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Optimizing productivity and profitability of chickpea: A comparative study of different cultivars across diverse cropping systems in the arid hot climate of india

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ABSTRACT

Chickpea (Cicer arietinum L.) is a significant legume due to its outstanding nutritional profile. However, the growth and crop productivity are greatly affected by the adverse impacts of global climate change. Thus, in this investigation, we conduct a comparative study of different cultivars across diverse cropping systems in the arid hot climate of Rajasthan, India. A field experiment was conducted to assess the economics and profitability of five chickpea varieties: GNG-2144, GNG-2261, GNG-1958, GNG-2171, and GNG-1581 across seven chickpea-based cropping systems. The experimental design was a split-plot arrangement. The cropping systems were assigned to main plots, while the chickpea varieties were arranged in sub-plots, with three replications. Our findings revealed that the GNG-1581 variety, when grown in the fallow-chickpea system, achieved the highest grain yield (25.00 q ha^{-1}), straw yield (28.89 q ha^{-1}), net returns of ₹102,773 ha^{-1}, and a benefit-cost ratios (BCR) of 3.94 over the pooled data from both years. Conversely, GNG-2261 and GNG-2144 demonstrated significantly higher grain yields (19.56 q ha^{-1} and 19.25 q ha^{-1}) and straw yields (25.20 q ha^{-1} and 24.97 q ha^{-1}) within the groundnut-chickpea system, yielding net returns of ₹263,365 and ₹268,943 ha^{-1}, respectively. Moreover, CEGY and CESY were maximized for GNG-2261 and GNG-2144 under the groundnut-chickpea system, emphasizing their economic advantages. The net returns and BCR further support these findings. Thus, this study highlights the significant influence of both variety and cropping systems on chickpea productivity and profitability, potentially improving economic returns for farmers in in arid and hot climate regions worldwide.

Keywords: *Cropping system; chickpea; net return; profitability; system productivity; comparative study; BC ratio.*

1. Introduction

Chickpea (*Cicer arietinum* L.) is an essential pulse crop in arid and semi-arid regions, particularly in Rajasthan, India, where they play a critical role in the diet of local populations and contribute significantly to the agricultural economy. Rajasthan, characterized by its hot climate, limited rainfall, and challenging soil conditions, presents unique challenges for crop production. Despite these difficulties, chickpeas are valued for their high protein content, ability to fix atmospheric nitrogen, and adaptability to marginal soils, making them an ideal choice for sustainable farming practices in these regions (1). The profitability of chickpea cultivation is influenced by various factors, including the selection of appropriate varieties, cropping systems, and management practices. Research has shown that integrating chickpeas into diverse cropping systems such as intercropping, rotation, and relay cropping can enhance soil fertility, improve water use efficiency, and increase overall yields (2,3). These practices not only maximize the economic returns for farmers but also promote sustainable agricultural practices by enhancing biodiversity and reducing dependency on chemical inputs (4).

Different chickpea varieties exhibit varying levels of resilience to abiotic stresses, such as drought and heat, which are particularly relevant in arid regions like Rajasthan. Identifying and promoting high-yielding, stress-resistant varieties can significantly impact profitability and sustainability (5,6).

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Furthermore, the choice of cropping system plays a crucial role in determining the economic viability of chickpeas. Studies indicate that mixed cropping systems can yield higher net returns compared to monoculture, due to reduced risk of crop failure and better utilization of resources (7,8). Sustainability in agriculture encompasses not only economic profitability but also environmental health and social equity. Sustainable practices, such as conservation tillage, improved irrigation techniques, and integrated pest management, are essential for maintaining soil health and enhancing productivity in arid conditions (1). This research aims to evaluate the profitability and sustainability of various chickpea varieties within diverse cropping systems in Rajasthan, focusing on yield performance, economic returns, and sustainability metrics. By providing insights into optimal cropping strategies, this study seeks to support local farmers and policymakers in making informed decisions that enhance food security and agricultural resilience in arid environments.

2. Materials and Methods

2.1 Site, Soil, and Climatic Conditions

A two-year field experiment was conducted at the Krishi Vigyan Kendra, Lunkaransar, Swami Keshwanand Rajasthan Agricultural University, Bikaner, India (longitude 73°-76° E, latitude 31°-26° N, and elevation 135 m) during the cropping seasons of 2021-22 and 2022-23. The soil in this region is classified as loamy sand. Chemical analysis of the soil revealed a pH of 7.6, 0.38% soil organic matter, an electrical conductivity of 0.35 dSm^{-1}, total nitrogen content of 0.05%, extractable phosphorus at 6.88 mg kg^{-1}, and extractable potassium at 163 mg kg^{-1}. The climatic conditions during the experimental period are characterized by hot summers and cool winters, typical of the arid regions of Rajasthan. The average rainfall during the cropping seasons varies, but irrigation is crucial for crop establishment and growth due to the region's erratic rainfall patterns. The temperature ranges significantly, with summer temperatures soaring above 40°C and winter temperatures dropping to around 5°C.

2.2 Experimental Details

The experiment aimed to assess the economics and profitability of five chickpea varieties: GNG-2144, GNG-2261, GNG-1958, GNG-2171, and GNG-1581, sown under seven different chickpea-based cropping systems. The cropping systems included: Fallow-chickpea, groundnut-chickpea, sesamum-chickpea, cluster bean-chickpea, green gram-chickpea, moth bean-chickpea and pearl millet-chickpea. A split-plot design was employed for the experiment. The cropping systems were assigned to the main plots, while the chickpea varieties were arranged in sub-plots, with three replications for statistical validity. This design allows for a comprehensive analysis of the interactions between cropping systems and chickpea varieties.

2.3 Date of Sowing

In the Kharif season groundnut was sown on June 15 in both years, while the other kharif crops were sown on July 15. The chickpea varieties during rabi seasons were sown on November 01 of the respective years. However, in the groundnut-chickpea system, all chickpea varieties were sown on December 01 due to the late harvesting of groundnut.

2.4 Crop Husbandry

Before to seedbed preparation, a pre-soaking irrigation of 4 inches was applied to ensure adequate soil moisture. Seedbeds were prepared when the soil reached field capacity, in accordance with the assigned treatments. A total of four irrigations were provided to the chickpea crop throughout the growing season to mitigate moisture stress. All crops were manually harvested upon reaching maturity. At harvest, eleven central rows from each plot were collected, sun-dried for one week, threshed manually, and the grains were separated and weighed to calculate grain yield, which was reported in quintals per hectare. All grain yields were adjusted to 10% moisture content for consistency.

2.5 Data Collection

Seed yield data from the chickpea crop were compiled to compute the economics and profitability of each cropping system. Yield data from all crops were recorded to facilitate comprehensive economic analysis. The Benefit-Cost Ratio was calculated using the formula: BCR= Total income/ Total expenditures. The performance of different cropping systems was evaluated in terms of Wheat Equivalent Yield (WEY): computed using the formula: WEY (crop)= Ya (Pa) / Pb. Where: Ya = yield of the crop 'a' (q ha^{-1}): Pa = price of the crop 'a' (₹) and Pb = price of chickpea. This calculation facilitated a standardized comparison of different cropping systems based on their economic value relative to wheat. Production efficiency was evaluated in terms of kg $ha^{-1}day^{-1}$, calculated accordingly.

2.6 Expenses Incurred

Both variable and fixed costs were calculated based on current market rates of inputs in Indian Rupees (₹). For kharif crops, fixed costs included fertilizer transport and application. The costs for land preparation, seeds, sowing, irrigation, fertilizers, and harvesting varied among the rabi crops. For chickpea cultivation, fixed costs encompassed seed cost, sowing, transportation of fertilizers, irrigation, and harvesting, while land preparation was categorized as a variable cost. Total expenditure incurred was computed by summing the variable and fixed costs for both kharif and rabi crops across the respective treatments.

3. Results and Discussions

3.1 Phenological and growth performance

The data reflect significant variations in growth and development across different treatments, indicating how preceding crops can influence chickpea performance (Table 1).

Table 1. Phenological performance and growth parameters of chickpea varieties under different cropping systems (Pooled of two years)

Treatments	Phenological performance in chickpea					Dry matter accumulation (g plant^{-1})				Plant height at harvest
	Days to emergence	Days to branching	Days to 50 % flowering	Days to pod formation	Days to Maturity	30 DAS	60 DAS	90 DAS	Harvest	(cm)
Cropping systems										
Fallow-Chickpea	8.2	47.3	72.7	90.9	128.2	2.09	6.04	15.24	21.61	52.49
Groundnut-Chickpea	11.3	45.8	70.3	88.3	115	1.84	5.08	12.34	17.46	45.78
Sesame-Chickpea	9.1	45.6	69.9	87.9	124.5	1.81	4.99	12.08	17.08	45.15
Cluster bean-Chickpea	10	48.3	74.3	92.8	130.4	2.07	5.98	15.06	21.36	52.11
Green gram-Chickpea	9.7	46.5	71.4	89.5	126.5	1.9	5.32	13.07	18.5	47.46
Moth bean-Chickpea	9.6	46.2	71	89.1	125.9	1.88	5.23	12.79	18.1	46.8
Pearl millet-Chickpea	9.3	44.5	68.2	86	122.2	1.7	4.55	10.74	15.15	42.02
S.Em.±	0.2	0.9	1.5	1.6	2	0.02	0.07	0.21	0.31	0.45
CD at 5%	0.5	2.7	4.4	4.8	5.8	0.05	0.21	0.63	0.9	1.33
Chickpea varieties										
GNG-2144	8.8	45.3	69.4	87.3	122.4	1.74	4.73	11.28	15.93	42.94
GNG-2261	9.2	45.7	70.1	88.1	123.3	1.79	4.91	11.84	16.74	44.27
GNG-1958	9.8	46.5	71.4	89.6	125.1	2.11	6.13	15.51	22	54.43
GNG-2171	9.9	46.8	72	90.1	125.8	1.9	5.3	13	18.4	46.98
GNG-1581	10.3	47.3	72.7	91	126.8	1.95	5.5	13.6	19.27	48.38
S.Em. ±	0.1	0.4	0.7	0.8	1	0.01	0.05	0.15	0.22	0.32
CD at 5%	0.3	1.3	2	2.2	2.7	0.04	0.14	0.42	0.61	0.9

The chickpea following the groundnut system exhibited the highest number of days to emergence (11.3 days): while the fallow-chickpea treatment had the shortest duration (8.2 days). This suggests that the moisture and soil structure effects of preceding crops play a crucial role in the initial germination phase. Earlier emergence in fallow systems may be attributed to less competition for moisture and nutrients (8).

Similar trends were observed in branching, with the fallow system resulting in the earliest branching (47.3 days) compared to the sesame system (45.6 days). The reduced competition for resources in fallow conditions likely promotes earlier branching (2,3). The fallow-chickpea system again outperformed others in terms of days to 50% flowering (72.7 days) and days to pod formation (90.9 days). The timely flowering and pod formation stages are critical for maximizing yield potential, particularly in chickpeas where reproductive stages are sensitive to environmental conditions (9,10). Groundnut and cluster bean systems resulted in the earliest maturity (115.0 and 130.4 days, respectively): whereas chickpea after fallow was the latest (128.2 days). This variability can be attributed to the residual nutrient and moisture content available from the preceding crop, which influences the overall developmental timeline of chickpeas (11). The highest dry matter accumulation was recorded in the fallow-chickpea treatment (21.61 g plant^{-1}): which significantly outperformed other systems such as pearl millet (15.15 g plant^{-1}) (Figure 1).

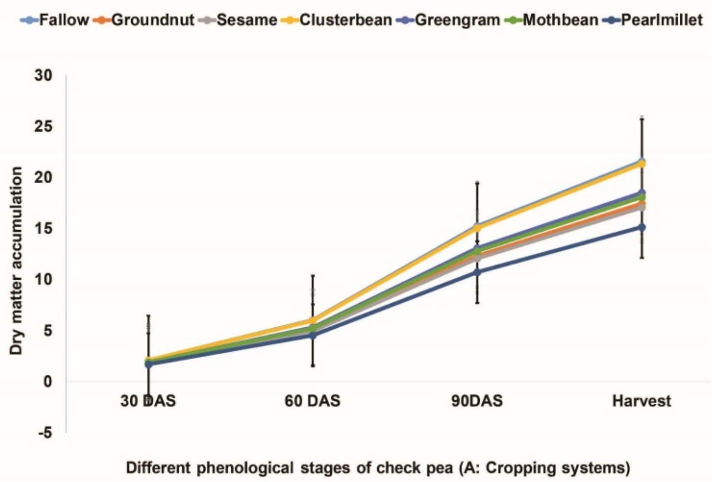

Figure 1. Dry matter accumulation in chickpea at various phenological stages under different cropping systems

The nutrient availability from the fallow period likely enhanced biomass production (12,13). The tallest plants were recorded in the fallow (52.49 cm) and cluster bean (52.11 cm) systems, while the pearl millet treatment resulted in the shortest plants (42.02 cm). Height is often correlated with biomass accumulation and overall plant health, indicating that the fallow and cluster bean treatments created favourable conditions for growth (Gupta *et al.*, 2022). Measurements taken at 30, 60, and 90 DAS also indicate significant differences across treatments.

The fallow system consistently showed the highest growth metrics at all stages, reflecting a more robust development trajectory, while pearl millet consistently showed the lowest values. This pattern reinforces the idea that previous crop selection directly impacts the growth potential of subsequent crops (14,15).

Further, the results highlight the significant differences among varieties in terms of emergence, branching, flowering, pod formation, and overall growth, which can inform breeding and management strategies for enhancing chickpea production. The variety GNG-2144 demonstrated the earliest emergence at 8.8 days, while GNG-1581 exhibited the latest at 10.3 days. This difference in emergence times can be critical, as quicker emergence often correlates with better establishment and reduced vulnerability to weeds and pests (16,17,18). The earlier emergence of GNG-2144 may also suggest better adaptation to local soil conditions or a more favourable seed morphology. The branching period ranged from 45.3 days for GNG-2144 to 47.3 days for GNG-1581. Early branching is important for maximizing the potential for pod development, as it allows for more extensive vegetative growth before reproductive phases begin (19,20,21). The variations in branching times may be due to genetic differences in growth habits and resource allocation strategies among the varieties. GNG-2144 again showed the shortest duration to 50% flowering (69.4 days): while GNG-1581 was the latest at 72.7 days. Early flowering can enhance yield potential by allowing plants to escape drought conditions common in the later growing season (22,23). The flowering period is critical for determining yield, and thus, earlier flowering varieties may be preferable in regions with short growing seasons. The time to pod formation closely mirrored the flowering results, with GNG-2144 taking 87.3 days and GNG-1581 taking 91.0 days. This consistency underscores the correlation between flowering and pod development stages, highlighting the impact of early flowering on overall productivity (14,15). Maturity times varied, with GNG-2144 maturing in 122.4 days and GNG-1581 taking the longest at 126.8 days. The differences in maturity could be significant for farmers needing to time harvests effectively, particularly in regions where late rainfall could affect seed quality (24).

Among the varieties, GNG-1958 exhibited the highest dry matter accumulation at 22.00 g plant^{-1}, while GNG-2144 had the lowest at 15.93 g plant^{-1} (Figure 2).

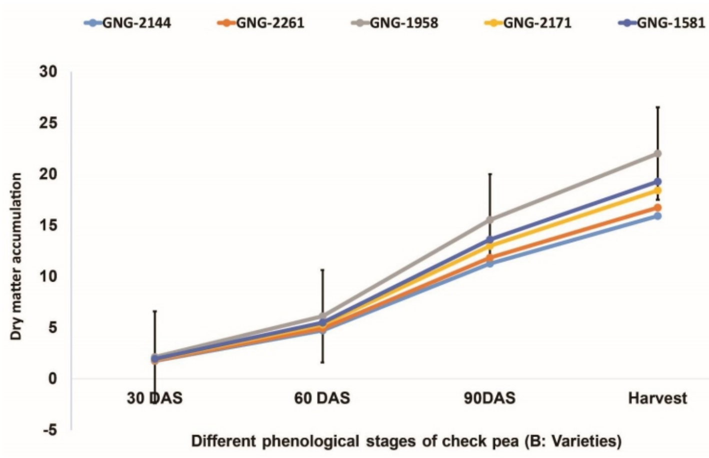

Figure 2. Dry matter accumulation in chickpea at diverse phenological stages across various varieties

Higher dry matter accumulation is generally associated with better resource utilization and can lead to improved yields (25). The superior performance of GNG-1958 suggests that it may be more efficient in photosynthetic capacity or nutrient uptake. Plant height varied significantly among varieties, with GNG-1958 reaching 54.43 cm, the tallest, while GNG-2144 was the shortest at 42.94 cm. Plant height can be a useful indicator of overall health and vigour, as taller plants often have a larger leaf area for photosynthesis (26,27,28). The significant height differences may also indicate genetic variations in growth patterns and adaptability.

3.2 Performance of crop growth rate (CGR) and relative growth rate (RGR) of chickpea

The data on the crop growth rate (CGR) and relative growth rate (RGR) for chickpea grown in various cropping systems presented in the Table 2.

Table 2. Performance of crop growth rate (CGR) and relative growth rate (RGR) of chickpea varieties under different cropping systems (Pooled of two years)

Treatments	Crop growth rate (CGR) (g m^{-2} day^{-1})				Relative growth rate (RGR) (mg g^{-1} day^{-1})		
	0-30 DAS	30-60 DAS	60-90 DAS	90 DAS- Harvest	30-60 DAS	60-0 DAS	90DAS- Harvest
Cropping systems							
Fallow- Chickpea	2.30	4.34	10.12	7.01	55.37	86.21	97.52
Groundnut- Chickpea	2.02	3.57	7.99	5.63	49.74	78.68	107.67
Sesame- Chickpea	2.00	3.50	7.80	5.50	49.23	78.00	89.03
Cluster bean- Chickpea	2.28	4.30	9.99	6.93	55.12	85.91	97.22
Green gram - Chickpea	2.09	3.76	8.52	5.97	51.29	80.84	91.98
Moth bean- Chickpea	2.06	3.69	8.32	5.84	50.70	80.03	91.13
Pearl millet- Chickpea	1.87	3.14	6.81	4.86	46.21	73.67	84.51
S.Em.±	0.02	0.06	0.16	0.10	0.41	0.56	0.60
CD at 5%	0.06	0.17	0.46	0.30	1.21	1.63	1.76
Chickpea varieties							
GNG-2144	1.92	3.28	7.20	5.11	47.44	75.46	88.78
GNG-2261	1.97	3.43	7.62	5.39	48.72	77.28	90.75
GNG-1958	2.33	4.42	10.32	7.14	55.94	86.98	101.10
GNG-2171	2.08	3.74	8.47	5.94	51.12	80.60	94.29
GNG-1581	2.14	3.90	8.92	6.23	52.25	82.06	95.84
S.Em. ±	0.01	0.04	0.11	0.07	0.30	0.42	0.46
CD at 5%	0.04	0.11	0.31	0.20	0.85	1.17	1.29

The highest CGR in the initial growth phase was recorded for the fallow-chickpea system at 2.30 g m^2 day^{-1}, followed closely by cluster bean at 2.28 g m^2 day^{-1}. These higher values suggest that these systems provided a more favourable environment for early seedling establishment compared to others, such as pearl millet, which recorded the lowest CGR (1.87 g m^2 day^{-1}) (Figure 3).

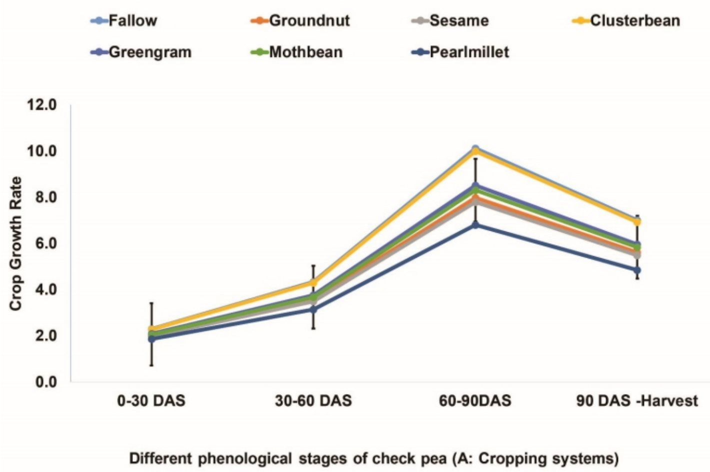

Figure 3. Crop Growth Rate (CGR) of chickpea at different phenological stages under diverse cropping systems

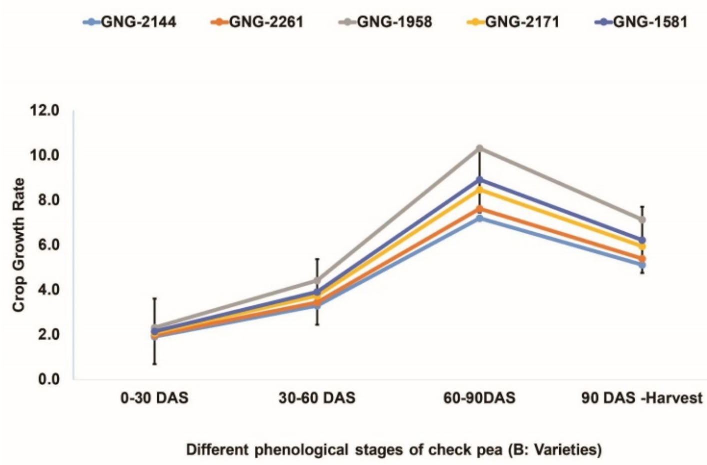

Figure 4. Crop Growth Rate (CGR) of chickpea at various phenological stages across different varieties

This trend indicates the significance of soil moisture and nutrient availability during the initial growth stages (29,30,31). The CGR continued to rise in most treatments, with the fallow system again showing superior performance (4.34 g m^2 day^{-1}) compared to groundnut (3.57 g m^2 day^{-1}) and sesame (3.50 g m^2 day^{-1}). The increase in CGR during this period reflects enhanced photosynthetic activity and biomass accumulation, crucial for setting the stage for flowering and pod development (22,23). The peak CGR was observed during this period, with fallow-chickpea reaching 10.12 g m^2 day^{-1}, indicating optimal growth conditions for pod formation. Other systems, such as cluster bean (9.99 g m^2 day^{-1}): also performed well, but pearl millet recorded significantly lower growth (6.81 g m^2 day^{-1}). This period is critical for determining yield potential, and higher CGR values suggest more effective resource utilization (19,20,21). During this final growth phase, the CGR decreased for all systems, reflecting the transition from growth to maturity. The fallow system maintained the highest rate (7.01 g m^2 day^{-1}): indicating sustained growth late into the season. In contrast, the groundnut system showed a notable decline to 5.63 g m^2 day^{-1}, which could affect final yield outcomes (16,17,18). The RGR during this phase was highest for the fallow system (55.37 mg g^{-1} day^{-1}): followed closely by cluster bean (55.12 mg g^{-1} day^{-1}). This indicates efficient biomass accumulation during a crucial vegetative growth phase, which can significantly impact subsequent reproductive stages (26,27,28). RGR values decreased across all systems during this phase, with the fallow system remaining relatively high at 97.52 mg g^{-1} day^{-1}. The consistent RGR in the fallow treatment suggests effective resource management and sustained growth potential up to harvest, while pearl millet demonstrated the lowest RGR (84.51 mg g^{-1} day^{-1}): which may reflect less favourable growth conditions during the reproductive phase (25) and (24). Among the chickpea varieties, GNG-1958 exhibited the highest CGR (2.33 g m^2 day^{-1}): followed closely by GNG-2261 (1.97 g m^2 day^{-1}) (Figure 4).

The lower CGR of GNG-2144 (1.92 g m^2 day^{-1}) suggests slower early establishment. The initial growth phase is critical for establishing a robust root system and effective canopy cover, which are essential for resource acquisition (19,20,21). Growth rates increased during this period, with GNG-1958 continuing to lead at 4.42 g m^2 day^{-1}. This stage is vital for vegetative growth and can be attributed to enhanced nutrient uptake and photosynthetic efficiency (22,23). The growth rates of the other varieties, such as GNG-2261 (3.43 g m^2 day^{-1}) and GNG-1581 (3.90 g m^2 day^{-1}): indicate effective competition for resources but were lower than the leading variety. The peak CGR was observed in GNG-1958 at 10.32 g m^2 day^{-1}, underscoring its strong performance during the critical reproductive phase. Higher CGR during this period correlates with improved pod formation and seed filling, essential for maximizing yield (32). The other varieties, including GNG-2171 (8.47 g m^2 day^{-1}) and GNG-1581 (8.92 g m^2 day^{-1}): also showed commendable growth, but the gap indicates that GNG-1958 may have superior traits for enhancing biomass accumulation. CGR decreased as plants neared maturity, with GNG-1958 maintaining the highest rate (7.14 g m^2 day^{-1}). The gradual decline in CGR is expected as plants shift resources towards seed development (16,17,18). The performance of other varieties such as GNG-1581 (6.23 g m^2 day^{-1}) remained competitive, indicating good maintenance of biomass during this phase. The RGR values during this phase reflected effective biomass accumulation, with GNG-1958 again leading at 55.94 mg g^{-1} day^{-1}. High RGR indicates that this variety efficiently converts available resources into plant biomass (27,28). Other varieties such as GNG-2144 (47.44 mg g^{-1} day^{-1}) and GNG-2171 (51.12 mg g^{-1} day^{-1}) also showed reasonable performance, although lower than GNG-1958. The RGR was highest for GNG-1958 at 101.10 mg g^{-1} day^{-1}, reinforcing its superiority in resource utilization during the reproductive phase. Efficient growth rates during this period are crucial for final yield potential (25). The other varieties had RGR values between 90 and 95 mg g^{-1} day^{-1}, indicating competitive growth but suggesting that GNG-1958 may have genetic traits that enhance its growth efficiency.

3.3 Performance of yield attributing parameters of chickpea

The yield attributing parameters of chickpea varieties cultivated under different cropping systems summarizes in Table 3.

Table 3. Performance of yield attributing parameters, yield and harvest index of chickpea varieties under different cropping systems (Pooled of two years)

Treatments	Yield attributing parameters in chickpea varieties				Yield (q ha^{-1})			Harvest Index (%)
	Branches per plant	Pods per plant	Seeds per pod	100 seed weight (g)	Seed yield (q ha^{-1})	Stover yield (q ha^{-1})	Biological yield (q ha^{-1})	
Cropping systems								
Fallow- Chickpea	10.53	46.10	2.18	16.32	21.51	26.34	47.85	44.74
Groundnut- Chickpea	9.59	41.63	1.76	16.20	16.42	22.91	39.33	41.42
Sesame- Chickpea	10.62	40.28	1.91	16.11	17.71	23.85	41.56	42.48
Cluster bean- Chickpea	11.36	44.73	2.16	16.27	20.38	26.17	46.54	43.65
Green gram - Chickpea	10.66	45.23	2.03	16.45	19.85	25.40	45.25	43.76
Moth bean- Chickpea	10.27	43.83	2.00	16.35	19.24	24.96	44.21	43.39
Pearl millet- Chickpea	9.42	34.72	1.75	15.66	14.82	21.74	36.55	40.35
S.Em.±	0.26	0.97	0.02	0.07	0.42	0.31	0.72	0.24
CD at 5%	0.77	2.82	0.07	0.19	1.22	0.89	2.11	0.71
Chickpea varieties								
GNG-2144	9.69	40.50	1.77	14.34	16.74	23.13	39.87	41.80
GNG-2261	10.14	41.49	2.11	14.40	17.82	23.92	41.74	42.53
GNG-1958	9.41	38.95	1.76	21.57	18.86	24.70	43.56	43.05
GNG-2171	11.23	43.57	1.94	15.24	19.23	24.98	44.21	43.26
GNG-1581	11.29	47.30	2.27	15.42	20.16	25.67	45.83	43.50
S.Em. ±	0.19	0.68	0.02	0.05	0.29	0.22	0.51	0.19
CD at 5%	0.53	1.89	0.05	0.13	0.82	0.61	1.43	0.53

The highest average number of branches per plant was observed in the cluster bean- chickpea treatment (11.36 branches per plant): followed closely by fallow-chickpea (10.53 branches per plant). A greater number of branches is typically associated with increased photosynthetic surface area, contributing positively to yield potential (29,30,31,32). Conversely, pearl millet-chickpea recorded the lowest branches per plant (9.42): correlating with its lower overall yield. The fallow- chickpea treatment produced the highest number of pods per plant (46.10): which is essential for determining seed yield (25). The lower pod count in the groundnut-chickpea system (41.63) may be attributed to competition for resources or unfavourable growth conditions. Increased pod production enhances the likelihood of higher seed yield. The average seeds per pod were highest in the fallow- chickpea system (2.18): which is a critical trait for yield enhancement. The groundnut- chickpea treatment exhibited the lowest seeds per pod (1.76): potentially impacting its yield negatively (26,27,28). Seed weight, an important trait affecting yield, was highest in the green gram- chickpea system (16.45 g). This trait is significant as heavier seeds often correlate with higher vigour and better establishment rates (16,17,18). The lowest seed weight was observed in the pearl millet- chickpea system (15.66 g): contributing to its reduced overall yield (Figure 5).

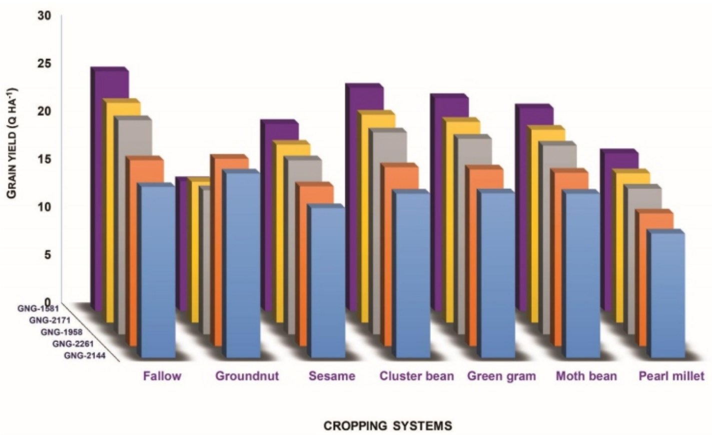

Figure 5. Seed yield performance of chickpea under various cropping systems

The variety GNG-2171 produced the highest number of branches per plant (11.23): indicating robust vegetative growth, which is positively correlated with increased yield potential (33).

In contrast, GNG-1958 had the lowest branches per plant (9.41): suggesting that lower branching could limit its overall productivity. The highest pod count was found in GNG-1581 (47.30 pods per plant). A higher number of pods per plant is critical for enhancing seed yield, as each pod can potentially contribute to overall production (34). The lowest was in GNG-1958 (38.95 pods): which may explain its comparatively lower yield. The variety GNG-1581 also led with the highest seeds per pod (2.27): which is crucial for maximizing yield. In comparison, GNG-2144 had the lowest (1.77): highlighting the importance of this trait in yield determination (16,17,18). The highest 100-seed weight was recorded for GNG-1958 (21.57 g) which suggests better seed quality and vigour, a trait linked to improved germination and seedling establishment (35). In contrast, the other varieties had lower weights, with GNG-2144 having the lowest at 14.34 g. The interaction effects of various cropping systems on the number of pods per plant and the 100 seed weight across different chickpea varieties are summarized in Table 4.

Table 4. Interaction effects of different cropping systems on the number of pods per plant and the 100-seed weight of chickpea varieties (pooled data)

Treatments	Pods per plant					100 seed weight (g)				
Cropping systems	**GNG-2144**	**GNG-2261**	**GNG-1958**	**GNG-2171**	**GNG-1581**	**GNG-2144**	**GNG-2261**	**GNG-1958**	**GNG-2171**	**GNG-1581**
Fallow- Chickpea	41.94	43.73	43.39	48.32	53.10	14.50	14.66	21.80	15.20	15.44
Groundnut-Chickpea	40.16	41.10	38.20	42.98	45.72	14.35	14.39	21.57	15.26	15.44
Sesame- Chickpea	39.79	40.41	36.65	41.19	43.38	14.24	14.25	21.43	15.24	15.40
Cluster bean-Chickpea	41.32	43.14	42.46	46.69	50.05	14.45	14.57	21.71	15.18	15.43
Green gram -Chickpea	43.40	44.51	41.88	46.73	49.64	14.57	14.62	21.91	15.48	15.67
Moth bean-Chickpea	43.25	43.70	40.23	44.83	47.16	14.45	14.47	21.76	15.47	15.62
Pearl millet-Chickpea	33.63	33.84	29.80	34.27	42.04	13.83	13.83	20.82	14.84	14.97
	Cropping systems	Chickpea varieties				Cropping systems	Chickpea varieties			
S.Em. ±	0.92	0.96				0.07	0.07			
CD at 5%	2.68	2.68				0.19	0.19			

The number of pods per plant is a critical determinant of chickpea yield. The results indicate significant variability based on both the chickpea variety and the cropping system employed that the highest pod count was observed in GNG-1581 (53.10 pods plant^{-1}): suggesting this variety is well-suited for production in fallow systems, benefiting from reduced competition and optimal soil moisture conditions (36). The variety GNG-2144 also performed well (41.94 pods): but others like GNG-1958 and GNG-2261 exhibited lower pod counts, indicating the need for variety-specific management practices. In this cropping system, GNG-1581 again showed superior performance (45.72 pods): while GNG-1958 yielded the lowest number of pods (38.20). This highlights how intercropping with groundnuts can favour certain varieties more than others (29,30,31). Varieties performed similarly in these systems, with GNG-1581 and GNG-2171 maintaining higher pod counts. This suggests that these chickpea varieties can effectively compete for resources in mixed cropping environments (26,27,28). The lowest pod counts were observed across all varieties, especially in GNG-2144 (33.63 pods). This underscores the competitive disadvantage of chickpea when grown alongside pearl millet, likely due to resource competition for light and nutrients (37,38,39,40).
The 100 seed weight is a crucial quality parameter impacting the marketability and viability of chickpea: The highest seed weight was noted in GNG-1958 (21.80 g): suggesting this variety excels in conditions that allow for better seed filling and growth. In contrast, lower weights were recorded for GNG-2144 (14.50 g): indicating poorer seed development in that variety under these conditions (41). The 100 seed weights for GNG-1581 (15.44 g) and GNG-2171 (15.18 g) remained competitive, demonstrating that these varieties maintain acceptable quality even when intercropped. This finding is essential for farmers considering intercropping strategies for economic benefits (16,17,18). Generally lower seed weights were observed, particularly with GNG-2144 showing the least weight (13.83 g) under the pearl millet system. This suggests that some varieties may struggle with stress from neighbouring crops, negatively impacting seed development (26.27,28).

3.4 Yield performance of chickpea

The highest seed yield was recorded in the fallow- chickpea system (21.51 q ha^{-1}): indicating optimal conditions for growth and resource availability (42). Conversely, the pearl millet-chickpea system had the lowest seed yield (14.82 q ha^{-1}): likely due to lower pod and seed numbers as discussed earlier. The stover yield, which is crucial for livestock feeding, was also highest in the fallow- chickpea treatment (26.34 q ha^{-1}). The yield of stover is an important consideration in integrated farming systems, as it provides additional resources for farmers (43). The biological yield (sum of seed and stover yields) was highest in the fallow- chickpea system (47.85 q ha^{-1}): demonstrating the system's efficiency in producing both edible and non-edible biomass (22,23). This contrasts with the pearl millet- chickpea treatment, which yielded only 36.55 q ha^{-1}, highlighting the disparity in growth potential across systems.
The maximum seed yield was achieved by GNG-1581 (20.16 q ha^{-1}): indicating its superior performance across the studied parameters. The lowest yield was recorded for GNG-2144 (16.74 q ha^{-1}): which aligns with its lower branch and pod counts (24). The stover yield was highest in GNG-1581 (25.67 q ha^{-1}): making it suitable for both grain and fodder production. This dual benefit is critical in integrated farming systems (22,23). GNG-2144 had the lowest stover yield (23.13 q ha^{-1}): affecting its overall biomass production. The biological yield (sum of seed and stover yield) was also highest in GNG-1581 (45.83 q ha^{-1}): indicating its overall efficiency in converting resources into biomass. The lowest biological yield was observed in GNG-2144 (39.87 q ha^{-1}): again highlighting the need for varieties that optimize resource use (25). The interaction effect of different chickpea varieties across various cropping systems on seed and stover yields is presented in Table 5.

Table 5. Seed and stover yields of chickpea varieties under various cropping systems (pooled data)

Treatments	Seed yield of chickpea (q ha-1)					Stover yield of chickpea (q ha-1)				
Cropping systems	GNG-2144	GNG-2261	GNG-1958	GNG-2171	GNG-1581	GNG-2144	GNG-2261	GNG-1958	GNG-2171	GNG-1581
Fallow- Chickpea	17.84	19.40	22.35	22.93	25.00	23.67	24.80	26.96	27.38	28.89
Groundnut-Chickpea	19.25	19.56	15.06	14.71	13.52	24.97	25.20	21.91	21.66	20.79
Sesame- Chickpea	15.64	16.68	18.17	18.57	19.52	22.33	23.10	24.18	24.47	25.16
Cluster bean-Chickpea	17.14	18.67	21.09	21.71	23.28	23.62	24.83	26.73	27.21	28.45
Green gram - Chickpea	17.20	18.45	20.42	20.96	22.21	23.47	24.39	25.82	26.21	27.13
Moth bean-Chickpea	17.13	18.10	19.71	20.14	21.14	23.42	24.13	25.30	25.62	26.35
Pearl millet-Chickpea	12.98	13.85	15.21	15.58	16.45	20.40	21.03	22.03	22.30	22.93
	Cropping systems	Chickpea varieties				Cropping systems	Chickpea varieties			
S.Em. ±	0.42	0.43				0.31	0.22			
CD at 5%	1.23	1.22				0.90	0.63			

The highest seed yield was recorded for GNG-1581 (25.00 q ha^{-1}): followed closely by GNG-2171 (22.93 q ha^{-1}) and GNG-1958 (22.35 q ha^{-1}). The performance of these varieties under fallow conditions suggests they are particularly well-suited for environments with minimal competition and optimal moisture availability (44,45). In contrast, GNG-2144 yielded the least (17.84 q ha^{-1}): indicating that it may be less competitive or less adapted to these conditions. Seed yields decreased across all varieties, with GNG-1958 showing the lowest yield (15.06 q ha^{-1}). This decline is likely due to resource competition with groundnut, which can affect the growth and development of chickpea plants (46,47). The yields of GNG-2144 (19.25 q ha^{-1}) and GNG-2261 (19.56 q ha^{-1}) were relatively higher compared to the others, indicating that these varieties may tolerate intercropping better. The seed yields in the sesame system were moderate, with GNG-1581 achieving the highest yield (19.52 q ha^{-1}). In the cluster bean system, GNG-1581 and GNG-2171 also performed well, indicating consistency across different intercropping conditions (26,27,28). The relative stability of GNG-1581 across systems suggests its adaptability, making it a promising choice for mixed cropping systems. Seed yields were also reasonably high in these systems, with GNG-1581 again performing well (22.21 q ha^{-1} for green gram and 21.14 q ha^{-1} for moth bean). This trend further confirms its robustness across different intercropping scenarios (37,38,39,40). The seed yields were significantly lower across all varieties in the pearl millet system, with GNG-2144 yielding only 12.98 q ha^{-1}. The competitive disadvantage of chickpea in this system is evident, likely due to increased resource competition from the millet crop (48,49,50,51,52).

The stover yield also peaked with GNG-1581 (28.89 q ha^{-1}) under fallow conditions, indicating that this variety not only produces good seed yields but also generates considerable biomass, which is vital for soil health and as fodder (44,45). Other varieties like GNG-2171 (27.38 q ha^{-1}) also showed substantial over yields, confirming the benefits of growing chickpea in fallow systems. Stover yields decreased slightly in the groundnut system but remained competitive. GNG-2261 yielded 25.20 q ha^{-1}, indicating that while seed yields were affected, biomass production remained relatively stable. In the sesame system, yields were slightly lower compared to the fallow system but still favourable, particularly for GNG-1581 (25.16 q ha^{-1}). Both systems maintained good stover yields, with GNG-1581 leading again. This suggests that chickpea varieties can thrive and produce ample biomass even in intercropping scenarios (26,27,28). Stover yields in these systems were lower compared to others, with GNG-2144 yielding only 20.40 q ha^{-1} in the pearl millet system. This suggests that competitive pressures in these intercropping scenarios may limit both seed and biomass production (48,49,50,51,52).

3.5 Equivalent yield of system

Data on chickpea equivalent yield (CEY) across different cropping systems over a two-year pooled analysis (Table 6; Figure 6).

Table 6. Chickpea equivalent yield, economic performance, production efficiency, and land resource use efficiency of chickpea varieties under different cropping systems (Pooled of two years)

Treatments	Chickpea equivalent yield during kharif (q ha-1)		Chickpea equivalent yield of Systems (q ha-1)		Economic performance of chickpea		Economic performance of system		Total duration (days)	Production efficiency (kg/ha/day)	LRUE (%)
	CEGY	CESY	CEGY	CESY	Net returns (₹ ha-1)	BC ratio	Net Returns (₹ ha-1)	BC ratio			
Cropping systems											
Fallow-Chickpea	-	-	21.51	26.34	83836	3.40	83836	3.40	128	16.80	35.11
Groundnut-Chickpea	40.24	121.24	56.66	144.15	56360	2.61	248315	4.10	263	21.57	71.93
Sesame-Chickpea	7.86	0.19	25.58	24.04	63373	2.81	93001	2.98	234	10.94	63.98
Cluster bean-Chickpea	18.87	47.28	39.24	73.45	77901	3.23	166934	4.04	234	16.77	64.09
Green gram - Chickpea	21.00	20.40	40.84	45.81	74985	3.14	164966	3.75	217	18.82	59.44

Moth bean-Chickpea	10.07	11.18	29.32	36.14	71714	3.05	112104	3.24	205	14.31	56.14
Pearl millet-Chickpea	5.90	40.94	20.71	62.68	47597	2.36	74905	2.59	231	8.95	63.33
S.Em.±	0.14	0.35	0.47	0.55	2270	0.06	2597	0.06	2.0	0.15	0.54
CD at 5%	0.40	1.05	1.38	1.62	6627	0.19	7580	0.18	5.8	0.45	1.59
Chickpea varieties											
GNG-2144	17.58	41.09	31.81	58.34	58096	2.66	126303	3.23	214	14.72	58.52
GNG-2261	17.33	40.14	32.67	58.33	63935	2.83	130853	3.34	215	15.11	58.77
GNG-1958	17.14	39.77	33.55	58.79	69578	2.99	135571	3.47	216	15.52	59.27
GNG-2171	17.98	41.54	34.64	60.58	71587	3.05	141697	3.59	217	16.01	59.46
GNG-1581	16.58	38.49	34.38	58.66	76638	3.19	139905	3.59	218	15.90	59.72
S.Em. ±	0.15	0.43	0.32	0.42	1599	0.05	1746	0.03	1.0	0.15	0.26
CD at 5%	0.42	1.20	0.89	1.17	4481	0.13	4894	0.10	2.7	0.43	0.74

CEGY= Chickpea equivalent seed yield, CESY= Chickpea equivalent stover yield, LRUE= land resource use efficiency

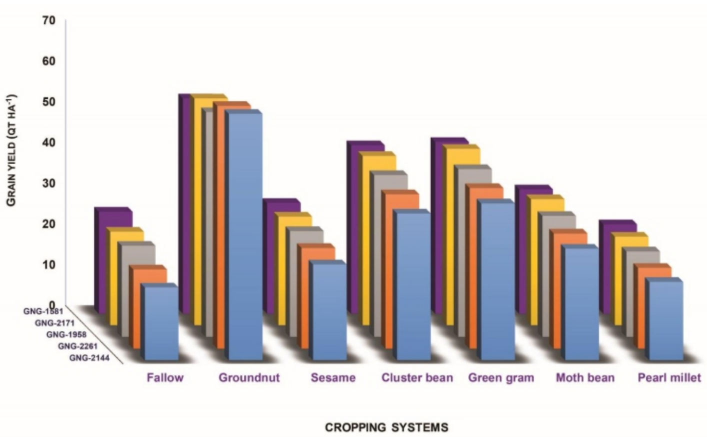

Figure 6. Performance of chickpea equivalent seed yield (CESY) across different cropping systems

The results of the pooled analysis of chickpea equivalent yield across various cropping systems reveal significant insights into the benefits of intercropping strategies. In kharif the fallow-chickpea system, no additional yield was observed, with a chickpea equivalent yield (CEGY) of 21.51 q ha^{-1} and a total duration of 128 days. This baseline performance underscores the potential for enhanced yields when chickpea are integrated with other crops.

The groundnut-chickpea system demonstrated remarkable results, with a CEGY of 40.24 q ha^{-1} and a chickpea equivalent yield of systems (CESY) reaching 56.66 q ha^{-1}. Conversely, the sesame-chickpea system yielded a lower CEGY of 7.86 q ha^{-1}, with a CESY of 25.58 q ha^{-1}. The cluster bean-chickpea system also exhibited strong performance, with a CEGY of 18.87 q ha^{-1} and a CESY of 39.24 q ha^{-1}. In contrast, the moth bean-chickpea system produced a CEGY of 10.07 q ha^{-1} and a CESY of 29.32 q ha^{-1}. The pearl millet-chickpea system had the lowest performance, with a CEGY of 5.90 q ha^{-1} and a CESY of 20.71 q ha^{-1}. Among the varieties, GNG-2171 exhibited the highest CEGY of 17.98 q ha^{-1} and a system equivalent yield (CESY) of 41.54 q ha^{-1}, indicating its superior productivity in the kharif season. Following closely was GNG-1958, which showed a CEGY of 17.14 q ha^{-1} and a CESY of 39.77 q ha^{-1}. GNG-2261 and GNG-2144 also demonstrated commendable performances with CEGYs of 17.33 q ha^{-1} and 17.58 q ha^{-1}, respectively. In the interaction between varieties and cropping systems (Table 7), GNG-2144 among the chickpea varieties displayed the highest CEGY of 60.37 q ha^{-1} when intercropped with groundnut, highlighting its outstanding performance in this system.

Table 7. Chickpea equivalent yield of the system (CEYS) for chickpea varieties under various cropping systems (pooled data)

Treatments	**Chickpea equivalent seed yield (CEGY) of systems (q ha^{-1})**					**Chickpea equivalent stover yield (CESY) of systems (q ha^{-1})**				
Cropping systems	**GNG-2144**	**GNG-2261**	**GNG-1958**	**GNG-2171**	**GNG-1581**	**GNG-2144**	**GNG-2261**	**GNG-1958**	**GNG-2171**	**GNG-1581**
Fallow- Chickpea	17.84	19.40	22.35	22.93	25.00	23.67	24.80	26.96	27.38	28.89
Groundnut-Chickpea	60.37	59.46	55.11	55.58	52.76	149.04	145.25	142.75	144.71	139.00
Sesame- Chickpea	23.47	24.68	25.95	26.63	27.16	22.53	23.29	24.37	24.67	25.35
Cluster bean-Chickpea	35.97	37.81	39.68	41.50	41.27	70.68	72.75	73.22	76.93	73.65
Green gram -Chickpea	38.43	39.34	41.11	43.23	42.10	44.02	44.81	45.85	47.92	46.44
Moth bean-Chickpea	27.34	28.21	29.67	30.90	30.46	34.72	35.39	36.32	37.60	36.67
Pearl millet-Chickpea	19.21	19.79	20.96	21.72	21.88	63.75	62.05	62.08	64.85	60.66
	Cropping systems	Chickpea varieties				Cropping systems	Chickpea varieties			
S.Em. ±	0.48	0.48				0.56	0.59			
CD at 5%	1.39	1.35				1.62	1.65			

The high yield can be attributed to the synergistic effects of intercropping, which often leads to improved resource utilization (29,30,31,32). Similarly, GNG-2261 and GNG-1958 followed closely with CEGYs of 59.46 q ha^{-1} and 55.11 q ha^{-1}, respectively, highlighting their potential for high productivity in combined cropping systems. In contrast, the CEGYs observed under the fallow-chickpea system were significantly lower, with GNG-1581 yielding 25.00 q ha^{-1}. This illustrates the positive impact of companion cropping on chickpea yields, which is consistent with findings by (53,54) regarding the benefits of intercropping for enhancing legume yields. In the interaction between varieties and cropping systems (Table 7), the stover yields exhibited comparable trends. Under the groundnut-chickpea system, GNG-2144 produced a stover yield of 149.04 q ha^{-1}, making it the top performer among all varieties. This high stover yield is beneficial for livestock feeding and soil fertility, as it contributes organic matter back to the soil (55). Other varieties, including GNG-2261 and GNG-1958, yielded 145.25 q ha^{-1} and 142.75 q ha^{-1} of stover, respectively. The cluster bean-chickpea system also yielded substantial stover outputs, with GNG-2171 achieving 76.93 q ha^{-1}. This demonstrates the versatility of chickpea varieties in providing both grain and fodder in mixed cropping systems (37,38,39,40).

3.6 Economic performance of system

Data on chickpea economic performance across different cropping systems over a two-year pooled analysis (Table 6). The results of the pooled analysis of economic performance, across various cropping systems reveal significant insights into the benefits of intercropping strategies. In Kharif the fallow-chickpea system resulted in net returns of ₹ 83,836 and a benefit-cost (BC) ratio of 3.40 (Figure 7).

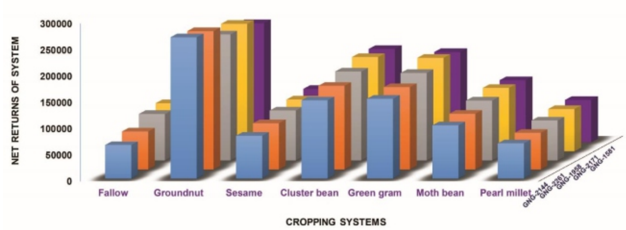

Figure 7. System net return performance across various cropping systems

This baseline performance underscores the potential for enhanced yields when chickpea are integrated with other crops. The groundnut-chickpea system not only provided the highest net returns of ₹ 248,315 but also achieved a BC ratio of 4.10, highlighting its economic viability and efficiency (46,47). Conversely, the sesame-chickpea system provided a lower net returns of ₹ 63,373. Despite the lower performance, the BC ratio of 2.81 suggests a reasonable economic return relative to the inputs (26,27,28). The cluster bean-chickpea system also exhibited strong performance, with net returns reached ₹ 166,934, reflecting a favourable BC ratio of 4.04 (37,38,39,40). The green gram-chickpea system had net returns of ₹ 74,985 and a BC ratio of 3.14, indicating its effectiveness (48,49,50,51,52). In contrast, the moth bean-chickpea system produced net returns of ₹ 71,714 (Singh *et al*., 2021). The pearl millet-chickpea system had the lowest performance, with net returns of ₹ 47,597 and a BC ratio of 2.36, indicating challenges associated with this combination (46,47). Among the varieties, GNG-2171 exhibited the highest net return of ₹ 71,587 and a benefit-cost (BC) ratio of 3.05, demonstrating its economic viability. Following closely was GNG-1958, which showed net return of ₹ 69,578 with a BC ratio of 2.99, indicating a robust economic performance albeit slightly lower than GNG-2171 (29,30,31). GNG-2261 and GNG-2144 varieties yielded comparable net returns and BC ratios, reflecting consistent profitability across the studied chickpea varieties. In the interaction of varieties and cropping systems (**Table 8**), the fallow-chickpea system showed that GNG-1581 generated the highest net returns of ₹102,773 ha^{-1}, closely followed by GNG-2171, which yielded ₹91,587 ha^{-1}.

Table 8. Net returns of chickpea varieties across different cropping systems (pooled data)

Treatments	Net returns of chickpea (₹ ha^{-1})					Net returns of system (₹ ha^{-1})				
Cropping systems	GNG-2144	GNG-2261	GNG-1958	GNG-2171	GNG-1581	GNG-2144	GNG-2261	GNG-1958	GNG-2171	GNG-1581
Fallow- Chickpea	63988	72409	88421	91587	102773	63988	72409	88421	91587	102773
Groundnut-Chickpea	71735	73439	48972	47047	40609	268943	263365	239903	242658	226705
Sesame- Chickpea	52124	57774	65820	68014	73134	81614	88094	95026	98660	101610
Cluster bean-Chickpea	60301	68645	81756	85127	93676	149096	159212	169191	179523	177649
Green gram - Chickpea	60613	67411	78093	81007	87804	151877	156848	166388	178000	171717
Moth bean-Chickpea	60253	65507	74237	76568	82006	101410	106108	114006	120790	118208
Pearl millet-Chickpea	37659	42360	49746	51760	56460	67194	69935	76063	80658	80675
	Cropping systems	Chickpea varieties				Cropping systems	Chickpea varieties			
S.Em. ±	2284	2359				2608	2643			
CD at 5%	6667	6611				7613	7407			

This high return is indicative of the variety's resilience and yield potential in a less competitive environment, as supported by studies showing that fallow systems can sometimes provide higher economic returns due to lower input costs (44,45). The groundnut-chickpea intercropping system resulted in lower net returns for most chickpea varieties compared to the fallow system. GNG-2144 yielded ₹71,735 ha^{-1}, while GNG-1958 returned only ₹48,972 ha^{-1}. This reduction in returns might be attributed to the competition for resources between the two crops, which can adversely affect individual crop performance (37,38,39,40). The sesame-chickpea combination yielded moderate net returns, with GNG-1581 achieving ₹73,134 ha^{-1}. This system appears beneficial for both crops, providing reasonable economic returns while ensuring sustainable resource use, as supported by intercropping benefits documented by Kumar *et al*. (2020). Net returns in the cluster bean-chickpea system ranged from ₹149,096 ha^{-1} for GNG-2144 to ₹177,649 ha^{-1} for GNG-1581, showcasing the potential of this system to maximize profitability. The green gram-chickpea system similarly yielded high returns, with the best-performing variety, GNG-1581, generating ₹87,804 ha^{-1}. These findings align with the notion that intercropping can enhance overall system productivity and economic returns (48,49,50,51,52). Net returns from the moth bean-chickpea system were modest, with GNG-1581 yielding ₹82,006 ha^{-1}. In contrast, the pearl millet-chickpea system resulted in the lowest net returns, particularly for GNG-2144, which yielded ₹37,659 ha^{-1}. This highlights the challenges posed by less favourable cropping combinations that may not optimize resource use effectively (29,30,31,32). In the interaction between varieties and cropping systems (Table 9), all chickpea varieties demonstrated favorable BCRs in the fallow-chickpea system, with GNG-1581 achieving the highest BCR of 3.94.

Table 9. Benefit-Cost Ratio during the rabi season and across systems for chickpea varieties under different cropping systems (pooled data)

Treatments	Benefit cost ratio in chickpea					Benefit cost ratio during system				
Cropping systems	GNG-2144	GNG-2261	GNG-1958	GNG-2171	GNG-1581	GNG-2144	GNG-2261	GNG-1958	GNG-2171	GNG-1581
Fallow- Chickpea	2.83	3.07	3.53	3.62	3.94	2.83	3.07	3.53	3.62	3.94
Groundnut-Chickpea	3.05	3.1	2.4	2.34	2.16	4.36	4.29	4	4.03	3.83
Sesame- Chickpea	2.49	2.65	2.88	2.94	3.09	2.74	2.87	3.02	3.1	3.16
Cluster bean-Chickpea	2.72	2.96	3.34	3.43	3.68	3.71	3.89	4.08	4.26	4.23
Green gram -Chickpea	2.73	2.93	3.23	3.31	3.51	3.53	3.61	3.77	3.97	3.86
Moth bean-Chickpea	2.72	2.87	3.12	3.19	3.34	3.03	3.12	3.28	3.42	3.36
Pearl millet-Chickpea	2.08	2.21	2.42	2.48	2.61	2.43	2.49	2.62	2.72	2.72
	Cropping systems	Chickpea varieties				Cropping systems	Chickpea varieties			
S.Em. ±	0.07	0.07				0.06	0.06			
CD at 5%	0.19	0.19				0.18	0.16			

This indicates a strong economic return relative to the costs incurred. The consistently high BCR across varieties suggests that fallow systems can provide stable profitability, aligning with findings that emphasize reduced competition and lower input costs in such systems (16,17,18). The groundnut-chickpea intercropping system yielded varied BCRs among the chickpea varieties. GNG-2144 had a BCR of 3.05, while GNG-1581 recorded the lowest at 2.16. The higher BCR for GNG-2144 indicates its superior performance in this system, likely due to its adaptability and efficient resource utilization. However, the system itself had a high overall BCR ranging from 3.83 to 4.36, reflecting the profitability of intercropping legumes with oilseeds, which has been reported to enhance overall yield and returns (37,38,39,40). In the sesame-chickpea system, the BCRs ranged from 2.49 for GNG-2144 to 3.09 for GNG-1581. This indicates moderate profitability, which can be attributed to both crops benefitting from intercropping dynamics, where legumes improve soil fertility and reduce pest incidence (46,47). The cluster bean-chickpea system yielded higher BCRs across all varieties, with GNG-1581 achieving 4.23. This demonstrates the effectiveness of intercropping legumes with cluster beans in maximizing profitability. Similarly, in the green gram-chickpea system, BCRs were also strong, with GNG-1581 recording a BCR of 3.51. These results align with the benefits of legume intercropping, which enhances nutrient cycling and improves overall system efficiency (48,49,50,51,52). The moth bean-chickpea system displayed a BCR ranging from 2.72 for GNG-2144 to 3.34 for GNG-1581, indicating a reasonable return. In contrast, the pearl millet-chickpea system yielded the lowest BCRs, with GNG-2144 at 2.08. This suggests that pearl millet may not be as advantageous as other cropping systems for chickpea cultivation, likely due to competition for resources and less favourable growth conditions (44,45).

3.7 Production efficiency and land resource use efficiency (LRUE)

Data on production efficiency, and land resource use efficiency (LRUE) across different cropping systems over a two-year pooled analysis (Table 6). The results of the pooled analysis of production efficiency, and land resource use efficiency across various cropping systems reveal significant insights into the benefits of intercropping strategies. In terms of production efficiency, the groundnut system stood out with 263 kg $ha^{-1} day^{-1}$, while the pearl millet system lagged at 8.95 kg $ha^{-1} day^{-1}$. Land resource use efficiency (LRUE) mirrored these findings, with the groundnut system achieving 71.93% LRUE, demonstrating optimal land use dynamics (46,47). Overall, these findings emphasize the importance of selecting suitable intercropping systems to enhance yield, economic viability, and resource efficiency in chickpea cultivation. In terms of land resource use efficiency, all varieties achieved LRUE values above 58%, with GNG-1581 reaching 59.72%, suggesting that these varieties effectively utilized the available land resources for production (37,38,39,40).

4. Conclusion

This study highlights the superior performance of the Fallow-Chickpea cropping system in terms of yield attributing parameters, seed yield, and harvest index. Such findings underscore the importance of optimizing cropping systems to enhance chickpea production and food security. Future research could focus on exploring the underlying mechanisms that contribute to these performance differences and on implementing agronomic practices that maximize yield potential. The study demonstrates that GNG-1581 is the most productive variety, excelling in both seed and stover yields. These findings underscore the importance of selecting appropriate chickpea varieties to enhance productivity and ensure sustainable agricultural practices. Future research should explore the genetic and environmental factors influencing these traits to further optimize chickpea production. The analysis of seed and stover yields across different chickpea varieties and cropping systems reveals that GNG-1581 consistently outperformed others, particularly in fallow conditions. The findings underscore the importance of selecting appropriate chickpea varieties for specific cropping systems to optimize both yield and stover production, thus enhancing overall agricultural sustainability.

Author Contributions

M.L.R., M.S.K. and B.S.K. Conceptualization; Data curation; Writing- original draft; review editing and supervision. N.K., R.P., K.K., S.C., P.R.R., S.R.C., A.C., C.K.D., V.K., A.S., C.M., R.P. M.K.D. and S.M. methodology, formal analysis and provided valuable feedback to this study. All authors have read and agreed to the published version of the manuscript.

Future line of interest

This studies can be extended with different varieties and different cropping systems to increase productivity and yield.

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