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ORIGINAL RESEARCH ARTICLE

Co-cultivation of basil (*Ocimum basilicum* L.) with fodder and vegetable crop for enhancing productivity and resource use efficiency

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ABSTRACT

To test this hypothesis in a representative location of the western Himalayan region, we study the intercropping of fodder and vegetable crops with basil. This experiment was laid out at CIMAP research Centre Purara, Bageshwar, Uttarakhand, during the years 2020-21 and 2021-22. Maize, sorghum, and pearl millet were cultivated as fodder crops, and okra and coriander were grown as vegetable crops with basil as an intercrop during both years. The biological efficiency of the intercropping system was assessed using LER, ATER, aggressivity, competitive ratio and relative crowding coefficient (K). It was found that sole basil had the highest yield, with 378.01 q ha^{-1} of fresh and 98.28 q ha^{-1} of dry herbs, followed by the intercrop of basil + coriander, with 218.19 q ha^{-1} of fresh herb and 56.73 q ha^{-1} of dry herb. The basil + coriander intercrop showed the highest LER (1.29), followed by basil + okra (1.27). Basil + okra had the highest MAI value of ₹ 129517.30 ha^{-1}, suggesting that the intercrop combination was the highest gainer, followed by basil + fodder maize combination with an MAI value of ₹ 92203.66 ha^{-1}. Basil + okra had the highest B:C ratio of 4.89 and the highest NR of ₹ 391497, followed by sole basil with an NR of ₹ 297655 and a B:C ratio of 3.72.

INTRODUCTION

Uttarakhand, a state in the lower Himalayas of India, spans 5,348 hectares, accounting for 1.63% of the country's total geographical area. The state's economy relies heavily on agriculture, which is the primary livelihood source for over 70% of its population. (Shukla *et al*., 2019). In most Uttarakhand, species like citrus, apple, peach, and pear are adopted as fruit crops, while wheat and paddy are preferred as cereal crops. If we talk about cultivating vegetables in the Kumaon and Garhwal regions, all the major vegetables are grown there (Negi *et al*., 2015). However, cultivation in the hilly regions needs to be improved for livelihoods. Crop production needs to meet demand due to small field sizes, terraced farming, low organic matter, rain-dependent irrigation, and wild animal interference.

Therefore, intercropping is a promising solution to boosting income, utilizing resources efficiently, and providing insurance against weather challenges. It optimizes land use, water, and nutrients while aiding weed control and preventing soil erosion. The co-cultivation of medicinal/aromatic crops with vegetable and fodder crops provides a sustainable livelihood option for farmers in hilly areas of Uttarakhand. Resilience

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to wildlife threats makes medicinal and aromatic crops suitable choices. Combining medicinal and vegetable crops brings multiple advantages while integrating fodder crops benefits livestock nutrition. This approach effectively addresses the challenges faced by farmers.

The Kumaon and Garhwal regions of Uttarakhand cultivate basil (*Ocimum basilicum* L.). Basil is in high demand from hilly regions. It belongs to Lamiaceae family and is cultivated as an aromatic and medicinal plant in tropical and subtropical regions worldwide (Aburjai *et al*., 2020). Considering the challenges faced by farmers and the demand for basil, this study aimed to find the ideal intercrops combination for fodder and vegetable crops with basil in hilly areas of the western Himalayan region. The study aims to support farmers, enhance their livelihoods, and promote a viable and widespread farming approach.

MATERIALS AND METHODS

Experimental Site

The investigation was conducted at CSIR-Central Institute of Medicinal and Aromatic Plant, Research Centre, Purara, Uttarakhand, India (29.92°_N latitude and 79.62°_E longitude, 1149 m above MSL) from 2020 to 2021 in the period from June to October. The temperature during summer ranges from 20 °C to 38 °C, and during winter, the temperature drops to a minimum of -2 °C with a maximum of 22 °C. The monsoon in the location usually arrives in June and recedes by mid-September. The soil sample was collected and analyzed before and after the cultivation of crops.

Experiment and Cultivation

Basil was taken as the main crop in all the crop combinations during the investigation. A total of 5 crop combinations were made, which included fodder and vegetable crops (Table 1 & Fig. 1-2). All the crops taken as intercrop were also grown as sole crops. The entire study was organized into a total of 11 treatments (C_1- sole basil; C_2- sole fodder maize; C_3- sole okra; C_4- sole fodder pear millet, C_5- sole fodder sorghum; C_6- sole coriander; C_7- basil + fodder maize; C_8- basil + okra; C_9- basil +fodder pear millet; C_{10}- basil + fodder sorghum; C_{11}- basil + coriander). All recommended packages of agricultural practices were followed in 2020 and 2021, as per Table 1.

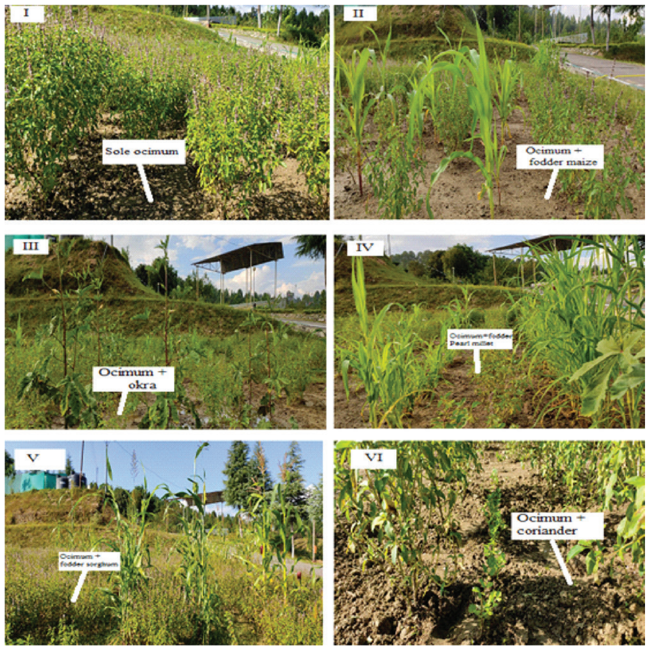

Figure 1: Visual representation of various treatments in the exprimental setup; (i) Basil sole crop; (ii) C_7: Basil + fodder maize; (iii) C_8: Basil + Okra, (iv) C_9: Basil + fodder pearl millet, (v) C_{10} Basil + fodder sorghum; (vi) C_{11}: Basil + Coriander

Essential Oil Analysis

To extract the essential oils of each treatment, fresh shoot portions were hydro-distilled in the glass Clevenger apparatus using the recommended method for 3 hours. Oil volume was measured directly in the extraction burette. GC was carried out on Thermo Fischer Trace GC-1300, equipped with a TG-5 capillary column (30m x 0.25mm, 0.25µm film thickness) (Safitri and Sinaga, 2021), with a flame ionization detector (FID). The oven temperature ranged from 70 to 220 °C, programmed at 4 °C min^{-1}, using N_2 as carrier gas at a constant flow rate of 1.0 ml min^{-1}. The Injector and detector (FID) temperatures were maintained at 240 °C and 250 °C, respectively. Injection volumes of the oils were 0.02µL neat with a split ratio of 1:40. The relative content of constituent was calculated based on the percentage peak area (FID response) without a correction factor.

Competitions Indices

The benefits of intercropping and the effect of competition between the two species in the combination were calculated using several competition indices. Because basil and fodder maize, sorghum and pearl millet were the desired species,

Table 1: Experimental details of sole crop and intercrop combination during 2020 and 2021 with agricultural practices

Treat-ment	Name of varieties	Planting date	NPK doses	FYM (q ha^{1})	Spacing (cm)	Plant population ha^{1}	Harvesting (DAT*)			
							I	II	III	IV
A. **Sole cropping**										
C_1	CIM-Soumya	30th June	120:60:60	160	50 X 50	40000	-	-	-	110
C_2	Jawahar	15th July	60:40:20	100	30 X 10	333333	30	55	80	105
C_3	KTCBH-81	15th July	150:120:80	120	45 X 30	74074	60	75	90	105
C_4	FBC-16	15th June	60:40:20	100	30 X 10	333333	30	55	80	105
C_5	CO-11	15th June	60:40:20	100	30 X 10	333333	30	55	80	105
C_6	Pant Haritama	15th June	80:40:40	120	20 X 15	333333	60	75	90	105
B. **Intercropping with 1:1 sown proportion**										
C_7	CIM-Soumya+ Jawahar	Crop A -30th June Crop B- 15th July	120:60:60	150	Crop A- 50 X 50 Crop B- 50 X 20	Crop A-20000; Crop B-100000	Crop B-30	Crop B-55	Crop B-80	Crop A -110; Crop B -105
C_8	CIM-Soumya+ KTCBH-81	Crop A -30th June Crop B - 15th July	120:60:60	160	Crop A- 50 X 50 Crop B- 50X 25	Crop A-20000; Crop B-80000	Crop B-60	Crop B-75	Crop B-90	Crop A-110; Crop B- 105
C_9	CIM-Soumya + FBC-16	Crop A-30th June Crop B - 15th June	120:60:60	140	Crop A- 50 X 50 Crop B- 50 X 20	Crop A-20000; Crop B-100000	Crop B-30	Crop B-55	Crop B-80	Crop A-110; Crop B -105
C_{10}	CIM-Soumya + CO-11	Crop A -30th June Crop B -15th June	120:60:60	130	Crop A- 50 X 50 Crop B- 50 X 20	Crop A-20000; Crop B-100000	Crop B-30	Crop B-55	Crop B-80	Crop A-110; Crop B-105
C_{11}	CIM-Soumya + Pant Haritama	Crop A-30th June Crop B- 15th June	120:60:60	120	Crop A- 50 X 50 Crop B- 50X 20	Crop A-20000; Crop B-100000	Crop B-60	Crop B-75	Crop B-90	Crop A-110; Crop B-105

C_1- Sole basil; C_2- Sole fodder maize; C_3-Sole okra; C_4- Sole fodder pear millet, C_5-Sole fodder sorghum; C_6- Sole coriander; C_7- basil + fodder maize; C_8- basil + okra; C_9- basil +fodder pear millet; C_{10}- basil +fodder sorghum; C_{11}- basil + coriander, the basil was harvested once after 110 days, while the remaining intercropping crops were harvested four times at different intervals, as stated in the table. *Day after transplanting, Crop A – basil; Crop B was planted as intercrop; The basil nursery was planted on 1st August in both years, and the seeds of all the crops were sown directly in their treatment plots; NPK were applied through urea, single super phosphate, and muriate of potash. Nitrogen through urea was given under three splits, and weed control was done manually.

the Land Equivalent Ratio (LER) was utilized as the criterion for mixed stand benefit. The LER was calculated as follows (Xu *et al.*, 2020):

i. $LER= L_{ba} +L_{be} =Y_{babe}=Y_{babe}/Y_{baba}+Y_{beba/}Y_{bebe}$ (Equation 1)

L_{ba} = yield of intercropped basil, L_{be} = yield of intercropped fodder and vegetable crop, Y_{baba} = sole crop of basil, and Y_{bebe} = intercropped fodder and vegetable crop. The second indicator is the area time equivalent ratio (ATER). This index provides a more realistic comparison of the yield benefits of an intercrop against a single crop in terms of the time taken by the intercropping system's constituent crops. ATER was calculated using the formula (Naveena *et al.*, 2015).

ii. $ATER= (RY_{ba} X\ t_{ba}) (RY_{be} X\ t_{be})/T$ (Equation 2)

Where RY_{ba} = relative yield of Basil, RY_{be} = relative yield of fodder and vegetable crops, t_{ba} = duration (days) for basil, t_{be} = duration (days) for fodder and vegetable crops and T = duration of whole cropping season. The aggressivity index is used in intercropping to measure yield variations between two component crops affected by inter-species competition (Gitari *et al.*, 2020). The aggressivity index was calculated using the method below to measure the competitiveness of basil, fodder, and vegetable crops in an intercropping system.

iii. $A_{babe}=Y_{babe}/Y_{baba} \times Z_{babe}-Y_{beba}/Y_{bebe} \times Z_{bebav}$ (Equation 3)

A_{babe} represents basil aggressiveness toward fodder and vegetable crops, Z_{babe} represents basil's

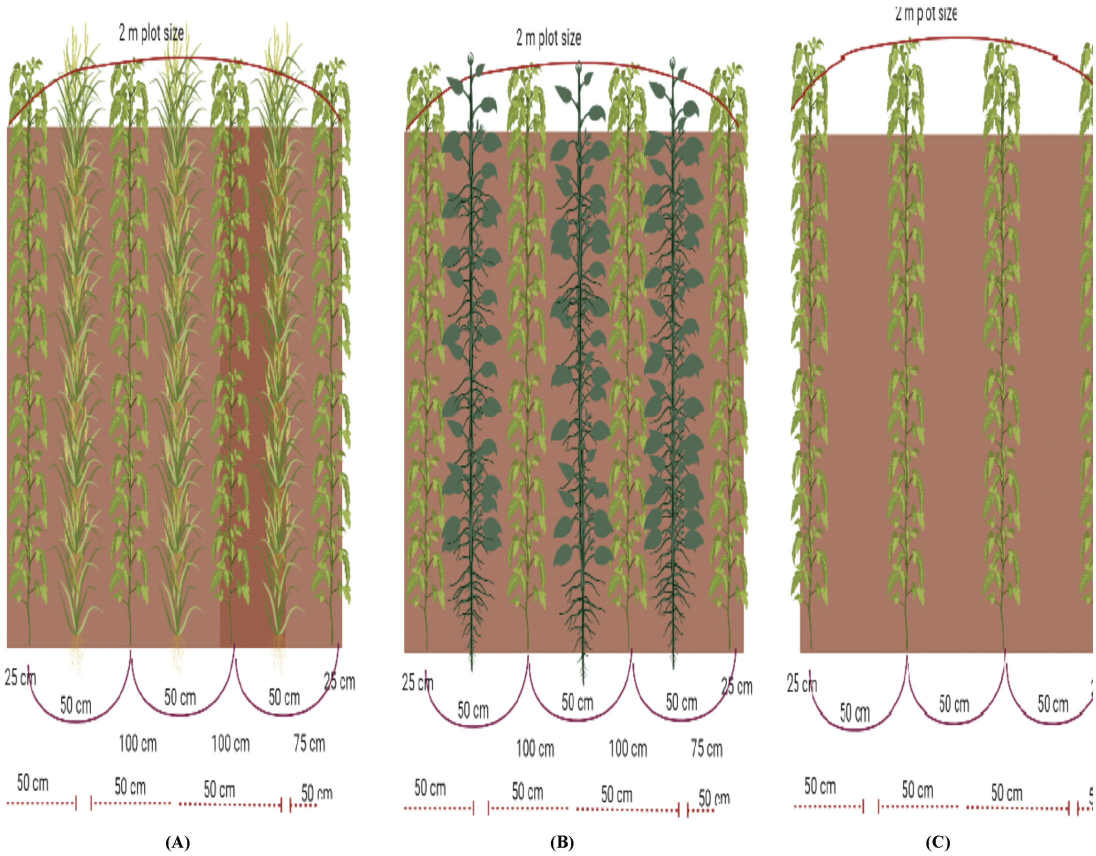

Figure 2: Visual representation showcasing the most profitable combination of (A) basil + fodder sorghum; (B) basil + okra, and (C) Sole basil planting arrangement of plants

sown proportion in fodder and vegetable crops, and Z_{beba} represents the sown proportion of fodder and vegetable crops in basil plots. The competitiveness ratio (CR) was calculated to examine which crops compete with one another in an intercropping system, and it was calculated by the formula below (Raza *et al*., 2019).

iv. $CR_{ba} = Y_{babe}/Y_{baba} \times Z_{beba}/Y_{bebe} \times Z_{beba}$ (Equation 4)

Where CR_{ba} stands for Competitive Ratio for basil, and all other abbreviations like Y_{baba}, Y_{babe}, Z_{babe}, and Z_{beba} are defined in the equations above. The relative crowding coefficient (RCC) measures the relative dominance of one species over another in a combination (Omezine and Teixeira Da Silva, 2016). It was calculated as follows.

v. $K=(K_{Basil} \times K_{Fodder\ and\ vegetable\ crop})$; $K_{Basil}=Y_{ml} \times Z_{lm}/((Y_m - Y_{ml}) \times Z_{ml})$; $K_{Fodder\ and\ vegetable\ crop}=Y_{lm} \times Z_{ml}/((Y_l - Y_{lm}) \times Z_{lm})$ (Equation 5)

Z_{ml} and Z_{lm} were the proportions of basil and intercrop in the combination, respectively. An important index called the monetary advantage index (MAI) shows how much profit is generated in the intercropping system (Bhadu *et al*., 2021). When the index value is higher, the cropping system is more profitable.

vi. MAI = Value of combined intercrops × (LER−1) / LER. (Equation 6)

Economics Calculation and Statistical Analysis

The income and expenditure of basil were calculated according to the price of dry herbs provided by CIMAP Lucknow. At the same time, crops such as fodder maize, sorghum and fodder pearl millet were calculated according to the local market value. The income and expenditure of okra and coriander were determined according to the price of the local market. The cost of cultivation for each crop, including labour, planting material and manure, transportation, etc., was considered. Cost of cultivation, gross profit, net profit and B:C ratio were estimated. The following formula calculated net return and B:C (Gómez-Candón *et al*., 2012).

vii. NR = Gross Return = cost of cultivation (Equation 7)

viii. B:C ratio = Gross return/cost of cultivation (Equation 8)

The experimental design used three random blocks and eleven plots as treatments. The data were subjected to analysis of variance (ANOVA) using Origin Pro 2018.

RESULTS AND DISCUSSION

The pooled data from the year 2020-21 and 2021-22 revealed significant effects of sole crop and intercropping combinations on the growth and development of basil (Table 2). C_1 (Sole basil) exhibited the highest plant height (90.20 cm), followed by C_{11} (basil + coriander) with a height of 82.80 cm. C_9 (Basil + fodder pear millet) and C_9 (basil + okra) had moderate plant heights of 75.73 cm and 73.33 cm, respectively, while C_{10} (basil + fodder sorghum) and C_7 (basil + fodder maize) had lowest plant heights of 55.53 cm and 54.40 cm, respectively. Regarding plant diameter (cm), sole basil had the highest measurement (90.93 cm), followed by C_{11} (basil + coriander) with a diameter of 86.40 cm. Conversely, C_7 (basil + fodder maize) exhibited the least diameter at 35.93 cm. C_1 (Sole basil) also had the highest number of leaves (628.53), Followed by C_{11} (basil + coriander) with 518.73 leaves, and C_9 (basil + fodder pearl millet) had the lowest number of leaves at 173. The number of branches in basil plants varied across different intercropping treatments. Among the intercrop treatments, C_{10} (basil + fodder sorghum) had the highest number of branches (18.06), followed by C_{11} (basil + coriander) with 17.93 branches, C_8 (basil + okra) with 15.66 branches, C_9 (basil + fodder pearl millet) with 15.73 branches, and C_7 (basil + fodder maize) with 14.73 branches. The highest leaf length was observed in C_1 (sole basil) at 3.4 cm, followed by C_9 (basil + fodder pearl millet) at 3.1 cm, while C_8 (basil + okra) showed the lowest leaf length at 2.5 cm. In terms of leaf width,

Table 2: Effect of intercrop combinations on basil plant growth and herb, seed, and oil output

A. **Growth**							
Treatment	**Plant height (cm)**	**Plant diameter (cm)**	**Number of leaves**	**Number of branches**	**Leaf length (cm)**	**Leaf width (cm)**	**Root length (cm)**
Basil sole crop	90.20	90.93	628.53	19.40	3.43	1.40	22.40
Basil + fodder maize	54.40	35.93	178.26	14.73	2.73	1.17	11.06
Basil + okra	73.33	65.20	219.86	15.66	2.52	1.29	10.66
Basil + fodder pearl millet	75.73	49.13	173.00	15.73	3.14	1.07	12.86
Basil + fodder sorghum	55.53	49.33	225.46	18.06	2.58	1.36	14.40
Basil + coriander	82.80	86.40	518.73	17.93	3.13	1.24	19.20
C.D.	5.920	10.023	29.628	1.852	0.491	0.146	2.068
SE(m)	1.855	3.140	9.283	0.580	0.154	0.046	0.648
B. **Yield**							
Treatment	**Root fresh weight plant^{-1} (g)**	**Root dry weight plant^{-1} (g)**	**Seed yield ha^{-1} (q)**	**Fresh herb weight ha^{-1} (q)**	**Dry herb weight ha^{-1} (q)**	**Oil %**	**Oil yield ha^{-1} (kg)**
Basil sole crop	49.64	21.28	5.96	378.01	98.28	0.80	302.41
Basil + fodder maize	21.46	10.66	3.82	137.18	35.66	0.80	109.74
Basil + okra	21.28	13.02	4.27	217.43	56.53	0.70	152.20
Basil + fodder pearl millet	23.79	9.08	4.71	146.37	38.05	0.60	87.82
Basil + fodder sorghum	25.08	8.21	3.48	160.05	41.61	0.60	96.03
Basil + coriander	43.81	19.28	5.10	218.19	56.73	0.70	152.73
C.D.	4.024	2.510	0.200	0.462	0.130	0.001	0.327
SE(m)	1.261	0.786	0.063	0.145	0.041	0.000	0.102

C_1 (basil sole crop) exhibited the highest significant difference at 1.40 cm, followed by C_{10} (basil + fodder sorghum) at 1.36 cm, and C_9 (basil + fodder pearl millet) had the least leaf width at 1.07 cm.

Overall, C_1 (sole basil) showed the best growth performance, followed by C_{11} (basil + coriander) in the vegetable combination and C_9 (basil + fodder pearl millet) in the fodder combination. C_7 (basil + fodder maize) had the poorest growth performance. The competition from other intercrops like okra, fodder maize, fodder pearl millet, and fodder sorghum decreased basil's growth.

In the sole basil treatment, all measured parameters, including plant height, plant diameter, number of leaves, number of branches, leaf length, leaf width, and root length, exhibited the highest values. In the vegetable intercropping combination, observations related to basil canopy with coriander showed superior performance compared to intercropping with okra. This disparity suggests that basil plants with larger canopies did not thrive well when intercropped with okra, potentially due to increased competition for sunlight, water, and nutrients. Conversely, basil canopy development in the coriander intercropping plot needed to be more varied, indicating minimal competition for essential resources. A similar pattern was observed in the intercropping combination with fodder crops.

These findings are supported by Kabura *et al.*, (2008), who reported that the competition of individual crops in the intercropping system for photosynthetically active radiation (PAR) started beyond a specific limit in higher population density. However, Islam *et al.*, (2011), Alabi *et al.*, (2014), and Thakur *et al.*, (2018) have reported maximum plant height values for higher population densities, which might be attributed to heavy shading in higher population densities that triggered plants to compete for solar radiation, resulting in increased internodal length. Similar results have been reported by Pereira *et al.*, (2016) and Mamo (2021) in their studies on intercropping with basil.

Meanwhile, C_1 (sole basil) had a significantly higher dry root yield, with 21.87 g/plant, followed by C_{11} (basil + coriander), with 19.28 g of dry root per plant. The C_8 (basil + okra) had the lowest dry root weight/plant (9.08 g) among all the combinations. Significantly higher seed yield/ha was found in C_1 (sole basil) at 5.96 q/ha, followed by C_{11} (basil + coriander) at 5.10 q/ha, with the lowest seed yield in C_7 (basil + fodder maize) at 3.82 q/ha. Regarding herb yield per hectare, C_1 (sole basil) also had the highest production, with 378.01 q/ha of fresh herb and 98.28 q/ha of dry herb. Following that, C_{11} (basil + coriander) yielded 218.19 q/ha of fresh herb and 56.73 q/ha of dry herb, while C_8 (basil + okra)

Table 3: Economic recovery data of sole crops and intercrop combinations

Crop combination		Gross return (INR)	Fixed cost (INR)	Variable cost (INR)	Total cost (INR)	Net return (INR)	Benefit-cost ratio
A. **Sole crop**							
C_1	Basil	37765	28996	51002.6	79999	297655	3.72
C_2	Fodder maize	120781	27301	51702.6	79004.3	41776.6	0.53
C_3	Okra	300001	27970	52034.3	80004	219996.5	2.75
C_4	Fodder pearl millet	105691.7	24846	50822.6	75669	30022.6	0.40
C_5	Fodder sorghum	109352	25002	50003	75005.3	34346.6	0.46
C_6	Coriander	96242.3	29002	51001.6	80004.3	16237.9	0.20
B. **Inter crop**							
C_7	Basil + fodder maize	337201	27504	51502.6	79007.3	258193.7	3.27
C_8	Basil + okra	471501.3	29571	50433.3	80004.3	391497	4.89
C_9	Basil + fodder pearl millet	288501	24962	51042.3	76004.3	212496.7	2.80
C_{10}	Basil + fodder sorghum	331201.3	22902	52102.6	75004.6	256196.7	3.42
C_{11}	Basil+ coriander	329800	29698	50303.3	80001.6	249798.3	3.12
C.D.		1.809	2.889	86.695	38.041	163.471	0.056
SE(m)		0.609	0.972	29.183	12.805	55.026	0.019

Table 4: Indicators of competition and basil oil composition in intercrop combinations

A. **Competition indices**							
Crop combination		**LER**	**A**	**CR**	**K**	**ATER**	**MAI**
C_7	Basil + fodder maize	1.01	0.610	1.82	1.45	0.98	92203.66
C_8	Basil + okra	1.27	0.153	1.22	0.60	1.26	129517.30
C_9	Basil + fodder pearl millet	0.68	-0.380	0.76	0.99	0.67	71964.34
C_{10}	Basil + fodder sorghum	1.11	0.462	1.63	1.34	1.08	61016.42
C_{11}	Basil + coriander	1.29	0.160	1.22	0.36	1.25	85658.68
C.D.		0.007	0.006	0.017	0.018	0.015	44.710
SE(m)		0.002	0.002	0.005	0.005	0.004	13.500

B. **Composition of basil oil**						
Compounds	C_1	C_7	C_8	C_9	C_{10}	C_{11}
β-pinene	0.1	0.1	t	0.1	0.1	t
(E)β-ocimene	0.4	0.2	0.2	0.2	0.2	0.2
Linalool	23.1	22.6	21.7	22.6	23.0	23.9
Terpinen-4-ol	-	0.2	t	-	t	0.1
Methyl chavicol	68.2	68.3	69.6	69.1	69.3	68.7
(E)-methyl cinnamate	0.1	0.4	0.2	0.1	0.1	t
β-elemene	-	t	t	0.6	t	-
β-caryophyllene	0.7	0.6	0.7	0.6	0.5	0.5
Germacrene-D	1.1	0.8	1.0	0.9	0.9	0.9
γ-cadinene	2.1	1.6	2.1	2.2	2.1	2.0
Total composition	95.8	94.8	95.5	96.4	96.2	96.3

LER- Land Equivalent Ratio; A- Aggressivity Index; CR- Competitive Ratio; K- Relative Crowding Coefficient; ATER- Area Time Equivalent Ratio; MAI- Monetary Advantage Index; C_1- Basil sole crop; C_7- Basil + fodder maize; C_8- Basil + okra; C_9- Basil + fodder pearl millet; C_{10} - Basil + fodder sorghum; C_{11}- Basil + coriander; t=trace amount (≤0.04)

produced 217.43 q/ha of fresh herb and 56.53 q/ha of dry herb. In contrast, C_7 (basil + fodder maize) had the lowest performance, with 137.18 q/ha of fresh herb and 35.66 q/ha of dry herb. The highest oil yield was obtained in C_1 (sole basil) with 302.41 kg/ha of oil production, in which 8% oil content was recorded, followed by the C_{11} (basil + coriander) with 56.73 kg/ha of oil at 7% content. C_8 (Basil + okra) was very close, producing 152.20 kg/ha of oil with 7% oil content. The lowest yield of 87 kg/ha with 6% oil was recorded in the C_9 (basil + fodder pearl millet). Overall, the results show that vegetable combinations, mainly C_{11} (basil + coriander) and C_8 (basil + okra), demonstrated higher yields of herb and oil, while fodder combinations had lower yields. These findings are consistent with previous studies on intercropping with basil (Singh *et al.*, 2013). In alignment with this, Bilasvar and Salmasi, (2016) have documented an increase in aboveground dry biomass yield per unit area with the escalation of basil population density. This phenomenon is attributed to plants' efficient utilization of light, water, and nutrients in higher population densities, resulting in a more substantial conversion into dry matter yield per unit area compared to lower population densities (Najafi and Keshtehgar, 2014). The aboveground dry biomass of basil represents the cumulative outcome of leaf and stem dry biomass yield, which is intricately influenced by various growth factors, including nutrients, light availability, water supply, and plant spacing (Najafi and Keshtehgar, 2014).

The Land Equivalent Ratio (LER) and Area Time Equivalent Ratio (ATER) were utilized to evaluate the mixed stand benefit. The highest

LER was observed in C_{11} (basil + coriander) and C_8 (basil + okra) combinations, with values of 1.29 and 1.27, respectively, indicating higher yields. These findings are consistent with previous research (Kordi *et al*., 2020) on *Ocimum basilicum* L. with forage maize intercropping. Similarly, ATER analysis demonstrated that C_8 (basil + okra) and C_{11} (basil + coriander) combinations yielded higher values of 1.26 and 1.25 compared to other intercrop combinations. Our findings are similar to the research reported by Silva *et al*., 2021. The Aggressivity Index (A) measures the competitiveness of the component crops in the intercropping system. The results showed positive aggressivity for most combinations, with basil being more aggressive toward its companion crops. However, in the C_9 (basil + fodder pearl millet), the negative aggressivity indicated that fodder pearl millet was dominant over basil. These observations were similar to the results obtained by Daneshnia *et al*., (2016) in berseem-based intercropping systems. The Competitive Ratio (CR) values greater than one in most combinations indicated that basil had a competitive advantage over the companion crops, except for the C_9 (basil + fodder pearl millet), where the CR was less than one. These findings align with the study by Doubi *et al*., (2016). The Relative Crowding Coefficient (RCC) values less than one in all combinations suggested a yield disadvantage in intercropping. The RCC values were consistent with those Nigussie *et al*., (2020) reported in rosemary and carrot intercrop combinations. The Monetary Advantage Index (MAI) highlighted the profitability of intercropping systems. The C_9 (basil + okra) demonstrated the highest Monetary Advantage Index (MAI) value (₹ 129517.30 ha^{-1}). Following closely, the C_7 (basil + fodder maize) exhibited an MAI value of ₹ 92203.66 ha^{-1}, indicating its superior profitability. Consistent findings were noted in Nebret *et al*., (2019) study involving basil intercropping with maize. This corroborates with earlier research by Ghosh (2004), Aasim *et al*., (2008) and Agegnehu *et al*., (2008), all reporting positive Monetary Advantage Index (MAI) values across different proportions of intercropping crop combinations.

Table 3 displays pooled data indicating that all interventions had a substantial and statistically significant impact on the economic aspects under consideration. Among the intercrop combinations, C_8 (basil + okra) was the most productive, with a Gross Return (GR) of ₹ 47,150.30. C_1 (sole basil) followed closely with a GR of ₹ 3,77,654.00. On the other hand, C_6 (sole coriander) had the lowest GR at ₹ 96,242.34. C_8 (basil + okra) exhibited the highest Benefit-Cost (B:C) ratio of 4.89 and the highest Net Return (NR) of ₹ 3,91,497. C_1 (Sole basil came next with an NR of ₹ 2,97,655 and a B:C ratio of 3.72. Conversely, C_6 (sole coriander) had the lowest NR of ₹ 16,237 and a B:C ratio of 0.2. Studies such as (Mutisya *et al*., 2016) have demonstrated that intercropping maize with basil leads to a higher net yield than monoculture. De Carvalho *et al*., (2010) studied that intercropping basil with tomatoes resulted in yield advantages and greater economic returns than sole cropping. Similarly, Bilasvar *et al*., (2016) conducted a study in Iran that reported increased yields through intercropping basil with maize compared to sole cropping. According to the pooled data in Table 4, analysis of basil oil composition across different combinations showed no clear pattern. The main components were linalool and methyl chavicol, with the highest amounts of methyl chavicol found in C_3 (sole okra) and C_5 (sole fodder sorghum); approximately 69% was recorded. The highest concentration of linalool was observed in C_6 (sole coriander) at 23.9%, followed by C_1 (sole basil) and C_5 (sole fodder sorghum), both at approximately 23%. These findings align with previous studies on basil crops and their intercropping combinations (Rezaei-Chiyaneh *et al*., 2021).

CONCLUSION

In the present study, intercropping of basil with vegetable and fodder crops showed potential for achieving optimal unity between crops. Basil performed best with coriander (C_{11}) among vegetables and with fodder sorghum (C_{10}) among fodder crops. Despite the competition, intercropping with basil provided economic advantages, especially with the basil + okra combination. Farmers in Uttarakhand can benefit from co-culturing basil with okra or fodder sorghum to improve their livelihoods. This study offers valuable insights into sustainable farming practices in the region and can inform policy decisions to support farmers in hilly areas.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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