The Journal of Agricultural Sciences - Sri Lanka
Vol. 19, No 2, May 2024. Pp 233-249
https://doi.org/10.4038/jas.v19i2.9988

On-Farm Crop Productivity and Economic Assessment of Mungbean-Sorghum Intercropping System Under Integrated Nutrient Management

G. Yousaf[1,2*], A. Anwar,[1] and F. A. Fayyaz[1]

Received: 16th October 2022 / Accepted: 28th December 2023

ABSTRACT

Purpose: *The small-holding farmers tend to follow traditional farming systems over sustainable systems of productivity. A strategy was devised to introduce an agricultural system that ensures sustainable yield production and restores diversity in the agroecosystem. The research trial was performed to evaluate the net productivity and economic viability of the sorghum and mungbean intercropping system using an integrated nutrient management strategy.*

Research Method: *The study comprised both split and combined doses of nationally recommended organic and mineral sources of fertilizers using mungbean and sorghum as sole and intercrops in the following sequence of treatments;* T_0 *= unfertilized,* T_1 *= 100% compost,* T_2 *= 100% farmyard manure,* T_3 *= 50% N & 50%* P_2O_5, T_4 *= 50% compost + 25% N & 25%* P_2O_5, T_5 *= 50% farmyard manure + 25% N & 25%* P_2O_5.

Findings: *The results revealed that the sole cropping system was dominant over intercrop with a maximum grain or seed yield of 2229.1 kg* ha^{-1}*, a biological yield of 7230.3 kg* ha^{-1}*, and a harvest index of 30.34% of mungbean was obtained in sole standing of the crop. Similarly, the sole culture of sorghum gave a maximum grain or seed yield of 2779.8 kg* ha^{-1}*, a biological or biomass yield of 10473 kg* ha^{-1}*, and a harvest index of 25.63% compared to the mixed culture of sorghum and mungbean. The treatments with integrated nutrient supply gave significant results (*$P \leq 0.05$*) of all yield parameters in mungbean and sorghum compared to those where these fertilizers were applied in split doses. The economic analysis showed that mungbean-sorghum intercrop gave maximum net income benefits of PKR 225628* ha^{-1} *and PKR 218635* ha^{-1} *and the highest benefit-cost ratio of 1.91 and 1.90 in NP + compost and NP + farmyard manure, respectively.*

Research Limitations: *A particular cereal might not be compatible with a legume, so further studies at the farmer field level in different locations are needed to ensure the compatibility of the crops and the suitability of the cropping system.*

Originality/Value: *The short-duration growth pattern of cereal and legume grown in proximity affirms maximum yield and income benefits per unit area of land and thereby has great significance for farming communities to get more returns with limited available resources.*

Keywords: *Crop production economics, Integrated nutrient management, Mungbean, Net benefits, Partial budget analysis, Sorghum*

INTRODUCTION

Risk reduction through crop yield stability and income are two of the major factors that insist farmers to diversify their cropping and livestock systems.

[1]Department of Agronomy, Faculty of Crop Food Sciences, Pir Mehr Ali Shah Arid Agriculture University, Shamsabad, Murree Road, Rawalpindi-46000, Pakistan.
[2]Cane Agriculture Department, Fatima Sugar Mills Ltd., Fazalgarh Sanawan, Kot Adu 34050, District Muzaffargarh, Pakistan.
ghufran729@yahoo.com
https://orcid.org/0000-0003-3583-0437

The cost of various intercultural operations is reduced with increased diversity in the on-farm cropping system because the costs can be spread out over several crop or animal enterprises (Preston, 2003).In most sub-tropical regions across the globe, multiple cropping as a form of crop diversification has been a prominent feature of crop production among smallholders and is dominated over monoculture.

Intercropping which is often known as polyculture is a method of cultivating two or more crops in proximity on the same land area that enhances the net productivity of the system through efficient utilization of growth resources. The main objective of this crop cultivation scheme is to maximize crop yield and net economic returns per unit area of land besides judicious use of available land resources and farming inputs including farm operations (Marer *et al.*, 2007). This cropping system has several advantages over mono-cropping as it helps in controlling erosion through soil and water conservation, suppression of weeds due to its better intensity of capturing solar radiations, reduces disease infestation, and provides overall yield advantages by suppressing pest outbreaks (Aziz *et al.*, 2015). It is recognized to provide steady yields from diverse crops while utilizing limited nutrient supply inputs and has a defensive mechanism against the unfavorable environment, with an emphasis on providing food under sustainable conditions (Hauggaard-Nielsen *et al.*, 2008).

One of the driving motivations behind intercropping has been the need to protect against the possible risk of monoculture, especially among smallholder farmers who heavily rely on the whims of nature and are exposed to a high level of risk in their production (Tahir *et al.*, 2003; Tsubo *et al.*, 2003). Smallholder farmers can raise the yield of the primary crop with an increased plant population of the component crop that ensures additional yield and potentially increases their net income. Crop insurance is a major principle of this system as it ensures yield stability, as some of the intercrops may not perform well due to specific environmental requirements or contrasting habitats while other crops provide a sufficient yield to make up the losses (Lithourgidis *et al.*, 2011; Gebru, 2015).

Although component crop yields are lower in intercropping systems than in pure stands, the improved resource use efficiency of the system exceeds net returns in terms of increased net income, benefit-cost ratio, and marginal return rate (Banik *et al.*, 2006; Ngwira *et al.*, 2012; Li *et al.*, 2020; Madembo *et al.*, 2020). However, because the need for the component crops must be complementary, crop options for designing suitable intercropping systems are limited. The significance of the intercropping system is quite evident among small growing farmers and its interest is increasing with time due to increased yield production potential and net income benefits compared to the mono-cropping system (Bhatti *et al.*, 2008).

Cereal-legume intercropping is amongst the most economical and effective agronomic strategies to boost crop productivity per unit area and monetary returns (Iqbal *et al.*, 2019). Growing a cereal with grain legume as an intercrop has superior stability in crop yields than planting the cereal alone or with a non-cereal-grain legume combination (Raseduzzaman and Jensen, 2017). It ensures the sustainability of the system, particularly in areas with limited resources and moisture-stress conditions. The cereal-legume combination provides natural crop failure insurance against several factors of biotic and abiotic stress, ensuring production sustainability and more economic benefits for small growers (Maitra *et al.*, 2019). For the successful planting of two or more crops together, several factors including crop maturity, crop compatibility, planting time, and density should be taken into consideration before and after cultivation. The compatibility of crops is determined by the growth patterns of plants, land, space, water, light, and the efficiency of utilizing fertilizers (Brintha and Seran, 2009).

When two or more crops are cultivated together, their peak growth periods do not overlap which causes their significant resource demands to occur at various times. The competition among different plant species can not only be reduced by the spatial arrangement but also by selecting compatible crops that can efficiently utilize soil nutrients (Seran and Brintha, 2010). As intercrops, mungbean (*Vigna radiata* L.) and sorghum (*Sorghum bicolor* L.) are compatible and can be cultivated in a mixed culture which can improve the quality contents in both crops and raise the production potential of the cropping system due to nitrogen fixation ability of mungbean (Shaker-Koohi and Nasrollahzadeh, 2014).

The use of mineral fertilizers alone is not economical for resource-poor farmers and is also a non-eco-friendly approach as it disturbs the natural ecosystem due to its acidic nature. Incorporating organic manures into the soil improves its organic matter contents and adds great nutritional value to the soil (Kumari and Singh, 2020). Organic fertilizers such as farmyard manure, chicken litter, cattle or sheep dung, compost, and bio-fertilizers can be used efficiently as an alternative to chemical fertilizers in various production systems of crops (Ghorbani *et al.*, 2008; Hammad *et* *al.*, 2011). The mixed application of organic manures and mineral fertilizers adds more nutrient value to the soil without much damaging its physical and chemical properties and is economically more viable for resource-poor farmers in terms of cost reduction due to the extremely high prices of the bags of mineral fertilizer (Alemu, 2015). It is a cost-effective approach and can produce maximum yield per unit area with minimum available inputs and thereby ensuring more income for farmers. Several researchers (Mahajan *et al.*, 2008; Farah *et al.*, 2014) demonstrated the beneficial impact of an integrated nutrient management strategy in mitigating the deficiency of macro- and micro-nutrients.

Economic analysis is performed to estimate the viability of applied treatments in a cropping system using a partial budget, dominance, and marginal analysis of each treatment. Partial budget analysis analyzes the costs and benefits of various unconventional treatments. It is a profitable technique for assessing the capability and effectiveness of new technology for an existing enterprise. It assesses risk, evaluates the relative profitability of various approaches, and gauges how resilient earnings are to fluctuations in input or product prices. Average yields for each treatment, adjusted yields, the gross field benefit, and the total variable expenses were all included in the partial budget. The sum of all expenditures for alternative treatments makes up the total costs that vary. It is possible to assess new technology by looking at how it affects farming systems' productivity, profitability, acceptability, and sustainability (Herdt, 1987). The production of the crop that is increased due to the application of inputs might or might not be beneficiary to farmers. Therefore, the net benefits of the system should be determined from the marginal return rate of each alternate treatment in partial budget analysis (CIMMYT, 1988).

It is hypothesized that by using an integrated nutrient management technique, the intercropping of mungbean in sorghum may increase the net income and benefit-cost ratio of the system and help restore soil fertility through efficient utilization of growth resources in a sustainable agro-ecosystem. Therefore, this study was designed to evaluate the bio-economic aspects of mungbean intercropping in sorghum sown in different patterns with the objectives: (i) to access the best intercrop and fertility management option in a sorghum-mungbean intercropping system for optimum economic benefits; (ii) to determine on-farm net production per unit area of land in the intercropping system compared to mono-cropping; I have acknowledged your previous message. Is there anything else I can help you with? (iii) to evaluate a reasonable cropping system along with the best possible fertility treatment through marginal return rate and sensitivity analysis.

MATERIALS AND METHODS

Land Preparation Before Sowing

The soil was cut and inverted to crush the clods using a blade harrow and disc harrow and convert it into the granular form which is a favorable structure for plant growth. Land levelers and plank were used later to level and smoothen the soil surface. The well-rotten farmyard manure and compost were broadcasted and incorporated into the plant root zone 20 days before crop sowing to get beneficial results.

Experimental Site Description & Layout

The research trial was carried out at Agronomic Research Farm (32.93^0 N Latitude, 72.85^0 E Longitude, and 769 m above sea level), Arid Agriculture University, Rawalpindi, Pakistan, during the summer of 2016. The experiment was laid out using a randomized complete block design with a two-factor factorial plan.

Analysis of Soil Used for the Experiment

Soil which serves as a growth medium for various crop plants was tested before performing this experiment. The soil was analyzed for its textural class, pH, electrical conductivity (dSm^{-1}), and bulk density ($mg\ m^{-3}$). The chemical properties of soil including total organic carbon (%), total N (%), N-NO_3 ($\mu g\ g^{-1}$), extractable phosphorus ($\mu g\ g^{-1}$), exchangeable potassium ($\mu g\ g^{-1}$), and amount of calcium carbonate (%) were also evaluated as given in Table 01.

Crop Husbandry

The seed was sown using a single-row hand drill having R×R=30 cm of rows and P×P =10 cm of planting space. The experiment was performed by following three different cropping patterns given five fertility treatments having three replications of each treatment. The treatments included nationally recommended doses of organic manures and synthetic fertilizers in a split and mixed doses in a given sequence; T_0 = unfertilized, T_1 = 100% Compost @ 10 t ha^{-1}, T_2 = 100% Farmyard manure @ 20 t ha^{-1}, T_3 = 50% N (40 kg ha^{-1}) & 50% P_2O_5 (30 kg ha^{-1}), T_4 = 50% Compost @ 5 t ha^{-1} + 25% N (20 kg

Table 1: Soil physicochemical properties of the experimental site

Soil Property	Unit	PMAS-UAAR farm
pH	-	7.6
EC	dSm^{-1}	0.35
Textural class	-	Sandy loam
TOC	%	0.38
Total N	%	0.02
$N\text{-}NO_3$	$\mu g\ g^{-1}$	11.2
Available phosphorus	$\mu g\ g^{-1}$	4.5
Exchangeable potassium	$\mu g\ g^{-1}$	124
Bulk density	$mg\ m^{-3}$	1.40
Calcium carbonate	%	11.63

**EC = Electrical conductivity*, *TOC = Total organic carbon*

ha^{-1}) & 25% P_2O_5 (15 kg ha^{-1}), T_5 = 50% Farmyard manure @ 10 t ha^{-1} + 25% N (20 kg ha^{-1}) & 25% P_2O_5 (15 kg ha^{-1}). The cropping systems included; a) sole sorghum, b) sole mungbean, and c) sorghum-mungbean. It contained 6 rows per plot each in sole sorghum and mungbean and 3 rows per plot each of sorghum and mungbean in intercrop.

Analysis of Macro and Micronutrients in Organic Manures

The sources of organic manure used in this experiment were analyzed to determine the composition of primary and secondary nutrients and other trace elements. The data in Table 02 revealed that compost and farmyard have an appreciable amount of nitrogen, phosphorus, and potassium contents which help to enrich soil fertility levels to a great extent. Compost is a rich source of major nutrient elements and contained 22.3% of organic carbon, 1.9% of N, 0.66% P, and 1.7% K. The composition of organic carbon in farmyard manure used for the experiment was 16.39%, 0.57% N, 0.26% P, and 0.63% K.

Moreover both these sources of organic material also contained a sufficient amount of trace elements including Ca, Mg, S, Fe, Zn, B, and Cu which play a crucial role in plant growth and developmental processes.

Data Collection

The major yield parameters of mungbean and sorghum were recorded manually by randomly selecting ten plants per plot in each replication of treatment, and their means were evaluated. The grain yield and biological yield of both crops in each treatment were determined manually in kg per m^2 by using a weighing balance which was later converted into kg per ha. The means of crop grain yield (kg/ha), biological yield (kg/ha), and harvest index (%) of mungbean and sorghum in two cropping patterns and six fertility treatments were evaluated separately and compared with each other to determine the overall results of these two factors in this experiment and net productivity of the system.

Harvest index:

$$HI(\%) = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100 \tag{3}$$

Economic Analysis of the Cropping Systems

This study used partial budget analysis, dominance analysis, and marginal analysis to examine the feasibility of different treatments applied in various cropping systems.

The partial budget analysis: A partial budget is a method of determining overall changing costs and net benefits in each treatment of a cropping system in a farm experiment. It estimated the positive or negative changes in a farming business. Its left side depicts the positive benefits on net income, which includes reduced expenses with additional income. To offset this effect, the right side includes the proposed change's negative repercussions in the form of additional costs and reduced income (Alimi and Manyong, 2000). It included each treatment's average yield, its modified or adjusted yield, gross benefits of the field, and the total variable costs. The average yield for a particular treatment is lowered by a specific percentage to account for differences between experimental yield and the yield that farmers could reasonably anticipate from the same treatment, which is termed adjusted yield. The gross benefits of the field were evaluated as;

Biological yield:

$$\text{Biological yield (kg ha}^{-1}\text{)} = \frac{\text{Total number of plants} \times 10000}{R \times \text{R distance} \times \text{row length} \times \text{total rows}} \quad (1)$$

Grain yield:

$$\text{Grain yield (kg ha}^{-1}\text{)} = \frac{\text{Total rows seed weight}}{\text{Row-row distance} \times \text{Length of row} \times \text{Total rows}} \times 10000 \quad (2)$$

Table 2: Chemical analysis and composition of macro and micronutrients in organic manures used in the experiment

Fertility source	Organic C (%)	Total N (%)	Total P (%)	Total K (%)	Ca (%)	Mg (%)	S (%)	Fe (%)	Zn ppm	B ppm	Cu ppm
Compost	22.3	1.9	0.66	1.7	1.21	0.73	0.64	1.53	217	51.5	154
Farmyard manure	16.39	0.57	0.26	0.63	1.82	0.92	0.44	0.76	132	202	30.4

$$\text{GB}_\text{f} = \text{F}_\text{p} \times \text{Adj}_\text{yield} \quad \text{(CIMMYT, 1988)} \quad (4)$$

Where:

GB_f: Gross benefits of field
F_p: Price in field
Adj_yield: Adjusted yield

Net income benefits were evaluated as; Here, the yield was adjusted downwards by 10% to account for the fact that farmers would obtain 10% lower yields than researchers using similar technologies and procedures.

$$\text{NIB} = \text{GB}_\text{f} - \text{TVC} \quad \text{(CIMMYT, 1988)} \quad (5)$$

Where:

NIB: Net benefits of income
GB_f: Gross benefits of field
TVC: Total variable costs

The variable total costs are the sum of field costs in all treatments which include the cost of field operations, seed, crop sowing, fertilizer application, crop protection measures, and harvesting. All costs and benefits were calculated based on hectares in Pakistani Rupees (PKR).

Benefit-cost ratio: The benefit-cost ratio was determined to analyze the suitability and feasibility of the mungbean-sorghum intercropping system. It is an important parameter that helps a farmer determine the gain in net returns of the cropping system with a given increase in total costs. It was calculated by using the given equation;

$$\text{BCR} = \frac{\text{Gross Income}}{\text{Total Expenditures}} \quad (6)$$

Dominance Analysis

This analysis was performed to gather information on marginal benefits from marginal costs involved for different cropping systems. For this purpose, all the applied treatments were listed in descending order of increasing expanses that varied. All the treatments were compared for net benefits and total varying costs depending upon the criterion that any treatment with net income benefits either lower than or equal to any other treatment with low varying costs was dominant and listed as ’D’. The treatments that provided fewer benefits at a higher cost were dominating, and as such the farmer would not contemplate investing in them (CIMMYT, 1988).

Marginal Rate of Return

The marginal analysis was carried out using total variable costs and local market seed prices of mungbean, sorghum, and bags of spent fertilizers. It was derived by dividing the change in total benefits by the change in total varying costs (CIMMYT, 1988).

$$\text{MRR (\%)} = \frac{\text{Marginal benefits}}{\text{Marginal cost}} \times 100 \qquad (7)$$

The treatments required farmers to switch from one cropping or farming system to another without learning new technological skills or purchasing new equipment, the minimum rate of acceptance was set at 50%. So the farmers will invest in any treatment that has a marginal rate of return greater than this acceptable rate (CIMMYT, 1988).

Sensitivity Analysis

The sensitivity analysis was performed to validate the results obtained within the farm-level framework and market uncertainties to assess the stability of recommendations under a worst-possible scenario of fluctuating input and output prices (CIMMYT, 1988).

Data Analysis

The recorded data of all the yield parameters of sorghum and mungbean was subjected to analysis of variance (ANOVA) using randomized complete block design with 2-factors factorial by using analytical software statistics 8.1. The treatment means were compared using the test of Fisher's least significant difference (LSD) at a 5% level of probability.

RESULTS AND DISCUSSION

Productivity of Mungbean

Mungbean grain yield, biological yield, and harvest index: The results of yield parameters in mungbean presented in Table 03 Table 04 revealed that the crop had maximum grain yield (2229.1 kg ha^{-1}), biological yield (7230.3 kg ha^{-1}), and harvest index (30.34%) when cultivated as sole culture compared to intercrop with sorghum and the difference was significant between cropping systems in all parameters. It was because short duration growth pattern of the crops induced severe competition for growth resources between two crop species such as water, space light, and nutrients in the intercropping system compared to the sole standing of mungbean. The results were in line with an experiment performed by Khan *et al.* (2012) in a mungbean-maize cropping system where all the yield parameters of mungbean recorded maximum in lone standing crop. The interaction effects of two cropping systems and fertility treatments showed that the grain yield of mungbean was highest when it was provided with a combined dose of organic and chemical fertilizer. The mean maximum grain or seed yield of 3237.8 kg ha^{-1} recorded in T_5= 50% FYM + 25% N & 25% P_2O_5 and 3085 kg ha^{-1} in T_4= 50% compost + 25% N & 25% P_2O_5 and both these treatments were statistically identical but significantly different from those where organic manures and inorganic fertilizers applied in split doses. This may be because organic manures are known to contain an abundance of plant nutrients and growth promoters which in combination with mineral fertilizers provide the plants with favorable conditions to enhance nutrient use efficiency. Armin *et al.* (2016) reported in an experiment that the application of vermicompost + 100% optimum dose of inorganic fertilizer and farmyard manure + 100% optimum dose of inorganic fertilizer gave maximum results for mungbean grain yield.

The biological yield and mungbean harvest index also revealed that the results were statistically significant in both the cropping systems and all fertility treatments. The solitary crop produced the highest biological yield of 7230.3 kg ha^{-1}, while it was recorded as a minimum of 6076.3 kg ha^{-1} in the mungbean-sorghum intercrop due to competition of growth resources between the two crop species. The treatment T_5= 50% FYM + 25% N & 25% P_2O_5 and T_4= 50% compost + 25% N & 25% P_2O_5 gave statistically identical results of biological yield 10410 kg ha^{-1} and 9962 kg ha^{-1}, respectively. These treatments were not statistically different from one another but they differed significantly from all those treatments where fertilizers were applied in split doses. Sole mungbean had a maximum harvest index (30.34%), while it was least in intercrop (28.89%). The interaction effects of cropping systems and fertility treatments gave a significant hike in harvest index T_5 (31.05%) and T_4 (30.91%) of mungbean, and these results were significant compared to all other treatments T_3 (29.76%), T_2 (28.82%), T_1 (28.81%) and T_0 (28.34%), respectively (Table 04). Tarafder *et al.* (2020) reported that the harvest index of mungbean increased significantly in an experiment applied with poultry manure and inorganic fertilizers in varying ratios.

Mean squares in the analysis of variance of grain yield, biological yield, and harvest index in Table 05 showed that two cropping systems and all six fertility treatments were significantly impacted in both these factors which ensured maximum yield potential and thereby generated profitable income with limited available resources. The interaction effects of both these factors indicated non-significant differences within some treatments due to the application of a similar source of fertilizers. These findings assured that yield parameters of mungbean are greatly influenced by

Table 3: Interaction effects of cropping pattern and integrated fertility management on grain yield and biological yield of mung bean (*Vigna radiata* L.)

	Grain yield (kg ha^{-1})			Biological yield (kg ha^{-1})		
Treatments	**Sole crop**	**Intercrop**	**Mean**	**Sole crop**	**Intercrop**	**Mean**
Unfertilized	896 hi	581 i	738.5 D	3113 gh	2082 h	2597 D
100 % Compost	1538 efg	1104 ghi	1321 C	5227 def	3914 fg	4571 C
100% FYM	1718 ef	1239 fgh	1478.5 C	5836 de	4397 efg	5116 C
50% N + 50% P	2378 cd	1952 de	2165.5 B	7830 bc	6696 cd	7263 B
50% Compost + 25% N & 25% P	3345 ab	2825 bc	3085 A	10519 ab	9405 ab	9962 A
50% FYM + 25% N & 25% P	3498.7 a	2977 ab	3237.8 A	10857 a	9963 a	10410 A
Mean	2229.1 A	1779.7 B	-	7230.3 A	6076.3 B	-

Mean of treatments sharing similar alphabet are not statistically significant from one another at ($P \leq 0.05$), FYM: farmyard manure, NP: nitrogen and phosphorus.

Table 4: Interaction effects of cropping pattern and integrated fertility management on harvest index of mung bean (*Vigna radiata* L.)

	Harvest index (%)		
Treatments	**Sole crop**	**Intercrop**	**Mean**
Unfertilized	28.77 g	27.90 i	28.33 D
100 % Compost	29.41 e	28.21 h	28.81 C
100% FYM	29.44 e	28.18 h	28.81 C
50% N + 50% P	30.38 c	29.14 f	29.76 B
50% Compost + 25% N & 25% P	31.79 b	30.03 d	30.91 A
50% FYM + 25% N & 25% P	32.23 a	29.88 d	31.05 A
Mean	30.34 A	28.89 B	-

**Mean of treatments sharing similar alphabet are not statistically significant from one another at ($P \leq 0.05$),FYM: farmyard manure, NP: nitrogen and phosphorus.*

the integrated source of nutrient management and gave profitable income with the least disturbance to natural resources.

Productivity of Sorghum

Sorghum grain yield, biological yield, and harvest index: The results in Table 06 Table 07 indicated that the cropping system and integrated nutrient management had significant impacts on the yield of grain (kg/ha), crop biological yield (kg/ha), and harvest index (%) of sorghum. Maximum crop grain yield (2779.8 kg/ha), biological yield (10473 kg/ha), and harvest index (25.63%) of sorghum were recorded when the crop was cultivated as sole culture and the results of these parameters were statistically significant compared to sorghum-mungbean intercrop. Borghi *et al.* (2013) concluded in a trial that yield parameters of sorghum were affected significantly when it was planted as an intercrop with palisade grass due to competition for natural resources between crop species. The interaction results showed that combining organic and inorganic fertility treatments had a substantial impact on sorghum yield characteristics. Treatments with mixed fertility doses yielded the maximum grain or seed yield of 3805.1 kg ha^{-1} in T_5= 50% FYM + 25% N & 25% P_2O_5, and 3465.3 kg ha^{-1} in T_4= 50% compost + 25% N & 25% P_2O_5, respectively. The findings agreed with Tamboli *et al.* (2013) where the combined application of farmyard manure + bio-fertilizer + $ZnSO_4$ in recommended doses gave maximum results of grain yield and biological yield of sorghum and all the results differed significantly compared to other treatments with separate fertilizer doses and unfertilized treatment. It may be because organic manures in combination with inorganic fertilizers supply plants with nutrient elements that trigger growth processes under favorable

Table 5: Mean square of analysis of variance of mungbean yield characteristics affected by the interaction of cropping patterns and fertility protocols

SOV	Df	GY	BY	HI
Replication	2	42832	402019	0.0084
C.S	1	1818003**	1.198E+07*	18.8501**
Treatment	5	6073340**	5.830E+07**	8.0389**
C.S×T	5	^{NS}8966	^{NS}57401.7	0.4190**
Error	22	104348	1154469	0.0192
Total	35	-	-	-
CV %	-	16.12	16.15	0.47

*SOV = Source of variation, df = degree of freedom, C.S= Cropping systems, CV= Coefficient of variation, GY= Grain yield, BY= Biological yield, HI= Harvest index, **=Highly significant, *= Significant, NS= Non-significant*

Table 6: Interaction effects of cropping pattern and integrated fertility management on grain yield and fodder/straw yield of sorghum (*Sorghum bicolor* L.)

	Grain yield (kg ha^{-1})			Fodder yield (kg ha^{-1})		
Treatments	Sole crop	Intercrop	Mean	Sole crop	Intercrop	Mean
Unfertilized	1369.5 fg	1012 g	1190.75 D	5634.5 def	4438.7 f	5036.6 C
100 % Compost	2212.6 d	1675.7 def	1944.15 C	7531 abcd	6486.4 cde	7008.7 B
100% FYM	2047.8 de	1524.5 efg	1786.15 C	6807 bcde	5479.8 ef	6143.5 BC
50% N + 50% P	2931.3 c	2270 d	2600.65 B	7830.4 abc	6458.7 cde	7144.6 B
50% Compost + 25% N & 25% P	4230.1 a	3380 bc	3805.05 A	9263.9 a	8605.7 ab	8934.8 A
50% FYM + 25% N & 25% P	3887.5 ab	3043 c	3465.25 A	9089.5 a	7952.1 abc	8520.8 A
Mean	2779.8 A	2150.9 B	-	7692.7 A	6570.2 B	-

**Mean of treatments sharing similar alphabet are not statistically significant from one another at (P≤0.05), FYM: farmyard manure, NP: nitrogen and phosphorus.*

environmental conditions that result in increased crop yields.

Similar treatments gave maximum results of biological yield and harvest index of sorghum and the use of an integrated source of fertility management ensured a significant impact among all the treatments in these parameters. The sole cropping system was superior in comparison to mixed cropping with the highest crop biological yield of 10473 kg ha^{-1} compared to that of 8721 kg ha^{-1} in sorghum-mungbean intercrop. Similarly, the maximum harvest index was recorded in the lone culture of the sorghum crop. The treatments with combined application of organic and mineral fertilizers viz; 50% Compost + 25% N 25% P & 50% FYM & 25% N & 25% P gave maximum biological yield and harvest index and had significant results compared to all those treatments with split doses of organic and mineral fertilizers (Table 07).

The results of mean squares of grain yield, biological yield, and harvest index of sorghum in the analysis of variance indicated a highly significant difference among cropping patterns and fertility treatments which ensured maximum production of sorghum per unit area and thereby increased net income of the system. The interaction effects of both these factors were somehow non-significant in some treatments due to the repetition of similar source fertilizer treatments. The use of sorghum in this cropping system gave maximum yield and income benefits without investing much in cultural operations due to its allelopathic impacts.

Economic Feasibility of Cropping Systems

Partial budget analysis of the cropping systems: The economic feasibility of the cropping system can be evaluated by net monetary gains. It was calculated

Table 7: Interaction effects of cropping pattern and integrated fertility management on biological yield and harvest index of sorghum (*Sorghum bicolor* L.)

Treatments	Biological yield (kg ha^{-1})			Harvest index (%)		
	Sole crop	Intercrop	Mean	Sole crop	Intercrop	Mean
Unfertilized	7004 fg	5451 g	6227 D	19.59 hi	18.53 i	19.06 D
100 % Compost	9744 cde	8162 ef	8953 BC	22.69 ef	20.55 gh	21.62 C
100% FYM	8855 def	7004 fg	7930 CD	23.06 e	21.71 fg	22.39 C
50% N + 50% P	10762 bcd	8729 def	9745 B	27.19 cd	25.98 d	26.59 B
50% Compost + 25% N & 25% P	13494 a	11986 abc	12740 A	31.32 a	28.13 c	29.72 A
50% FYM + 25% N & 25% P	12977 ab	10995 abcd	11986 A	29.95 b	27.62 c	28.79 A
Mean	10473 A	8721 B	-	25.63 A	23.76 B	-

**Mean of treatments sharing similar alphabet are not statistically significant from one another at ($P \leq 0.05$), FYM: farmyard manure, NP: nitrogen and phosphorus.*

Table 8: Mean square of analysis of variance of sorghum yield characteristics affected by the interaction of cropping patterns and fertility protocols

SOV	Df	GY	FY	BY	HI
Replication	2	183718	767665	1396691	2.427
C.S	1	**3559951	1.134E+07*	2.761E+07*	**31.734
Treatment	5	**6204590	1.267E+07**	3.619E+07**	**110.547
C.S×T	5	^{NS}56923	^{NS}99384.2	^{NS}80845.4	^{NS}1.016
Error	22	150473	1319891	2324006	0.469
Total	35	-	-	-	-
CV %	-	15.73	16.11	16.15	2.77

SOV = *Source of variation, df = degree of freedom, C.S= Cropping systems, CV= Coefficient of variation, GY= Grain yield, FY= Fodder yield, BY= Biological yield, HI= Harvest index, **=Highly significant, *= Significant, NS= Non-significant*

using the average yield across all repetitions of each treatment and gave an insight into the total varying cost and net gains from any cropping system. The net income benefits of all treatments used in each cropping system are given in Table 09. It demonstrated that the solitary mungbean yielded the highest net income of PKR 98626.2 ha^{-1} in treatment with farmyard manure +NP and PKR 95857 ha^{-1} in compost manure +NP, while the same cropping system with unfertilized treatment gave minimum net income of PKR 26919 ha^{-1}, respectively. Sole sorghum planted with treatment 50% compost + 25% N & 25% P and 50% FYM + 25% N & 25% P gave maximum net income of PKR 107443.1ha^{-1} and PKR 96991.6 ha^{-1}, respectively. The income benefits recorded minimum in the sole culture of sorghum with split doses of chemical and organic fertilizers, T_3= 50% N + 50% P (PKR 73583.95 ha^{-1}), followed by T_1= 100% compost (PKR 51948.6 ha^{-1}), T_2= 100% FYM (PKR 44769.9 ha^{-1}) and the lowest net income of PKR 35991.95 ha^{-1} was recorded in T0 which was an unfertilized treatment. The high-cost prevailing treatment combinations giving fewer crop yields resulted in fewer income benefits (Table 09).

The results of the partial budget analysis given in Fig.01 represented that the mungbean-sorghum intercrop was the best among all cropping systems as it gave maximum net income in each treatment compared to the sole planting system. The highest net income benefits of PKR 225628 ha^{-1} and PKR 218635 ha^{-1} were obtained in sorghum-mungbean intercrop in treatment with 50% compost + 25% N & 25% P and 50% FYM + 25% N & 25% P, respectively. The net benefits obtained in sorghum-mungbean intercrop with split doses of organic and mineral fertilizers were higher than the sole culture of mungbean and sorghum with similar treatments, T_3= 50% N + 50% P (PKR 152719.6 ha^{-1}), followed by T_1= 100% compost (PKR 96842.2 ha^{-1}), T_2= 100% FYM (PKR 96233.2 ha^{-1}) and the lowest net income of PKR

Table 9: Partial budget analysis and benefit-cost ratio of sorghum and mungbean sole and intercropping system using the integrated source of fertility management

Cropping Systems	Fertility Treatments	Total varying costs (PKR ha^{-1})	Gross field benefits (PKR ha^{-1})	Net income benefits (PKR ha^{-1})	Total expenses (PKR ha^{-1})	B: C ratio
Sole Mungbean	Control	485	27404	26919	23482	1.16
	Compost	8773	47062.8	38289.8	37648	1.25
	FYM	12778	52570.8	39792.8	41685	1.26
	NP	5432	72766.8	67334.8	51789	1.40
	Compost + NP	6483	102340	95857	67729	1.51
	FYM + NP	8433	107059.2	98626.2	69979	1.53
Sole Sorghum	Control	355	23346.95	35991.95	19971	1.18
	Compost	6780	58728.6	51948.6	47681	1.23
	FYM	9575	54344.9	44769.9	43227	1.25
	NP	4240	77823.95	73583.95	54819	1.42
	Compost + NP	4890	112333.1	107443.1	72945	1.54
	FYM + NP	6220	103211.6	96991.6	67758	1.52
Mungbean + Sorghum	Control	785	60215.4	59430.4	46892	1.28
	Compost	8225	105067.2	96842.2	77352	1.36
	FYM	8225	104458.2	96233.2	78252	1.33
	NP	6872	159591.6	152719.6	98974	1.61
	Compost + NP	8921	234549	225628	118952	1.97
	FYM + NP	8921	227556	218635	116684	1.95

**All the costs calculated in Pakistani Rupees; 1 US$ = 218 PKR Approx. PKR = Pakistani Rupee.*

Treatments: Control = unfertilized; Compost= 100% composted manure; FYM = 100% farmyard manure; NP = 50% N + 50% P; Compost + NP = 50% Compost + 25% N & 25% P;
FYM + NP = 50% FYM + 25% N & 25% P, FYM: farmyard manure, NP: nitrogen and phosphorus.

59430.4 ha^{-1} was recorded in unfertilized treatment (Fig.01). The results were affirmed by Saleem *et al.* (2011) in an experiment where the plots treated with half PK + half chicken manure + inoculation of rhizobacteria as growth-promoting substance gave the highest net returns in the maize-mungbean and maize-mash bean system compared to the sole cropping system of maize.The increased net returns could be explained based on increased overall productivity in the sorghum-mungbean intercropping system under the influence of organic manures and a chemical source of fertility treatments. The profitability studies showed that treatment with the highest net benefits was the best time to apply fertilizers, indicating that total expenses increased up to a particular level with higher net benefits received. However, the net benefits were lowered as the total variable costs exceeded the optimum level due to high costs with low earnings.

The benefit-cost ratio of the system: The economic feasibility of any treatment or approach determines its success and adaptation. The benefit-cost ratio in different cropping systems under varying combined fertility doses of organic and inorganic fertilizers in sorghum-mungbean intercrop outperformed the sole cropping system of these crops and gave a maximum benefit-cost ratio of 1.97 in treatments with 50% compost + 25% N 25% P_2O_5 and 1.95 in 50% FYM + 25% N & 25% P_2O_5. The benefit-cost ratio of other treatments in an intercropping system with split doses of organic and inorganic fertilizers was higher than those of treatments in the sole crop. Although sorghum and mungbean yielded less in the intercropping system than their standalone crops, the crop relative yields of mungbean and sorghum compensated for the loss in this cropping system and outperformed the solitary system with better income returns and benefit-cost ratio (Jabbar *et al.*, 2010).

Dominance Analysis of the System

The farmers always prefer that particular cropping practice or treatment which gives more income at a lower cost. A dominant treatment is one that has net benefits always lower than any other treatment that has less variable cost (Melese *et al.*, 2017). The dominance analysis approach described by CIMMYT (1988) was devised to choose potentially profitable

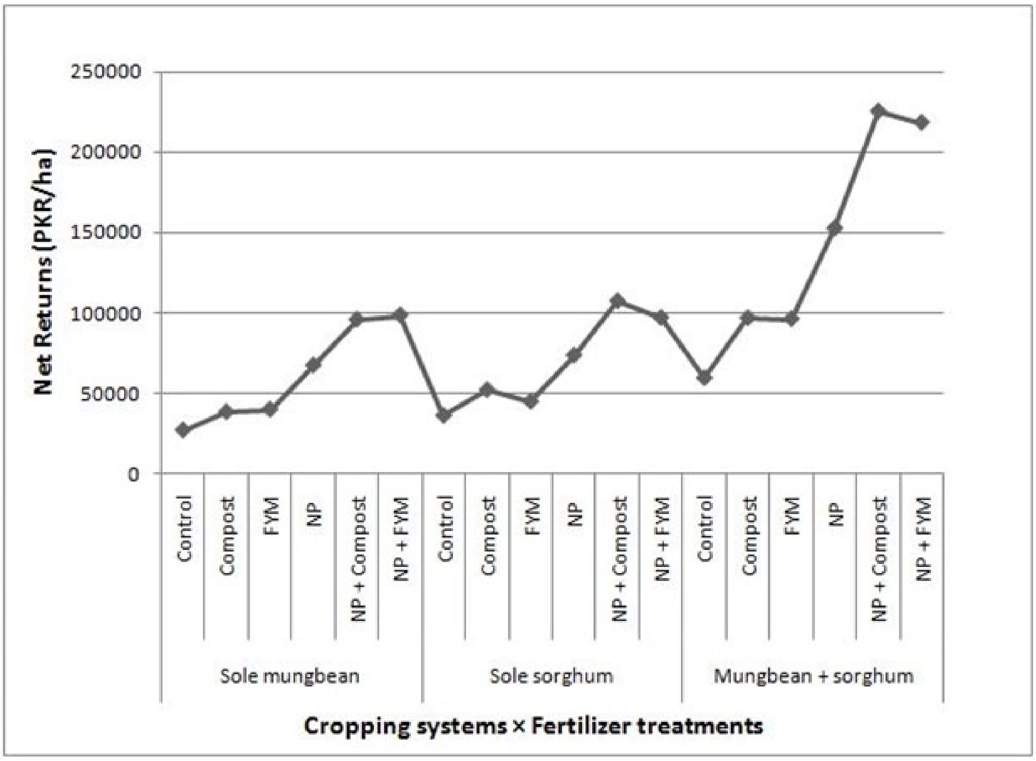

Figure 1: Net income returns among sorghum-mungbean cropping systems under different sources of fertility treatments

treatments from the evaluated range and simplified the analysis by eliminating non-profitable treatments. The dominance analysis in Table 10 eliminated some of the treatments in the cropping system against the backdrop that no rational farmer will consider those treatments or farming practices, which comparatively have low-income benefits at a higher cost. The results indicated that in a sole and intercropping system, the treatments with split doses of organic fertilizers e.g.100% Compost and 100% FYM were dominant and non-profitable in any cropping system as they gave fewer income benefits at a higher cost so they were eliminated and not considered for further analysis. The dominance analysis in sole and intercropping of mungbean-sorghum showed that an unfertilized treatment and other treatments with nationally recommended dose of inorganic fertilizers e.g. NP (40 kg N ha^{-1}) + (30 kg P_2O_5 ha^{-1}) and integrated application of compost manure and NP (50% compost @ 5 t ha^{-1} + 25% N (20 kg ha^{-1}) & 25% P_2O_5 (15 kg ha^{-1}) were un-dominated treatments which gave profitable income and analyzed for marginal return rate, while all other treatments eliminated as they dominated the system (Table 10). This finding suggested that the net benefit declined when the total varying cost rose beyond the application of un-dominated fertilizer treatments and therefore, these treatments may not be considered by any farmer for investment due to non-profitable income.

Net Benefit Curve

It was plotted to compare all the treatments and get useful information regarding the best possible treatment for farmer recommendation. Each of the non-dominant treatments was plotted on the net benefit curve based on its net benefits and varying total costs. The net benefit curve in Fig.02 showed that as the total cost rose from the lowest, so did the net benefits and reached a peak at PKR 8921 and started reducing with further increase in the cost. The net benefit curve was positive because non-dominated treatments had the highest net returns at lower costs.

The Marginal Return Rate of the Intercropping System

The dominance analysis confirmed that an unfertilized treatment along with treatments having 50% compost + 25% N & 25% P_2O_5 and 50%N + 50% P_2O_5 were un-dominated and therefore, marginally beneficial in sole and intercropping systems of sorghum and mungbean. The results indicated that in studied cropping systems, the values of marginal return rate reduced in treatment with split application of inorganic fertilizers in recommended doses compared to where organic manure and inorganic fertilizers were applied in mixed doses. In sole mungbean, the maximum marginal return rate of 2713.8% was recorded in 50% compost + 25% N & 25% P_2O_5 and it was reduced to

Table 10: Dominance analysis of sorghum and mungbean sole and intercropping system using the integrated source of fertility management

Cropping Systems	Fertility Treatments	Total varying costs (PKR ha^{-1})	Net income benefits (PKR ha^{-1})	Dominance
Sole Mungbean	Control	485	26919	U
	Compost	5432	67334.8	U
	FYM	6483	95857	U
	NP	8433	98626.2	U
	Compost + NP	8773	38289.8	D
	FYM + NP	12778	39792.8	D
Sole Sorghum	Control	355	35991.95	U
	Compost	4240	73583.95	U
	FYM	4890	107443.1	U
	NP	6220	96991.65	D
	Compost + NP	6780	51948.6	D
	FYM + NP	9575	44769.9	D
Mungbean + Sorghum	Control	785	59430.4	U
	Compost	6872	152719.6	U
	FYM	8225	96233.2	D
	NP	8225	96842.2	D
	Compost + NP	8921	225628	U
	FYM + NP	8921	218635	D

**All the costs calculated in Pakistani Rupees*;
1 US$ = 218 PKR Approx. PKR = Pakistani Rupee.

Treatments: Control = unfertilized; Compost= 100% composted manure;
Farmyard manure = 100% farmyard manure;
NP = 50% N + 50% P; Compost + NP = 50% Compost + 25% N & 25% P;
Farmyard manure + NP = 50% Farmyard manure + 25% N & 25% P,
NP: nitrogen and phosphorus, D: dominant treatment,
U: un-dominated treatment

816.98% in 50%N + 50% P_2O_5. Sole sorghum gave the maximum results of marginal return with 5209.1% in compost manure +NP and 967.62% in NP. The overall analysis given in Table 11 indicated the sorghum-mungbean intercropping system was beneficial as it had a reasonable marginal return rate of 3558.2% in compost manure + NP followed by 1532.6% in NP. The minimum acceptable rate in the study was above 50% to be effectively considered by the farmers for future investments. The marginal return rate was greater than the minimum rate acceptable in both treatments. So the use of a cereal-legume intercropping system with the application of 5 t ha^{-1} compost + 25% N (20 kg ha^{-1}) & 25% P_2O_5 (15 kg ha^{-1}) was the best possible recommendation. The most suitable recommendation of treatment concerning marginal return rate is not solely dependent upon the highest returns rate, it is rather based on treatment with the highest net benefits together with an acceptable marginal rate of return that becomes a tentative recommendation (CIMMYT, 1988).

An intercropping system with higher economic returns compared to sole standing crops using integrated nutrient management systems has been demonstrated for intercropping systems including; rice and legumes, maize and common bean, maize and grain legumes, wheat and lupine, and sorghum and mungbean (Kinyau *et al.*, 2013; Deressa *et al.*, 2015; Kermah *et al.*, 2017; Bayeh *et al.*, 2022; Temeche *et al.*, 2022).

Sensitivity Analysis of the System

The results of sensitivity analysis of the cropping systems in Table 12 affirmed that treatment with 50% compost + 25% N & 25% P_2O_5 gave reasonable results under the worst possible scenario of fluctuating input and output prices in the intercropping of mungbean and sorghum. The values of marginal return rate in sensitivity analysis were recorded maximum

Table 11: Marginal return rate (%) analysis of sorghum and mungbean sole and intercropping system using the integrated source of fertility management

Cropping Systems	Fertility Treatments	Total varying costs (PKR ha^{-1})	Net income benefits (PKR ha^{-1})	Cost of marginal expenses (PKR ha^{-1})	Cost of marginal benefits (PKR ha^{-1})	Marginal return rate (%)
Sole Mungbean	Control	485	26919	-	-	-
	NP	5432	67334.8	4947	40415.8	816.98
	Compost + NP	6483	95857	1051	28522.2	2713.8
	FYM + NP	8433	98626.2	1950	2769.2	142
Sole Sorghum	Control	355	35991.95	-	-	-
	NP	4240	73583.95	3885	37592	967.62
	Compost + NP	4890	107443.1	650	33859.1	5209.1
Mungbean + Sorghum	Control	785	59430.4	-	-	-
	NP	6872	152719.6	6087	93289.2	1532.6
	Compost + NP	8921	225628	2049	72908.4	3558.2

**All the costs calculated in Pakistani Rupees; 1 US$ = 218 PKR Approx. PKR = Pakistani Rupee.*

Treatments: Control = unfertilized; Compost= 100% composted manure; FYM = 100% farmyard manure; NP = 50% N + 50% P; Compost + NP = 50% Compost + 25% N & 25% P; FYM + NP = 50% FYM + 25% N & 25% P, FYM: farmyard manure, NP: nitrogen and phosphorus.

Table 12: a) Sensitivity analysis with input and output costs increased by 20%

Cropping Systems	Fertility Treatments	Total varying costs (PKR ha^{-1})	Net income benefits (PKR ha^{-1})	Cost of marginal expenses (PKR ha^{-1})	Cost of marginal benefits (PKR ha^{-1})	Marginal return rate (%)
Sole Mungbean	Control	485	32302.8	-	-	-
	NP	5432	80801.76	4947	48498.96	980.37
	Compost + NP	6483	115028.4	1051	34226.24	3256.54
	FYM + NP	8433	118351.44	1950	3323.04	170.23
Sole Sorghum	Control	355	43190.34	-	-	-
	NP	4240	88300.74	3885	45110.4	1332.65
	Compost + NP	4890	128931.72	650	40630.98	6250.92
Mungbean + Sorghum	Control	785	71316.48	-	-	-
	NP	6872	183263.52	6087	111947	1839.11
	Compost + NP	8921	270753.6	2049	87490.08	4269.89

*All the costs calculated in Pakistani Rupees; 1 US$ = 218 PKR Approx. PKR = Pakistani Rupee.

Treatments: Control = unfertilized; Compost= 100% composted manure; FYM = 100% farmyard manure; NP = 50% N + 50% P; Compost + NP = 50% Compost + 25% N & 25% P; FYM + NP = 50% FYM + 25% N & 25% P, FYM: farmyard manure, NP: nitrogen and phosphorus.

with either a 20% increase or decrease in prices. The intercropping system gave maximum returns of 4269.89% with increasing prices while the returns were also highest with 2846.59% in the same cropping system with decreasing input and output prices. It was followed by treatment with 50% N & 50% P_2O_5 which provided the marginal return of 1839.11% with a 20% rise and 1226% with a 20% fall in prices in the intercropping system. So it was evident from the outcomes that treatments with 50% compost + 25% N & 25% P_2O_5 and 50% N & 50% P_2O_5 performed better in all cropping systems and emerged as the most promising treatments persistently under the worst possible conditions of fluctuating prices and hence were highly recommended for farmers having limited resource availability. Saka *et al.* (2007) reported that

Table 12: b) Sensitivity analysis with input and output costs reduced by 20%

Cropping Systems	Fertility Treatments	Total varying costs (PKR ha^{-1})	Net income benefits (PKR ha^{-1})	Cost of marginal expenses (PKR ha^{-1})	Cost of marginal benefits (PKR ha^{-1})	Marginal return rate (%)
Sole Mungbean	Control	485	21535.2	-	-	-
	NP	5432	53867.84	4947	32332.64	653.58
	Compost + NP	6483	76685.6	1051	22817.76	2171
	FYM + NP	8433	78900.96	1950	2215.36	113.60
Sole Sorghum	Control	355	28793.56	-	-	-
	NP	4240	58867.16	3885	30073.6	774
	Compost + NP	4890	85954.48	650	27087.32	4167.28
Mungbean + Sorghum	Control	785	47544.32	-	-	-
	NP	6872	122175.68	6087	74631.36	1226
	Compost + NP	8921	180502.4	2049	58326.72	2846.59

*All the costs calculated in Pakistani Rupees; 1 US$ = 218 PKR Approx. PKR = Pakistani Rupee.
Treatments: Control = unfertilized; Compost= 100% composted manure; FYM = 100% farmyard manure; NP = 50% N + 50% P; Compost + NP = 50% Compost + 25% N & 25% P; FYM + NP = 50% FYM + 25% N & 25% P, FYM: farmyard manure, NP: nitrogen and phosphorus.

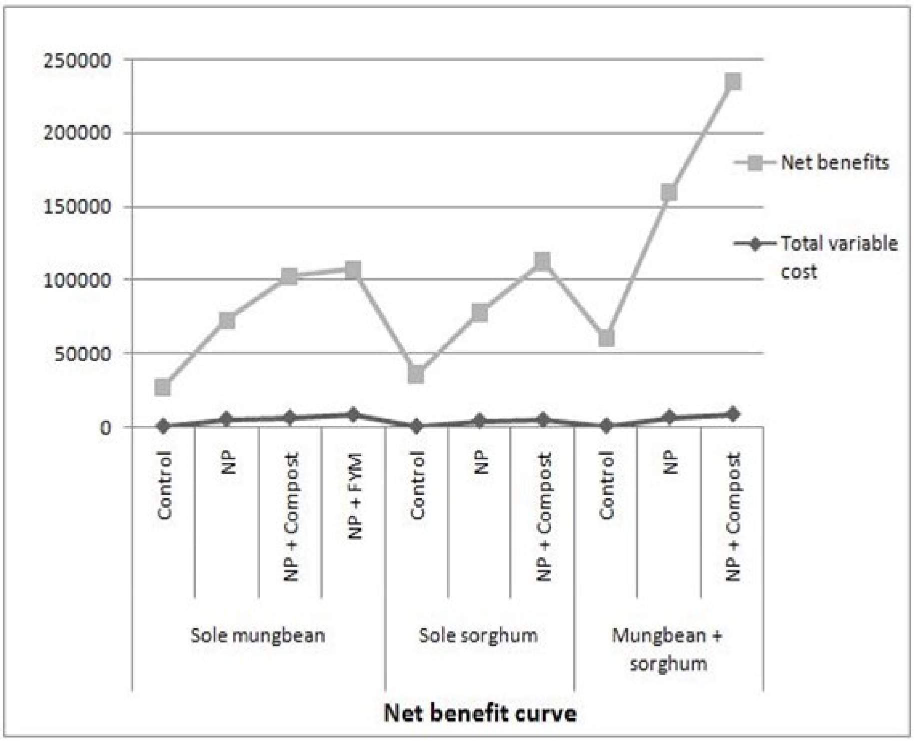

Figure 2: Net benefit curve of the sole and intercropping of mungbean and sorghum under different sources of fertility treatments

kenaf and African yam bean intercrop gave maximum economic benefits under the circumstances of changing prices.

CONCLUSION

The results based on this study concluded that the cereal-legume intercropping system was beneficial for resource-poor farmers as it had maximum net productivity and was economically more viable provided with an integrated source of nutrients compared to a mono-cropping system. Maximum grain yield, biological yield, and harvest index of mungbean and sorghum were observed in treatments with a mixed application of organic and chemical fertilizers in a sole culture of both these crops and results in these treatments were highly significant compared to those where both sources of fertilizer applied in split doses and planted as mungbean-sorghum intercrop. The intercropping system gave the maximum income returns and benefit-cost ratio as it gave maximum productivity per unit area of land. The partial budget analysis showed that the highest net income benefits of PKR 225628 ha^{-1} and benefit-cost ratio of 1.97 were obtained in sorghum-mungbean intercrop in treatment with 50% compost + 25% N & 25% P that was followed by a treatment with 50% FYM + 25% N & 25% P having income benefits of PKR 218635 ha^{-1} and benefit-cost ratio of 1.95 in the similar cropping system, respectively. The treatments with split doses of organic fertilizers in both cropping systems were dominant as they gave fewer income benefits with higher costs and were not recommended for farmers. The treatments with a mixed application of organic and inorganic fertilizers had more than acceptable marginal returns rate of 3558.2% in 50% compost + 25% N & 25% P_2O_5 and 1532.6% in 50% N & 50% P_2O_5 in mungbean-sorghum intercrop compared to their sole cropping systems. It was highly recommended especially for small growing farmers to introduce cereal and legumes in cropping systems with integrated application of nutrients as it ensured maximum production potential of the system with more economic benefits at minimum cost.

REFERENCES

Alemu, M.M. (2015). Effect of tree shape on coffee crop production. *Journal of Sustainable Development*, 8(9), 66-70. DOI: https://doi.org/10.5539/jsd.v8n9p66.

Alimi, T. and Manyong, V.M. (2000). Partial budget analysis for on-farm research. International Institute of Tropical Agriculture, Ibadan, Nigeria. 1-52.

Armin, W., Zaman, Kh. A.U., Zamil, S.S., Rabin, M.H., Bhadra, A.K. and Khatun, F. (2016). The combined effect of organic and inorganic fertilizers on the growth and yield of mungbean (Bari Mung 6). *International Journal of Scientific and Research Publications*, 6 (7), 557-561. ISSN 2250-3153.

Aziz, M., Mahmood, A., Asif, M. and Ali, A. (2015). Wheat-based intercropping: A review. *The Journal of Animal & Plant Sciences*, 25(4), 896-907. ISSN 1018-7081.

Banik, P., Midya, A., Sarkar, B.K. and Ghose, S.S. (2006). Wheat and chickpea intercropping systems in an additive series experiment: Advantages and weed smothering. *European Journal of Agronomy*, 24, 325-332. DOI: 10.1016/j.eja.2005.10.010

Bayeh, B., Alemayehu, G., Tadesse, T. and Alemayehu, M. (2022). Evaluation of nutrient requirements of sweet lupine in bread wheat-sweet lupine under additive design intercropping system in Northwest Ethiopia. *International Journal of Agronomy*, 1, 1-8. DOI: https://doi.org/10.1155/2022/3939178

Bhatti, I.H., Ahmad, R., Jabbar, A., Virk, Z.A. and Aslam, M. (2008). Agro-economic performance of mungbean intercropped in sesame under different planting patterns. *Pakistan Journal of Agricultural Sciences*, 45(3), 25-28.

Borghi, E., Crusciol, C.A.C., Nascente, A.S., Sousa, V.V., Martins, P.O., Mateus, G.P. and Costa C. (2013). Sorghum grain yield, forage biomass production and revenue as affected by intercropping time. *European Journal of Agronomy*, 51, 130-139. DOI: 10.1016/j.eja.2013.08.006

Brintha, I. and Seran, T.H. (2009). Effect of paired row planting of raddish (Raphanus sativus L.) intercropped with vegetable amaranths (Amaranths tricolor L.) on yield components in sandy regosol. *The Journal of Agricultural Sciences*, 4, 19-28. DOI: https://doi.org/10.4038/jas.v4i1.1642

CIMMYT. (1988). From agronomic data to farmer recommendations: An economics training manual. Completely revised edition. The International Maize and Wheat Improvement Center, Mexico City, Mexico. 1-79.

Deressa, H., Tufa, A., Ayele, D., Ketema, K., Ketema, M., Dechassa, N., Amanu, T., Abebe, T. and Tefera, T. (2015). Maize-common bean intercropping and Tef Relay cropping to enhance productivity and profitability for smallholder farmers. In: Scaling innovations and agricultural best practices in Ethiopia: Experiences and Challenges. (Elias, E. and Beek, C.van. Eds.). CASCAPE project, Wageningen University and Research Centre, Wageningen, The Netherlands. 200p.

Farah, G.A., Dagash, Y.M.I. and Yagoob, S.O. (2014). Effect of different fertilizers (Bio, Organic and Inorganic fertilizers) on some yield components of rice (Oryza sativa L.). *Universal Journal of Agricultural Research*, 2(2), 67-70. DOI: https://doi.org/10.13189/ujar.2014.020206

Gebru, H. (2015). A review of the comparative advantage of intercropping systems. *Journal of Biology, Agriculture and Healthcare*, 5(7), 28-38. ISSN 2224-3208 (paper), 2225-093X (online).

Ghorbani, R., Koocheki, A., Jahan, M. and Asadi, G.A. (2008). Impact of organic amendments and compost extracts on tomato production and storability in agroecological systems. *Agronomy for Sustainable Development*, 28, 307-311. DOI: 10.1051/agro:2008003

Hammad, H.M., Khaliq, A., Ahmad, A., Aslam, M., Malik, A.H., Farhad, W. and Laghari, K.Q. (2011). Influence of different organic manures on wheat productivity. *International Journal of Agriculture & Biology*, 13, 137-140. ISSN 1560-8530 (print), 1814-9596 (online).

Hauggaard-Nielsen, H., Jørnsgaard, B., Kinane, J. and Jensen, E.S. (2008). Grain legume-Cereal intercropping: The practical application of diversity, competition, and facilitation in arable and organic cropping systems. *Renewable Agriculture and Food Systems, Researching Sustainable Agricultural Systems*, 23(1), 3-12. DOI: 10.1017/S1742170507002025

Herdt, R. (1987). Whither farming systems? In: how systems work. Proceedings of farming systems research symposium, University of Arkansas, Fayetteville, USA. 3-7.

Iqbal, M.A., Hamid, A., Hussain, I., Siddiqui, M.H., Ahmad, T., Khaliq, A. and Ahmad, Z. (2019). Competitive indices in cereal and legume mixtures in a South Asian Environment. *Crop Economics, Production and Management, Agronomy Journal*, 111(1), 242-249. DOI: 10.2134/agronj2017.11.0658

Jabbar, A., Ahmad, R., Bhatti, I.H., Rehman, A., Virk, Z.A. and Vains, S.N. (2010). Effect of different rice-based intercropping systems on rice grain yield and residual soil fertility. *Pakistan Journal of Botany*, 42(4), 2339-2348. ISSN 0556-3321

Kermah, M., Franke, A.C., Adjei-Nsiah, S., Ahiabor, D.K., Abaidoo, R.C. and Giller, K.E. (2017). Maize-grain legume intercropping for enhanced resource use efficiency and crop productivity in the Guinea savanna of northern Ghana. *Field Crops Research*, 213, 38-50. DOI: https://doi.org/10.1016/j.fcr.2017.07.008

Khan, M.A., Naveed, K., Ali, K., Ahmad, B. and Jan, S. (2012). Impact of mungbean-maize intercropping on growth and yield of mungbean. *Pakistan Journal of Weed Science Research*, 18(2), 191-200. ISSN: 1815-1094 (print), 2225-7942 (online).

Kinyau, M., Ley, G.J., Hella, J.P., Tenge, A.J., Opio, F. and Rwomshana, I. (2013). Economic analysis of rice legume rotation systems in Morogoro, Tanzania. *International Journal of Agricultural Policy and Research*, 1(2), 041-047. Available online at https://www.journalissues.org/journals-home.php?id=1

Kumari, R. and Singh, D.P. (2020). Nano-biofertilizer: An emerging eco-friendly approach for sustainable agriculture. *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences*, 90, 733–741. DOI: https://doi.org/10.1007/s40011-019-01133-6

Li, C., Hoffland, E., Kuyper, T.W., Yu, Y., Zhang, C., Li, H., Zhang, F. and Werf, W.vd. (2020). Syndromes of production in intercropping impact yield gains. *Nature Plants*, 6, 653-660. DOI: 10.1038/s41477-020-0680-9

Lithourgidis, A.S., Dordas, C.A., Damalas, C.A. and Vlachostergios, D.N. (2011). Annual intercrops: an alternative pathway for sustainable agriculture. *Australian Journal of Crop Science*, 5, 396–410. ISSN 1835-2693

Madembo, C., Mhlanga, B. and Thierfelder, C. (2020). Productivity or stability? Exploring maize-legume intercropping strategies for smallholder Conservation Agriculture farmers in Zimbabwe. *Agricultural Systems*, 185, 102921. DOI: 10.1016/j.agsy.2020.102921

Mahajan, Dr. A., Bhagat, Dr. R.M. and Gupta, Dr. R.D. (2008). Integrated nutrient management in sustainable rice-wheat cropping for food security in India. *SAARC Journal of Agriculture*, 6(2), 1-16.

Maitra, S., Palai, J.B., Manasa, P. and Kumar, D.P. (2019). The potential of an intercropping system in sustaining crop productivity. *International Journal of Agriculture, Environment and Biotechnology*, 12(1), 39-45. DOI: 10.30954/0974-1712.03.2019.7

Marer, S.B., Lingaraju, B.S. and Shashidhara, G.B. (2007). Productivity and economics of maize and pigeon pea intercropping under rainfed conditions in the northern transitional zone of Karnataka. *Karnataka Journal of Agricultural Sciences*, 20(1), 1–3.

Melese, K., Mohammed, W. and Hadgu, G. (2017). On-farm partial budget analysis of pepper (Capsicum annum L.) to the application of NP fertilizer and farmyard manure in Raya Azebo District, Northern Ethiopia. *African Journal of Agricultural Research*, 10(4), 127-134. DOI: https://doi.org/10.5897/JDAE2017.0858

Ngwira, A., Aune, J.B. and Mkwinda, S. (2012). On-farm evaluation of yield and economic benefit of short-term maize legume intercropping systems under conservation agriculture in Malawi. *Field Crops Research*, 132, 149-157. DOI: https://doi.org/10.1016/j.fcr.2011.12.014

Preston, S. (2003). Intercropping principles and production practices. *Agricultural Systems Guide. Appropriate Technology Transfer for Rural Areas (ATTRA)*. https://attra.ncat.org/attra-pub/PDF/intercrop.pdf.

Raseduzzaman, Md. and Jensen, E.S. (2017). Does intercropping enhance yield stability in arable crop production? A meta-analysis. *European Journal of Agronomy*, 91, 25-33. DOI: 10.1016/j.eja.2017.09.009

Saka, J.O., Adeniyan, O.N., Akande, S.R. and Balogun, M.O. (2007). An economic evaluation of intercropping African yam bean, kenaf and maize in the rain forest zone of Nigeria. *Middle-East Journal of Scientific Research*, 2(1), 01-08. ISSN 1990-9233

Saleem, R., Ahmed, Z.I., Ashraf, M., Arif, M., Malik, M.A., Munir, M. and Khan, M.A. (2011). Response of maize-legume intercropping system to different fertility sources under rainfed conditions. *Sarhad Journal of Agriculture*, 27(4), 503-511.

Seran, T.H. and Brintha, I. (2010). Review on maize-based intercropping. *Journal of Agronomy*, 9(3), 135-145. DOI: https://doi.org/10.3923/ja.2010.135.145. ISSN 1812-5379.

Shaker-Koohi, S. and Nasrollahzadeh, S. (2014). Evaluation of yield and advantage indices of sorghum (Sorghum bicolor L.) and mungbean (Vigna radiate L.) intercropping systems. *International Journal of Advanced Biological and Biomedical Research*, 2(1), 151-160.

Tahir, M., Muhammad, A. M., Asif, T. and Rashid, A. (2003). Agro-economic advantages of different canola-based intercropping systems. *Pakistan Journal of Agronomy*, 2(1), 40-43. DOI: 10.3923/ja.2003.40.43

Tamboli, B.D., Bagwan, I.R., Pawar, A.B., Bhakare, B.D., Shelke, S.R., Kadam, J.R. and Deshpande, A.N. (2013). Integrated nutrient management for sustaining rabi sorghum yield, economics and soil fertility on inceptisol under dryland conditions. *Indian Journal of Dryland Agricultural Research and Development*, 28(1), 70-73. ISSN 0971-2062

Tarafder, S., Rahman, Md. A., Hossain Md. A. and Chowdhury, Md. A.H. (2020). Yield of Vigna radiata L. and post-harvest soil fertility in response to integrated nutrient management. *Agricultural and Biological Sciences Journal*, 6(1), 32-43. ISSN: 2381-7178 (print), 2381-7176 (online).

Temeche, D., Getachew, E., Hailu, G. and Abebe, A. (2022). Effect of sorghum-mungbean intercropping on sorghum-based cropping system in the lowlands of North Shewa, Ethiopia. *Advances in Agriculture*, 1, 1-7. DOI: https://doi.org/10.1155/2022/6987871

Tsubo, M., Mukhala, E., Ogindo, H.O. and Walker, S. (2003). Productivity of maize-bean intercropping in a semi-arid region of South Africa. *Water SA*, 29 (4), 381-388. DOI: https://doi.org/10.4314/wsa.v29i4.5038