field capacity (Wattar), two cultivations followed by

planking were carried out for seed planting. Sowing of both the crops and all the treatments was completed with manual dibbling on 5th of August 2023. Maize and soybean seeds were used at 25 kg ha⁻¹ and 75 kg ha⁻¹ respectively. Fertilizers were provided in the form of Diammonium Phosphate (DAP), Urea and Potassium Sulphate (SOP) at 250-125-125 kg ha⁻¹, respectively. These rates were used for maize-soybean intercropping and sole maize, however for sole soybean fertilizers

rates were applied at 57.5-57.5-62.5 kg ha⁻¹ respectively. Complete doses of phosphorus and potassium were applied at the time of sowing, whereas nitrogen was applied in three splits (4-5 leaf stage, knee height and at flowering in maize). Irrigation was done according to crop requirement and environmental conditions. During, first 10-20 days of sowing, shoot fly attack was observed, and an insecticide named Advantage (FMC) at 400 ml in 120 liters of water per acre was used to control shoot fly. Armyworm and fall armyworm attack was seen 20-25 days after sowing. Radiant (Emamectin + Leufenuron) at 400 ml per acre in 120-liter water were applied to control armyworm and fall armyworms.

However, to control pre-emergence weeds the Dual Gold (S-metolachlor) at 1000 ml in 120 liter of water as a pre-emergence (for all the treatments) and Atrazine (Atrazine) at 500 ml in 120 liter of water as a post-emergence weedicide (only for sole maize cultivation) were used. For sole soybean treatments, as a post-emergence weedicide, Targa (Quizilofop-ethyl) at 500 ml in 120 liters of water per acre was applied. The other agronomic practices were performed according to the crops. In third week of November 2023, both crops were manually harvested. After harvesting, the maize plants sun dried for five days. After drying, cobs were separated from the stalks before shelling. Soybean plants were harvested, tied into bundles and sun dried in the field for 4 to 5 days then manually threshed.

Observations recorded

Maize

1. Plant height at maturity of inner rows and outer rows (cm)
2. Maize grain rows per cob of inner and outer rows
3. Maize grains per cob of inner and outer rows
4. Biological yield, grain yield and harvest index:

Soybean

1. Soybean pods plant⁻¹ of inner and outer rows
2. 1000-grain weight of inner and outer rows (g)
3. Biological yield, grain yield and harvest index
4. Land Equivalent ratio
5. Benefit Cost Ratio

Measurements and analysis

Maize:

Plant height at maturity for inner and outer rows (cm): Ten plants from outer rows and ten from inner rows of each experimental unit (treatment) were randomly selected and their height was measured by using a measuring tape. Height was taken from the ground surface to the top of the flag leaf. The values were averaged thereafter separately for inner and outer rows.

Maize grain rows per cob for inner and outer rows: Ten plants from outer rows and ten from inner rows of each experimental unit (Treatment) were randomly selected and their cobs were separated. From each

selected cob, grain rows were counted and then averaged separately for inner and outer rows.

Maize grains per cob for inner and outer rows: Ten plants from outer rows and ten from inner rows of each experimental unit (treatment) were randomly selected and their cobs were separated. Grains from each cob were separated, counted and then averaged separately for inner and outer rows.

Grain yield (t ha⁻¹): After sun drying, the maize cobs and soybean pods were shelled with the help of mechanical sheller and yield was recorded separately of each plot. Later it was converted into tons per hectare.

Biological yield (t ha⁻¹): At maturity, maize and soybean were harvested, plants were tied up into small bundles and left in their respective plots for sun drying. After few days, sun-dried bundles were weighed and biological yield of each experimental unit was recorded which was then converted into tons per hectare.

Harvest index (%): Harvest index is the ratio of grain yield to biological yield expressed in terms of percentage. Harvest index was calculated by formula recommended by Beadle (1987) separately for inner and outer rows.

$$\text{Harvest Index (\%)} = (\text{Grain yield/Biological yield}) \times 100$$

Land Equivalent Ratio (LER)

Following formula was used to calculate land equivalent ratio:

$$\text{LER} = \text{LER}_{\text{Maize}} + \text{LER}_{\text{soybean}}$$

$$\text{LER}_{\text{Maize}} = (Y_{yz} / Y_{yy})$$

$$\text{LER}_{\text{soybean}} = (Y_{yz} / Y_{yy})$$

$$Y_{yz} = \text{Yield of maize in intercropping}$$

$$Y_{yy} = \text{Yield of sole maize}$$

$$Y_{zy} = \text{Yield of soybean in intercropping}$$

$$Y_{zz} = \text{Yield of sole soybean}$$

Economic analysis: For all treatments benefit cost ratio was calculated by using the following formula.

$$\text{BCR} = \text{Gross income} / \text{Total income}$$

Statistical analysis: All parameter data was collected and statistically analyzed by using Fisher's analysis of variance. Statistic 8.1 was used to compare the treatment means using the Least Significant Difference (LSD) test at a 5% probability level (Steel *et al.*, 1997).

RESULTS

Maize:

Plant height at maturity (cm) of inner rows and outer rows: Data shows that maximum plant height of inner rows (201.43 cm) was recorded with T₃ (Maize soybean intercropping) while minimum plant height at maturity of inner rows (192.18 cm) was recorded with T₁ (sole maize plantation). Planting techniques, particularly intercropping, significantly impact the height of maize plants in inner rows.

Table. 2. Statistical summary (mean square values) of yield related parameters of sole maize and maize-soybean intercropping

Maize	Planting geometries (G)	Planting techniques (T)	(G x T)
Plant height inner rows (cm)	438.02 ^{NS}	285.18*	42.94 ^{NS}
Plant height outer rows (cm)	3780**	931.04 ^{NS}	147.70 ^{NS}
Maize grain rows per cob inner rows	0.02 ^{NS}	10.26*	3.96 ^{NS}
Maize grain rows per cob outer rows	0.16 ^{NS}	17.76*	9.01 ^{NS}
Maize grains per cob inner rows	694.34 ^{NS}	5559.05*	3724.87*
Maize grains grain per cob outer rows	113.3 ^{NS}	14030.9*	4035.9*
Biological yield (t ha ⁻¹)	2.00 ^{NS}	8651*	20.02 ^{NS}
Grain yield (t ha ⁻¹)	0.11 ^{NS}	4.29*	0.55 ^{NS}
Harvest index	5.55 ^{NS}	1.56 ^{NS}	1.48 ^{NS}
	Planting geometries (G)	Planting techniques (T)	(G x T)
	1220**	1180**	12.20**

*= Significant, **= Highly significant, N.S= Non-significant

Maize grain rows per cob of inner and outer rows:

Data regarding the number of grain rows/cob of inner rows and outer rows of maize as influenced by two factors i.e. planting geometries (G) and planting techniques (T) in maize soybean intercropping are described in Table. 3. Comparison between treatments' means (Table. 5) shows that maximum number of grain rows/cob (17.20) was recorded with T₁ (Sole maize) while minimum number of grain rows/cob (15.35) was recorded with T₃ (Maize Soybean intercropping). Planting techniques significantly impact the number of grain rows in maize cobs, influencing overall yield potential. Comparison between treatments' means shows that maximum number of grain rows/cob of outer rows (18.25) was recorded with T₁ (Sole maize) while minimum number of grain rows/cob (15.81) was recorded with T₃ (Maize Soybean intercropping).

Maize grains per cob of inner and outer rows: Data regarding the number of grains per cob of inner and outer rows of maize as influenced by two factors i.e. planting geometries (G) and planting techniques (T) in maize soybean intercropping are described in Table. 3. Comparison between treatments' means (Table. 4.10 b) shows that maximum number of grains per cob (545.18) was recorded with G₂T₁ (Sole maize plantation) while minimum number of grains (466.90) was recorded with G₂T₃ (Maize Soybean intercropping). Comparison between treatments' means shows that maximum number of grains of outer rows of maize (549.20) was recorded with G₂T₁ (75 cm apart ridge plantation of Sole maize) while minimum number of grains (444.13) was recorded with G₂T₃ (75 cm apart ridge plantation of Maize Soybean intercropping).

Biological yield, grain yield and harvest index:

Data regarding the biological yield, grain yield and harvest index of maize as influenced by two factors i.e. planting geometries (G) and planting techniques (T) in are described in Table. 3. Comparison between treatments' means shows that maximum biological yield (31.49 t ha⁻¹) was recorded with T₁ (Sole maize plantation) while minimum biological yield (26.12 t ha⁻¹) was recorded with T₃ (Maize-soybean intercropping). Maximum biological yield with sole maize plantation might be due to the fact that optimized use of resources such as light, water, and nutrients occurred with this planting technique. Comparison between treatment's means shows that maximum grain yield (8.19 t ha⁻¹) was recorded with T₁ (Sole maize plantation) while minimum grain yield (6.99 t ha⁻¹) was recorded with T₃ (Maize Soybean intercropping).

Soybean

Soybean pods per plant of inner and outer rows:

Data regarding the number of pods per plant of inner and outer rows of soybean as influenced by two factors i.e. planting geometries (G) and planting techniques (T) are described in Table. 4. Comparison between treatments' means (Table. 4) shows that maximum number of pods of inner rows (29.98) was recorded with T₂ (Sole Soybean plantation) while minimum number of pods (23.26) was recorded with T₃ (Maize Soybean intercropping). Comparison between treatments' means (Table. 6) shows that maximum number of pods (30.88) of outer rows was recorded with T₂ (Sole Soybean plantation) while minimum number of pods (24.13) was recorded with T₃ (Maize Soybean intercropping).

Table. 3. Statistical summary (mean square values) of yield related parameters of sole soybean and maize-soybean intercropping.

Soybean	Planting geometries (G)	Planting techniques (T)	(G x T)
Soybean pods of inner rows	50.02*	135.34*	2.00 ^{NS}
Soybean pods of pods outer rows	50.02*	136.68*	5.46 ^{NS}
Biological yield (t ha ⁻¹)	0.59**	24.99**	0.09 ^{NS}
Grain yield (t ha ⁻¹)	0.11 ^{NS}	10.54*	3.33 ^{NS}
Harvest index	14.49 ^{NS}	614.23**	2.24 ^{NS}
1000 grain weight (g) inner rows	92.40 ^{NS}	542**	3.101 ^{NS}
1000 grain weight (g) outer rows	20.54 ^{NS}	70.56*	3.74 ^{NS}

*= Significant, **= Highly significant, N.S= Non-significant

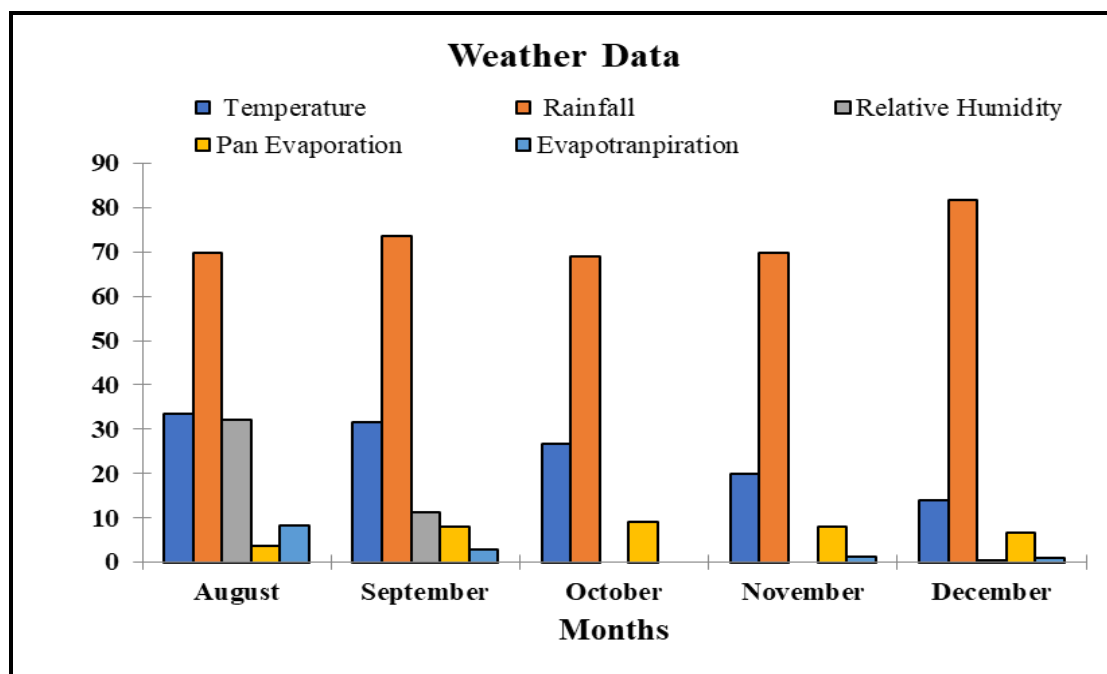


Figure 1. Average weather data collected during the crop season.

1000-grain weight (g) of inner and outer rows: Data regarding the 1000-grain weight of inner and outer rows of soybean as influenced by two factors i.e. planting geometries (G) and planting techniques (T) are described in table 4. Comparison between treatments' means (table 6) shows that maximum 1000-grain weight of inner rows (124.63g) was recorded with T₂ (Sole soybean) while minimum 1000-seed weight of inner rows (111.18g) was recorded with T₃ (Maize soybean intercropping).

Biological yield, grain yield and harvest index: Data regarding the biological yield, grain yield, harvest index of soybean as influenced by two factors i.e. planting geometries (G) and planting techniques (T) in are described in table 4. Comparison between treatments' means (table 6) shows that maximum biological yield (5.36 t ha⁻¹) was recorded with T₂ (Sole Soybean plantation) while minimum biological yield

(2.47 t ha⁻¹) was recorded with T₃ (Maize Soybean intercropping). Biological yield refers to the total dry matter produced by a crop, including its vegetative parts and grains. Sole cropping typically allows for uniform spacing and optimal resource allocation, maximizing individual plant growth and yield. Comparison between treatments' means shows that maximum grain yield (2.72 t ha⁻¹) was recorded with T₂ (Sole Soybean plantation) while minimum grain yield (0.84 t ha⁻¹) was recorded with T₃ (Maize Soybean intercropping). Comparison between treatments' means shows that maximum harvest index (50.91%) was recorded with T₂ (Sole soybean plantation) while minimum harvest index (36.60%) was recorded with T₃ (Maize Soybean intercropping). The planting techniques of sole cropping significantly affect the harvest index (HI) of soybeans, which is the ratio of grain yield to total above-ground biomass.

Table No. 4. Effect of planting geometries and techniques on yield related parameters of sole maize and maize-soybean intercropping.

Treatments Planting techniques (T)	Planting geometries (G)			Plant height inner rows (cm) Planting geometries (G)			Plant height outer rows (cm) Planting geometries (G)		
	G ₁	G ₂	Mean	G ₁	G ₂	Mean	G ₁	G ₂	Mean
T ₁				196.33	188.03	192.18 b	181.23	184.70	182.97
T ₃				209.87	194.00	201.93 a	205.87	195.30	200.58
Mean				203.10	191.02		193.55 a	190.00 b	
LSD (5%)				T	G	T × G	T	G	T × G
				9.67	NS	NS	NS	1.08	NS
				Number of grains per cob inner rows			Number of grains per cob outer rows		
T ₁				494.73 ab	545.18 a	519.96	506.38 ab	549.20 a	527.79
T ₃				486.92 ab	466.90 b	476.91	474.67 bc	444.13 c	459.40
Mean				490.83	506.04		490.52	496.67	
LSD (5%)				T	G	T × G	T	G	T × G
				39.4	NS	40.79	32.43	NS	34.47
				Number of grain rows per cob inner rows			Number of grain rows per cob outer rows		
T ₁	16.66	17.73	17.20 a	17.26	19.23	18.25 a	29.79	33.19	31.49 a
T ₃	15.96	14.73	15.35 b	16.56	15.06	15.81 b	27.00	25.24	26.12 b
Mean	16.31	16.23		16.91	17.15		28.40	29.21	
LSD (5%)	T	G	T × G	T	G	T × G	T	G	T × G
	1.79	NS	NS	1.88	NS	NS	3.19	NS	NS
				Grain yield (t ha ⁻¹)			1000 grain weight (g) Inner rows		
T ₁	8.07	8.30	8.19 a	261.05 a	267.06 a	264.06	251.65	259.72	255.68 a
T ₃	7.30	6.68	6.99 b	253.66 ab	237.35 b	245.51	240.37	230.97	235.67 b
Mean	7.69	7.49		257.36	252.21		246.01	245.34	
LSD (5%)	T	G	T × G	T	G	T × G	T	G	T × G
	0.82	NS	NS	15.32	NS	14.34	12.80	NS	NS
				Harvest index			1000 grain weight (g) outer rows		
T ₁	27.11	25.04	26.07						
T ₃	27.13	26.47	26.80						
Mean	27.12	25.76							
LSD (5%)	T	G	T × G						
	NS	NS	NS						

T₁= Sole Maize, T₃= Maize-soybean Intercropping, G₁= 60 cm apart ridge plantation, G₂= 75 cm apart ridge plantation, T= Planting techniques, G= Planting geometries; N.S= Non-significant. This means sharing different letters, within row and column, differ significantly for each trait from each other at $p \leq 0.05$.

Table. 5. Effect of planting geometries and techniques on yield related parameters of sole maize and maize-soybean intercropping.

Treatments Planting techniques (T)	Planting geometries (G)			Plant height inner rows (cm) Planting geometries (G)			Plant height outer rows (cm) Planting geometries (G)		
	G ₁	G ₂	Mean	G ₁	G ₂	Mean	G ₁	G ₂	Mean
	No. of pods inner rows			No. of pods outer rows					
T ₂	27.53	32.43	29.98 a	28.16	33.60	30.88 a			
T ₃	21.63	24.90	23.26 b	22.76	25.50	24.13 b			
Mean	24.58 b	28.66 a		25.46	29.55				
LSD (5%)	T	G	T × G	T	G	T × G			
	5.29	2.04	NS	15.47	NS	NS			
				1000 grain weight (g) Inner rows			1000 grain weight (g) outer rows		
T ₂				122.37	126.90	124.63 a	120.90	124.63	122.77 a
T ₃				107.90	114.47	111.18 b	117.17	112.87	117.92 b
Mean				115.13	120.68		119.03	121.65	
LSD (5%)				T	G	T × G	T	G	T × G
				5.85	NS	NS	4.73	NS	NS
	Grain yield (t ha⁻¹)			Biological yield (t ha⁻¹)			Harvest index		
T ₂	2.62	2.81	2.72 a	5.23	5.50	5.36 a	50.24	51.58	50.91 a
T ₃	0.75	0.94	0.84 b	2.16	2.79	2.47 b	35.07	38.13	36.60 b
Mean	1.68	1.88		3.69 b	4.14 a		42.66	44.86	
LSD (5%)	T	G	T × G	T	G	T × G	T	G	T × G
	0.12	NS	NS	0.37	0.13	NS	7.38	NS	NS

T₂= Sole Soybean, T₃= Maize-soybean Intercropping, G₁= 60 cm apart ridge plantation, G₂= 75 cm apart ridge plantation, T= Planting techniques, G= Planting geometries; N.S= Non-significant. This means sharing different letters, within row and column, differ significantly for each trait from each other at $p \leq 0.05$.

Table. 6. Effect of planting geometries and techniques on Benefit Cost Ratio of sole maize, sole soybean and maize soybean intercropping

TREATMENTS	Maize grain Yield ton/hac	a. Maize grain income (Rs.) @ 1800 Rs./Monds	Maize Straw yield (tonns)	b. Maize Straw income Rs./ton	c. Maize Gross Income (Rs.) c = a + b	Soybean Yield ton/hac	d. Soybean grain income (Rs.) @ 8000 Rs./Monds	e. Gross income (Rs.) (Maize + Soybean) e = c + d	f. Total expenditures in a hectare (Rs.) (Maize + Soybean)	g. Net benefit (Rs.) e – f	BCR
G ₁ T ₁ = 60 cm apart ridge plantation of Sole Maize	8.07	363150.0	15.23	15230.0	378380.0	0.0	0.0	378380.0	292546.8	85833.2	1.29
G ₁ T ₂ = 60 cm apart ridge plantation of Sole Soybean	0	0.0	0.0	0.0	0.0	2.62	524000.0	524000.0	211602.43	312397.6	2.48
G ₁ T ₃ = 60 cm apart ridge plantation of Maize Soybean intercropping	7.3	328500.0	14.56	14555.4	343055.4	0.75	150000.0	493055.4	325056.9	167998.4	1.52
G ₂ T ₁ = 75 cm apart ridge plantation of Sole Maize	8.3	373500.0	14.61	14613.7	388113.7	0.00	0.0	388113.7	292546.8	95566.9	1.33
G ₂ T ₂ = 75 cm apart ridge plantation of Sole Soybean	0	0.0	0.0	0.0	0.0	2.81	562000.0	562000.0	211602.43	350397.6	2.66
G ₂ T ₃ = 75 cm apart ridge plantation of Maize Soybean intercropping	6.68	300600.0	13.14	13136.8	313736.8	0.94	188000.0	501736.8	325056.9	176679.8	1.54

Equivalent Ratio: Data related to LER reflects that in all the treatments in which intercropping was followed, significant improvement in LER value (more than 1) was observed in comparison with sole cropping. Maximum LER (1.18) was recorded in treatment G₁T₃ (60 cm apart ridge sowing of Maize Soybean intercropping) while minimum LER (1.15) was recorded in G₂T₃ (75 cm apart ridge sowing of Maize Soybean intercropping). The Land Equivalent Ratio (LER) is the relative area of a sole crop required to produce the yield achieved in intercropping.

Benefit Cost Ratio: Economic analysis of experiment (Table 8) was conducted to examine the results from the perspective of a farmer, who is primarily interested in the benefits and costs of a particular technology, as well as the risks associated with the adoption of new practices. In terms of benefit cost ratio (BCR) as shown in Table 4, the highest value of (2.66) was recorded in case of G₂T₂ (75cm apart ridge plantation of Sole Soybean) while minimum value (1.29) was recorded by G₁T₁ (60 cm apart ridge plantation of Sole Maize).

DISCUSSION

Maize: The presence of companion crops can alter light availability, nutrient distribution, and water competition, often resulting in increased height of inner row maize plants as they compete for resources. These results are also in line with Kane *et al.*, 2021. Andrade *et al.* (2002) found that optimal planting techniques promote better resource availability, leading to improved grain row development. The arrangement and spacing of plants influence resource distribution, with outer rows often receiving more light and experiencing less competition than inner rows. These results are also in line with Agele *et al.*, 2016.

When maize was planted as a sole crop, there was no competition from other crops, enabling maize plants to fully explore available resources. Studies have shown that this can lead to higher biomass production. According to Sari and Kirda (2008), sole maize plantation resulted in a significant increase in biomass yield compared to intercropped systems due to the absence of interspecific competition for resources. Sole cropping allows for precise control over plant spacing and density, ensuring that each maize plant has enough space to grow optimally and maximize its yield potential. According to Li *et al.* (2019), sole maize plantations exhibit improved nutrient use efficiency which translates to higher grain yield.

The harvest index of maize is a critical parameter indicating the efficiency with which a plant converts its biomass into economic yield (grain). Despite the importance of various agronomic practices in influencing crop performance, the effect of planting geometries and planting techniques on the harvest index of maize often appears to be non-significant. These results are also in line with Ghosh *et al.* (2006). Narrower rows can lead to increased competition for resources, while optimal spacing reduces competition

and enhances growth. Hence, the strategic use of planting geometries and techniques is crucial for optimizing soybean production. These results are also according to the findings of Kane *et al.*, 2022. In sole cropping, where soybeans are grown exclusively, management practices can be specifically tailored to maximize both biomass and grain yield. This focused approach can lead to a higher harvest index as the resources are dedicated solely to the soybean crop, potentially optimizing the conversion of biomass into grain. These results are also in line with Iqbal *et al.*, 2019.

Soybean: Planting techniques, particularly sole cropping significantly affects the number of pods in the inner rows of soybean plants. This uniformity generally leads to a higher number of pods in the inner rows as each plant can maximize its growth potential. Sole cropping tends to be more favorable for maximizing pod production in the inner rows of soybean crops. These results are also in line with Chu *et al.*, 2004. In sole cropping, soybeans are planted in a uniform pattern, leading to consistent resource allocation. This uniformity can enhance the growth and pod formation in the outer rows due to better access to light, nutrients, and water. However, the outer rows may still experience some edge effects, such as increased light exposure, which can further boost pod production. These results are also in line with Asad *et al.*, 2020.

Planting techniques and planting geometries do not significantly affect the 1000- grain weight of outer rows in soybean cultivation. This finding suggests that factors influencing seed weight in outer rows may be less sensitive to planting arrangements and spacing. These results are also supported by Mao *et al.*, 2015.

The grain yield of soybean is profoundly affected by planting geometries and techniques. Sole cropping, with its uniform plant spacing, often maximizes individual soybean plant growth by reducing intra-species competition for light, nutrients, and water, leading to potentially higher grain yields per plant. This focused attention can potentially maximize the yield potential of soybeans by minimizing resource limitations and allowing for precise management practices throughout the growth cycle. These results are also in line with Liu *et al.*, 2022.

According to Jabbar *et al.* (2009) when LER value is equivalent to one, it implies that there is no yield advantage, but when LER is more than one, it means that, there is a yield advantage. The data on LER of different intercropping systems indicated that LER values were greater than one in all the intercropping treatments and the range of yield advantage over sole cropping. These results are in the same line with these obtained by Abou-Elela *et al.* (2012), who concluded that intercropping increased LER values when compared with sole plantings of maize and soybean. These findings are consistent with those of Nazir *et al.* (2000) who found that intercropping systems

produced significantly higher net income than pure stand.

CONCLUSION

It was concluded that in order to get best results from maize-soybean intercropping, 75 cm apart ridge sowing of maize-soybean intercropping would be a feasible approach for the farming community under agro-ecological conditions of Faisalabad, Pakistan.

AUTHORS' CONTRIBUTION

MAI, HZK designed and conducted the experiment, HZK, AN, edited the manuscript and improve English language, HZK, supervise and provided critical guidance and MAI, MQ, MFR carried out statistical analysis and MAI, HZK, MFR, oversight throughout the research process.

AUTHORS CONFLICT OF INTEREST

The authors have no conflict of interest.

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