**Assessment of Growth Indices and Forage Quality in Cowpea Based Intercropping Systems: A Study on Quality-Economics Relationship**

**ABSTRACT**

An experiment was conducted to study the impact of fertilization and intercropping on growth, quality and relative economics of cowpea-based intercropping systems. The experiment was laid in RCBD with three levels of fertilization treatment (0% RDF, 75% RDF, and 100% RDF) and five intercropping systems (sole cowpea, sole sorghum, sole maize, sorghum + cowpea (1:1), and maize + cowpea (1:1)), replicated thrice. The key parameters assessed during the study were CGR, RGR, quality and along with economic indices. The data revealed that the treatment F2I1 consistently performed good with respect to quality parameters. However, relative economics of the treatments of indicated that 100 % RDF along with intercropping of sorghum + cowpea and maize + cowpea resulted in higher net returns and BCR of (3.19 and 2.73) and (2.98 and 2.65) respectively. The interaction effects were also significant indicating a strong relationship between fertilization and cowpea-based intercropping. Furthermore, clustering and correlation showed a good relation between quality parameters and economic indices. Overall, the study demonstrated that intercropping of fodder cereals with cowpea under 100% RDF resulted in improved forage quality while making it economically viable fodder production strategy under temperate conditions.

***Keywords:*** *correlation, CGR, forage quality, maize, relative economics, RGR, sorghum*

1. **INTRODUCTION**

Since ancient times, maize is one of the important fodder crops grown at higher altitudes as well as plain regions of the UT of J&K due to its wide range of climatic adaptability and production of high biomass. It produces high quality energy-rich and nutritious fodder with high palatability and digestibility (Soe-Htet *et al.,* 2021). The crop is rich in carbohydrates that makes it suitable for silage and can be preserved for future use (Chaudhary *et al.,* 2014). Sorghum is another important fodder crop. It is drought-tolerant, and can withstand high temperatures and low rainfall, making it well-suited for cultivation in areas with limited water availability. It is also a prolific biomass producer, with high yields of green fodder upto 30 t ha-1 under temperate conditions (ICAR-IGFRI, 2021). In addition to its high biomass production, sorghum can be used to produce high-quality forage. It has a high fiber content and a reasonable protein content (11 %), making it an ideal feed for ruminants such as cattle, sheep, and goats (Mohapatra *et al.,* 2017). In general, the farming community makes the selection of fodder crops on the basis of their adaptability and generation of huge biomass but fodder quality is not provided due attention that further decreases the productivity of livestock. Although cereal forages provide a significant source of feed to livestock by yielding high amount of dry matter, but often have a low protein content which limits their nutritional value for livestock (Uher *et al.,* 2019). By intercropping cereal forage with legumes, it is possible to improve the fodder quality as legumes are supposed to possess characteristic feature of nitrogen fixation and provide a good source of protein for livestock. Cowpea (*Vigna unguiculata*), is a short duration leguminous crop that can be intercropped with cereal forages to balance the production of protein from the unit area while being a valuable source of fodder for livestock (Kulkarni *et al.,* 2018), which can increase farmers' income. To develop an understanding of interaction between grass-legume a study was conducted to investigate the effect of grass-legume intercropping on growth indices, forage quality and relative economics under varied fertilization treatments.

1. **MATERIALS AND METHODS**

A study was carried out during *Kharif* 2023 and 2024 at Agronomy Research Farm, Faculty of Agriculture SKUAST-K, Wadura, Sopore. The experiment followed a factorial randomized complete block design (RCBD) consisting of two factors: Fertilization treatment (F0: Absolute control, F1: 75 % RDF and F2: 100 % RDF) and Intercropping systems (I1: Sole cowpea; I2: Sole sorghum; I3: Sole maize; I4: Sorghum + Cowpea (1:1) and I5: Maize + Cowpea (1:1)) making 15 treatment combinations which were replicated thrice. The varieties used were MP chari in Sorghum, SFM-1 in Maize and UPC-625 in Cowpea. The experiment was conducted over two consecutive years and the data were pooled across years after verifying homogeneity of variance using Bartlett’s test. The data was subjected to statistical analysis using Microsoft excel and RStudio (2023.12.1). Residual diagnostic plots were used to check the assumptions of normality and homoscedasticity. A linear model was fitted using lm() function with given model: Response variable ~ Fertilization treatment × Intercropping systems. LSD was calculated for treatment comparisons (α = 0.05).

1. **RESULTS AND DISCUSSION**

**3.1 Crop Growth Rate**

Among the fertilization treatments, the numerically higher CGR was consistently recorded under 100% RDF, which was 4.24 and 3.43 g m⁻² day⁻¹ at 20-40 DAS, 5.71 and 6.15 g m⁻² day⁻¹ at 40-60 DAS showing significant variation at this stage, and 3.79 and 3.57 g m⁻² day⁻¹ at 60-80 DAS during 2023 and 2024, respectively (Table 1a). This was followed by 75% RDF, while the lowest CGR was observed under the absolute control. Regarding intercropping systems, sole cowpea exhibited the significantly higher CGR at all growth stages in both years, attaining 5.86 and 4.66 g m⁻² day⁻¹ at 20-40 DAS, 7.80 and 8.59 g m⁻² day⁻¹ at 40-60 DAS, and 5.96 and 5.87 g m⁻² day⁻¹ at 60-80 DAS during 2023 and 2024, respectively. Among intercropping systems, sorghum in sorghum + cowpea (1:1) attained maximum values of 3.69 and 3.71 g m⁻² day⁻¹ and maize in maize + cowpea (1:1) attained highest values of 3.67 and 4.03 g m⁻² day⁻¹ at 60-80 during 2023 and 2024 respectively (Table 1b). Sole sorghum recorded the highest CGR across all the stages in both years and, achieving higher values of 36.89 and 24.64 g m⁻² day⁻¹ at 60-80 DAS during 2023 and 2024, respectively. This was followed by sole maize where maximum CGR of 28.94 and 22.32 g m⁻² day⁻¹ at 60-80 DAS during 2023 and 2024, respectively. Among the intercropping treatments, sorghum + cowpea (1:1) recorded higher CGR than maize + cowpea (1:1) throughout the growth period.

The increase in CGR of cowpea under higher fertilization levels could be attributed to better nutrient availability, which supports enhanced leaf area, photosynthesis, and biomass production, ultimately reflecting in higher crop growth rate. These observations are in line with the findings of Gupta *et al.* (2019) and Jadav *et al.* (2018), who reported that application of 100% RDF significantly enhanced CGR and dry matter accumulation in maize and legumes under Indian rainfed conditions. Similarly, Kumar *et al.* (2016) reported that balanced fertilization improved crop growth rate and green fodder yield of maize and cowpea. Intercropping systems exhibited a suppressive effect on CGR of crops as compared to their respective sole cropping, which can be explained by the competition for light, space, and nutrients among the crops. Among the intercropping systems, sorghum + cowpea (1:1) exhibited higher CGR compared to maize + cowpea (1:1), indicating the superior competitive ability and growth potential of sorghum under intercropping situations. These findings are consistent with Ginwal *et al.* (2019) and Singh *et al.* (2023), who reported that intercropping of legumes with cereals reduced the CGR of the legumes due to shading and resource competition.

**Table 1a: Impact of fertilization treatment and intercropping systems on crop growth rate of cowpea.**

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| **Crop growth rate (g m-2 day-1)** |
| Treatments | 20 DAS | 40 DAS | 60 DAS80 DAS |
| 2023 | 2024 | 2023 | 2024 | 2023 | 2024 |
| **Fertilization treatment** |
| F0: Absolute control | 3.64 | 2.54 | 4.09 | 4.47 | 3.14 | 2.79 |
| F1: 75 % RDF | 3.92 | 3.01 | 5.36 | 5.70 | 3.45 | 3.26 |
| F2:100 % RDF | 4.24 | 3.43 | 5.71 | 6.15 | 3.79 | 3.57 |
| SE(m)± | 0.16 | 0.17 | 0.31 | 0.27 | 0.48 | 0.24 |
| **CD (p ≤ 0.05)** | NS | 0.52 | 0.93 | 0.80 | NS | NS |
| **Intercropping systems** |
| I1: Sole cowpea | 5.86 | 4.66 | 7.80 | 8.59 | 5.96 | 5.87 |
| I2: Sole sorghum | - | - | - | - | - | - |
| I3: Sole maize | - | - | - | - | - | - |
| I4: Sorghum + Cowpea (1:1) | 2.69 | 2.11 | 3.69 | 3.71 | 1.76 | 1.38 |
| I5: Maize + Cowpea (1:1) | 3.25 | 2.21 | 3.67 | 4.03 | 2.66 | 2.37 |
| SE(m)± | 0.20 | 0.22 | 0.40 | 0.35 | 0.61 | 0.31 |
| **CD (p ≤ 0.05)** | 0.61 | 0.67 | 1.21 | 1.04 | 1.84 | 0.94 |

**Table 1b: Impact of fertilization treatment and intercropping systems on crop growth rate of sorghum and maize.**

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| **Crop growth rate (g m-2 day-1)** |
| **Treatments** | **20-40 DAS** | **40-60 DAS** | **60-80 DAS** |
| **2023** | **2024** | **2023** | **2024** | **2023** | **2024** |
| **Fertilization treatment** |
| F0: Absolute control | 8.66 | 7.52 | 14.09 | 11.89 | 19.86 | 14.18 |
| F1: 75 % RDF | 13.16 | 12.05 | 16.54 | 16.14 | 22.02 | 15.84 |
| F2:100 % RDF | 15.90 | 13.98 | 17.67 | 18.27 | 23.49 | 17.63 |
| **SE(m)±** | **0.45** | **0.32** | **0.79** | **0.72** | **0.59** | **0.67** |
| **CD (p ≤ 0.05)** | **1.31** | **0.94** | **2.32** | **2.12** | **1.74** | **1.98** |
| **Intercropping systems** |
| I1: Sole cowpea | - | - | - | - | - | - |
| I2: Sole sorghum | 23.61 | 20.45 | 18.90 | 18.74 | 36.89 | 24.64 |
| I3: Sole maize | 14.15 | 11.60 | 17.82 | 17.91 | 28.94 | 22.32 |
| I4: Sorghum + Cowpea (1:1) | 8.85 | 8.84 | 14.06 | 12.59 | 12.30 | 8.77 |
| I5: Maize + Cowpea (1:1) | 3.69 | 3.84 | 13.63 | 12.50 | 9.03 | 7.80 |
| **SE(m)±** | **0.57** | **0.42** | **1.02** | **0.94** | **0.77** | **0.87** |
| **CD (p ≤ 0.05)** | **1.69** | **1.22** | **3.00** | **2.74** | **2.24** | **2.55** |

**3.2 Relative Growth Rate of crops**

Among the fertilization treatments, the highest RGR was observed under absolute control during 20-40 DAS interval, with values of 0.062 and 0.050 g g⁻¹ day⁻¹ in 2023 and 2024, respectively (Table 2a), while at later stages, fertilization had no significant influence. Regarding intercropping systems, sole cowpea recorded higher RGR at maximum growth stages in both years, with no significant variations. Likewise, among the intercropping systems, no statistically significant variation was observed, however sorghum + cowpea (1:1) at 60-80 DAS recorded marginally higher RGR than maize + cowpea (1:1) at 40-60 DAS whereas maize + cowpea (1:1) recorded marginally higher RGR than sorghum + cowpea (1:1) at 60-80 DAS. The intercropping systems exhibited inconsistent pattern where sole sorghum recorded the highest RGR of 0.070 and 0.073 g g⁻¹ day⁻¹ at 20-40 DAS. In subsequent interval 40-60 DAS the maximum RGR was recorded in maize under maize + cowpea (1:1) and at 60-80 DAS, sole maize outperformed others (Table 2b).

The higher RGR at the early growth stages and the subsequent decline at later stages is a common physiological response as the crop progresses towards maturity, where dry matter accumulation shifts more towards reproductive parts rather than vegetative growth. Similar trends were reported by Kumar *et al.* (2016) and Gupta *et al.* (2019), who observed decreasing RGR with crop age in maize and legumes due to canopy closure and resource competition. In the present study, the highest RGR at 20-40 DAS was recorded under absolute control, possibly due to smaller initial plant biomass, which inherently leads to higher relative increase in biomass during early growth stages. This is in line with the findings of Ginwal *et al.* (2019), who reported similar trends in cowpea and maize intercropping systems. The intercropping systems had a significant negative impact on RGR of crops as compared to sole cropping at 20-40 and 60-80 DAS growth intervals. These observations corroborate with Bhagat *et al.* (2017) and Saad *et al.* (2016).

**Table 2a: Impact of fertilization treatment and intercropping systems on relative growth rate of cowpea.**

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| **Relative growth rate (g g-1 day-1)** |
| **Treatments** | **20-40 DAS** | **40-60 DAS** | **60-80 DAS** |
| **2023** | **2024** | **2023** | **2024** | **2023** | **2024** |
| **Fertilization treatment** |
| F0: Absolute control | 0.062 | 0.050 | 0.028 | 0.035 | 0.014 | 0.013 |
| F1: 75 % RDF | 0.050 | 0.038 | 0.031 | 0.036 | 0.012 | 0.011 |
| F2:100 % RDF | 0.047 | 0.038 | 0.031 | 0.034 | 0.013 | 0.012 |
| **SE(m)±** | **0.002** | **0.002** | **0.002** | **0.002** | **0.002** | **0.001** |
| **CD (p ≤ 0.05)** | **0.006** | **0.007** | **NS** | **NS** | **NS** | **NS** |
| **Intercropping systems** |
| I1: Sole cowpea | 0.050 | 0.044 | 0.030 | 0.037 | 0.015 | 0.015 |
| I2: Sole sorghum | - | - | - | - | - | - |
| I3: Sole maize | - | - | - | - | - | - |
| I4: Sorghum + Cowpea (1:1) | 0.051 | 0.041 | 0.031 | 0.034 | 0.010 | 0.008 |
| I5: Maize + Cowpea (1:1) | 0.057 | 0.040 | 0.028 | 0.034 | 0.013 | 0.013 |
| **SE(m)±** | **0.002** | **0.003** | **0.002** | **0.003** | **0.003** | **0.002** |
| **CD (p ≤ 0.05)** | **NS** | **NS** | **NS** | **NS** | **NS** | **0.005** |

**Table 2b: Impact of fertilization treatment and intercropping systems on relative growth rate of sorghum and maize.**

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| **Relative growth rate (g g-1 day-1)** |
| Treatments | 20-40 DAS | 40-60 DAS | 60-80 DAS |
| 2023 | 2024 | 2023 | 2024 | 2023 | 2024 |
| **Fertilization treatment** |
| F0: Absolute control | 0.048 | 0.048 | 0.039 | 0.037 | 0.025 | 0.024 |
| F1: 75 % RDF | 0.050 | 0.056 | 0.034 | 0.036 | 0.022 | 0.018 |
| F2:100 % RDF | 0.053 | 0.057 | 0.032 | 0.035 | 0.021 | 0.017 |
| **SE(m)±** | **0.002** | **0.001** | **0.002** | **0.001** | **0.001** | **0.001** |
| **CD (p ≤ 0.05)** | **NS** | **0.003** | **0.005** | **NS** | **NS** | **0.003** |
| **Intercropping systems** |
| I1: Sole cowpea | - | - | - | - | - | - |
| I2: Sole sorghum | 0.070 | 0.073 | 0.024 | 0.027 | 0.028 | 0.022 |
| I3: Sole maize | 0.052 | 0.054 | 0.031 | 0.036 | 0.028 | 0.025 |
| I4: Sorghum + Cowpea (1:1) | 0.053 | 0.057 | 0.036 | 0.033 | 0.018 | 0.016 |
| I5: Maize + Cowpea (1:1) | 0.028 | 0.032 | 0.048 | 0.047 | 0.018 | 0.018 |
| **SE(m)±** | **0.002** | **0.002** | **0.002** | **0.002** | **0.001** | **0.001** |
| **CD (p ≤ 0.05)** | **0.007** | **0.004** | **0.006** | **0.005** | **0.004** | **0.004** |

**3.3 Quality parameters of cowpea, sorghum, and maize**

Before conducting ANOVA, the data was examined to verify the assumptions i.e. normality of residuals and homogeneity of variances. This was performed using residual diagnostic plots, including Q-Q plots and residual vs fitted plots for each quality parameter (Fig. 1). The residuals showed approximate symmetry and linearity indicating normal distribution of residuals and no deviation from homoscedasticity across treatments. The results revealed that among fertilization treatments, 100% RDF recorded the highest crude protein content (12.92 and 12.78% during 2023 and 2024, respectively), followed by 75% RDF (10.42 and 10.94%), while the lowest values were recorded under absolute control (11.92 and 11.72%) (Table 3). Crude fibre content decreased with the increase in fertilization level. The lowest crude fibre was observed under 100% RDF (22.30 and 24.40%), while the highest was recorded under absolute control (28.20 and 30.30%). Mineral ash content was significantly influenced, with the highest values recorded under 100% RDF (11.83 and 12.45%) and lowest under absolute control (9.55 and 9.81%). Nitrogen Free Extract (NFE) showed an inverse trend with crude protein, being highest in absolute control (52.72 and 54.93%) and lowest in 100% RDF (46.66 and 45.35%). Among intercropping systems, sole cowpea recorded the maximum crude protein (13.83 and 13.78%), followed by sorghum + cowpea (1:1), while the lowest was recorded in sole maize. Similarly, sole cowpea registered the lowest crude fibre content (22.90 and 24.53%) compared to higher values in sole maize (27.81 and 29.19%). Sole cowpea recorded the highest mineral ash (12.94 and 13.18%) compared to other systems. Among intercropping systems, the highest NFE was observed in sole maize (54.20 and 53.88%), while the lowest was in sole cowpea (44.72 and 44.02%).

The enhancement in crude protein and mineral ash contents under higher fertilization levels (100% RDF) could be due to enhanced nitrogen availability, promoting better synthesis of proteins and accumulation of essential minerals. This is in line with Gupta *et al.* (2019) and Jadav *et al.* (2018), who reported improvement in fodder quality attributes under balanced fertilization in maize and cowpea under Indian conditions. Similar findings were also reported by Ginwal *et al.* (2019), where legumes recorded superior forage quality attributes over cereals. The higher crude protein content in sole cowpea can be attributed to its nitrogen-fixing ability and lower competition for resources, while cereals (especially maize) diluted the protein concentration due to their higher carbohydrate-rich biomass. These results align with the findings of Saad *et al.* (2016), Bhagat *et al.* (2017), and Moneesa (2020), who reported reduction in forage quality in cereal-legume intercropping systems, though sorghum + cowpea recorded relatively better quality than maize + cowpea due to lesser competition and better synchrony of growth between the components.

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**Fig. 1:** Residual diagnostic plots of quality parameters assessing ANOVA assumptions

**Table 3: Impact of fertilization treatment and intercropping systems on quality of cowpea, sorghum and maize.**

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| **Treatments** | **Crude protein** **(%)** | **Crude fibre** **(%)** | **Mineral ash****(%)** | **Nitrogen free extract****(%)** |
| **2023** | **2024** | **2023** | **2024** | **2023** | **2024** | **2023** | **2024** |
| **Fertilization treatment** |
| F0: Absolute control | 10.21 | 9.93 | 28.20 | 30.30 | 9.55 | 9.81 | 52.72 | 54.93 |
| F1: 75 % RDF | 11.92 | 11.72 | 24.53 | 25.98 | 10.94 | 11.23 | 49.73 | 48.54 |
| F2:100 % RDF | 12.92 | 12.78 | 22.30 | 24.40 | 11.83 | 12.45 | 46.66 | 45.35 |
| **SE(m)±** | **0.23** | **0.19** | **0.47** | **0.36** | **0.19** | **0.21** | **0.86** | **0.97** |
| **CD (p ≤ 0.05)** | **0.67** | **0.56** | **1.36** | **1.03** | **0.55** | **0.61** | **2.50** | **2.82** |
| **Intercropping systems** |
| I1: Sole cowpea | 13.83 | 13.78 | 22.90 | 24.53 | 12.94 | 13.18 | 44.72 | 44.02 |
| I2: Sole sorghum | 10.97 | 10.74 | 26.97 | 28.39 | 10.01 | 9.74 | 51.99 | 53.27 |
| I3: Sole maize | 10.21 | 9.92 | 27.81 | 29.19 | 9.26 | 10.00 | 54.20 | 53.88 |
| I4: Sorghum + Cowpea (1:1) | 11.99 | 11.75 | 24.43 | 26.30 | 11.24 | 11.13 | 48.61 | 48.40 |
| I5: Maize + Cowpea (1:1) | 11.43 | 11.19 | 22.95 | 26.05 | 10.41 | 11.76 | 49.01 | 48.45 |
| **SE(m)±** | **0.30** | **0.25** | **0.61** | **0.46** | **0.24** | **0.27** | **1.11** | **1.26** |
| **CD (p ≤ 0.05)** | **0.87** | **0.73** | **1.75** | **1.33** | **0.71** | **0.78** | **3.23** | **3.65** |

**3.4 Interaction effect of fertilization treatments and intercropping systems on forage quality**

The interaction effect of pooled data of fertilization and intercropping systems revealed that the quality parameters of crops were significantly influenced (Fig. 2). The application of 100 % RDF to sole cowpea recorded the highest crude protein content (16.00%), followed by F₂I₄: 100 % RDF + Sorghum + cowpea (1:1) (12.76%) and F₂I₅: 100 % RDF + Maize + cowpea (1:1) (12.56%). The application of 75% RDF also enhanced crude protein in cowpea (F₁I₁: 13.90%) over absolute control followed by 12.29 % in I₄: Sorghum + cowpea (1:1)) and 11.88 % in I₅: Maize + cowpea (1:1)). Under absolute control crude protein was considerably lower ranging from 9.23 %in I3 to 11.50 % in I1. For crude fibre an inverse trend was noted where highest crude fibre was recorded in the absolute control plots under F₀I₃: Sole maize (No fertilizer) (31.79%) followed by F₀I₂: Sole sorghum (No fertilizer) (30.74%). With the application of 75% RDF (F₁), crude fibre reduced across treatments, with the lowest crude fibre observed in F₁I₁: 75 % RDF + Sole cowpea (23.84%). On further increasing the levels of fertilization, crude fibre declined with F₂I₁: 100 % RDF + Sole cowpea (20.71%) showing the lowest value followed by F₂I₅: 100 % RDF + Maize + cowpea (1:1) (22.12%) and F₂I₄: 100 % RDF + Sorghum + cowpea (1:1) (22.38%). The interaction effect showed a clear increase in mineral ash with higher fertilization. Under 100 % RDF, sole cowpea recorded highest mineral ash of 14.25 % which was followed by application of 75 % RDF in sole cowpea (13.95). Among intercropping systems 100 % RDF in sorghum (12.49 %) showed good response followed by maize (11.96 %). In contrast, absolute control exhibited lower mineral ash, with sorghum (8.42%). For nitrogen-free extract, an inverse relation was observed with fertilization. Under absolute control, maize recorded the higher value of nitrogen-free extract (64.78 %) followed by sorghum. The minimum nitrogen-free extract values were consistently observed in sole cowpea under fertilized treatments, indicating a shift towards protein and mineral synthesis over carbohydrate accumulation. The treatment combination of F₂I1: 100 % RDF + cowpea recorded lowest nitrogen-free extract content of 43.71 % which was at par with F₂I5: 100 % RDF + Maize + cowpea (1:1) 44.38 % and F₂I4₄: 100 % RDF + Sorghum + cowpea (1:1) 44.97 %.

The interaction effects depict a clear trend where adequate fertilization (especially 100% RDF) in sole cowpea (I₁) and intercropped systems like F₂I₄ and F₂I₅ optimally enhanced quality attributes. The significant improvement in crude protein content under treatments can be attributed to enhanced nitrogen availability, which is crucial for protein synthesis through increased nitrate reductase and amino acid assimilation (Kumar *et al.*, 2016). Additionally, balanced nutrition promoted efficient nutrient uptake and photosynthate partitioning towards economic parts. These findings align with Yadav *et al.* (2016) and Kumar *et al.* (2016). The reduction in crude fibre under fertilized treatments is a well-documented phenomenon that reflects better quality fodder, as fertilization likely supports finer cellular development over lignified structures. This inverse relationship was also highlighted by Iqbal *et al.* (2012) in legume-cereal intercropping systems, suggesting that improved nutrient availability reduces lignification in plant tissues. Likewise, NFE which primarily represents soluble carbohydrates, declined in sole cowpea and intercropping systems under increased level of fertilization. Thus, suggesting better nutrient allocation towards proteinaceous and assimilatory tissues under nutrient-rich conditions. This transformation is essential for fodder quality, as excessive NFE in unfertilized plants (as seen in F₀I₃) merely reflects stress-induced carbohydrate accumulation without proportional biomass conversion. Furthermore, the increment in mineral ash indicates higher mineral uptake efficiency which is possible under adequate availability of nutrients. The sole cowpea as well as its intercropping systems showed higher values of mineral ash under 100 % RDF that confirms the increased nutrient uptake facilitated by improved root growth and microbial activity in legume intercropping systems. This aligns with studies by Yadav *et al.* (2016), highlighting legumes’ role in enhancing rhizospheric nutrient dynamics through nitrogen fixation and root exudation.

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**Fig. 2:** Interaction effect of pooled data of fertilization levels and intercropping systems on forage quality.

**3.5 Relative economics**

The economic analysis reveals that the treatment combination F₂I4 (100% RDF + sorghum + Cowpea (1:1)) secured the highest net returns (NR) and benefit-cost ratio BCR in both years (Table 4). Specifically, net returns were ₹1,20,497ha⁻¹ (2023) & ₹ 1,02,955 ha⁻¹ (2024) with corresponding BCR values of 3.19 and 2.73, respectively. Following this, F₂I5 (100% RDF + Maize + Cowpea (1:1)) gained net returns (NR) of ₹1,13,127 ha⁻¹ (2023) & ₹ 1,00,569 ha⁻¹ (2024) with corresponding BCR values of 2.98 and 2.65, respectively. F₂I₂ (100 % RDF + Sole Sorghum) achieved net returns of ₹ 1,00,041 ha⁻¹ & ₹85,265 ha⁻¹ with BCR of 2.09 and 1.78, respectively. The lowest net returns and BCR were recorded under F₀I₃ (absolute Control + Sole Maize) with ₹47,237 ha⁻¹ & ₹34,797 ha⁻¹, and BCR values of 1,12 & 0.83, respectively.

The superior economic performance of F₂I4 (100% RDF + sorghum + Cowpea (1:1)) is primarily attributed to the synergistic effects of optimum nutrient supply and the inclusion of legumes, which improve nitrogen availability through biological nitrogen fixation (Saad *et al.*, 2016; Bhagat *et al.*, 2017). The higher fodder yield under this combination directly resulted in enhanced gross returns, outweighing the marginal increase in cultivation cost. The 100% RDF application ensured adequate nutrient uptake, leading to higher biomass production and thereby higher marketable yields, a fact well supported by earlier studies (Kumar *et al.*, 2016; Gupta *et al.*, 2019). Furthermore, legumes like cowpea contribute organic matter and improve soil health, enhancing long-term productivity and profitability (Padhi & Panigrahi, 2006; Ummaisa & Raja, 2020). On the other hand, sole cropping systems like F₂I₂ (Sorghum) and F₂I₃ (Maize) maintained higher absolute returns due to their higher per hectare productivity. However, intercropping combinations like F₂I4 and F₂I₅ outperformed them in terms of benefit-cost ratio due to better resource use efficiency, nitrogen economy, and cumulative biomass returns. Lower BCR in absolute control treatments (F₀I₂, F₀I₃) can be attributed to poor biomass production, nutrient deficiencies, and absence of synergistic interactions, which is consistent with findings of Sharma *et al.* (2008) and Ginwal *et al.* (2019).

**Table 4: Impact of fertilization treatment and intercropping systems on relative economics.**

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| **Treatment combinations** | **Cost of cultivation****(₨ ha-1)** | **Gross returns****(₨ ha-1)** | **Net returns****(₨ ha-1)** | **BCR****BCR** |
| **2023** | **2024** | **2023** | **2024** | **2023** | **2024** | **2023** | **2024** |
| F0 I1 | 25200 | 25200 | 66226 | 60439 | 41026 | 35239 | 1.63 | 1.40 |
| F0 I2 | 40920 | 40920 | 91059 | 81843 | 50139 | 40923 | 1.23 | 1.00 |
| F0 I3 | 42150 | 42150 | 89387 | 76947 | 47237 | 34797 | 1.12 | 0.83 |
| F0 I4 | 30915 | 30915 | 93807 | 87589 | 62892 | 56674 | 2.03 | 1.83 |
| F0 I5 | 31530 | 31530 | 90786 | 80572 | 59256 | 49042 | 1.88 | 1.56 |
| F1 I1 | 29194 | 29194 | 97426 | 93778 | 68232 | 64585 | 2.34 | 2.21 |
| F1 I2 | 46058 | 46058 | 131129 | 118492 | 85071 | 72434 | 1.85 | 1.57 |
| F1 I3 | 46988 | 46988 | 128395 | 119300 | 81407 | 72313 | 1.73 | 1.54 |
| F1 I4 | 36053 | 36053 | 139517 | 124419 | 103465 | 88366 | 2.87 | 2.45 |
| F1 I5 | 36368 | 36368 | 134071 | 122607 | 97704 | 86240 | 2.69 | 2.37 |
| F2 I1 | 30525 | 30525 | 113324 | 110057 | 82799 | 79532 | 2.71 | 2.61 |
| F2 I2 | 47770 | 47770 | 147811 | 133035 | 100041 | 85265 | 2.09 | 1.78 |
| F2 I3 | 48600 | 48600 | 142547 | 134022 | 93947 | 85422 | 1.93 | 1.76 |
| F2 I4 | 37765 | 37765 | 158262 | 140720 | 120497 | 102955 | 3.19 | 2.73 |
| F2 I5 | 37980 | 37980 | 151107 | 138549 | 113127 | 100569 | 2.98 | 2.65 |

**3.6 Pearson’s correlation matrix heatmap clustering**

The matrix showing Pearson's correlation coefficients between variables highlights strong statistical associations which can be used to develop relation of forage quality parameters with economic efficiency. The matrix depicted that crude protein possessed a strong direct relationship with BCR (r= 0.75) while being highly significant, which can indicate that the treatments that improved crude protein also intended to give better economic output (Fig. 3). For crude fibre a strong but negative correlation was observed with respect to returns (r= -0.75) and BCR (r= -0.93) varying significantly. Mineral as showed a significant positive relationship with BCR (r= 0.77). Nitrogen-free extract possessed negative correlation with NR (r = -0.52) and BCR (r = -0.73). Among the quality parameters crude protein showed strong positive relation with mineral ash (r = 0.93) which indicates that mineral-rich forages also tend to be high in protein, suggesting nutrient synergy under good fertility conditions and showed negative relation with crude fibre (r = -0.88), as higher protein content is often associated with lower fibre content. A similar trend was noted with respect to nitrogen-free extract (r = -0.76) as energy is diverted to protein synthesis instead of carbohydrate storage. Hence it can be inferred that quality parameters like crude protein and mineral ash enhancing treatment coincided with higher economic returns thus, emphasizing the need to minimize fibre while enhancing protein and mineral content.

Further the relation of forage quality with economics was visualized using heatmap clustering approach given in Fig. 3. Heat maps provide visual depiction of variation of treatment combinations with respect to parameters using the colour gradient to identify treatment combinations performing better or poor for each parameter. The heatmap revealed that treatment combination of F2I2 e and F1I5, formed closest cluster, indicating similarity in their performance especially in terms of crude protein (CP), mineral ash (MA) and NR. F2I3 joined this cluster which showed moderate to high intensity with respect to mineral ash (MA), crude fibre (CF) and NR. F2I4 and F2I5 appear grouped together, possessing similarity in high intensity for crude protein (CP), crude fibre (CF) and lower intensity for nitrogen-free extract (NFE) and crude fibre (CF). These combinations also aligned with strong economic returns, as seen in their higher BCR and NR, making them optimal from both agronomic and economic perspectives. In contrast, combinations like F0I3, F0I2 and F1I1 were grouped in a lower-performing cluster with distinctly lighter shades under NR, BCR, crude protein (CP) and mineral ash (MA) and darker shades were noted under crude fibre (CF) and nitrogen-free extract (NFE), suggesting poor performance across most parameter with minimal economic viability. Overall, it can be inferred that treatments receiving full RDF (F₂) and intercropping with sole cowpea or cowpea-based intercropping (I₁, I₄, I₅) tend to cluster with higher values of crude protein (CP), mineral ash (MA), NR, and BCR and lower crude fibre (CF) and nitrogen-free extract (NFE), thus showing that application of fertilizers not only enhances quality but improves economic viability. Further, it supports the positive relationship between improved forage quality and economic performance.

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**Fig. 3:** Correlation matrix and heatmap clustering

1. **CONCLUSION**

The findings underscore the pivotal role of fertilization and intercropping systems in enhancing the qualitative as well as economic results of cowpea-based intercropping systems. The interaction effects further highlighted that the intercropping systems i.e. sorghum + cowpea (I₄) and maize + cowpea (I₅) responded positively to forage quality under 100 % RDF which also translated into higher net returns and BCR. Correlation matrix and clustering confirmed that forage quality parameters especially crude protein and mineral ash were positively associated with economic returns, while higher fibre content tended to lower profitability.

**DISCLAIMER (ARTIFICIAL INTELLIGENCE)**

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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