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Land equivalent ratio as influenced by intercrops in cauliflower (*Brassica oleracea var. botrytis*).

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ABSTRACT

The field investigations were conducted at the Vegetable Experimental Farm, Division of Vegetable Science and Floriculture, SKUAST, Chatha, Jammu to examine the impact of intercropping systems on the yield and economics of various sole and intercrops. The experiment employed a Randomized Complete Block Design (RCBD) with three replications and fifteen treatments. The sole crop treatments included T1- Cauliflower, T2- Knol-khol, T3- Spinach beet, T4- Swiss chard, T5- Lettuce, T6- Fenugreek, T7- Coriander, and T8- Radish. The intercrop treatments were T9- Cauliflower + Knol-khol, T10- Cauliflower + Spinach beet, T11- Cauliflower + Swiss chard, T12- Cauliflower + Lettuce, T13- Cauliflower + Fenugreek, T14- Cauliflower + Coriander, and T15- Cauliflower + Radish. The sole treatment of Cauliflower produced the highest yield (220.00 q/ha) compared to the intercropping treatments. Among the intercropping treatments, the combination of cauliflower and coriander produced the highest values for Land Equivalent Ratio (LER) at 1.35, Monetary Advantage Index (MAI) at 63.29, and Cabbage Equivalent Yield (CEY) at 284.54 q/ha, while cauliflower and fenugreek had the highest production efficiency at 2.45 q/ha/day. Economically, the cauliflower and coriander intercrop achieved the highest gross return (711,350 Rs./ha), net return (596,352 Rs./ha), and Benefit-Cost (BC) ratio (5.19). Therefore, the research concluded that intercropping cauliflower with leafy vegetables like coriander and fenugreek is more profitable than cultivating cauliflower alone. The study confronted challenges in balancing yield and economic viability across diverse crop combinations, yet it highlights the profitability and efficiency of intercropping cauliflower with leafy vegetables, offering valuable insights for optimizing vegetable farming practices.

Keywords: *Brassica oleracea var. botrytis, Cauliflower-based intercropping, Climate adaptation in farming, Economics, Intercrop, Land Equivalent Ratio (LER), Production efficiency, Sole crop, Yield optimization*

1. INTRODUCTION

The global rise in population and industrialization has steadily reduced cultivable land, increasing the demand for arable land to support food production, especially in regions like Asia and Africa where smallholder farming dominates [3]. A primary strategy to address this issue involves boosting productivity per unit area or expanding the area under cultivation, though this becomes increasingly difficult. Therefore, developing vegetable-based cropping systems that efficiently utilize both natural and artificial resources is essential to meet the needs of a growing population. Intercropping offers a promising approach due to its efficient use of space, water, nutrients, and sunlight, resulting in higher crop productivity compared to monoculture systems [34]. This method involves cultivating multiple crops on the same plot in a structured row-planting format to achieve increased productivity per area unit. Success in intercropping depends on factors like plant density, timing of sowing and harvest, maturity rates, crop selection, and regional socio-economic conditions. The land equivalent ratio (LER) is a key metric used to evaluate land productivity in intercropping systems [4].

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Cauliflower, known for its wide spacing, is especially suitable for intercropping and is widely cultivated in nations like China, India, the U.S., Spain, Mexico, and Italy. As a long-duration, nutrient-intensive winter crop, cauliflower requires regular management throughout its growth period. However, during the early stages, it does not develop sufficient leaf area to capture all the sunlight available in the field, and its wide spacing often results in unused sunlight between rows. This lost sunlight can be effectively utilized by intercropping short-duration, dwarf crops like Fenugreek, Coriander, Lettuce, Swiss chard, Spinach beet, Knol-khol, and Radish in the gaps between cauliflower rows. This approach maximizes returns per unit area by optimizing land and input use for the main crop. Given the pressing need to feed a growing population and make efficient use of diminishing farmland, adopting vertical cropping systems or more intensive land use models is critical. Studies indicate that efficient vegetable-based cropping systems can achieve an LER greater than 1, reflecting increased productivity [3,19,22,8]. In this context, a study was conducted to explore optimal land and resource use in vegetable-based cropping systems, specifically calculating the LER of cauliflower intercropped with quick-growing cash crops like Fenugreek, Coriander, Lettuce, Swiss chard, Spinach beet, Knol-khol, and Radish to enhance yields and returns for farmers.

2. MATERIAL AND METHODS

The field experiment was conducted at the Vegetable Experimental Farm, Division of Vegetable Science and

Floriculture, Sher-e-Kashmir University of Agricultural Science & Technology, Jammu, during the Rabi season of 2021-2022. The soil at the experimental site was sandy loam with a pH of 7.35, containing 0.35% organic carbon and 215.15, 18.00, and 130.70 kg/ha of available nitrogen, phosphorus, and potassium respectively. The study involved three replications and a total of fifteen different treatments. Among these, eight were dedicated to individual crops, specifically: T1 for Cauliflower, T2 for Knol-khol, T3 for Spinach beet, T4 for Swiss chard, T5 for Lettuce, T6 for Fenugreek, T7 for Coriander, and T8 for Radish. Additionally, there were seven treatments involving intercropping combinations: T9 with Cauliflower and Knol-khol, T10 with Cauliflower and Spinach beet, T11 with Cauliflower and Swiss chard, T12 with Cauliflower and Lettuce, T13 with Cauliflower and Fenugreek, T14 with Cauliflower and Coriander, and T15 with Cauliflower and Radish. The varieties used were for Cauliflower (Snowball-16), Knol Khol (G-40), Spinach beet (Jammu Spinach beet-07), Swiss chard (Jammu swisschard-01), Lettuce (Chinese Yellow), Fenugreek (Jammu Fenugreek-07), Coriander (Jammu Coriander-07), Radish (CR-45). The study was carried out employing a Randomized Complete Block Design. Seeds of cauliflower, knol-khol, and lettuce were sown on 6th September 2021 to raise healthy seedlings on raised beds, following the recommendations of the Package of Practices for Vegetable Crops, 2020. The main crop, cauliflower, was transplanted with a spacing of 60 centimeters by 60 centimeters and intercrops were sown between the rows at a plant spacing of 20 cm on 9th October 2021. The necessary cultural operations were performed according to the recommendations of the Package of Practices for Vegetable Crops, Division of Vegetable Science and Floriculture at SKUAST, Jammu, 2020. In addition to the basal application of well-rotted farmyard manure (FYM) at 25 t/ha, chemical fertilizers were applied as recommended for cauliflower (120 kg N, 60 kg P2O5, 60 kg K2O). The well-rotted FYM was applied to the individual plots a few days before preparation, along with one-third of the nitrogen dose and the full doses of P2O5 and K2O. The remaining two-thirds of the nitrogen was top-dressed in two equal doses, 30 and 45 days post-transplantation of the main crop cauliflower. Other intercultural operations were carried out as recommended. The crop duration of the main cauliflower was used as a benchmark for harvesting sole crops and intercrops. The intercrops in the intercropping system were harvested before the main crop cauliflower's canopy spread. In sole cultivation, along with the harvesting of cauliflower, a single crop of lettuce and a double crop of radish and knol-khol were harvested. For leafy vegetables, only two cuts were taken.

3. RESULT AND DISCUSSION

3.1 Yield of main crop and intercrops as sole and in intercropping

The yield data indicated that cauliflower as a sole crop achieved the highest yield at 220.00 q/ha, significantly outperforming most intercropping treatments except when combined with fenugreek (209.96 q/ha) and coriander (200.00 q/ha). Intercropping is most effective when the intercrops have different growth patterns and durations, allowing their peak resource needs to occur at different times. The differences in growth period, maturity, and resource use between cauliflower and intercrops like fenugreek and coriander likely minimized or delayed competition, allowing cauliflower to fully capitalize on available resources after the intercrops were harvested. The high yield in sole cauliflower was attributed to larger curds and increased plant weight, consistent with findings by [25], who observed similar results in sole-cropped carrot compared to intercropping with groundnut, as did [16, 29].

In contrast, intercropping with knol-khol and radish reduced cauliflower yield (136.23 q/ha and 138.90 q/ha, respectively), likely due to the broad spread of their leaves and roots, which monopolized resources around the cauliflower. Similarly, [6] reported lower fruit yield in a chili-radish intercropping system, and [33] observed adverse effects of knol-khol intercropping on cabbage, potentially due to allelochemicals from root exudates of plants in the same botanical family. For intercrops, sole cropping outperformed intercropping, as the latter limited yield-attributing characteristics due to increased competition. In monocropping, plants had better access to space, light, and resources, leading to higher photosynthetic rates and more efficient photosynthate translocation, which boosted yield. These findings align with [25], who reported maximum yield parameters in sole crops compared to intercropping with groundnut, with similar observations by [23, 24] in carrot-coriander and carrot-fennel systems, and by [20] and [6] in okra and chili. Reduced intercrop yields were primarily due to a 30-40% decrease in plant population needed to accommodate the main crop, as supported by findings in brinjal-garlic [17], cowpea-tomato [27], coriander-based [21], and chili-based [32] intercropping systems.

Table 1: Yield of cauliflower (main) and intercrops as sole crop and as influenced by intercropping

Notation(s)	Treatment (s)	Cauliflower yield /ha (q)	Intercrop yield /ha (q)
	A) Sole crop		
T1	Cauliflower (Snowball-16)	220.00	-
T2	Knol-khol (G-40)	-	295.20
T3	Spinach beet (Jammu Spinach beet- 07)	-	162.13
T4	Swiss chard (Jammu Swiss chard- 01)	-	169.00
T5	Lettuce (Chinese Yellow)	-	110.32
T6	Fenugreek (Jammu Fenugreek- 07)	-	140.95
T7	Coriander (Jammu Coriander- 07)	-	95.30
T8	Radish (CR-45)	-	258.60
	B) Inter crops		
T9	Cauliflower + Knol-khol	136.23	102.60
T10	Cauliflower + Spinach beet	158.80	83.22
T11	Cauliflower + Swiss chard	162.50	93.50
T12	Cauliflower + Lettuce	155.10	63.40
T13	Cauliflower+ Fenugreek	209.96	45.27
T14	Cauliflower + Coriander	200.00	42.27
T15	Cauliflower + Radish	138.90	121.23
SEm (±)		3.38	2.25
C.D (5%)		10.35	6.95

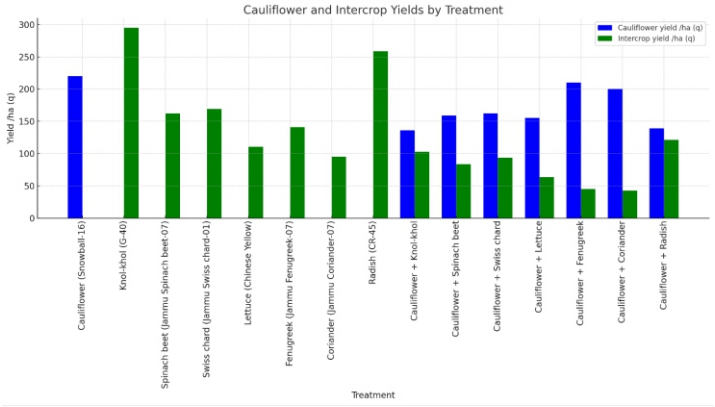

Fig 1: Yield of cauliflower (main) and intercrops as sole crop and as influenced by intercropping

3.2 Evaluation of yield advantage in an intercropping system

a) Land Equivalent Ratio (LER)
b) Monetary Advantage Index (MAI)
c) Production Efficiency (PE)
d) Cauliflower Equivalent Yield (CEY)

In this study, the yield advantage of various intercropping systems was assessed by calculating the Land Equivalent Ratio (LER). For monocropping, the LER is always 1, while an LER above 1 indicates a yield benefit in intercropping due to more efficient land use [13]. Results showed that all intercropping treatments achieved higher LERs than their respective sole crops, except cauliflower intercropped with knol-khol, which had an LER of 0.97. The cauliflower-coriander intercropping achieved the highest LER of 1.35, closely followed by cauliflower-fenugreek at 1.30. These values imply that sole cropping would require an additional 0.35 and 0.30 ha, respectively, to match the intercropping yields, effectively saving 10% to 35% of land for additional cultivation and offering a clear yield advantage. These LER findings align with [10] for fenugreek-cauliflower and with [2], who recorded the highest LER in cabbage-broad bean intercropping. High LER values were also reported in maize-potato [5, 11] and other intercropping systems such as chili-garlic, tomato-okra, and brinjal-garlic [9, 15, 17].

Monetary Advantage Index (MAI) values further highlighted the economic benefit of intercropping, as higher LERs were associated with higher MAI. All intercropping treatments, except cauliflower-knol-khol (-8.19), had positive MAI values, with the cauliflower-coriander intercropping recording the highest MAI at 63.29, followed by fenugreek and Swiss chard. The negative MAI in cauliflower-knol-khol reflects its economic unsuitability. These results align with [31], who found high MAI values in sugarcane + beetroot intercropping, as well as [17] in brinjal-garlic and [11] in groundnut-maize intercropping.

Production efficiency was also highest in the cauliflower-fenugreek system (2.45 q/ha/day), followed by Swiss chard, radish, and coriander, reflecting these systems' productivity and profitability over sole cropping. This outcome is supported by [14], who recorded the highest production efficiency in banana-cauliflower-potato intercropping, followed by banana-radish-potato, and [5] in maize-potato.

Finally, cauliflower equivalent yield (CEY) was higher in all intercrops except for radish and knol-khol combinations, with the cauliflower-coriander intercrop recording the highest CEY (284.54 q/ha) and Swiss chard following (274.70 q/ha). These findings on increased production through intercropping are consistent with studies on cabbage-based [7], chilli-garlic [9], groundnut-vegetable [26], coriander-brinjal [28], and brinjal-based [18] intercropping systems.

Table 2: LER, MAI, PE and CEY of cauliflower as influenced by intercropping

Notation(s)	Treatment (s)	LER	MAI	PE (q/ha/day)	CEY (q/ha)
A) Sole crop					
T1	Cauliflower	1.00	-	2.16	220.00
B) Inter crops					
T9	Cauliflower + Knol-khol	0.97	-8.19	2.12	218.31
T10	Cauliflower + Spinach beet	1.24	46.13	2.24	242.02
T11	Cauliflower + Swiss chard	1.29	57.85	2.35	274.70
T12	Cauliflower + Lettuce	1.28	47.74	1.96	256.53
T13	Cauliflower + Fenugreek	1.30	59.07	2.45	255.23
T14	Cauliflower + Coriander	1.35	63.29	2.29	284.54
T15	Cauliflower + Radish	1.10	23.84	2.30	211.64
SEm (±)		0.01	3.36	0.03	3.30
C.D (5%)		0.05	10.49	0.11	10.28

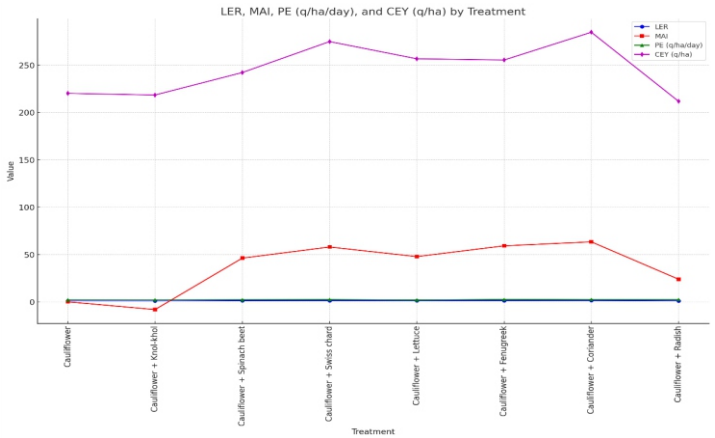

Fig 2: LER, MAI, PE and CEY of cauliflower as influenced by intercropping

3.3 Economics of production

The economic analysis showed that intercropping cauliflower with coriander was the most profitable system, yielding the highest net return of Rs. 596,352/ha and a benefit-cost (BC) ratio of 5.19. This was closely followed by cauliflower intercropped with lettuce (Rs. 536,352/ha, BC ratio 5.11) and with fenugreek (Rs. 532,327/ha, BC ratio 5.03). Conversely, sole cropping of radish was the least profitable, with a net return of Rs. 290,551/ha and a BC ratio of 3.0. Among the intercropping setups, cauliflower with radish recorded the lowest profitability, with a net return of Rs. 423,772/ha and a BC ratio of 4.02. The higher profitability in cauliflower-coriander intercropping resulted from maximum cauliflower equivalent yield (CEY) and added income from coriander, whereas lower returns in the cauliflower-radish combination were due to a reduced CEY and minimal extra income from radish.

These findings align with [7], who observed the highest returns and BC ratio for cabbage intercropped with peas, while cabbage-beet intercropping was the least remunerative. [23] similarly reported the highest BC ratio in coriander-based intercropping systems, and [12] found optimal returns in a potato-Dolichos system, echoing results from studies by [1] and [31] that support these conclusions.

Table 3: Economics of production in sole crops and in various intercropping

Notation(s)	Treatment (s)	Cost of cultivation (Rs. /ha)	Yield (q/ha)	Gross return (Rs. /ha)	Net return (Rs. /ha)	BC ratio
A) Sole crop						
T1	Cauliflower	97123	220.00	550000	452877	4.66
T2	Knol- khol	95815	295.20	590400	494585	5.16
T3	Spinach beet	100575	162.13	405325	304750	3.06
T4	Swiss chard	111075	169.00	507000	395925	3.56
T5	Lettuce	97255	110.32	441280	344025	3.54
T6	Fenugreek	89711	140.67	364875	275164	3.10
T7	Coriander	100739	95.30	476500	375761	3.73
T8	Radish	97349	258.60	387900	290551	3.00
B) Inter crops						
T9	Cauliflower + Knol-khol	104248	136.23 + 102.60	545775	441527	4.24
T10	Cauliflower + Spinach beet	109748	158.80 + 83.22	605050	495302	4.51
T11	Cauliflower + Swiss chard	114998	162.50 + 93.50	686750	571752	4.97
T12	Cauliflower + Lettuce	104998	155.10 + 63.40	641350	536352	5.11
T13	Cauliflower + Fenugreek	105748	209.96 + 45.27	638075	532327	5.03
T14	Cauliflower + Coriander	114998	200.00 + 42.27	711350	596352	5.19
T15	Cauliflower + Radish	105323	138.90 + 121.23	529095	423772	4.02

Sale price of cauliflower @ Rs. 25/kg, Knol-khol @ Rs. 20/kg, Spinach beet @ Rs. 25/kg, Swiss chard @ Rs. 30/kg, Lettuce @ Rs. 40/kg, Fenugreek @ Rs. 25/kg, Coriander @ Rs. 50/kg, Radish @ Rs. 15/kg.

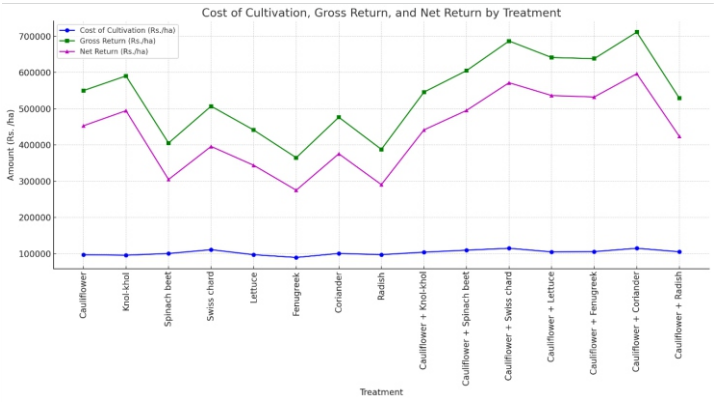

Fig 3: Economics of production in sole crops and in various intercropping

4. CONCLUSION

Drawing from the research findings, it can be concluded that intercropping cauliflower with coriander emerged as the most lucrative option among the various intercropping combinations. This combination stood out due to its highest values of LER, MAI, and CEY, closely followed by intercropping cauliflower with fenugreek. Regarding the economic viability of treatments, cauliflower intercropped with coriander recorded the highest values for gross return (711,350 Rs./ha), net return (596,352 Rs./ha), and BC ratio (5.19). Consequently, the intercropping combinations of Cauliflower + Coriander and Cauliflower + Fenugreek are recommended as the best options for farmers aiming to maximize land utilization and achieve optimal economic returns.

5. FUTURE SCOPE

Future studies could focus on optimizing intercropping models for diverse climates, improving soil health, and enhancing water and nutrient efficiency. Research on mechanization compatibility, economic viability for small farms, and adaptation to climate change will further support sustainable and profitable intercropping practices.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest related to this study.

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