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Interaction of Cropping Pattern and Fertility Treatments on Yield and Sustainability of Mixed Cropping System under Moisture Regime

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A B S T R A C T

The farmers in most regions of Pakistan are heavily reliant on traditional farming approaches all year round and tend to cultivate exhaustive crops like wheat, cotton, maize, and sugarcane in most areas of the country. Consistently adopting this system leads to depleting the soil fertility status, which they overcome by instigating an uneconomical way of using excessive chemical fertilizers to maximize crop yields. These fertilizers are truly acidic and adversely affect soil health. Adopting sustainable farming approaches by the incorporation of legumes into the farming system with an integrated nutrient supply restores soil fertility and maintains the sustainability of the agro-ecosystem. A field experiment was performed to determine the significance of the integrated source of nutrient management on the growth and yield of sole and mixed cultures of sorghum and mungbean crops in areas with moisture regimes. The fertility treatments applied to the sole and intercrops of sorghum and mung-bean in a given sequence; i) Control, ii) Compost @ 10 t/ha, iii) FYM @ 20 t/ha, iv) NP @ 40 kg N + 30 kg P_2O_5 ha^{-1}, v) ½ of recommended Compost @ 5 t/ha + ½ of recommended NP @ 20 kg N & 15 kg P_2O_5 ha^{-1}, vi) ½ of recommended FYM @ 10 t/ha + ½ of recommended NP @ 20 kg N & 15 kg P_2O_5 ha^{-1}. The sole crop of mungbean gave a maximum grain yield of 2229.1 kg/ha over an intercrop of 1779.7 kg/ha. Similarly, the highest grain yield of 2779.8 kg/ha of sorghum was obtained in sole culture over its intercrop of 2150.9 kg/ha. The interaction effect of cropping pattern and fertility treatments showed that sorghum and mungbean gave significant results for growth and yield parameters where a combined dose of organic & mineral fertilizers were provided in comparison to the plots where these fertilizers were applied in split doses.

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Introduction

Mixed cropping is the simultaneous cultivation of two or more coexisting crops in the same field to maximize resource use efficiency and enhance crop production potential (Bonke and Musshof, 2020). This cropping system is receiving great attention from the farming community as it offers potential advantages in terms of limited required inputs and improved sustainability of crop production (Liu et al., 2013). In a mixed culture of cereal-legume, the N fixed by legumes is transferred to cereals throughout their shared growing period and becomes a vital resource for cereals (Shen and Chu, 2004). The quality contents e.g. crude protein and yield of mixed forage can be enhanced significantly in non-legume with legume intercropping system (Iqbal et al., 2006). Planting a grain legume crop in mixed culture enhances biological pest control and thereby reduces infestation of disease in the non-legume crop through increased diversity and activity of microbes (Lupwayi et al., 2011). A mixed cropping system also protects the total crop failure in adverse and harsh climates and increases land productivity per unit area by efficient utilization of all available resources including farming inputs e.g. labor (Himanen et al., 2016). The minimum requirement for mineral fertilizers, improving crop water use efficiency, and reducing the leaching loss of nitrogen through soil root zone are some important advantages commonly associated with mixed stands (Gaba et al., 2015).

Sorghum (*Sorghum bicolor L.*) is mostly grown for fodder. The total area under sorghum crop cultivation is 0.457 million hectares, with an annual total production of 0.303 million tons. Its average green forage yield is about 620 kg ha^{-1} (Habib et al., 2013). It is cultivated on a large scale for grain and used as a staple food to feed poor and hungry people, feed for poultry, and fodder for livestock in irrigated as well as rain-fed areas across the globe (Teferra et al., 2019). Grain sorghum has a short growing season and can be successfully grown in areas with a stressful environment, temperature extremes, shortage of water, and soils that have a very poor status of nutrients e.g. nitrogen

(N), and phosphorus (P) (Assefa et al., 2010). The grain of sorghum is abundant with dietary elements having a total of 10-12% protein, 3% fats, and 70% carbohydrates (Amanullah et al., 2007). The grain constitutes a substantial amount of iron (>70 ppm) and zinc (>50 ppm), so it may be very helpful for the reduction of global micronutrient malnutrition (Reddy et al., 2005).

Mungbean (*Vigna radiata L.*) is a major summer legume crop in the subtropical climate of Pakistan. It is successfully grown twice a year in rain-fed and irrigated areas of the country with either autumn or spring cultivation (Rehman et al., 2019). It is short-duration and drought tolerant, important to the poor as it supplies a substantial amount of protein (Rachie and Roberts, 1974; Singh, Chhabra and Kharb, 1988; Thirumaran and Seralathan, 1988). Seeds of mung-bean contain a total of 24.20% protein contents, 1.30% total fats, and 60.4% total carbohydrates, with Ca and P levels of 118 & 340 mg/100g of seed, respectively (Imran et al., 2016). The total area under its cultivation is 135.90 thousand hectares; and its annual total production of 90.00 thousand tons with a grain yield of 662.25 kg/ha (AVRDC, 2016). Mungbean fits very well in rain-fed ecosystems as it helps in soil water conservation and nutrient recycling having a major contribution towards soil fertility through nitrogen fixation. The deep root system helps in increasing organic matter contents in the depth through crop residues, improves soil structure, and protects soil from erosion (Asim et al., 2006).

Using synthetic fertilizers in our agricultural systems is a more expensive and non-sustainable approach as its excessive use pollutes the environment in three ways; water pollution through the leaching loss of nitrate, soil pollution due to the high level of sodium and potassium-containing fertilizers which deteriorates soil structure and upset its pH, air pollution caused by emissions of nitrogen oxides (NO, N_2O, NO_2) if nitrogenous fertilizers applied at inadequate rates (Savci, 2012). Organic manure or bio-fertilizers are natural, eco-friendly, and more cost-effective than synthetic fertilizers, hence use of organic manures should be emphasized (Sahoo et al., 2013). The use of organic manures alone may not fulfill the nutritional demand of various crops (El Sheikha, 2016). Thus, in such cases integrated source of nutrients supply can be a better choice to meet the increasing nutritional demand of crops for enhancing their growth (Jat et al., 2015). Therefore, keeping in view the significance of all these factors, a field experiment was conducted having the following objectives; i) to determine the feasibility of multiple cropping systems with limited available resources ii) to ensure the sustainability of agro-ecosystems in areas with moisture regimes iii) to evaluate the overall yield benefits of sorghum and legume in sole and mixed culture with integrated nutrients supply.

Materials and Methods

Field Preparation

The field was left exposed to sunlight for several days before the plowing. The field was cut and inverted by using disc harrows, and blade harrows and later it was leveled by a land leveler and plank. All these operations were aimed at obtaining a good tilth for crop cultivation. The land was ready two days before sowing.

Experimental Layout and Treatments

An experiment in the field was performed to investigate the impact of organic and mineral fertilizers on sorghum-mungbean cropping systems in areas with moisture regimes. The experiment was performed during the summer season at the research farm of Arid Agriculture University (Latitude = 32.930 N, Longitude = 72.850 E and 769 m above sea level) Chakwal Road, Rawalpindi. Randomized complete block design with 2 factors factorial used as layout plan of the experiment having six fertility treatments and two cropping patterns in three replications. The two crops sorghum and mungbean were planted as sole and intercrops. The fertility treatments applied in standard doses were as following; (i) T_0: Control; (ii) T_1: Compost @ 10 t/ha; (iii) T_2: FYM @ 20 t/ha; (iv) T_3: NP @ 40kg N + 30kg P_2O_5 ha^{-1}; (v) T_4: ½ Compost + ½ NP @ 5 t/ha + 20kg N & 15kg P_2O_5 ha^{-1}; (vi) T_5: ½ FYM + ½ NP @ 10 t/ha + 20kg N & 15kg P_2O_5 ha^{-1}, respectively. Plant height and different yield contributing factors for both sorghum and mungbean were recorded and analyzed for results.

Yield Parameters

Yield and its contributing parameters of mungbean and sorghum were recorded in the field. The recorded parameters in mungbean were; plant height (cm), no. of seeds per pod, no. of pods per plant, and grain yield (kg/ha). The parameters observed in sorghum were; plant height (cm), length of panicle (cm), the weight of panicle (g), and grain yield (kg/ha). The plant height and yield contributing parameters of mungbean and sorghum were recorded manually by randomly selecting ten plants per plot in each replication of a treatment, and their means were evaluated. The grain yield of both crops in each treatment was determined manually in kg per m^2 by using a weighing balance which was later converted into kg per ha.

Interaction of Cropping Pattern and Fertility Treatments

The interaction effects of cropping patterns and mixed fertility treatments on growth and yield parameters of sorghum and mungbean were studied separately with a graphical representation. The means of two cropping patterns and six fertility treatments were evaluated and compared with each other to determine the better cropping system and fertility level and their interaction effects were studied to evaluate the overall results of these two factors in this experiment.

Statistical Analysis

The data were subjected to analysis of variance (ANOVA) for the recorded parameters in all treatments with a 2-factor factorial design using Statistics 8.1. Treatment means of all parameters were later separated by using the least significant difference (LSD) at 5% probability level.

Regression Analysis

Relationship of yield with its parameters performed by linear regression using SigmaPlot and represented with given equation;

$$y = y0 + ax + e,$$

where; y = dependent variable, x = independent variable, y0 = y intercept, a = slope of the line, e = error terms (Ju et al., 2019).

Coefficient of Determination (R^2)

The coefficient of determination, or R^2, is a measure that indicates how well a model fits. In the context of regression, it is a statistical measure of how well the regression line approximates the actual data. It is crucial when a statistical model is used to forecast future results or to test a hypothesis.

$$R^2 = 1 - \frac{\text{Residual sum of squares (RSS)}}{\text{Total sum of squares (TSS)}} \;,\; 1 - \frac{\sum(yi-fi)^2}{\sum(yi-\bar{y})^2}$$

The R^2 value is measured in the range of 0-1. It is a measure of the variation of one component induced by its relationship to another. Higher the value of R^2 represents variability in yield parameters caused by cropping patterns and fertility treatments and it is the best fit system. Whereas, if R^2= 0, then it means the system was not fit due to no impact on crop yield (Chicco et al., 2021).

Results and Discussion

Growth and Yield Attributes of Mungbean

The results presented in Figure 1 revealed that all the parameters of mungbean e.g. plant height, no. of seeds pod^{-1}, no. of pods plant^{-1}, and grain yield gave significant results between the two cropping patterns. Maximum results were obtained when mungbean was planted as the sole crop in comparison to intercrop with sorghum. It was due to less competition for growth resources such as; moisture, nutrients, space and light intensity, etc. While the given fertility treatments showed statistically significant results for all parameters of yield. The results of all the parameters were highly significant when treatments were applied as a mixture of organic and mineral fertilizers compared to those treatments in which both sources of fertilizers were applied in separate doses (Table 1).

The results in interaction effects of cropping patterns and fertility treatments revealed that all the yield attributes had maximum results when the crop was planted in sole culture. This was because the sole crop had efficient utilization of applied fertility treatments with less competition for available resources compared to when the crop was planted in mixed culture. The plant height was maximum in the sole crop (53 cm) of mungbean. Similarly, the results of plant height were statistically significant in treatments with mixed fertility treatments of NP + farmyard manure (68.63 cm) and NP + compost (60.66 cm) compared to those treatments in which organic and mineral fertilizers were given in split doses, respectively (Figure 1).

In an experimental study carried out by Armin et al. (2016) and Arsalan et al. (2016), a significant increase in plant height in mung-bean was observed when it was sown in a plot with mixed doses of organic and inorganic fertilizer. They reported that organic manures help in enhancing the organic matter contents of soil, and thereby have a role in reducing its bulk density and compaction. Thus it provided the plant with a better growing environment to encourage its growth and development. The maximum seeds pod^{-1} (12.17 in sole crop), NP + FYM (14.53), and NP + compost (13.5), were maximum when compared with intercrop mungbean and split doses of these fertilizers, respectively (Figure 1). Similar results were given by Kaur and Singh (2017) in the pearl-millet and green-gram cropping system in which the no. of seeds pod^{-1} of mungbean were maximum in sole culture compared to intercrop.

Table 1. Impact of cropping pattern and fertility treatments on plant height (cm) and number of seeds pod^{-1} of mung-bean *(Vigna radiata L.)*

Treatments	Plant height (cm)			Number of seeds per pod		
	Sole crop	Intercrop	Mean	Sole crop	Intercrop	Mean
Control	33.40 ef	27.26 f	30.33 E	7.60 ghi	5.66 i	6.63 E
Compost	41.26 de	34.26 ef	37.76 D	9.60 efg	7.46 hi	8.53 D
FYM	48.06 cd	40.46 de	44.26 D	11.40 cde	8.93 fgh	10.16 C
NP	54.46 bc	48.73 cd	52.60 C	13.26 bc	10.93 def	12.10 B
NP + Compost	65.0 ab	56.33 bc	60.66 B	15.0 ab	12.0 cd	13.5 AB
NP + FYM	73.80 a	63.46 ab	68.63 A	16.20 a	12.86 cd	14.53 A
Mean	53.00 A	45.08 B	-	12. 17 A	9.64 B	-

Means not sharing a similar letter are statistically significant at 5% level of probability

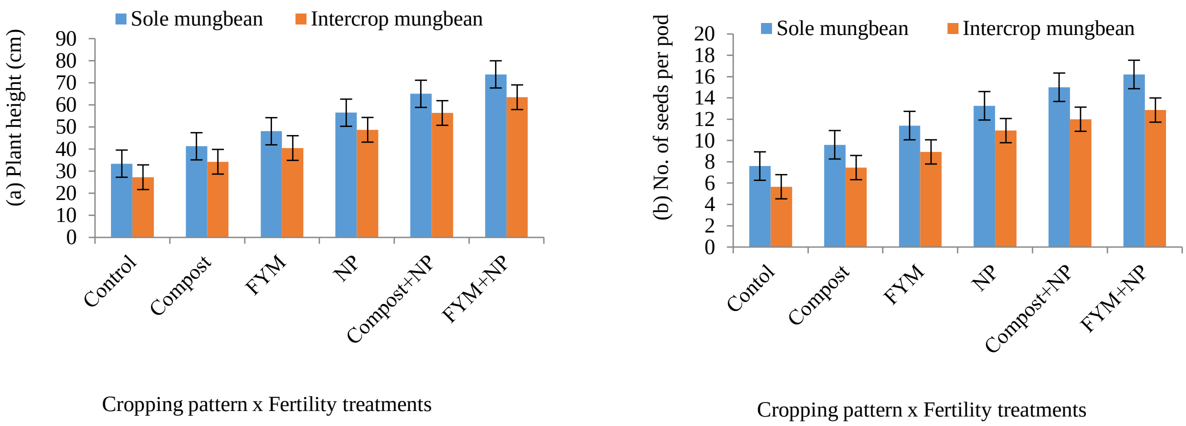

Figure 1. (a) Plant height (cm), (b) No. of seeds per pod in mung-bean, as affected by the interaction of cropping pattern and fertility treatments

Table 2. Impact of cropping pattern and fertility treatments on pods plant^{-1} and grain yield (kg/ha) of mung-bean *(Vigna radiata L.)*

Treatments	Number of pods per plant			Grain yield (kg/ha)		
	Sole crop	Intercrop	Mean	Sole crop	Intercrop	Mean
Control	14.33 e	8.46 f	11.40 E	896 hi	581 i	738.5 D
Compost	18.26 d	11.0 ef	14.63 D	1538 efg	1104 ghi	1321 C
FYM	20.13 d	14.20 e	17.16 D	1718 ef	1239 fgh	1478.5 C
NP	28.0 b	21.33 cd	24.66 C	2378 cd	1952 de	2165.5 B
NP + Compost	35.26 a	27.46 b	31.36 A	3345 ab	2825 bc	3085 A
NP + FYM	32.13 a	24.80 bc	28.46 B	3498.7 a	2977 ab	3237.8 A
Mean	24.46 A	17.87 B	-	2229.1 A	1779.7 B	-

Means not sharing a similar letter are statistically significant at 5% level of probability

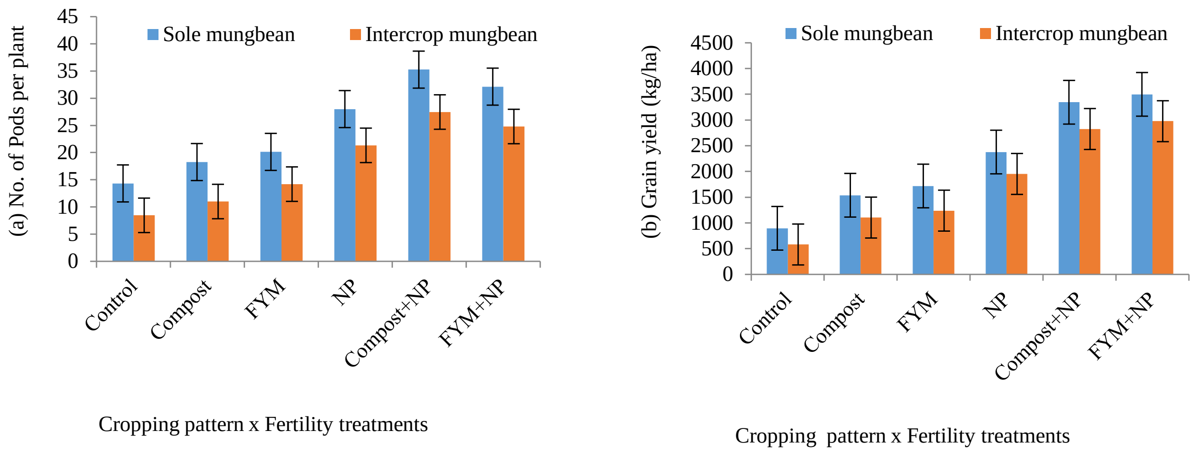

Figure 2. (a) No. of pods per plant, (b) Grain yield (kg/ha) of mungbean, as affected by the interaction of cropping pattern and fertility treatments

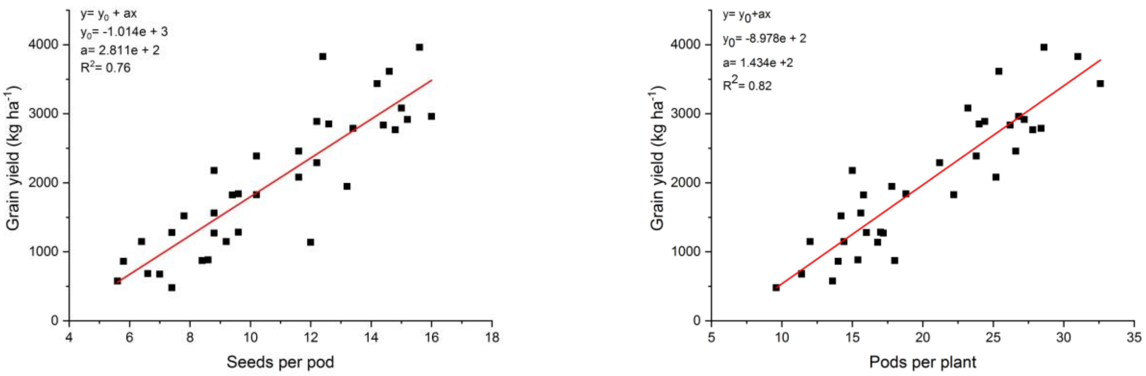

Figure 3. Relationship of mung bean grain yield with its number of seeds per pod and number of pods per plant, respectively.

No. of pods plant^{-1} is a major parameter and yield is highly dependent upon it. Maximum no. of pods plant^{-1} recorded in monoculture of mung-bean (24.46) given mixed treatments of fertilizer. NP + farmyard manure (28.46) and NP + compost (31.36) gave maximum pods per plant in comparison with all other treatments (Table 2). Maximum grain yield was recorded in the sole crop (2229.1 kg/ha), while it was minimum when the crop was planted as an intercrop (1779.7 kg/ha). The results for all these yield contributing factors were in line with the findings of Shaker-Koohi and Nasrollahzadeh (2014) in the sorghum-mungbean cropping system.

The treatments with a mixture of organic and chemical fertilizers gave significant results in grain yield. NP + FYM (3237.8 kg/ha), NP + compost (3085 kg/ha) were maximum in comparison to all other treatments with split fertilizer doses; NP (2165.5 kg/ha), FYM (1478.5 kg/ha), Compost (1321 kg/ha), Control (738.5 kg/ha) (Figure 2). Similar results were given by Abbas et al. (2011) in an experiment in which integrated nutrient supply significantly increased the yield contributing parameters and grain yield (kg/ha) of mungbean.

Relationship of Mung Bean Grain Yield With Its Parameters

The linear regression curve in Figure 3 represented the relationship between the two parameters and stated that yield was a highly dependent factor on seeds pod^{-1} and pod plant^{-1} in mungbean. It rose exponentially with increasing both these factors in all treatments. The coefficient of determination (R^2) stated that variability in yield was caused by both these parameters. The value represented that no. of seeds per pod accounted for 76 % and pods per plant 82% of the grain yield of mungbean in this cropping system.

Growth and Yield Attributes of Sorghum

The results of growth (plant height) and yield parameters e.g. panicle length, panicle weight, and sorghum grain yield were statistically significant in two cropping patterns. Maximum results were obtained when sorghum was planted as the sole crop, compared to intercrop sorghum. It was due to intense competition between two crop species for growth resources essential for plant growth such as; moisture, nutrients, space, photoperiod, etc. The combined doses of organic and synthetic fertilizers gave significant results for all the parameters against split doses of fertility treatments (Table 3).

The interaction results revealed that the plant height of sorghum was highest when it was cultivated in sole culture (164.23 cm), with the mixture of NP + farmyard manure (171 cm) and NP + compost (180.83 cm), respectively. Maximum panicle length was observed (29.10 cm in sole crop), NP + FYM (31.73 cm), and NP + compost (35.30 cm), compared to intercrop sorghum and split doses of organic and mineral fertilizers (Figure 4).

Panicle weight (g) has significant importance in ensuring the grain yield of sorghum. Maximum panicle weight was recorded in monoculture (107.04 g) with mixed fertility treatments of NP + farmyard manure (124.53 g) and NP + compost (135.87 g) (Table 4). The sorghum grain yield was maximum in the sole crop (2779.8 kg/ha), while it was minimum when the crop was planted as an intercrop (2150.9 kg/ha). This reduction in all these yield contributing parameters was due to the reduced number of grains panicle^{-1}of sorghum caused by the limited availability of resources in the sorghum-legume cropping system compared to sole sorghum. The results were in line with the study carried out by Rashid et al. (2004) in sorghum-mungbean and sorghum-guar cropping systems in an experiment where the grain yield and all its contributing factors of sorghum reduced when it was intercropped either with mungbean or guar.

Similarly, the treatments with a mixture of organic and chemical fertilizer gave maximum results for the grain yield of sorghum. The treatments of NP + FYM (3465.25 kg/ha), and NP + compost (3805.05 kg/ha) gave maximum results of sorghum grain yield in comparison to those where organic and inorganic fertilizers were applied in separate doses (Table 4).

The impacts of integrated (organic + inorganic) nutrient supply caused the increase in grain yield by reducing N losses and formed organic-mineral complexes which helped in the conservation of soil N and thereby ensured continuous availability of N to sorghum plant. N also has a major role in the activation of photosynthates and metabolic processes, which leads to increased plant growth and components of grain yield. The results were similar to the experiment performed by Mahfouz et al. (2015) in which the integration of organic & chemical fertilizers significantly affected the grain yield of sorghum.

Table 3. Impact of cropping pattern and fertility treatments on plant height (cm) and panicle length of sorghum *(Sorghum bicolor L.)*

Treatments	Plant height (cm)			Panicle length (cm)		
	Sole crop	Intercrop	Mean	Sole crop	Intercrop	Mean
Control	137.60 fg	124.80 g	131.20 E	18.46 efg	13.26 g	15.86 E
Compost	162.6 bcde	144.33 ef	153.47 CD	27.06 cd	20.33 ef	23.70 CD
FYM	148.67 def	141.40 fg	145.03 D	24.0 de	17.06 fg	20.53 D
NP	167.87 bc	156.0 cdef	161.93 BC	31.46 bc	24.06 de	27.76 BC
NP + Compost	191.0 a	170.67 bc	180.83 A	38.33 a	32.26 bc	35.30 A
NP + FYM	177.67 ab	164.33 bcd	171.0 AB	35.26 ab	28.20 cd	31.73 AB
Mean	164.23 A	150.26 B	-	29.10 A	22.53 B	-

Means not sharing a similar letter are statistically significant at 5% level of probability

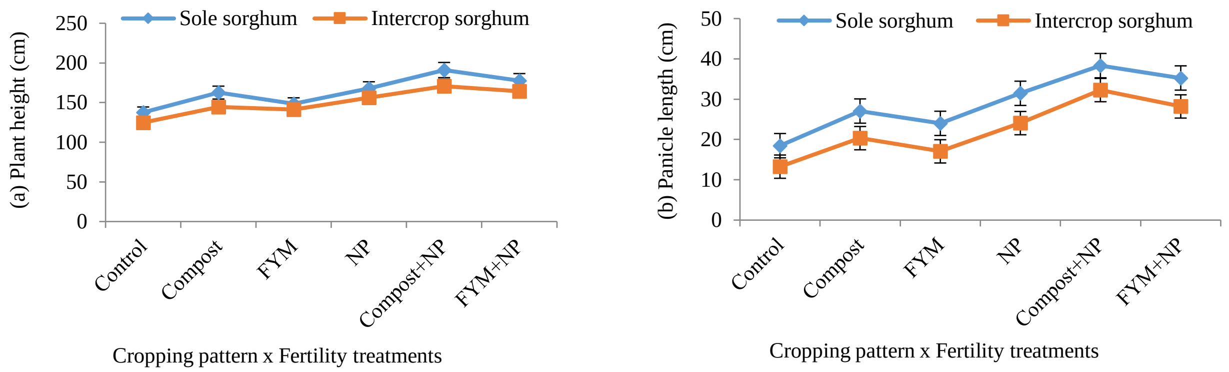

Figure 4. (a) Plant height (cm), (b) Panicle length of sorghum, as affected by the interaction of cropping pattern and fertility treatments.

Table 4. Impact of cropping pattern and fertility treatments on panicle weight (g) and grain yield (kg/ha) of sorghum *(Sorghum bicolor L.)*

Treatments	Panicle weight (g)			Grain yield (kg/ha)		
	Sole crop	Intercrop	Mean	Sole crop	Intercrop	Mean
Control	68.40 fg	58.93 g	63.67 D	1369.5 fg	1012 g	1190.75 D
Compost	86.4 def	75.47 efg	80.93 C	2212.6 d	1675.7 def	1944.15 C
FYM	99.2 cd	88.13 de	93.67 C	2047.8 de	1524.5 efg	1786.15 C
NP	114.53 bc	102.53 cd	108.53 B	2931.3 c	2270 d	2600.65 B
NP + Compost	142.0 a	129.73 ab	135.87 A	4230.1 a	3380 bc	3805.05 A
NP + FYM	131.73 ab	117.33 bc	124.53 A	3887.5 ab	3043 c	3465.25 A
Mean	107.04 A	95.36 B	-	2779.8 A	2150.9 B	-

Means not sharing a similar letter are statistically significant at 5% level of probability

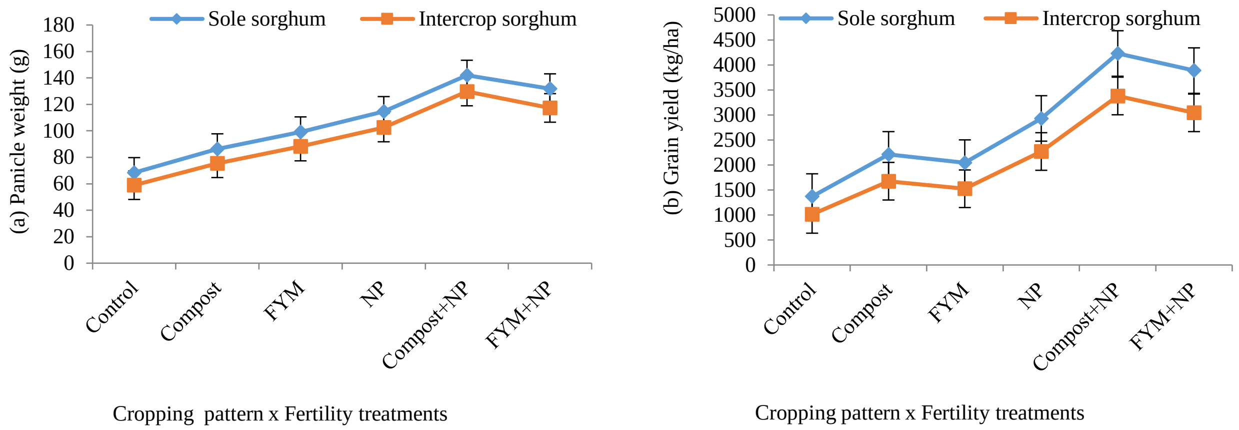

Figure 5. (a) Panicle weight (g), Grain yield (kg/ha) of sorghum, as affected by the interaction of cropping pattern and fertility treatments.

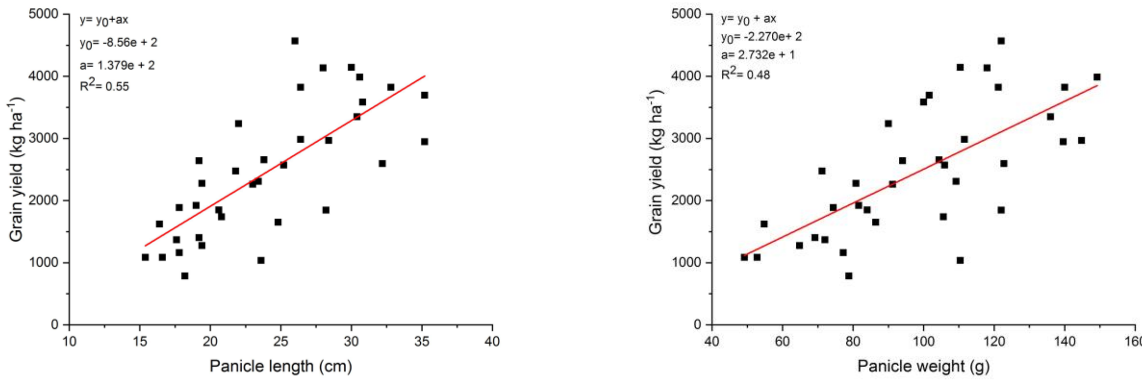

Figure 6. Relationship of sorghum grain yield with its panicle length (cm) and panicle weight (g), respectively.

Relationship of Sorghum Grain Yield with Its Parameters

The grain yield and its dependent factors showed a relationship with each other in the linear regression curve showing that yield was least dependent on panicle weight compared with panicle length in sorghum. The curve in Figure 6 showed an increase in yield with increasing both these factors in all treatments. The coefficient of determination (R^2) represented that variability in sorghum yield was caused by panicle length and panicle weight. The value of R^2 stated that both these parameters accounted for 55% and 48% of the grain yield and thereby represented the suitability of the cropping system.

Conclusion

The results of this experiment concluded that crop yield contributing parameters and grain yield of mungbean and sorghum had maximum results when both these crops were planted in a sole culture and provided with a combined dose of organic and chemical fertilizers. The highest grain yield of mungbean (2229.1 kg/ha) was recorded when it was sown as a sole crop, while it was minimum (1779.7 kg/ha) in mungbean-sorghum intercrop. Likewise, sorghum also gave the highest grain yield of 2779.8 kg/ha in pure crop standing compared to 2150.9 kg/ha in its intercrop with mungbean. Interaction results of cropping pattern and fertility treatments showed that all parameters of sorghum and mungbean had maximum results in plots where a combined dose of organic and mineral fertilizers was provided in comparison with the plots where both sources of fertilizer were applied in split doses. The treatments with mixed application of organic manures and chemical fertilizer gave increased grain yield of mungbean (3237.8 kg/ha in NP + FYM) & (3085 kg/ha in NP + Compost) and sorghum (3805.05 kg/ha in NP + Compost) & (3465.25 kg/ha in NP + FYM), respectively. The yield in both these crops was highly dependent upon their respective factors and their linear relationship showed that no. of seeds per pod accounted for 76% and pods per plant 82% of the grain yield of mungbean, while panicle length contributed 55% and panicle weight 48% in the grain yield of sorghum, respectively. The variability in crop yield dependent factors was caused by the availability and efficient utilization of growth resources. The overall productivity of the system was highest in intercrop as it simultaneously provided maximum yield per unit area of land. So it was evident in this research trial that the inclusion of legumes in a cropping system and adopting an integrated nutrient supply was a sustainable farming approach as it restored the fertility status of soil due to the ability of legumes to fix soil N_2 and using an integrated source of nutrients was economically more feasible for farmers as it limited the use of mineral fertilizers and increased total crop yields on the same field with limited available resources.

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