

Sustaining turmeric productivity and resource use efficiency under compatible intercropping systems

P Sachithanantham^{1*}, B S Harish¹, B N Maruthi Prasad¹, R L Raghunatha Reddy², K Padmanabha³ & B R Premalatha⁴

¹Department of Plantation, Spices, Medicinal and Aromatic Crops, College of Horticulture, UHS campus, GKVK Post, Bengaluru

²Department of SS&AC, RHREC, GKVK Post, Bengaluru

³Department of Vegetable Science, College of Horticulture, UHS campus, GKVK Post, Bengaluru

⁴Department of NRM, College of Horticulture, UHS campus, GKVK Post, Bengaluru

*Email: sachivj66@gmail.com

Received 23 November 2025; Revised 05 August 2026; Accepted 06 August 2026

Abstract

Turmeric is a slow-growing crop in its initial stages so it does not rapidly cover the soil and solar energy remains underutilized leading to weed growth. Hence, it offers ample scope for growing intercrops. Therefore, a field study was conducted to assess the compatibility of intercrops on turmeric productivity. The study comprised eight treatment combinations *viz.*, T₁ - Turmeric as a sole crop (control), T₂ - Turmeric + fenugreek, T₃ - Turmeric + french bean, T₄ - Turmeric + aggregatum onion, T₅ - Turmeric + vegetable soybean, T₆ - Turmeric + coriander, T₇ - Turmeric + sweet corn and T₈ - Turmeric + marigold. Intercrops were grown as sole crops for evaluating the intercropping systems (T₉ to T₁₅). Results showed that, turmeric with aggregatum onion as intercrop produced the highest yield (35.08 t ha⁻¹) compared to pure crop of turmeric (32.36 t ha⁻¹). Turmeric intercropped with vegetable soybean (Land Equivalent Ratio [LER] 2.06 and Area Time Equivalent Ratio [ATER] 1.44) and aggregatum onion (LER 1.85 and ATER 1.37) exhibited significantly higher land use efficiency. Turmeric with aggregatum onion achieved the highest Turmeric Equivalent Yield (10.12 t ha⁻¹), followed by marigold (8.85 t ha⁻¹) and vegetable soybean (8.18 t ha⁻¹). The highest B:C ratio (2.06) was in turmeric with aggregatum onion, while the lowest B:C (0.90) was found in turmeric intercropped with french bean, emphasizing the enhanced profitability of intercropping turmeric with aggregatum onion.

Keywords: Turmeric, intercrops, Area Time Equivalent Ratio (ATER), Land Equivalent Ratio (LER), Turmeric Equivalent Yield (TEY).

Introduction

Turmeric (*Curcuma longa* L.) is a perennial herb commercially cultivated as an annual crop that belongs to the Zingiberaceae family, which is the subterranean rhizome and it is believed to have originated in South East Asia. Among approximately 117 species in the genus *Curcuma*, about 40 have been identified as occurring in India (Velayudhan *et al.*, 1999). It is an ancient, holy spice from India known as “Indian Saffron”. In India, it is grown in an area of 3,10,963 ha with a production of 11,05,321 t and a productivity of 3.55 t ha⁻¹ during the year 2024-2025. Turmeric is one of the major spice crops and it is cultivated in many Indian states such as Maharashtra, Telangana, Karnataka, Tamil Nadu, Madhya Pradesh, Andhra Pradesh, Odisha, West Bengal, Mizoram, Assam and Gujarat. In Karnataka, it is grown in an area of 14,710 ha with a production of 82,746 t and productivity of 5.62 t ha⁻¹ (Spices Board, 2026).

Intercropping is one of the major cropping systems followed in horticultural crops. Turmeric-based intercropping systems enhance resource utilization, suppress weeds, improve soil fertility and increase productivity through complementary use of nutrients, water and light (Lithourgidis *et al.*, 2011). These systems also contribute to soil organic carbon buildup and carbon sequestration by increasing biomass addition and improving soil health. Therefore, intercropping offers a sustainable approach to enhance the productivity, profitability, resource use efficiency and environmental sustainability of turmeric cultivation. Since turmeric grows slowly in early stages, it does not quickly cover the soil, allowing solar energy to remain unused and increasing weed growth. It is reported that the critical period of weed interference was between 8-12 weeks after planting in turmeric (Njoku *et al.*, 2012). To produce more rhizomes, turmeric needs a long period of weed-free soil. However, hand weeding becomes expensive, takes a lot of time and is laborious. The turmeric

production can occasionally be severely decreased due to a lack of labour, particularly during critical periods of growth. It provides a good opportunity for intercropping, which aids in making use of most of solar radiation and available space during the early stages of crop growth. As a result, short-duration crops such as vegetables, legumes and annual spices can be successfully cultivated in the interspaces (Paramesh *et al.*, 2023). Growing more of these short-duration crops will raise cultivation costs proportionately, but the additional revenue will compensate for this rise. The same land can yield a second source of revenue through intercropping. As a result of weed growth inhibition, system productivity, nutrient, land and light use efficiency are increased. With this background, the above study was delineated with the following objectives.

1. To elucidate the impact of intercrops on growth, yield and quality of turmeric.
2. To assess the influence of intercrops on weed dynamics and suppression.
3. To quantify the resource use efficiency and to study the economics of intercropping in turmeric.

Material and methods

This experiment was conducted during May 2023 to January 2024 at the College of Horticulture, Bengaluru (13.095777° N, 77.565131° E), located in the Eastern Dry Zone of Karnataka (Agro-climatic Zone V) at an elevation of 930 m above mean sea level. The experimental site had red sandy loam soil with an acidic reaction (pH 5.37), medium organic carbon (0.67%), low available nitrogen (200 kg ha⁻¹), medium available phosphorus (23.38 kg P₂O₅ ha⁻¹) and potassium (188.28 kg K₂O ha⁻¹). During the experimental period, the mean maximum and minimum temperatures ranged from 28.1 to 31.4°C and 18.1 to 21.1°C, respectively, while the relative humidity ranged from 46 to 87%. The study comprised

eight treatment combinations *viz.*, T₁ - Turmeric as a sole crop (control), T₂ - Turmeric + fenugreek, T₃ - Turmeric + french bean, T₄ - Turmeric + aggregatum onion, T₅ - Turmeric + vegetable soybean, T₆ - Turmeric + coriander, T₇ - Turmeric + sweet corn and T₈ - Turmeric + marigold. Intercrops were grown as sole crops for evaluating the intercropping systems (T₉ to T₁₅). The experiment was conducted in a randomized complete block design and replicated thrice.

A recommended fertilizer dose of 150:125:250 kg N: P₂O₅: K₂O ha⁻¹, as prescribed in the package of practices of the ICAR-Indian Institute of Spices Research (IISR), Calicut and the University of Horticultural Sciences (UHS), Bagalkot (Anonymous, 2013) was uniformly applied to all experimental plots. Nutrients were supplied through urea (54.3 kg ha⁻¹), 20:20:0:13 fertilizer (625 kg ha⁻¹) and muriate of potash (MOP; 416.5 kg ha⁻¹) as the respective sources of nitrogen, phosphorus and potassium. The entire dose of phosphorus, 50 per cent of the recommended dose of nitrogen and 50 per cent of K were applied basally at the time of planting and the remaining 50 per cent of the recommended dose of nitrogen and potassium were top-dressed in two equal splits at the second and third month, respectively. In the intercropping treatments, the fertilizer dose was applied only for turmeric on an area basis (per hectare of the experimental plot) and no additional fertilizers were applied specifically for the intercrops. For each treatment, the experimental field comprised three raised beds, each measuring 3.30 m × 3.45 m with a height of 15 cm (Figure 1). The gross plot size was 3.30 m × 3.45 m (11.38 m²), with a net plot area of 6.75 m². Irrigation was applied through an inline drip irrigation system. Each raised bed was provided with two 16 mm drip laterals, one for each of the two crop rows. The laterals had a wall thickness of 0.80 mm, with inline emitters spaced at 30 cm intervals and having a discharge rate of 2.0 L h⁻¹ at 1.0

bar pressure. Irrigation was applied based on crop evapotranspiration (ET_c), estimated using reference evapotranspiration (ET₀) and the crop coefficient (Kc). The irrigation schedule was adjusted according to crop growth stage and prevailing weather conditions, with modifications made based on rainfall to avoid excess irrigation. All component crops received the same irrigation schedule and quantity of water throughout the experiment. Disease-free seed rhizomes of turmeric variety 'IISR Pragati' were used for planting at a seed rate of 2,500 kg ha⁻¹. Prior to planting, the rhizomes were treated with mancozeb at 0.3% (3 g L⁻¹ of water) for 30 minutes, shade-dried for 3-4 hours and subsequently planted on raised beds at a spacing of 45 × 30 cm. Seeds of fenugreek, coriander and bulbs of aggregatum onion were sown as two lines in between the rows of turmeric as an additive series (Table 1). Seeds of french bean, vegetable soybean, sweet corn were sown and seedlings of marigold were planted as one row in between the two rows of turmeric as an additive series on May 24, 2023. Cultural operations pertaining to crop production and protection were followed as per the standard package of practices

Five plants from each treatment were randomly selected and observations were recorded. The plant height was measured from the base to the tip of the petiole on the uppermost (youngest) leaf. The fully opened leaves present in the plant on the tagged plant was counted. The number of tillers produced by the randomly selected tagged plant was counted at monthly intervals. Harvesting of intercrops was carried out according to the horticultural maturity of each crop. Fenugreek and coriander were harvested for green leaves at 30-35 days after sowing (DAS) in a single harvest. French bean was harvested for tender green pods at horticultural maturity, with pickings carried out at 3-4-day intervals. Aggregatum onion was harvested once at 90 days after planting (DAP) after the leaves had completely dried and the

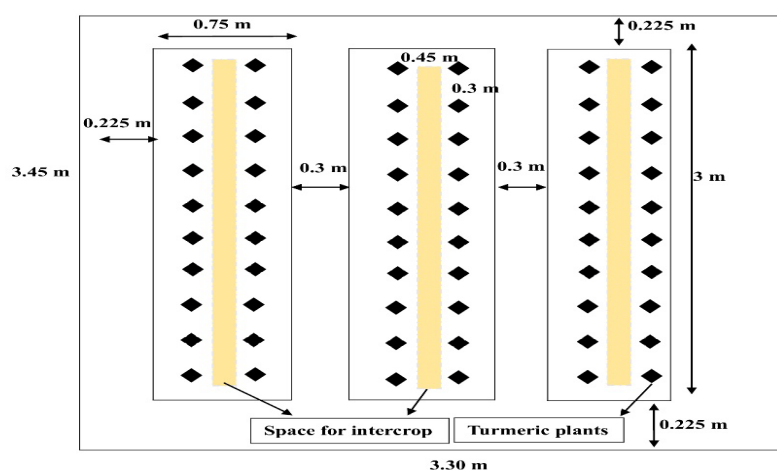


Fig. 1. Layout of a single treatment

Table 1. Details of the intercrop treatments

Intercrop	Botanical name	Variety	No. of rows as intercrop	No. of rows as sole crop	Spacing (cm)	Seed rate for intercrop (kg ha ⁻¹)	Seed rate for sole crop (kg ha ⁻¹)
Fenugreek	<i>Trigonella foenum-graecum</i> L.	CO 1	2	4	20 × 15	20	40
French bean	<i>Phaseolus vulgaris</i> L.	Arka Arjun	1	3	30 × 15	16	50
Aggregatum onion	<i>Allium cepa</i> L. var. <i>aggregatum</i>	CO (On) 5	2	4	20 × 12	438 bulbs	875 bulbs
Vegetable soybean	<i>Glycine max</i> (L.) Merr.	KBVS-1 (Karune)	1	2	40 × 10	25	50
Coriander	<i>Coriandrum sativum</i> L.	DCC-46	2	4	20 × 15	15	30
Sweet corn	<i>Zea mays</i> L. var. <i>saccharata</i>	Mithas	1	2	45 × 20	7.5	20
Marigold	<i>Tagetes erecta</i> L.	Tennis ball orange	1	2	45 × 35	23,100 seedlings	46,200 seedlings

bulbs had attained physiological maturity. Vegetable soybean was harvested at the green pod stage with pickings carried out at 5-day intervals. Sweet corn was harvested once at the milk stage, approximately 20-25 days after silking. Marigold flowers were harvested at full bloom, with flower pickings carried out at 2-3-day intervals until the end of the flowering period. After the signs of yellowing, withering, drying of the leaves and full maturity, rhizomes

were harvested and the yield per plot was determined in kilograms. The yield was extrapolated to tons per hectare and reported as fresh rhizome yield per hectare.

Using the American Spice Trade Association (ASTA) recommended approach, spectrophotometry was used to determine the total curcuminoids content by measuring the absorbance at 425 nm. (Thimmaiah, 1999).

$$\text{Total curcuminoids content (\%)} = \frac{D_s \times A_s}{100 \times W_s \times 1650} \times 100$$

Where,

D_s = Dilution volume of sample, where in the dilution schedule using this method was 20,000 for raw turmeric powder (ml)

A_s = Absorbance of the sample at 425 nm

W_s = Weight of the sample in grams

1650 = Estimation of absorptivity (E 1%, 1 cm) value at 425 nm for total curcuminoids

Hand weeding was carried out at 30, 45 and 75 days after planting (DAP). Immediately before each hand weeding, all weeds present within the entire net plot area were manually uprooted and collected separately for each experimental plot. Thus, the entire net plot served as the sampling unit and no quadrat sampling was employed. The collected weed samples were cleaned to remove adhering soil, shade-dried to remove excess surface moisture and subsequently oven-dried at $60 \pm 5^\circ\text{C}$ until a constant weight was attained. The oven-dried weed biomass was recorded in grams per plot using a digital balance. Weed dry matter was expressed on a hectare basis by converting the plot-wise dry weight (g plot^{-1}) to kilograms per hectare.

Light transmission ratio (LTR) was determined using a digital lux meter (Votcraft MS-1300 Light Meter; measuring range: 200–50,000 lux). Observations were recorded at 60, 90, 120, 150 and 180 days after planting (DAP) on clear, sunny days between 12:00 noon and 2:00 p.m. to minimize variation due to solar angle and cloud cover. For each treatment, three observations were recorded and the mean value was used for statistical analysis. Light intensity above the crop canopy was measured by positioning the sensor above the leaves without any obstruction from the crop foliage. Subsequently, light intensity below the

canopy was measured by placing the sensor at ground level directly beneath the crop canopy at the corresponding location. Care was taken to maintain the sensor in a horizontal position during all measurements to ensure uniformity. The light transmission ratio was calculated as per the following formula (Yoshida *et al.*, 1972):

$$\text{Light Transmission Ratio (\%)} = \frac{\text{Light intensity received at ground level}}{\text{Light Intensity received above the canopy of crop}} \times 100$$

The Land Equivalent Ratio (LER) was calculated as per the following formula suggested by Mead and Willey (1980).

$$\text{LER} = \text{LA} + \text{LB} = (\text{YA}/\text{SA}) + (\text{YB}/\text{SB})$$

Where, LA and LB are the LER for the individual crops, YA and YB are the individual crop yields in intercropping and SA and SB are their sole crop yields.

Area Time Equivalent Ratio (ATER) was calculated as per the following formula suggested by Hiebsch and McCollum (1987).

$$\text{ATER} = \frac{(\text{RYA} \times t_A) + (\text{RYB} \times t_B)}{T}$$

Where, RY = Relative yield of species A and B

t = Duration (days) of species A and B; T = Duration (days) of the intercropped system

$$\text{RY} = \frac{\text{Yield of intercrop per ha}}{\text{Yield of sole crop per ha}}$$

Turmeric equivalent yield (TEY) was calculated as per the following formula (Islam *et al.*, 2018):
TEY = Yield of intercrop + Price of turmeric.

After the harvesting of rhizomes, representative soil samples were taken as per the standard procedure from each treatment and replications. The quartering method was used to make the treatment-wise composite soil samples. The samples were allowed to air dry in the shade, then they were pounded into a fine powder using a wooden mortar and pestle and sieved

using a 2 mm sieve. These soil samples were used for the estimation of primary, secondary and micronutrients. Quantitative analysis of micronutrients was done using SHIMADZU (AAS-AA6880). The nutrient uptake was determined by multiplying the percentage of nutrients in the pseudostem and rhizome with the dry biomass of the corresponding plant part.

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \frac{\text{Nutrient concentration (\%)} \times \text{Total biomass (kg ha}^{-1}\text{)}}{100}$$

Fisher's method of analysis of variance (ANOVA), as described by Sundararaj *et al.* (1972), was used to statistically analyse the experimental data collected on various growth, physiological, yield and quality parameters during the study. The data were subjected to analysis in WASP 2.0.

Results and discussion

Growth parameters

The results showed that intercropping did not significantly influence plant height of turmeric (Table 2). At 180 Days After Planting (DAP), The data revealed that the number of leaves per plant did not differ significantly among treatments at 150 DAP. However, significantly a greater number of leaves per plant was noticed at 180 DAP. The effect of intercrops on turmeric leaf production was seen at later stages. Turmeric intercropped with coriander and marigold produced a significantly higher number of leaves (6.53) which was *at par* with turmeric intercropped with aggregatum onion (6.00), intercropped with vegetable soybean (6.00) and turmeric grown as a sole crop (5.80). The lowest leaf count (4.80) was in turmeric intercropped with fenugreek. The physical space and light availability affected by the canopy structure of the intercrops play a crucial role in leaf production and that might be reflected in the later stages of turmeric leaf production. The higher leaf production in

turmeric intercropped with coriander is due to the production of maximum number of tillers as evident in Table 2. The lower light transmission in the initial stages of turmeric intercropped with marigold forces the plants to produce more leaves to harvest the maximum amount of light.

Yield parameters

The significantly higher fresh rhizome yield (Table 2) was recorded in turmeric intercropped with aggregatum onion (35.08 t ha⁻¹) which was *at par* with turmeric intercropped with vegetable soybean, coriander and the turmeric grown as a sole crop. This indicates that intercropping with aggregatum onion, vegetable soybean or coriander did not adversely affect turmeric rhizome yield compared with sole cropping. The comparable yields observed in these treatments may be attributed to efficient utilization of available resources and reduced interspecific competition during the critical growth stages of turmeric, enabling the crop to maintain rhizome production at a level similar to that of the sole crop. However, monocropping failed to produce the maximum yield. This is due to higher weed dry matter accumulation in the early growth stages in this system as evident in Table 4. When turmeric was intercropped with aggregatum onion, soybean and coriander, its yield was significantly higher compared to other intercrop combinations. At 45 and 75 DAP, lower weed dry matter accumulation (Table 2) by these systems could also contribute to the higher yield (Chitra and Hemalatha, 2017). The higher weed smothering efficiency (Table 4) of aggregatum onion in the early growth stages of turmeric might have contributed to the higher yield. Through the formation of root nodules, soybean contribute nitrogen to the soil environment. Studies have demonstrated that growing soybeans can boost nitrogen cycling by approximately 3.6 times, along with an increase in nitrogen-fixing bacteria (Yoshiki *et al.*, 2013). The higher fresh rhizome yield in turmeric intercropped with

vegetable soybean might be due to considerable amount of atmospheric nitrogen fixation and thereby increased the soil fertility (Rajanna *et al.*, 2022). The lowest yield (19.96 t ha⁻¹) was observed in turmeric intercropped with sweet corn. Maize exhausts a considerably higher amount of nutrients from soil as compared to other cereals (Harish *et al.*, 2025; Hasanain *et al.*, 2026). Lesser rhizome production in sweet corn intercropping systems might be due to the highly nutrient-exhaustive nature of sweet corn. Because of the semi-spreading growth habit of the beans, they occupied a significant amount of space, intercepted a large portion of sunlight and absorbed more moisture and nutrients (Varatharajan *et al.*, 2022; Hirani *et al.*, 2024). This might be the reason for lesser yield

when turmeric was intercropped with french bean. The higher nutrient uptake and the root biomass by the intercrops may be attributed to the lesser rhizome production in those systems. The decrease in turmeric yield with other intercrops might due to increased competition for resources and reduced photosynthetic efficiency. The total curcuminoids content was found to be non-significant among the treatments (Table 2).

Light transmission ratio

The light transmission ratio (LTR) varied significantly among treatments at 60 and 90 DAP (Table 3), while the differences beyond 90 DAP were not significant. At 60 DAP, sole turmeric (T₁) recorded the highest LTR (62.73%), which

Table 2. Influence of intercropping on the growth, fresh rhizome yield and total curcuminoids content of turmeric

Treatment	Plant height (cm)		Number of leaves		Number of tillers		Fresh rhizome yield ha ⁻¹ (t)	Total curcuminoids content (%)
	150 DAP	180 DAP	150 DAP	180 DAP	150 DAP	180 DAP		
T ₁ - Turmeric (sole crop)	38.93	26.86	6.66	5.80 ^{abc}	3.86	4.40	32.36 ^{ab}	4.59
T ₂ - Turmeric + fenugreek	37.40	26.36	6.46	4.80 ^d	3.40	4.20	26.07 ^{bc}	4.11
T ₃ - Turmeric + french bean	34.60	26.54	6.13	4.86 ^{cd}	3.60	3.80	21.98 ^c	4.29
T ₄ - Turmeric + aggregatum onion	36.66	26.93	6.13	6.00 ^{ab}	3.26	3.80	35.08 ^a	4.63
T ₅ - Turmeric + vegetable soybean	37.56	27.66	6.20	6.00 ^{ab}	4.06	4.73	33.05 ^{ab}	4.32
T ₆ - Turmeric + coriander	34.80	29.86	6.53	6.53 ^a	4.26	5.00	32.93 ^{ab}	4.34
T ₇ - Turmeric + sweet corn	35.73	25.66	6.46	5.46 ^{bcd}	3.33	4.26	19.96 ^c	3.63
T ₈ - Turmeric + marigold	36.73	27.46	6.93	6.53 ^a	4.26	4.60	27.27 ^{bc}	4.14
S.Em ±	1.88	2.22	0.28	0.31	0.37	0.46	2.52	0.28
CD at 5%	NS	NS	NS	0.96	NS	NS	7.66	NS

Note: Means with the same letter in each column are not significantly different, as indicated by the DMRT test (P< 0.05). NS: Non-significant

was significantly higher than all intercropped treatments. Among the intercrops, the lowest LTR was observed in turmeric + marigold (T_8) with a value of 1.15 per cent, followed by turmeric + vegetable soybean (T_5) at 3.27 per cent. A similar trend was noted at 90 DAP, turmeric + marigold (T_8) with a value of 2.20 per cent followed by turmeric + vegetable soybean (T_5) and turmeric + sweet corn (T_7) (3.90% and 3.91%, respectively). Although plant height was not significantly different among the treatments, field observations indicated that turmeric plants intercropped with marigold appeared comparatively taller with relatively slender stems up to 90 DAP, suggesting a greater shading effect during the early crop growth period. The dense and continuous canopy formed by marigold, together with the associated ground cover must have reduced the amount of solar radiation reaching the soil surface, thereby limiting weed establishment and growth. Similar reductions in weed growth under dense crop canopies have been attributed to improved interception of incident light and greater ground cover, resulting in lower light availability for weed emergence and development (Hirani *et al.*, 2024). However, after 120 DAP, crop growth became more uniform across all treatments and no noticeable differences in plant canopy was observed.

Weed dry matter accumulation

At 30, 45 and 75 DAP, corresponding to the critical crop-weed competition period in turmeric, all weeds present in the net plot were removed manually, collected and oven-dried to a constant weight for the estimation of weed dry matter. Thus, the weed dry matter represented the weed biomass present immediately before each hand weeding operation, while the dry weight was determined after oven drying. Therefore, the weed data were recorded under the recommended crop management practices and not under unweeded conditions. The data presented in Table 4 revealed that the

weed dry matter accumulation have shown significant variations among treatments. At 30 DAP, turmeric grown as a sole crop had the significantly highest weed dry matter accumulation (131.50 kg/ha), which was *at par* with turmeric intercropped with coriander (124.4 kg/ha). Turmeric intercropped with marigold had the lowest weed dry matter accumulation per hectare (59.5 kg/ha). At 45 DAP, significantly lower dry weight of weeds recorded in turmeric intercropped with marigold (77.2 kg/ha), while the highest amounts were in turmeric grown as a sole crop, followed by turmeric intercropped with coriander and sweet corn (362.4 kg/ha, 324.2 kg/ha and 322.6 kg/ha, respectively). At 75 DAP, turmeric intercropped with marigold again significantly had the lowest value (73.14 kg/ha), which was *at par* with turmeric intercropped with vegetable soybean (141.41 kg/ha), whereas the highest weed dry matter accumulation was in turmeric grown as a sole crop (400.17 kg/ha). Mono-cropped turmeric consistently had the highest weed dry matter accumulation all the time, while the turmeric intercropping system had the lowest accumulation throughout the cropping period. This could be because the additive series of intercrops guaranteed improved soil surface coverage and reduced light penetration to the soil, which inhibited weed growth (Varatharajan *et al.*, 2022).

Resource use efficiency

The highest yield advantage (Table 4), as indicated by the Land Equivalent Ratio (LER) was in turmeric intercropped with vegetable soybean (2.06) followed by aggregatum onion (1.85). A LER of 2.06 indicates that approximately 106 per cent more land would be required under sole cropping to obtain the same combined yield as turmeric intercropped with vegetable soybean. Among the intercropping systems, turmeric intercropped with French bean had the lowest LER (1.05). Hence, intercropping of turmeric with fenugreek, French bean, aggregatum

onion, vegetable soybean, coriander, sweet corn and marigold was better than growing sole crop in terms of land use efficiency. The increased LER in all intercropping systems may be attributed to the complementary use of available resources by the component crops and reduced weed competition, resulting in greater combined productivity per unit land area. The increased LER in all intercropping systems might be due to more efficient spatial and temporal resource utilization, leading to a higher combined economic yield of both the main crop and the intercrops (Khan *et al.*, 2018). Nurbakhsh *et al.* (2013) also found similar results in intercropping of sesame and bean.

Intercropping turmeric with vegetable soybean resulted in a higher (1.44) ATER, followed by aggregatum onion (1.37), compared to the sole cropping of turmeric (1.00) (Table 4). This represents a 44 and 37% increase in ATER for these intercropping systems, respectively, over the sole crop. These higher ATER values indicate superior efficiency in the utilization of land over time by accounting for the duration of the component crops. However, when turmeric

was intercropped with fenugreek, French bean and sweet corn, the ATER values were less than one (0.85, 0.83 and 0.90 respectively). It indicated the disadvantages of these systems in terms of land-use efficiency over time. Similar findings were reported by Abdelkader & Mohsen (2016) in aggregatum onion with fennel and coriander.

To assess the relative efficiency of various treatments, the yield of the component crops was converted into turmeric equivalent yield (TEY). Turmeric intercropped with aggregatum onion achieved the highest TEY of 10.12 t ha⁻¹ (Table 4), compared to the other intercropping systems, indicating greater economic productivity under the prevailing market conditions. This was followed by turmeric intercropped with marigold with a yield of 8.85 t ha⁻¹ and vegetable soybean with 8.18 t ha⁻¹. Turmeric intercropped with coriander also had a relatively high TEY (7.70 t ha⁻¹). The higher market prices of aggregatum onion (₹ 40,000 t⁻¹), marigold (₹ 20000 t⁻¹), vegetable soybean (₹ 30000 t⁻¹) and coriander (₹ 50000 t⁻¹) at the time of marketing could have contributed to

Table 3. Influence of intercropping on light transmission ratio at different growth stages of turmeric of turmeric

Treatment	Light transmission ratio (%)				
	60 DAP	90 DAP	120 DAP	150 DAP	180 DAP
T ₁ - Turmeric (sole crop)	62.73 ^a	9.35 ^a	21.67	11.16	5.86
T ₂ - Turmeric + fenugreek	30.44 ^b	8.96 ^a	23.15	10.19	7.96
T ₃ - Turmeric + french bean	8.95 ^d	6.63 ^b	18.01	11.20	6.02
T ₄ - Turmeric + aggregatum onion	13.91 ^c	9.61 ^a	21.00	9.74	5.65
T ₅ - Turmeric + vegetable soybean	3.27 ^e	3.90 ^c	17.26	9.56	7.09
T ₆ - Turmeric + coriander	9.40 ^d	8.67 ^{ab}	16.51	7.83	5.86
T ₇ - Turmeric + sweet corn	12.42 ^c	3.91 ^c	33.17	10.67	7.00
T ₈ - Turmeric + marigold	1.15 ^e	2.20 ^c	29.91	9.73	6.81
S.Em ±	3.05	0.69	3.73	0.89	0.69
CD at 5%	2.37	2.11	NS	NS	NS

Table 4. Influence of intercropping on weed dry matter accumulation and resource use efficiency in turmeric

Treatment	Weed dry matter accumulation (kg ha ⁻¹)			LER	ATER	TEY (t ha ⁻¹)
	30 DAP	45 DAP	75 DAP			
T ₁ - Turmeric (sole crop)	131.50 ^a	362.36 ^a	400.17 ^a	1.00 ^d	1.00 ^{cde}	6.89 ^{cde}
T ₂ - Turmeric + fenugreek	105.53 ^c	190.21 ^c	172.46 ^c	1.22 ^{cd}	0.85 ^e	5.85 ^{de}
T ₃ - Turmeric + french bean	78.67 ^d	190.65 ^c	162.03 ^c	1.05 ^d	0.83 ^e	5.43 ^e
T ₄ - Turmeric + aggregatum onion	109.98 ^c	163.70 ^c	160.42 ^c	1.85 ^{ab}	1.37 ^{ab}	10.12 ^a
T ₅ - Turmeric + vegetable soybean	102.31 ^c	258.55 ^b	141.41 ^{cd}	2.06 ^a	1.44 ^a	8.18 ^{abc}
T ₆ - Turmeric + coriander	124.40 ^{ab}	324.16 ^a	323.34 ^b	1.52 ^{bc}	1.11 ^{cd}	7.70 ^{bcd}
T ₇ - Turmeric + sweet corn	120.44 ^b	322.64 ^a	158.31 ^c	1.25 ^{cd}	0.90 ^{de}	5.99 ^{de}
T ₈ - Turmeric + marigold	59.53 ^e	77.15 ^d	73.14 ^d	1.62 ^{abc}	1.16 ^{bc}	8.85 ^{ab}
S.Em ±	2.65	15.83	23.85	0.14	0.07	0.64
CD at 5%	8.05	48.03	72.35	0.44	0.21	1.94

Note: Means with the same letter in each column are not significantly different, as indicated by the DMRT test ($P < 0.05$).

higher TEY in those systems. Higher TEY was reported by Islam *et al.* (2018) in turmeric, Rymbai *et al.* (2021) in ginger and Sunitha *et al.* (2022) in greater yam; whereas, the lowest TEY (5.43 t ha⁻¹) was in turmeric intercropped with French bean, while turmeric intercropped with fenugreek and sweet corn produced lower TEY values of 5.85 t ha⁻¹ and 5.99 t ha⁻¹, respectively. Turmeric intercropped with French bean, fenugreek and sweet corn produced lower TEY when compared to monocropping. The lesser TEY from these systems was due to low yield and selling price at the time of marketing.

Soil fertility status

The significantly higher level of available soil nitrogen was in turmeric intercropped with coriander (177.28 kg ha⁻¹), but it was *at par* with French bean intercropping (T₃) and plants grown as a sole crop (T₁) (Table

5). On the other hand, the lowest available soil nitrogen (127.8 kg ha⁻¹) was recorded in turmeric intercropped with aggregatum onion (T₄), than other intercropping systems. Among the various treatments, turmeric intercropped with coriander (T₆) exhibited the significantly higher-level of available soil potassium (306.32 kg ha⁻¹), which was *at par* with turmeric intercropped with french bean (T₃); whereas, the lowest available soil potassium (165.43 kg ha⁻¹) was observed in turmeric intercropped with sweet corn (T₇), fenugreek (T₂), vegetable soybean (T₅) and marigold (T₈) systems. The amount of available nitrogen in all the cropping systems decreased when compared to the initial levels. In the case of nitrogen and potassium, the highest available nitrogen observed in the turmeric intercropped with coriander might be due to a significantly lower uptake of nitrogen and shorter crop duration in that system which leads to less depletion.

The lowest available nitrogen in turmeric intercropped with aggregatum onion (T_4) and marigold (T_8) might be due to the higher uptake of the crops that had contributed to the higher yield in the cropping system. The lesser available potassium in turmeric intercropped with sweet corn (T_7) indicated that sweet corn exhausted the nutrients due to its higher biomass production in an effective manner. It is evident from the Table 7 that the fresh rhizome yield was significantly and positively correlated to the potassium and secondary nutrients uptake from the soil. The data pertaining to available phosphorus showed that there was a significant difference among the treatments. The significantly highest levels of available soil phosphorus were recorded in turmeric sole crop (T_1), intercropped with fenugreek (T_2) and sweet corn (T_7), with values of 36.20, 39.65 and 39.75 kg ha⁻¹ respectively; whereas, the lowest level of available soil phosphorus (20.45 kg ha⁻¹) was recorded in turmeric intercropped with marigold (T_8). The reduction in phosphorus might be due to higher foliage producing nature of marigold. The soil phosphorus had increased when compared to the initial soil phosphorus except in turmeric intercropped with marigold (T_8). The higher available soil phosphorus could also be due to the addition of fertilizers. Zhang and Li (2003) demonstrated that the interactions between different species in intercropped systems, such as competition and facilitation, can influence the nutrient uptake in plants either enhancing or reducing it.

The data related to exchangeable magnesium showed substantial variations among the treatments (Table 5). Turmeric sole crop (T_1) significantly had the highest magnesium content in the soil (3.33 meq 100g⁻¹). Whereas, the lowest magnesium content (0.60 meq 100g⁻¹) was in turmeric intercropped with fenugreek (T_2). The main nutrients for legumes include phosphorus, sulphur, calcium and zinc, with the plants being able to fix significant amounts of nitrogen through biological fixation (Hitsuda

et al., 2005); whereas, the sole turmeric had higher available magnesium in the soil which might be due to no competition for nutrients. Available sulphur content in soil was significant among the treatments (Table 5). Among the various treatments, turmeric intercropped with aggregatum onion (T_4) significantly had the highest available soil sulphur content (31.02 ppm) than turmeric grown as a sole crop (T_1), intercropped with coriander (T_6) and marigold (T_8). Turmeric intercropped with aggregatum onion turmeric intercropped with marigold (T_4) had a significantly lower uptake of sulphur which might be due to lower uptake in this system. This might be due to the less foliage in onion crop. The higher available sulphur could also be due to the addition of fertilizers.

The data pertaining to Diethylene triamine penta acetate (DTPA) extractable iron, copper and manganese showed that there was a substantial difference among all the treatments (Table 5). Turmeric intercropped with fenugreek (T_2) exhibited the highest available soil iron content (66.28 ppm), while the lowest levels were in turmeric grown as a sole crop (T_1), followed by intercropped with vegetable soybean (T_5) and french bean (T_3). For available soil copper, turmeric intercropped with coriander (T_6) had the highest content (2.28 ppm), with the lowest levels in turmeric grown as a sole crop (T_1), intercropped with fenugreek (T_2), vegetable soybean (T_5) and sweet corn (T_7). Regarding soil manganese, turmeric intercropped with aggregatum onion (T_4) had the highest content (41.10 ppm), while the lowest content was in turmeric intercropped with french bean (T_3). Only around 10 per cent of the micronutrients present in the soil are available in soluble or exchangeable forms for plants to absorb (Lake *et al.*, 1984). The acidic nature of the soil might have influenced the availability of micronutrients in the soil in the intercropping systems. Also, the addition of organic manures and presence of crop would have improved the micronutrient status of the soil.

Table 5. Chemical properties of soil after harvest

Treatment	N	P	K	Ca	Mg	S	Fe	Cu	Zn	Mn	B
	(kg/ha)			(meq/100g)			(ppm)				
T ₁ - Turmeric (sole crop)	164.83 ^{ab}	36.20 ^a	232.34 ^{bc}	2.75	3.33 ^a	21.92 ^{ab}	20.58 ^d	1.71 ^c	2.53	28.45 ^{cd}	1.00
T ₂ - Turmeric + fenugreek	142.79 ^{bcd}	39.65 ^a	211.31 ^{bcd}	2.78	0.60 ^c	5.25 ^d	66.28 ^a	1.78 ^c	1.76	37.40 ^{ab}	1.28
T ₃ - Turmeric + french bean	161.91 ^{abc}	28.58 ^{bc}	263.21 ^{ab}	3.10	1.78 ^b	7.82 ^{cd}	25.97 ^d	2.06 ^{ab}	2.36	25.31 ^d	1.06
T ₄ - Turmeric + aggregatum onion	127.76 ^d	32.98 ^{ab}	243.16 ^{bc}	2.03	2.00 ^b	31.02 ^a	43.38 ^{bc}	1.82 ^{bc}	1.81	41.10 ^a	1.14
T ₅ - Turmeric + vegetable soybean	134.51 ^{cd}	24.71 ^{cd}	223.87 ^{bcd}	3.35	1.23 ^{bc}	17.6 ^{bc}	24.24 ^d	1.75 ^c	2.38	29.68 ^{cd}	1.18
T ₆ - Turmeric + coriander	177.28 ^a	35.31 ^{ab}	306.32 ^a	2.96	1.28 ^{bc}	24.18 ^{ab}	49.86 ^{ab}	2.28 ^a	2.46	34.45 ^{bc}	0.82
T ₇ - Turmeric + sweet corn	137.32 ^{bcd}	39.75 ^a	165.43 ^d	3.65	1.57 ^{bc}	10.33 ^{cd}	33.78 ^{bcd}	1.72 ^c	2.34	33.74 ^{bc}	0.82
T ₈ - Turmeric + marigold	123.22 ^d	20.45 ^d	199.15 ^{cd}	2.77	1.17 ^{bc}	24.56 ^{ab}	26.96 ^{cd}	1.98 ^{bc}	2.57	30.60 ^{cd}	1.06
S. Em±	9.84	2.46	20.23	0.43	0.32	3.67	5.69	0.09	0.20	2.04	0.23
CD	29.84	7.45	61.36	1.30	0.97	11.14	17.28	0.27	0.60	6.20	NS
Initial soil	200	23.38	188.28	2.85	1.2	6.59	7.43	0.25	0.9	20.26	0.48

The data on primary nutrient uptake by the pseudostem and rhizome for different treatments is presented in Table 6. There was no significant difference among the treatments in primary nutrients uptake. However, for nitrogen uptake, T₄ exhibited the highest total uptake (154.78 kg ha⁻¹), with 43.45 kg ha⁻¹ from the pseudostem and 111.3 kg ha⁻¹ from the rhizome, while the lowest total N-uptake was observed in T₇ (104.56 kg ha⁻¹). Phosphorus uptake varied among treatments, with T₄ again showing the highest total uptake (14.55 kg ha⁻¹), followed by T₅ (13.09 kg ha⁻¹), whereas T₂ had the lowest P-uptake (8.55 kg ha⁻¹). In terms of potassium uptake, T₄ showed the highest total uptake (370.37 kg ha⁻¹) and T₇ recorded the lowest (182.81 kg ha⁻¹). The absence of variation in nutrient uptake across different intercrops in

long-duration crop like turmeric indicates that, despite the higher yields from intercrops, they do not adversely affect the quality or nutrient absorption by the main crop. The initial soil fertility of the experimental field was assessed using a composite soil sample collected before the layout of the experiment to characterize the overall fertility status of the site. Since treatment-wise initial soil samples were not collected, the post-harvest soil nutrient values presented in this study represent the residual nutrient status after harvest. The variation in post-harvest soil nutrient status among treatments may be attributed to differences in nutrient uptake and nutrient removal by the component crops, reflecting their distinct nutrient requirements and biomass production.

Table 6. Primary nutrients uptake in turmeric as influenced by intercrops

Treatment	N-uptake (kg ha ⁻¹)			P-uptake (kg ha ⁻¹)			K-uptake (kg ha ⁻¹)		
	Pseudostem	Rhizome	Total	Pseudostem	Rhizome	Total	Pseudostem	Rhizome	Total
T ₁ - Turmeric (sole crop)	29.65	85.64	115.29	1.61	11.30	12.91	46.50	300.21	346.71
T ₂ - Turmeric + fenugreek	55.83	58.56	114.39	2.12	6.42	8.55	48.66	118.28	166.93
T ₃ - Turmeric + french bean	40.60	96.94	137.53	2.79	9.49	12.28	110.52	163.70	274.21
T ₄ - Turmeric + aggregatum onion	43.45	111.3	154.78	3.20	11.35	14.55	91.99	278.38	370.37
T ₅ - Turmeric + vegetable soybean	23.94	107.4	131.37	1.80	11.29	13.09	61.06	239.39	300.44
T ₆ - Turmeric + coriander	45.35	69.58	114.93	2.64	8.91	11.54	76.44	158.54	234.98
T ₇ - Turmeric + sweet corn	35.98	68.59	104.56	2.09	8.67	10.76	41.46	141.35	182.81
T ₈ - Turmeric + marigold	31.93	79.98	111.91	1.99	8.67	10.67	45.33	110.26	155.58
S. Em ±	14.25	26.13	-	0.71	1.75	-	25.45	49.73	-
CD at 5%	NS	NS	-	NS	NS	-	NS	NS	-

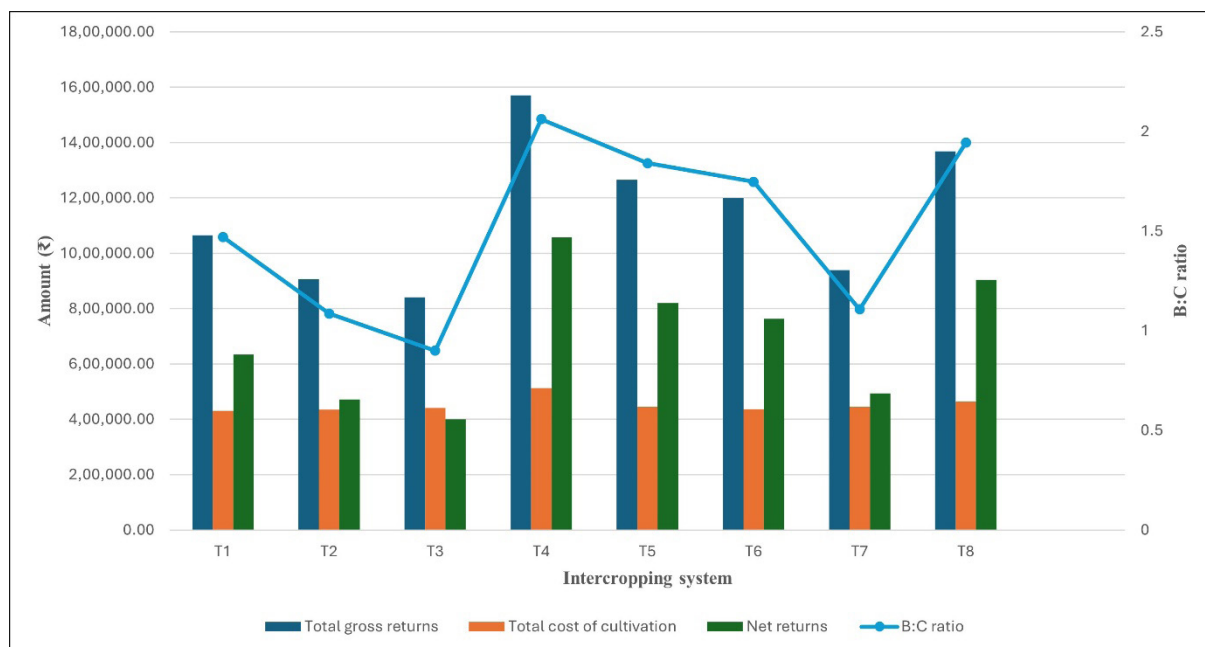
**Fig. 2.** Economics of different intercropping treatments

Table 7. Correlation coefficients among the total curcuminoids, nutrient uptake by rhizome and fresh yield of turmeric

	Total curcuminoids	NUR Nitrogen	NUR Phosphorus	NUR Potassium	NUR Calcium	NUR Magnesium	NUR Sulphur	NUR Iron	NUR Copper	NUR Zinc	NUR Manganese	Fresh rhizome yield
Total curcuminoids	1.00	0.003	0.164	0.339	0.404	0.571**	0.366	0.291	-0.015	0.137	0.333	0.513*
NUR Nitrogen		1.00	0.448*	0.447*	0.66***	0.302	0.396	0.442*	0.318	0.567**	0.422*	0.15
NUR Phosphorus			1.00	0.666***	0.232	0.316	0.777***	0.493*	0.512*	0.823***	0.497*	0.395
NUR Potassium				1.00	0.348	0.455*	0.73***	0.594**	0.565**	0.458*	0.445*	0.505*
NUR Calcium					1.00	0.671***	0.307	0.564**	0.161	0.264	0.537**	0.503*
NUR Magnesium						1.00	0.53**	0.729***	0.341	0.23	0.625**	0.585**
NUR Sulphur							1.00	0.696***	0.462*	0.57**	0.6**	0.585**
NUR Iron								1.00	0.614**	0.288	0.569**	0.547**
NUR Copper									1.00	0.362	0.247	0.429*
NUR Zinc										1.00	0.605**	0.113
NUR Manganese											1.00	0.379
Fresh rhizome yield												1.00

Note: NUR –nutrient uptake by rhizome

Economics

The highest gross return (₹ 15.70 lakhs ha⁻¹), net return (₹ 10.57 lakhs ha⁻¹) with B: C ratio (2.06) was in turmeric intercropped with aggregatum onion (Figure 2). The higher B:C ratio was due to higher yield in this system and also additional income from the intercropped aggregatum onion. Intercrops like aggregatum onion, vegetable soybean and coriander in turmeric demonstrated positive results when compared to sole turmeric. Moreover, the net returns from this study are notably profitable and attractive. Least gross return (₹ 8.41 lakhs ha⁻¹), net return (₹ 4.0 lakhs ha⁻¹) and B:C ratio (0.90) was observed in turmeric intercropped with french bean. This is due to less yield and returns from the intercropped french bean. These results are in agreement with Chitra and Hemalatha (2017) who obtained a maximum B:C ratio (2.68) in turmeric + bhendi followed by turmeric + chilli (2.63).

Correlation

The correlation analysis between various nutrient uptake ratios and fresh rhizome yield (FY) reveals several significant relationships (Table 7). The uptake of nitrogen by rhizome showed a positive but moderate correlation with FY ($r = 0.15$), indicating that nitrogen uptake is not strongly associated with fresh rhizome yield. However, phosphorus uptake by rhizome has a stronger positive correlation with FY ($r = 0.395$), suggesting a notable influence on yield. Potassium uptake by rhizome displays a moderate correlation ($r = 0.505^*$), emphasizing its importance for fresh rhizome yield. Calcium and magnesium uptake by the rhizome also exhibit positive correlations with FY, with values of $r = 0.503^*$ and $r = 0.585^{**}$, respectively. Iron uptake by the rhizome was moderately correlated with FY ($r = 0.547^{**}$), while copper had a weaker correlation ($r = 0.429^*$), indicating a less pronounced but still relevant role in determining yield. Zinc did not significantly correlate with FY ($r = 0.113$), but manganese had a moderate positive

relationship ($r = 0.379$). Overall, nutrients like magnesium, sulphur, potassium, calcium and iron show the strongest positive relationships with fresh rhizome yield, indicating their critical roles in enhancing turmeric output. This suggests that proper nutrient management particularly with these key elements, plays a vital role in enhancing the yield of turmeric. Total curcuminoids also exhibited a positive relationship with some nutrient uptakes and fresh rhizome yield, emphasizing the interplay between nutrient uptake and the quality attributes of turmeric (Thippeshappa *et al.*, 2013).

Conclusion

Turmeric intercropped with aggregatum onion resulted in the highest fresh rhizome yield per hectare accounting for the highest gross and net returns with the highest benefit-cost ratio of 2.06. Therefore, as an economically viable technology and to attain maximum production, this intercropping system can be suggested for farmers for commercial cultivation of turmeric. Alternatively, turmeric with vegetable soybean as an intercrop can be recommended for higher productivity, better resource use efficiency and higher weed smothering efficiency.

References

- Abdelkader M A & Mohsen A A M 2016 Effect of intercropping patterns on growth, yield components, chemical constituents and competition indices of onion, fennel and coriander plants. *Zagazig J. Agric. Res.* 43(1): 67–83.
- Anonymous 2013 Horticulture Package of Practices. University of Horticultural Sciences, Bagalkot. Available at: https://uhsbagalkot.in/documents/Horticulture_POP%5b1%5d.pdf. Accessed 31 July 2026.
- Chitra R & Hemalatha P 2017 Effect of intercrops on growth and yield of turmeric. *J. Spices Aromat. Crops* 26(1): 51–54.

- Harish M N, Choudhary A K, Dass A, Singh V K, Rajanna G A, Bana R S, Paramesh V, Varatharajan T, Bhupenchandra I, Sadhukhan R, Kumar A, Sachin K S, Teli K G, Singh S R K, Raut A A, Sannagoudar M S, Muniyappa L & Prasad H P N 2025 Double zero-tilled bed-planting and optimized P-fertilization in maize-wheat rotation: an empirical investigation on root architecture, carbon-phosphorus dynamics and soil carbon pools. *J. Environ. Manag.* 392: 126668.
- Hasanain M, Singh V K, Rathore S S, Meena V S, Singh R K, Shekhawat K, Dwivedi B S, Upadhyay P K, Meena S K, Kumar A & Kumar A 2026 Trade-offs and synergies of conservation agriculture practices in the maize-wheat system: improving yield, profitability and soil resilience in a changing climate. *Field Crops Res.* 343: 110486.
- Hiebsch C K & McCollum R E 1987 Area $\times$ time equivalency ratio: a method for evaluating the productivity of intercrops. *Agron. J.* 79(5): 945–946.
- Hirani A K, Korav S, Rajanna G A, Elansary H O & Mahmoud E A 2024 Determination of critical crop-weed competition period: impact on growth, nutrient dynamics and productivity of green gram (*Vigna radiata*). *Heliyon* 10(17): e36855.
- Hitsuda K, Yamada M & Klepker D 2005 Sulfur requirement of eight crops at early stages of growth. *Agron. J.* 97(1): 155–159.
- Islam M, Mohammad A, El Sabagh A, Barutcular C, Ratnasekera D, Kizilgeci F & Islam M S 2018 Evaluation of turmeric-mung bean intercrop productivity through competition functions. *Acta Agric. Slov.* 111(1): 199–207.
- Khan M, Sultana N, Akter N, Zaman M & Islam M 2018 Intercropping garden pea (*Pisum sativum*) with maize (*Zea mays*) at farmer's field. *Bangladesh J. Agric.* 43(4): 691–702.
- Lake DL, Kirk P W W & Lester J N 1984 Fractionation, characterization and speciation of heavy metals in sewage sludge and sludge-amended soils: a review. *J. Environ. Qual.* 13(2): 175–183.
- Lithourgidis A S, Dordas C A, Damalas C A & Vlachostergios D N 2011 Annual intercrops: an alternative pathway for sustainable agriculture. *Aust. J. Crop Sci.* 5(4): 396–410.
- Mead R & Willey R W 1980 The concept of a 'land equivalent ratio' and advantages in yields from intercropping. *Exp. Agric.* 16(3): 217–228.
- Njoku S C, Olojede A O & Melifonwu A A 2012 Effect of the critical period of weed interference on optimum performance of turmeric at Umudike, Nigeria. *J. Agric. Soc. Res.* 12(1): 84–88.
- Nurbakhsh F, Koocheki A & Nassiri M M 2013 Evaluation of yield, yield components and different intercropping indices in mixed and row intercropping of sesame (*Sesamum indicum* L.) and bean (*Phaseolus vulgaris* L.). *Iran. J. Pulses Res.* 6(2): 73–86.
- Paramesh V, Kumar M R, Rajanna G A, Gowda S, Nath A J, Madival Y, Jinger D, Bhat S & Toraskar S 2023 Integrated nutrient management for improving crop yields, soil properties and reducing greenhouse gas emissions. *Front. Sustain. Food Syst.* 7: 1173258.
- Rajanna G A, Dass A, Suman A, Babu S, Venkatesh P, Singh V K, Upadhyay P K & Sudhishri S 2022 Co-implementation of tillage, irrigation and fertilizers in soybean: impact on crop productivity, soil moisture and soil microbial dynamics. *Field Crops Res.* 288: 108672.
- Rymbai H, Das A, Mohapatra K P, Talang H D, Nongbri B & Law I 2021 Ginger (*Zingiber officinale*) based intercropping systems for enhancing productivity and income – a farmer's participatory approach. *Indian J. Agric. Sci.* 91(7): 956–960.
- Spices Board 2026 Major spice state-wise area production 2025–26. Available at: <https://www.indianspices.com/sites/default/files/Major%20spice%20state%20wise%20area%20production%202024-25%20web.pdf>. Accessed 11 July 2026.

- Sunitha S, Kumar J S, Sreekumar J, Nedunchezhiyan M, Mamatha K, Kamalkumaran P R, Pradnya G, Ketan D & Shanker D 2022 Influences of intercropping on productivity and profitability of greater yam (*Dioscorea alata* L.). J. Crop Weed 18(2): 85–93.
- Sundararaj N, Nagaraj S, Venkataramu M N & Jagannath M K 1972 Design and Analysis of Field Experiments. UAS, M.Sc. Series No. 22. University of Agricultural Sciences, Bengaluru, India, 255p.
- Thimmaiah S K 1999 Standard Methods of Biochemical Analysis. Kalyani Publishers, New Delhi, pp. 49–77.
- Thippeshappa G N, Ramesha Y S & Ravi C S 2013 Influence of levels of nutrients on nutrient content and uptake by ginger plant parts and their correlation coefficient to rhizome yield. Indo-Am. J. Agric. Vet. Sci. 1(1): 17–23.
- Varatharajan T, Dass A, Choudhary A K, Sudhishri S, Pooniya V, Das T K, Rajanna G A, Prasad S, Swarnalakshmi K, Harish M N & Dhar S 2022 Integrated management enhances crop physiology and final yield in maize intercropped with black gram in semiarid South Asia. Front. Plant Sci. 13: 975569.
- Velayudhan K C, Muralidharan V K, Amalraj V A, Gautam P L, Mandal S & Kumar D 1999 Curcuma Genetic Resources, Scientific Monograph No. 4. National Bureau of Plant Genetic Resources, New Delhi, 149p.
- Yoshida S, Forno D D, Cock J H & Gomez K A 1972 Laboratory Manual for Physiological Studies of Rice, 3rd Ed. International Rice Research Institute, Manila, Philippines, pp. 67–68.
- Yoshiki M, Sachie H, Toshihide M & Motoki K 2013 Soybean as a nitrogen supplier. In: James E B (Ed.) A Comprehensive Survey of International Soybean Research – Genetics, Physiology, Agronomy and Nitrogen Relationships. InTech, Rijeka, pp. 49–60.
- Zhang F & Li L 2003 Using competitive and facilitative interactions in intercropping systems enhances crop productivity and nutrient-use efficiency. Plant Soil 248: 305–312.