ECONOMIC ANALYSIS, YIELD OPTIMIZATION, AND COMPETITION DYNAMICS OF GROUNDNUT/CEREAL FODDER INTERCROPPING SYSTEMS IN PAKISTAN'S SEMI-ARID TROPICS

ABSTRACT

This research focuses on the intercropping management options including aspects of yield performance, nitrogen contribution to groundnut and economical considerations through the usage of intercrop Maize, Sorghum and Pearl Millet under varying cuttings treatments. Intercropping is effective in increasing land productivity and efficiency in nutrient use and provides economic returns yet the best combinations have not been well explored. Randomised complete block design was used to assess the growth characteristics of plant height, modulation and nitrogen in sole cropping and intercropping treatments in which they make cuts. For sole crop, both, maize and pearl millet produced the highest green fodder yields of 13.40 t ha^{-1} and 19.10 t ha^{-1}, respectively, and intercropping reduced the productivity for both crops but it was statistically significant, yield recorded in Maize (one cut) groundnut = 3.10 t ha^{-1}. Both nodulation and nitrogen content were maximum in sole groundnut, but they were lower when groundnut was grown in association with other crops. Among all competitive indices, the LER was the highest on maize (LER=1.72), pearl millet and sorghum indicated that intercropping enhances land use efficiency. This was facilitated by the Monetary Advantage Index (MAI) that provided much support to maize-groundnut intercrop, which was easily identified as the most appropriate option for inter-crop revenue generation with an MAI of Rs. 17,800. These results provide evidence for the suitability of maize as the best intercrop for the enhancement of productivity and profitability in groundnut based intercropping systems. This study adds valuable input to sustainable agriculture, particularly in that it expresses the yields and profits from distinct intercrop associations as numeral digits deemed useful by both the scientific and agricultural communities.

Keywords: Economic viability, Groundnut, Intercropping, Land Equivalent Ratio, Sustainable agriculture

INTRODUCTION

Sustainable intensification of agriculture is important for food security and income stability for smallholders in the semi-arid tropics of Pakistan. This growing pressure on the demand for land and water resources calls for cropping systems that can maximize yield and return on investment and improve resource utilisation (Tseng et al., 2021). To meet such demands, the recommended technique of intercropping is groundnut with cereal fodder crops like maize, sorghum, and pearl millet (Emran et al., 2022). Intercropping involves growing crops with different ecological requirements, increasing yields per unit area, declining soil erosion, and enhancing the efficiency of smallholder farmer’s land base (Glaze et al., 2020). Leguminous crops such as groundnut positively affect soil nitrogen through biological nitrogen fixation, which limits the application of synthetic fertilizers for improved neighboring non-leguminous crop growth (Kebede et al., 2021). When grown along with the cereal crops there are possibilities of having maximum nitrogen input required for cereal fodder productions along with the conservation of soil health by groundnut. In areas such as Pakistan, where soil fertility as well as water is a constraint, having crop adaptations that provide such synergies helps in crop productivity and economic viability (Maitra et al., 2021).In similar semi-arid environments, intercropping groundnut with cereals was proven to have a LER of 1.3 or more, which means an increment by 30% to the sole cropping systems (Yang et al., 2021).

The recent studies on the productivity and profitability of groundnut-maize and groundnut-pearl millet intercropping system in pakistani semi-arid tropics revealed that groundnut intercropped with maize or pearl millet improved both crop and fodder production. The analysis and integration of this system in the smallholder agriculture of Pakistan could be revolutionary for their crops and livestock feed production (Amanullah et al., 2020). Off-farm income has become a source of livelihood due to fodder scantiness in the Pakistan and during the dry season, its supply is less and causes low productivity of livestock and enhance vulnerability in rural area. Since animal farming an important sector contributing 11 % of Pakistan’s GDP and supports small holders 35 million rural population, there is high demand of continuous green fodder production through intercropping systems (Musa&Musta, 2020; Khan et al., 2022). In intercropping, the benefits are twofold namely, food crop (groundnut) and fodder cereal crop hence increasing returns for a specific area of land. Thus, the economic consideration of intercropping consists of the higher resource-use efficiency (Maitra et al., 2021). Pakistani studies reveal that groundnut/cereal intercropping can increased net returns by 20-25% in comparison with monoculture practice as intercropping utilization of the land well, low input and total production yield are high (Vlahova, 2022). For the farmers of Pakistan such income gains are making lots of sense due to the fact that the average size of farming holding is relatively small. Intercropping reduces competition for nitrogen by supplying nitrogen of intimately through modulated groundnut and, at the same time, allowing cereals to utilize mineral nitrogen with no much competition hence streamlined nitrogen use (Hossain et al., 2022; Zakir et al., 2023). Moreover, patterns of spatial and temporal interactions in intercropping systems affect the overall system output. For example, numbers of plants per area and number of times fodder crops are harvested actually affect both the groundnut and the cereal production due to local conditions and availability of the market. Minimum LERs of 1.5 in the semi-arid zones of Pakistan might mean that crop planning for planting arrangements and cutting schedules might result in 50% higher combined productivity of both crops, grown individually (Ravi et al., 2021). This outcome may lead to improvements in farm revenues, likely to make food more available and secure and recommend sustainable use of land.

Competition as a result of light, water and nutrient sharing within intercropping systems is another area of interest when it comes to optimizing yield. Some studies demonstrate that this density and spacing help to reduce conflicting dependency during water shortages typical of arid regions or areas such as Saudi Arabia (Wang et al., 2021). It also has an impact on ecological resilience where different plant form and root mass enhances the soil structure and combined with water that's minimized in in drought ridden rain-fed agricultural country like Pakistan. Hence, there are increases in production from the involvement of the groundnut/cereal intercropping system adding on to that there are improvements in the environment by addressing issues on the health of the soils. This research was endeavored to provide needed data on the economic and ecological returns on groundnut/cereal intercropping for the particular physical environment of Sargodha, Pakistan. The profitability and yield potential under different intercropping arrangements is investigated using economic factors such as partial budget analysis and cost-benefit coefficients. In doing so ,it makes available findings does which can be useful to policymakers and other agricultural stakeholders who may wish to embrace initiatives that can be supportive of Pakistan's agriculture sustainability ad rural development .

Therefore, the findings of this study provide the avenue of groundnut/cereal fodder inter cropping system as an effective and viable model of production for scriai-arid agriculture of Pakistan. This system could improve resource use productivity, support farmer revenues, and fortify food and fodder supplies if ecological relations between legumes and cereals was enlisted. Thus, intercropping would go a long way towards constructing capable forms of agriculture in the semi-arid tropics of Pakistan, key to the overall food security, economic stability, sustainable resource management in the region.

Materials and Methods

Experimental Site

Field experiments were conducted during two dry seasons at the research farm of the Adaptive Research Farm, Sargodha Pakistan. The site is a semi-arid one with a geographical position of 72.67 east longitude and 32.08 north latitude, and at an elevation of 189 meters above sea level. Sargodha receives mean annual rainfall of nearly 400mm and it is mainly received from June to September or during June- September. There is scarce rainfall in winter but in summer the temperatures can rise to as high as 42 - 44 degrees centigrade. The lowest temperature is in January and ranges from 10-12 C. Soil type in the study area is described as silty loam, with a medium texture, slightly calcareous, and with an approximate pH of 7.5. two, land fertility or nutrient capicity; the amount of organic carbon is at 0.60%, nitrogen availability is between 100 and 120 kilograms per hectare, phosphorus availability is about eight kilograms hectare. Available potassium is comparatively higher in the study area and varies between 300 and 320 kg ha^{-1}. Groundnut and fodder crop mixed cropping system is well suited to this type of soil stratum as indicated by the current cereal and legume intercropping.

Experimental Design and Crop Culture

Cereal fodders used in the experiment were maize, sorghum and pearl millet harvested and treated as single and mixed crop with groundnut in the first week of February. At planting, 3–5 seeds per hill were used with row spacing of 60 cm and the seed later thinned to one plant per hill to give a plant density of 50, 000 plants per hectare. Groundnut was planted at a row spacing of 30 cm and resulted to plant population density of 300000 plants per hectare. Intercropping was done in a 1:3 arrangement where one row contained cereal fodder while the other contained groundnut, effective for calculating plant populations in both crops with the regard to spatial arrangements. In the intercropping arrangement the spacing between cereal rows was 120cm. For competition indices calculation, monoculture stands of each crop were also established. The number of cuts for sorghum and pearl millet harvesting treatment was one or two; first cut at 50 DAS and the second one at 95 DAS. Hence, there were nine treatment combinations including sole and mixed stand of groundnut and each cereal crop cultivated under four replicates in a completely randomized block design.

Pre sowing treatments included fungicide treatment of all the seeds. Groundnut got basal rates of 50 kg P_2O_5 , 30 kg K_2O, 12.5 kg N ha^{-1} at planting and split application of nitrogen 25 days after planting. Cereal fodders received 60 kg N, 40 kg P_2O_5 and 30 kg K_2O per hectare while in treatments receiving two cuts 20 kg N per hectare was applied subsequent to first cut. Urea containing 46.4% Nitrogen, single super phosphate containing 16% P_2O_5 and muriate of potash containing 60% K2O were used as nutrient sources. Crop management practices encompassed nine 50-mm irrigations in 10 days infected with a hand weeder one month after planting to minimize the weed infestation. They concluded that there was no major tendency toward pest or disease outbreak. Plots of 4.8m ×10m were established and total biomass was removed per plot per treatment. The entire experiment was conducted on groundnut pods and they were manually pulled out at 105 days with the purpose of recording the yield.

Plant and Soil Sampling

In the growth analysis of groundnut, plants were collected at 15 days interval from 15 days after sowing (DAS) up to the time of harvest. Sample was dehydrated in an oven at 65°C to a constant mass for a period of 72 hours. Leaf area was estimated using the dry mass ratios with the help of a leaf area meter, LI-COR, Lincoln NE. To compare growth in a row adjacent to fodder and a middle row, groundnut plants were collected from four different plot sites. The plant height and the number of tillers was determined on five tagged plants in each plot at the time of cutting. A preliminarily estimation of groundnut nodulation was done by rinsing the root ball with clean water and then weighing nodules detached from the roots in terms of dry weight. Sprig shoot tissue nitrogen was determined micro Kjeldahl method and was taken at 30 and 60 days of growth.

Growth Analysis

Crop Growth Rate (CGR) was calculated as the increase in dry weight per unit ground area over time: Specific DM losses amount to [W2−W1)/(t2−t1][W2 – W1) / (t2 – t1)(W2−W1)/(t2−t1, where W1W1W1 and W2W2W2 are DW at times t1t1t1 and t2t2t2, in g m^{-2} day^{-1}. Net Assimilation Rate (NAR) was obtained as [W2 – W1] [ln L2– ln L1] / [t2 – t1] [L2 – L1] [W2−W1][ln L2−ln L1]/[t2−t1][L2−L1][W2—W1][lnL2- lnL1]/ [LAI was calculated as the ratio of the leaf area to the ground area.

In accordance with the presented benchmarks of the Nielsen Company, the Competition indices have been calculated as well as the economic analysis has been made.

Competition yields in intercropping were used to evaluate based on competition indices of Ofori & Stern (1987), Wasey &Osiru (1972) and Wasey & Rao (1980). The Land Equivalent Ratio (LER), representing intercropping efficiency, was calculated as: LER = (Yab/Yaa) + (Yba/Ybb)LER = (Yab/Yaa) + (Yba/Ybb)Yaa=Yaa of sole crop, yab= yab of intercrop, Ybb=Ybb of sole crop, yba=yba of intercrop A yield advantage is portrayed by LER values above one. The two factors or two results The Relative Crowding Coefficient (RCC) and Aggressivity Index offered quantitative approximation of the dominance in the inter-cropping systems. RCC was determined by means of formula K=(Yab×Xba)/((Yaa−Yab)×Xab)K = (Yab \times Xba) / ((Yaa - Yab) \times Xab)K=(Yab×Xba)/((Yaa−Yab)×Xab) where RCC values above 1 mean the yield benefit. The ‘‘Aggressivity Index” (AabAabAab) of the partial competition was the extent of quantitative competitive advantage with values of greater than or less than zero in favor of crop ‘a.’ For determining crop proportions in the early stages of planting the Competition Ratio (CR) was employed and a CRa< 1 defines a favorable relationship. For economic feasibility, the Monetary Advantage Index (MAI) was calculated as: MAI=value of combined intercrops×(LER−1)/LERFAsize={\displaystyle MAI=\frac{\text{value of combined intercrops}\times (LER - 1)}{LERFA}} MAI was found to increase with cropping system intensity which implies that systems with higher values are more profitable.

Data analysis

Data obtained in different studies were tested for analysis of variance (ANOVA) appropriate to the design as described by Cochron and Cox (1958). The test done to check the significance of the treatment difference weredone using a ‘T-test.’ The treatments’ averages were compared against the critical difference at 5% level of probability as used to identify important differences.

RESULTS

1. **Growth Attributes of Fodder Crops in Sole and Intercropping Systems**

The differences in plant height and tiller numbers between sole cropping and intercropping revealed significant differences in growth between maize, sorghum, and pearl millet intercrops (Table 1). During sole cropping the greatest average plant height at the first cut was sampled in pearl millet with a mean height of 125. 6 cm followed by sorghum with 121.8 cm and maize with

120. 5 cm. Specifically, plant heights of the crops under intercropping were slightly lower than those grown under monoculture system and were recorded as 112.1 cm for maize, 115.4 cm for sorghum and 118.3 cm for pearl millet crops that were harvested twice as top third of the plants were cut, during their growth period.The plant height in case of sorghum and pearl millet cuts during the second cut were drastically affected

The same as with intercropping, production of tilters was also influenced. In sole cropping, maize yielded the highest number of tillers 11.5, while intercropped maize yielded only 10.2 tillers at first cut. The study also noticed decline in tillering in sorghum and pearl millet under intercropping as; sorghum 3.3 sole cropping, and 2.6 inter cropping. Production of tillers at the second cut followed a similar trend, and therefore it was agreed that intercropping could reduce the amount of vegetation due to competition factors.

2. Yield Performance of Fodder Crops

Yield analysis proved that in both cases of sole and intercropping, green and dry fodder yields were significantly higher in sole cropping. Green fodder yield in sole cropping systems was 15.02 t ha^{-1} and maximum green fodder yield in pearl millet by yielding 19.1 t ha^{-1}. Intercropping systems on the other hand, produced slightly lower green fodder yield of 14.05 t/ha respectively with pearl millet, 17.3 t/ha, demonstrated its vigor even under inter cropping environment. The result for dry fodder yield was also comparable, and sole cropping produced an average of 4.5 t ha^{-1} which was higher than the 3.61 t ha^{-1} yielded by the different intercropping systems.

3. Statistical Analysis and Interprertation

On the basis of statistical analysis, difference in tiller number and yield of the cropping systems was statistically significant. In the present study, tiller number was analyzed for the main effects of Intercropping and Sole Cropping using Tukey's test and was found to be significantly lower ($p < 0 . 05$) in Intercropping treatment because intercropping is one of the most competitive forms of vegetation production. Likewise, the results on total green and dry fodder yield revealed that intercropping system caused a drastic reduction in total green and dry fodder yield hence showing large yield sacrifice when compared to monoculture. This accords with other authors (Ofori & Stern, 1987) who postulated that the intercropping system generally leads to a decline in specific crop yields because of competition for water and nutrients, and light.

These findings achieve the purpose of the study by showing that whilst intercropping has some advantages in terms of agronomics, sole cropping systems are better in growth attributes and yield for cereal fodders under semi-arid conditions. However, there were variations in their mean yields and performance, across the two cropping systems where the crop being established, pearl millet, especially, demonstrated the ability for both systems, but achieved superior yield in monoculture. While intercropping may have other advantages such as; establishing crop diversification and perhaps a range of soil improvement benefits from the legume component this evidence demonstrates that intercropping imposes yield constraints. In terms of fodder production potentiality in resource graded sum-areas, the sole cropping of high yielding varieties such as pearl millet appears quite beneficial, however, inter-cropping exert significant competitive influence on a range of attributes pertaining both to quantity and quality and succeeding yield capacity.

Table 1. Yields and Growth Attributes of Fodders in Intercrops and Monoculture (2023)

Treatment	Plant Height at First Cut (cm)	Tiller Number at First Cut	Total Green Fodder Yield (t ha–1)	Total Dry Fodder Yield (t ha–1)
Sole Cropping				
Maize (one cut)	120.5	11.5	3.80	4.10
Sorghum (one cut)	121.8	2.0	10.50	3.30
Pearl Millet (one cut)	125.6	2.8	13.40	4.20
Sorghum (two cuts)	130.7 (153.2)a	3.3 (5.0)b	16.30	5.10
Pearl Millet (two cuts)	128.4 (156.1)a	3.7 (5.5)b	19.10	5.80
Mean	125.4	3.06	15.02	4.5
Intercropping				
Maize (one cut)	112.1	10.2	3.10	3.60
Sorghum (one cut)	115.4	2.1	9.15	2.90
Pearl Millet (one cut)	118.3	2.7	12.50	3.95
Sorghum (two cuts)	120.6 (149.5)a	2.6 (4.8)b	12.20	4.30
Pearl Millet (two cuts)	119.8 (146.7)a	3.4 (5.2)b	17.30	5.30
Mean	116.6	3.0	14.05	3.61
LSD (5%)	NS	0.62	3.16	0.89

Notes:

- (a) Plant height at second cut.
- (b) Tiller number at second cut.

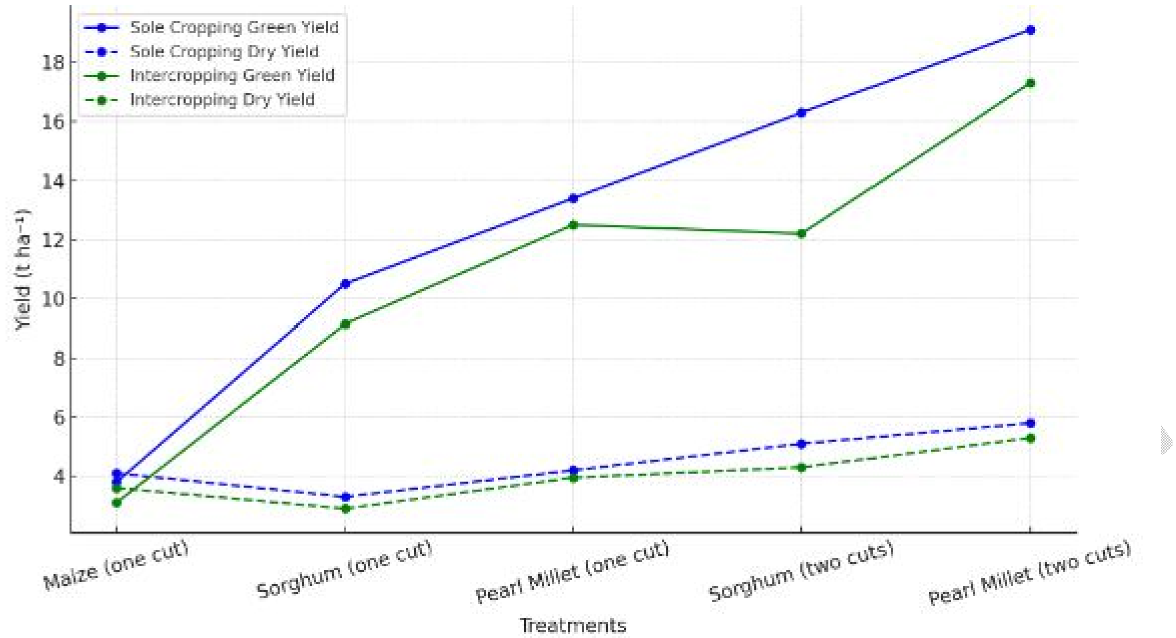

Fig 1. Yield probability comparison of fodders in sole and intercropping systems

Nodulation and Nitrogen content

Nodulation and nitrogen content of groundnut plants under different treatments indicated that the yield response depends on the type of fodder crop and number of cuttings (table 2). Sole groundnut treatment had the greatest number of nodules per plant, averaging 12.1 while integrated systems such as sorghum/pearl millet intercrop with two cuts of sorghum/pearl millet had the lowest number of nodules per plant at 9.8/9.2 respectively. The nodule mass followed the same trend as that of nodule number, with sole groundnut producing the highest nodule mass (198.5 mg/plant) while pearl millet (two cuts) produced the least nodule mass (155.9 mg/plant). Similarity in nitrogen content per plant was observed; they retrieved the highest nitrogen content in sole groundnut treatment (367 mg per plant) and the lowest nitrogen content in pearl millet (two cuts) with the amount of 285 mg per plant.

Yield Attributes:

Intercropping affected principal yield parameters of groundnut such as kernel mass, number of pods per plant and pod yield per plant. Sole cropping yielded a significantly higher 100-kernel mass (39.5 g) while intercropping systems, especially with sorghum (two cuts) and pearl millet (two cuts) the comparable 100-kernel mass was much less, 33.5 g and 34.8 g respectively. Likewise the number of pods per plant was also at its maximum in sole groundnut (11.2) as compared to the inter cropping with pearl millet and sorghum two cuts being minimum at 6.1 and 5.8 respectively. Interactions observed on the pod yield per plant were significant whereby sole groundnut produced the highest yield (8.5 g per plant) compared with intercrop of groundnut/ pearl millet of the two-cut, (4.1 g per plant).

Total Pod Yield and Total Harvest Index

The pod yield on a per hectare basis was also different in the various treatments. The pearl millet first cut treatment gave the highest pod yield 2.75 t ha–1 and the lowest yield observed was with second cut pearl millet 2.14 t ha–1. Further, the harvest index was higher in sole cropping system (marking = 0.44) due to better biomass-to yield conversion efficiency than intercropped treatments where marking ranged lowered and was the least (0.34) in pearl millet (two cuts).

It was observed from the findings that only cropping of groundnut always yielded a higher result to the inter cropping treatments as evaluated from the yield parameters. These results are also in line with the study aim of making an evaluation on yield efficiency under various forms of intercropping inter phase; and that sole cropping is still more productive for realizing ‘high pod yield’ and ‘best nodule characters’ in groundnut. On the other hand, intercropping exhibited a decline in productivity indices implying that intercropping arrangements such as with two-cut sorghum and pearl millet had little agronomic advantage.

Table 2. Nodulation, Nitrogen Content, Yield, and Yield Attributes of Groundnut under Different Combinations of Fodder and Number of Cuttings (2023)

Treatment	**Nodules per Plant**	**Nodule Mass (mg per plant)**	**N Content (mg per plant)**	**100-Kernel Mass (g)**	**Pods per Plant**	**Pod Yield per Plant (g)**	**Pod Yield (t ha–1)**	**Harvest Index**
30 DAS								
Sole Groundnut	12.1	198.5	367	39.5	11.2	8.5	2.75	0.44
Maize (one cut)	10.4	185.4	331	36.8	8.4	6.1	2.52	0.42
Sorghum (one cut)	10.0	173.7	309	35.5	7.6	5.8	2.42	0.40
Pearl Millet (one cut)	9.7	162.3	298	34.2	6.2	5.4	2.34	0.39
Sorghum (two cuts)	9.8	168.2	305	33.5	6.1	4.6	2.19	0.35
Pearl Millet (two cuts)	9.2	155.9	285	34.8	5.8	4.1	2.14	0.34
Mean	10.2	174.0	315.8	35.7	7.22	5.9	2.39	0.39
LSD (5%)	NS	1.52	NS	15.2	17.5	1.90	1.8	0.04

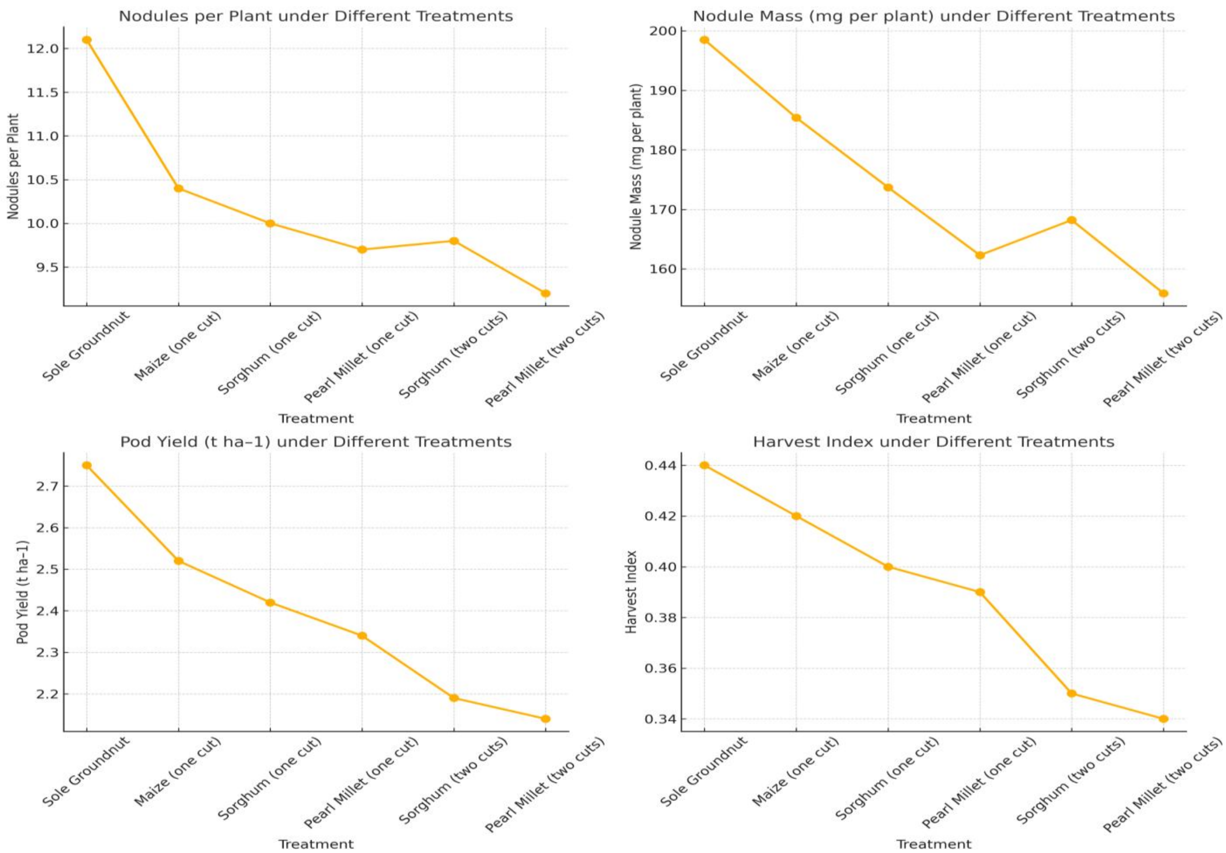

Fig 2. Graphical presentations showing total Pod Yield and Total Harvest Index

Land Equivalent Ratio (LER) and Relative Crowding Coefficient (RCC)

The results of LER displayed in Table 3 depicting yield advantage signify that the study treatment of growing groundnut intercropped with fodder crops had a biological superiority over sole cropping. As presented in the above result, maize treatment gave the highest LER (LERa = 1.72) which showed that intercropping with Maize yields 72% more land equivalent ratio than the groundnut monoculture. In the same manner, high RCC was obtained with the highest value associated with maize (27.45), implying the strongest competition of maize with other crops in intercropping opportunities.

Measures as Aggressivity And Competition Ratio

Inter crop aggressivity coefficients revealed that the fodder crops had higher competition ability over groundnut as all the values exhibited zero and negative aggressivity, showing that groundnut was out competed in the inter sowing combination. Maize produced the least negative aggressivity (- 1.92), implying that it has the least suppression on groundnut among the fodder crops. On the contrary, the competition ratio was least in pearl millet (two cuts) at 3.55 and followed by sorghum (two cuts) at 2.99 which assesses high level of competitiveness in these crops under intercropping system.

Economic Viability:

Interpreting the results of each intercropping treatment, Monetary Advantage Index (MAIc) was determined. Among different treatments, maize at one cut achieve the highest MAI Rs 17,800 which show that intercropping with maize is more profitable in this system chance. Two cuts of sorghum and pearl millet also generated interesting MAI values of 15620 and 15700 respectively which re-establish the economic viability at intercropping these crops.

The experiments lead to the conclusion that groundnut intercropped with maize, sorghum or pearl millet produce a higher groundnut biological yield and higher economic profitability compared to sole cropping. Hence overall, maize particularly in operation that received only one cut had the best acceptable biological efficiency, lower intercrop suppressive effects on groundnut and the best monetary intercrop index. This study confirms the potential for enhanced yield and economic return in intercropping groundnut with competitive fodder crops, aligning with the objective of optimizing intercropping systems for both biological efficiency and economic gain.

Table 3. Yield Advantage Assessment Under Different Competition Treatments (2023)

Treatment	**LERa**	**RCCb**	**Aggressivity**	**Competition Ratio**	**Monetary Advantage Index (MAIc, Rs.)**
Maize (one cut)	1.72	27.45	-1.92	2.06	17800
Sorghum (one cut)	1.40	18.98	-1.70	2.52	15620
Pearl Millet (one cut)	1.56	10.12	-2.07	3.18	13654
Sorghum (two cuts)	1.48	11.05	-2.02	2.99	14510
Pearl Millet (two cuts)	1.61	13.9	-2.36	3.55	15800
Mean	1.55	16.10	-2.01	2.86	15480
LSD (5%)	0.18	5.65	0.58	NS	3200

Notes:

- (a) Land Equivalent Ratio.
- (b) Relative Crowding Coefficient.
- (c) Monetary Advantage Index in Rs.

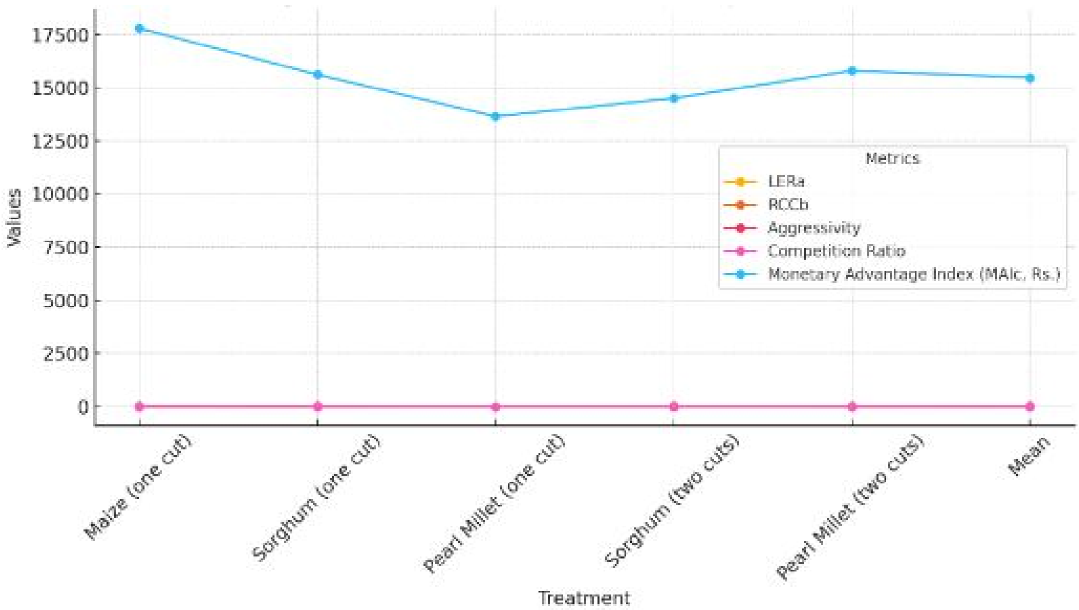

Fig 3. Yield Advantage Assessment Under Different Competition Treatments

DISCUSSION

The findings revealed towards this study are awfully essential in order to better understand the dynamism and competition prevailing in groundnut/cereal fodder intercropping systems in the context of climate of Pakistan's semi-arid tropics. Interpreting the yield advantage and the economic assessment point towards different balance points relating to intercropping and sole cropping for the enhancement of growth attributes, yield and economic returns under low resource environments. This analysis provides new information that can improve farming efficiency in such areas, because water and nutrient availability are critical for productivity in dry farming systems where competition between crops is intensified.

Among the growth attributes, plant height and the number of tillers was greatly influenced by intercropping because of resource competition, including light, water, and nutrients.This is in line with the study done by (Gebru, 2015) have noted that even though intercropping provides for diversification it hinders growth of these crops since competition is many than two different specific crops. In the present study, sole cropping systems had a higher plant height and number of tillers than the inter cropping systems for the maize/sorghum/ pearl millet and this showed that sole cropping free from interferences from other plants has an edge in competing for the lacks the struggles from other plant components of the soil (Bankole, 2022). As shown in inter cropping, both green and dry fodder yields were significantly lower compare with those obtained from sole cropping implying the effect of competition on the yields. Angon et al. (2023) came up with similar findings pointing at the fact that while intercropping is advantageous environmentally and agriculturally in the sense that the overall health of the soil and the occurrence of more diverse crops improve, the dimension of yield per crop is normally a problem. This Study's findings confirm this assertion, showing that pearl millet sole cropping is favorable in topping the green and dry fodder yields among the treatments for maximum biomass production in the semi-arid regions.

LER and RCC factually explain the competitive benefit afforded by intercropping in quantitative terms. Hence, the LER values of greater than 1 for all the treatments indicated the existence of a biological superiority of intercropping systems particularly with maize (LERa= 1.72); which implies that this form of production gave groundnut a yield advantage of 72% more space than sole cropping. Higher RCC values for maize and sorghum reinforce these crop's c ompetitive advantage in intercropping scenario. These results agree with the concepts of Kumar (2021) where he substantiated that systems of intercropping utilizing diversified resource niche demands showed a higher degree of land-use productivity than pure stand cropping systems. Maize, sorghum, and pearl millet are competitive in their resilience, but pearl millet net yield in intercropping system suggests the crop is well adapted to semi-arid environments. The monetary advantage index (MAI) represents the profitability standpoint by the application of the economic analysis on intercropping systems. The highest MAI was obtained by intercropping of maize (one cut) which was Rs. 17,800 and made it to be ranked as financially most viable intercrop than other crops with groundnut. This result supports other studies conducted by Hussainy et al. (2020) pointing out that intercropping systems on maize and groundnut enhance both biological and economical yields under low input. The observed MAI values for sorghum and pearl millet depict that intercropping these crops with groundnut also has strong economic implications in relation to income diversification goal desired in the smallholder farming systems for economic enhanced resilience (Zhu et al., 2023; Sajjad et al., 2023).

The aggressivity and the competition ratios of the intercropped fodder crops demonstrate the cad of the intercropping management regimes. For instance, pearl millet, which ranked the highest competition ratio of 3.55 in the two-cut system, increases yield stability but competition pressure on groundnut as well. (Zhang et al., 2024) has found that the successful intercropping concerns the proportional demands of the crops, without sheer suppressive influences. While intercropping increases yield and economic return, growers need to implement an appropriate choice of crops and their planting density to avoid competition-based detrimental effects and obtain high system output.

Conclusion

This research work also concludes that, even though, there are advantages and disadvantages of both sole cropping and intercropping systems, the best way to increase yield is done under sole cropping especially with pearl millet which gave highest green and dry fodder yield in the favourable climate of Pakistan's semi- arid region. Monoculture allows crops to receive full optimum development because one type of crop does not compete with a different kind of plant, something that is detrimental in polyculture. While all three intercropping models are remunerative; intercropping with groundnut and maize reveals a very high Monetary Advantage Index (MAI) of Rs. 17,800. Further, the LER values above 1 quantify the productivity gain per unit area, hence meets the objectives of this study which sought to evaluate yield optimization together with monetary profitability. Therefore, although sole cropping has high yield, intercropping with maize offers a better, economically balanced package. These insights endorse intercropping as a sustainable option for those farmers wasing to diversify income and improve yields in the resource-constrained semi-arid environments.

REFERENCES

1. Amanullah, Khalid, S., Khalil, F., &Imranuddin. (2020). Influence of irrigation regimes on competition indexes of winter and summer intercropping system under semi-arid regions of Pakistan. Scientific Reports, 10(1), 8129.
2. Angon, P. B., Anjum, N., Akter, M. M., KC, S., Suma, R. P., & Jannat, S. (2023). An overview of the impact of tillage and cropping systems on soil health in agricultural practices. Advances in Agriculture, 2023(1), 8861216.
3. Bankole, J. A. (2022). Growth and Yield of Sorghum Cultivars as Influenced by Population Density of Components of Soya Bean (Master's thesis, Kwara State University (Nigeria)).
4. Emran, S. A., Krupnik, T. J., Aravindakshan, S., Kumar, V., & Pittelkow, C. M. (2022). Impact of cropping system diversification on productivity and resource use efficiencies of smallholder farmers in south-central Bangladesh: a multi-criteria analysis. Agronomy for sustainable development, 42(4), 78.
5. Gebru, H. (2015). A review on the comparative advantages of intercropping to mono-cropping system. Journal of Biology, Agriculture and Healthcare, 5(9), 1-13.
6. Glaze-Corcoran, S., Hashemi, M., Sadeghpour, A., Jahanzad, E., Afshar, R. K., Liu, X., & Herbert, S. J. (2020). Understanding intercropping to improve agricultural resiliency and environmental sustainability. Advances in agronomy, 162, 199-256.
7. Hossain, A., Maitra, S., Ahmed, S., Mitra, B., Ahmad, Z., Garai, S., ... & Meena, R. S. (2022). Legumes for nutrient management in the cropping system. In Advances in Legumes for Sustainable Intensification (pp. 93-112). Academic Press.
8. Hussainy, S. A. H., Brindavathy, R., & Vaidyanathan, R. (2020). Production potential of groundnut (Arachis hypogaea L.) under intercropping system-A review. Crop Research, 55(1and2), 36-47.
9. Kebede, E. (2021). Contribution, utilization, and improvement of legumes-driven biological nitrogen fixation in agricultural systems. Frontiers in Sustainable Food Systems, 5, 767998.
10. Khan, I., Akram, A., Fatima, S., Ahmad, B., Rehman, Z., Arshad, N., ... & Ahmad, Z. (2022). Problems of agriculture in Pakistan: an insight into their solution. Pakistan Journal of Biotechnology, 19(02), 73-83.

11. Kumar, A., Shabnam, S., & Malik, M. S. (2021). Doubling Farmers Income through Agroforestry. Scientific Publishers.
12. Maitra, S., Hossain, A., Brestic, M., Skalicky, M., Ondrisik, P., Gitari, H., ... & Sairam, M. (2021). Intercropping—A low input agricultural strategy for food and environmental security. Agronomy, 11(2), 343.
13. Maitra, S., Hossain, A., Brestic, M., Skalicky, M., Ondrisik, P., Gitari, H., ... & Sairam, M. (2021). Intercropping—A low input agricultural strategy for food and environmental security. Agronomy, 11(2), 343.
14. Musa, M., & Mustafa, M. I. (2020). Livestock Feeds and Feeding Practices in Pakistan. Livestock Feeds and Feeding Practices in South Asia, 129.
15. Ravi, V., Suja, G., Saravanan, R., & More, S. J. (2021). Advances in cassava□based multiple□cropping systems. Horticultural Reviews, 48, 153-232.
16. Sajjad, Z., Zohaa, F., Rizwan, M., Rashid, I., Muhammad, B., Muhammad, S., ... & Zawar, S. (2023). The effects of foliar application of sulphur on yield and quality of Rohi Sarsoon (Brassica juncea) crop: EFFECTS OF FOLIAR APPLICATION OF SULPHUR ON (BRASSICA JUNCEA). JOURNAL OF OASIS AGRICULTURE AND SUSTAINABLE DEVELOPMENT, 5(3), 11-16.
17. Tseng, M. C., Roel, Á., Macedo, I., Marella, M., Terra, J. A., & Pittelkow, C. M. (2021). Synergies and tradeoffs among yield, resource use efficiency, and environmental footprint indicators in rice systems. Current Research in Environmental Sustainability, 3, 100070.
18. Vlahova, V. (2022). Intercropping-an opportunity for sustainable farming systems. A review. Scientific Papers. Series A. Agronomy, 65(1).
19. Wang, F., Xiao, J., Ming, B., Xie, R., Wang, K., Hou, P., ... & Li, S. (2021). Grain yields and evapotranspiration dynamics of drip-irrigated maize under high plant density across arid to semi-humid climates. Agricultural Water Management, 247, 106726.
20. Yang, H., Zhang, W., & Li, L. (2021). Intercropping: Feed more people and build more sustainable agroecosystems. Front. Agric. Sci. Eng, 8(3), 373-386.
21. Zakir, I., Wahab, A. A., Abbas, T., HAIDER, S. T. A., Irum, S., Sabir, S., ... & Ahmad, S. (2023). Cereal–vegetable intercropping: hindrances and strategies to increase intercropping. Turkish Journal of Agriculture and Forestry, 47(6), 1115-1129.
22. Zhang, W. P., Surigaoge, S., Yang, H., Yu, R. P., Wu, J. P., Xing, Y., ... & Li, L. (2024). Diversified cropping systems with complementary root growth strategies improve crop adaptation to and remediation of hostile soils. Plant and Soil, 1-24.
23. Zhu, L. I. U., Nan, Z. W., Lin, S. M., Yu, H. Q., Xie, L. Y., Meng, W. W., ... & Wan, S. B. (2023). Millet/peanut intercropping at a moderate N rate increases crop productivity and N use efficiency, as well as economic benefits, under rain-fed conditions. Journal of Integrative Agriculture, 22(3), 738-751.