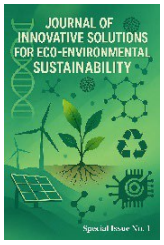
YEREVAN STATE UNIVERSITY PUBLISHING HOUSE

Journal of Innovative Solutions for Eco-Environmental Sustainability

journal homepage: https://journals.ysu.am/index.php/jisees



Research Article

The Combined Influence of Intercropping and Arbuscular Mycorrhizae on Cauliflower Growth and Yield

Nikhil Malav [1], Shipra Singh Parmar [1,*], Divya Pandey [1], Pushpendra Kumar [1], Ranjith Reddy [1], Satish Kumar [1], João Ricardo Sousa [2], Rupesh Kumar Singh [2]

[1] *Department of Horticulture, School of Agriculture, ITM University, Gwalior, India*
[2] *Centro de Investigação e Tecnologias Agroambientais e Biológicas (CITAB), Universidade de Trásos-Montes e Alto Douro, Vila Real, Portugal*

ARTICLE INFO

Keywords:
cauliflower,
intercropping,
arbuscular mycorrhizal fungi,
cole crop,
carrot

ABSTRACT

A field study was undertaken during the winter season of 2024–2025 at CRC-3, Turari, Department of Horticulture, ITM University, Gwalior (M.P.), to assess the influence of intercropping and arbuscular mycorrhizal fungi on the performance of cauliflower. The experiment was laid out in a Randomized Block Design with three replications, comprising eleven treatments: T_1—cauliflower as sole crop without AMF; T_2—cauliflower as sole crop with AMF; T_3—cauliflower (without AMF) + coriander; T_4—cauliflower (with AMF) + coriander; T_5—cauliflower (without AMF) + fenugreek; T_6—cauliflower (with AMF) + fenugreek; T_7—cauliflower (without AMF) + carrot; T_8—cauliflower (with AMF) + carrot; T_9—coriander as sole crop; T_{10}—fenugreek as sole crop; and T_{11}—carrot as sole crop. The results revealed that intercropping systems significantly influenced the growth and yield of cauliflower, and these effects were further enhanced by the application of arbuscular mycorrhizal fungi at the time of transplanting. Application of AMF at 10 kg ha^{-1} significantly improved growth and yield attributes of cauliflower. Among the treatments, T_6 (cauliflower + fenugreek with AMF) recorded the highest gross curd weight, net curd weight, yield per plot, and yield per hectare. This treatment also exhibited the highest values of phosphorus solubilizing bacteria population, land equivalent ratio (LER), and monetary advantage index (MAI), indicating the biological and economic superiority of the system.

1. Introduction

With the rise in global food demand, more stringent environmental protection regulations and sustainability measures are proposed to curtail agricultural expansion and deforestation [1]. Enhancing agricultural sustainability is a crucial goal for entire food and feed production and transformation chains. Intercropping two or more crop species on the same area of land at the same time has long been thought to improve crop production stability [2]. One of the most attractive strategies is to increase productivity per unit area of available land or expanding the area of land under production, which seems shrinking day by day. It becomes imperative to develop vegetable-based cropping systems that make efficient use of both natural and artificial resources to feed the ever-growing population. Therefore, the intercropping has been considered advantageous in terms of economy of space, through more effective use of water, nutrients and solar energy which can significantly enhance crop productivity as compared to the growth of sole crops. The intercropping refers to growing two or more crops simultaneously on the same piece of land with a definite row-planting pattern to obtain higher productivity per unit area. Several factors can affect intercropping viz. plant density, sowing time, harvesting time, maturity period, selection of the crop and the region's socio-economic conditions. In intercropping, the land equivalent ratio (LER) is used to measure the productivity of land.

The species selected for intercropping must not skeptically impact the primary crop's growth, must not compete with it, and

* Corresponding authors.
Email: shipraparmar690@gmail.com (Shipra Singh Parmar)

https://doi.org/10.46991/JISEES.2026.02.1.13853
Received 7 October 2025; Received in revised form 17 January 2026; Accepted 11 February 2026; Available online 4 March 2026

should offer benefits that enhance the primary crop's cultivation and yield greater income per unit area compared to monoculture. Cauliflower is a popular and widely commonly cultivated vegetable in India and a great source of vitamins, minerals, phytochemicals and carbs. The carrot and cauliflower intercropping markedly diminished the incidence of forked carrots and enhanced cauliflower yield [3]. Carrots' erect foliage allows better daylight penetration for cauliflower while the awning of abolish helps weeds around carrots. Intercropping Cauliflower (*Brassica oleracea* var. *botrytis)* with coriander (*Coriandrum sativum*) is a sustainable agricultural practice that enhances resource use efficiency, improves yields, and helps with pest management. The complementary nature of these crops lies in their differing nutrient and space requirements. Cauliflower, a nutrient-demanding crop, especially benefits from the pest-repelling properties of coriander. The strong scent of coriander can deter common cauliflower pests like aphids and caterpillars, thus reducing pesticide assurance [4]. Fenugreek (*Trigonella foenum-graecum* L) family Leguminosae an annual herb is well known as flavor, curry powder, and spice [5]. The crop is autogenous flowers occasionally attracted to insects [6]. Arbuscular mycorrhizal fungi start a symbiotic union with roots of 80% land crops. In AMF, plants coexist symbiotically with glomeromycotan fungi, which were primarily created to enhance plant uptake of water and nutrients. Apart from the function of arbuscular mycorrhizal fungi (AMF), intercropping provides a sustainable way to increase total yield and minimise the risk of crop failure [7]. One of the most prevalent genera of AM fungus is *Glomus*. AM fungus generates (lipochitooligosaccharides), which are symbiotic signals, to promote improved branching and root growth. Kinases sense the calcium spike that is caused by the chitooligo saccharides. The fungal infection is thus accommodated within the cells, and the plant cells' arbuscules are consuming nutrients. One of the first symbiotic interactions on Earth was mycorrhizal symbiosis. By providing a suitable supply of minerals, it aids in the growth and development of the plant, and in exchange, the fungi feed on the roots of the plant. In addition to increasing plant yield, AM fungi also improve the plants' ability to withstand stress [8,9].

A thorough understanding of these processes is necessary for successful ecosystem conservation and management. These fungi are also known to offer important advantages to the plants they associate with, including enhanced nutrient and water uptake, increased resistance to disease and nutrient mobilisation from organic substrates [10]. These interactions can result in significant changes in the composition, structure, and functioning of plant communities [3]. In light of this, the current study was designed to determine the best crop combination for an intercropping system based on cauliflower, to analyse land use efficiency and monetary advantage indices under intercrop and cauliflower combinations, and to determine how AMF inoculation affects cauliflower yield and quality.

2. Materials and Methods

The Field experiment was regulated at crop Research Centre (CRC-3), School of Agriculture Department of Horticulture, ITM University in Gwalior, (M.P.). During 2024-25 from the first week of November to February under agro-climatic and soil conditions. It is geographically located in the Grid region of India 26º 21, N altitude and 78 º 20, E longitudes and an altitude of 211.5 m above sea level. The meteorological data regarding the temperature relative humidity and rainfall was recorded during the cropping season from the meteorological observatory, School of Agriculture ITM University Gwalior presented in Fig. 1.

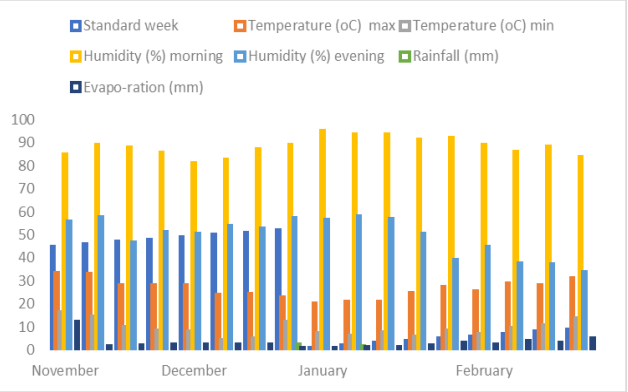


Fig. 1. Meteorological data during the cropping season

The experiment comprised eleven treatments (Table 1): cauliflower sole crop without AMF (T1) and with AMF (T2); cauliflower intercropped with coriander without AMF (T3) and with AMF (T4); cauliflower intercropped with fenugreek without AMF (T5) and with AMF (T6); cauliflower intercropped with carrot without AMF (T7) and with AMF (T8); and sole crops of coriander (T9), fenugreek (T10), and carrot (T11).

Table 1. Treatment details

T_1	:	Cauliflower as sole crop (Without AMF)
T_2	:	Cauliflower as sole crop (With AMF)
T_3	:	Cauliflower (Without AMF) + Coriander
T_4	:	Cauliflower (With AMF) + Coriander
T_5	:	Cauliflower (Without AMF) +Fenugreek
T_6	:	Cauliflower (With AMF) +Fenugreek
T_7	:	Cauliflower (Without AMF) +Carrot
T_8	:	Cauliflower (With AMF) + Carrot
T_9	:	Coriander as sole crop
T_{10}	:	Fenugreek as sole crop
T_{11}	:	Carrot as sole crop

Main crop cauliflower was transplanted at a spacing of 60 x 60 cm and sowing of intercrops (Table 2) was done in between the rows at a plant spacing of 20 cm. AMF was applied with cauliflower at the time of transplanting. AMF at the rate of 10 kg ha^{-1} (NIPHM, 2015) was mixed with powdered organic manure and applied along the line of sowing of cauliflower.

Table 2. Experimental Details

Cropping Pattern	Crop	Variety	Source
Main crop	Cauliflower	(Pusa Himjoyti)	IARI, NewDelhi
Intercrop	Coriander	(Arka Isha)	IIHR, Bengaluru
	Fenugreek	(Pusa Early Bunching)	IARI, NewDelhi
	Carrot	(Pusa Prateek)	IARI, NewDelhi

Statistical analysis

The data recorded will be analyzed using MS-Excel and OPSTAT as per the design of experiment. The data recorded on different parameters will be statistically analyzed by using randomized block design (RBD) given by Gomez and Gomez (1984).

3. Results and Discussion

3.1 Cauliflower as sole crop and in intercropping

The data collected on various aspects of plant growth of cauliflower as sole crop and in intercropping presented in Table 3–4.

The minimum number of days to marketable curd maturity, indicating crop earliness, was recorded in T_5 [cauliflower (without AMF) + fenugreek] with 67.40 days, whereas the maximum duration to maturity was observed in the sole crop of cauliflower (T_1), which required 72.30 days.

Data on plant height revealed significant variation among the treatments. The tallest plants (53.35 cm) of cauliflower were recorded in T_5 [cauliflower (without AMF) + fenugreek], while the shortest plants of cauliflower (48.33 cm) were observed in T_4 [cauliflower (with AMF) + coriander]. Differences in the impacts of intercropping on crop competition and nutrient availability can account for the variation in plant height and days to marketable curd maturity among treatments. increased nitrogen availability from the leguminous intercrop may be the cause of the early maturity seen in cauliflower interplanted with fenugreek (T_5), which accelerated curd initiation and increased early development. On the other hand, substantially poorer resource-use efficiency may be linked to delayed maturity in the sole crop (T_1). Shorter plant stature, as seen in cauliflower intercropped with coriander along with AMF application (T_4), is seen as agronomically advantageous in cauliflower because it lowers the danger of lodging and improves plant stability, even though T_4 recorded the maximum plant height. Therefore, crop maintenance may benefit from treatments that result in modest plant height.

While in other investigations showed the maximum growth parameters in sole crop of cauliflower as compared to intercropping treatments. This can be attributed to the lack of competition for sunlight, space, nutrients and moisture in sole cultivation of the crop [9].

The maximum leaf length (43.17 cm) of cauliflower was recorded in T7 [Cauliflower (without AMF) + Carrot], whereas the minimum leaf length (37.55 cm) was observed in T1 [Cauliflower as sole crop without AMF]. This may be attributed to the delayed emergence and slow initial growth of carrot, which resulted in minimal competition for nutrients, moisture, and light during the early growth stages of cauliflower. This allowed the cauliflower plants to utilize available resources efficiently, leading to enhanced leaf expansion. Although Amoli (2012), the length of leaves in cauliflower cultivated solely was observed to be greater than that of cauliflower cultivated with intercrops. This may be explained by the availability of vital nutrients and other resources, which were sufficient because there was less competition than with the intercropped plant [10]. Maximum number of leaves per plant (21.82) of cauliflower was observed in T2 [Cauliflower as sole crop with AMF]. This was followed by T6 [Cauliflower (with AMF) + Fenugreek] (20.75) and T7 [Cauliflower (with AMF) + Carrot] (20.45), which were statistically at par. Accordingly, the increased rate of photosynthesis leads to a higher number of leaves. Furthermore, the spacing between plants has a notable impact on the number of leaves. As in sole cropping, spacing increases than intercropping, the number of leaves per plant increases in sole crop [10]. The minimum stalk length (4.42 cm) was observed in T2 [Cauliflower as sole crop with AMF]. The data on cauliflower curd polar diameter as a sole crop and under different intercropping systems, presented in Table 3, revealed that the highest curd polar diameter (11.09 cm) was recorded in T8 [Cauliflower (with AMF) + Carrot], followed by T5 [Cauliflower (without AMF) + Fenugreek] (10.98 cm). The maximum equatorial diameter (10.45 cm) was recorded in T4 [Cauliflower (with AMF) + Coriander], followed by T7 [Cauliflower (without AMF) + Carrot] (10.30 cm) and T8 [Cauliflower (with AMF) + Carrot] (10.37 cm). The results obtained at this stage for indicators are in contrast to the data from [12], where the sole cabbage has a larger diameter and height of the cabbage heads compared to the intercropping options.

Data revealed that the highest gross weight (1455.00 g) of cauliflower was recorded in T6 [Cauliflower (with AMF) + Fenugreek]. The data on cauliflower net curd weight as a sole crop and under different intercropping systems, presented in Table 4, revealed that the highest net curd weight (845.00 g) was recorded in T6 [Cauliflower (with AMF) + Fenugreek]. This was statistically at par with T4 [Cauliflower (with AMF) + Coriander] (565.20 g). The combination of the leguminous intercrop and mycorrhizal association may have increased nutrient uptake, especially nitrogen and phosphorus, resulting in the maximum gross and net curd weight seen in cauliflower intercropped with fenugreek coupled with AMF application (T_0). Curd development was encouraged by improved soil fertility and resource utilisation under this system, and comparable results in T_4 indicate that AMF plays a beneficial role in increasing curd weight even under non-leguminous intercropping. Weight of cabbage head was significantly influenced by intercropping which was in accordance with previous studies by [13]. Higher weight of head was seen in cabbage intercropped with palak. When short seasoned vegetables are cultivated as intercrop might have benefited by resource sharing as long duration crop had an opportunity to utilize nutrients, space for later maturing vegetable thereby increasing their yield [12].

The maximum yield (7,605.00 g/plot) was recorded in the treatment Cauliflower (with AMF) + Fenugreek (T6), followed by 6,155.10 g/plot in T2 and 6,017.52 g/plot in both Cauliflower as sole crop (with AMF) and Cauliflower (with AMF) + Carrot (T8). While in other studies the productivity of cauliflower is outstandingly improved in sole cropped plot [14] demonstrated similar findings in their study on cauliflower when applying the proper dosage of fertilizer [15] also found similar results on broccoli. Intercropping has been shown to increase yield efficiency of re-source utilization [16].

Table 3. Effect of AMF and intercropping on different parameters of cauliflower as sole crop and influenced by intercropping

Treatment	Days 50 % Maturity curd	Plant height (cm)	Leaf Length (cm)	Leaf breadth (cm)	Number of leaves per plant	Stalk Length (cm)	Curd Polar diameter (cm)	Curd equatorial diameter (cm)
T_1	71.39^{ab}	48.84^{d}	37.55^{d}	18.78^{c}	19.18^{b}	4.42^{c}	10.35^{abc}	8.72^{bc}
T_2	71.40^{ab}	50.60^{bcd}	38.99^{cd}	20.61^{b}	21.82^{a}	5.57^{ab}	8.15^{d}	10.15^{ab}
T_3	70.11^{bc}	51.88^{ab}	41.01^{abc}	21.52^{ab}	21.51^{a}	5.15^{b}	9.96^{abc}	8.18^{c}
T_4	71.46^{ab}	48.83^{d}	40.41^{bc}	22.37^{a}	21.56^{a}	5.60^{ab}	9.66^{c}	10.45^{a}
T_5	72.30^{a}	53.35^{a}	39.75^{cd}	21.45^{ab}	19.59^{b}	5.60^{ab}	10.98^{ab}	9.33^{abc}
T_6	71.11^{ab}	52.02^{ab}	42.43^{ab}	20.59^{b}	20.75^{ab}	5.25^{ab}	9.79^{bc}	10.11^{ab}
T_7	69.12^{c}	51.46^{abc}	43.17^{a}	22.37^{a}	20.45^{ab}	6.85^{a}	11.09^{a}	10.30^{a}
T_8	67.40^{d}	49.06^{cd}	42.60^{ab}	22.41^{a}	21.44^{a}	5.84^{a}	10.76^{abc}	10.37^{a}
SEm (±)	0.76	1.12	1.03	0.77	0.75	0.30	0.59	0.67
CD(5%)	1.63	2.41	2.22	1.66	1.61	0.65	1.27	1.44

Table 4. Effect of AMF and intercropping on different parameters of cauliflower as sole crop and influenced by intercropping

Treatment	Gross curd weight (g)	Net curd weight (g)	Marketable curd yield per plot (g/plot)	Marketable curd yield Per (q/ha)	chlorophyll content in leaves (mg/100g)	Total soluble solids (°Brix)	Ascorbic acid (mg/100g)
T_1	1304.90^{bc}	543.10^{c}	4887.90^{c}	81.46^{c}	43.16^{c}	8.47^{bc}	4.27^{bc}
T_2	1355.66^{a}	683.90^{a}	6155.10^{a}	102.58^{a}	45.56^{b}	8.33^{bc}	3.95^{c}
T_3	1281.53^{c}	584.56^{b}	5261.10^{b}	87.68^{b}	44.63^{bc}	9.84^{ab}	4.40^{bc}
T_4	1335.26^{ab}	565.20^{b}	5086.80^{b}	84.78^{b}	49.03^{a}	10.47^{a}	4.35^{bc}
T_5	1265.63^{c}	581.10^{b}	5229.90^{b}	87.16^{b}	53.30	10.38^{a}	4.80^{abc}
T_6	1455.00	845.00	7605.00	126.75	44.53^{bc}	8.55^{bc}	4.92^{ab}
T_7	1184.76^{d}	465.13^{d}	4186.20^{d}	69.77^{d}	48.73^{a}	8.15^{c}	5.45^{a}
T_8	1365.00^{a}	670.28^{a}	6017.52^{a}	100.54^{a}	44.63^{bc}	9.44^{abc}	3.98^{c}
SEm (±)	18.48	9.43	85.53	1.41	0.91	0.73	0.40
CD (5%)	39.65	20.23	183.44	3.036	1.96	1.57	0.86

The maximum chlorophyll content (53.30 mg/100 g) was recorded in T5 [Cauliflower (without AMF) + Fenugreek], followed by T8 [Cauliflower (with AMF) + Carrot] (44.63 mg/100 g) and T3 [Cauliflower (without AMF) + Coriander] (44.63 mg/100 g). The data regarding TSS (°Brix) of cauliflower, presented in Table 4, showed that TSS content was generally higher in sole cropping compared to intercropping systems. The maximum TSS (10.47 °Brix) was recorded in T4 [Cauliflower (with AMF) + Coriander], followed by T5 [Cauliflower (without AMF) + Fenugreek] (10.38 °Brix), which was statistically at par with T3 [Cauliflower (without AMF) + Coriander] (9.84 °Brix). The increase in quality parameters with sole cropping of pea, radish and carrot may be attributed to increased availability of nutrients in the oil that might lead to synthesis and accumulation of more photo synthetic which could have mobilized the biosynthesis [17]. It might be due to increased photo-synthetic activity and other minerals resulted in improved levels of carbohydrates and other quality parameters of cauliflower curd through the way of enzymatic activity stimulated by plant growth substances produced by the application of biofertilizers and other nutrients [18]. The maximum ascorbic acid content (5.45 mg/100 g) was recorded in T_7 [Cauliflower (without AMF) + Carrot], followed by T6 [Cauliflower (with AMF) + Fenugreek] (4.92 mg/100 g). The results are in confirmation with the outcome achieved by in eggplant [19], in fenugreek [20], in tomato [23], in cabbage [21].

3.2 Evaluation of yield advantage in intercropping system

The intercropping treatments significantly influenced resource-use efficiency and economic returns. The highest land equivalent ratio (1.93) was recorded in T_6 [cauliflower (with AMF) + fenugreek], indicating superior land-use efficiency, followed by T_3 [cauliflower (without AMF) + coriander] with an LER of 1.56. Similarly, the maximum monetary advantage index (12.83) was observed in T_6, followed by T_8 [cauliflower (with AMF) + carrot] (10.78), reflecting the economic superiority of these intercropping systems (Table 5). Production efficiency was highest in T_8 [cauliflower (with AMF) + carrot] (225.11 kg ha^{-1} day^{-1}), whereas the lowest value (52.14 kg ha^{-1} day^{-1}) was recorded in T_{11} [fenugreek as sole crop] (Figure 2). The maximum cauliflower equivalent yield (193.04 q ha^{-1}) was obtained in T_8, which was statistically at par with T_4 [cauliflower (with AMF) + coriander] (186.23 q ha^{-1}), indicating the yield advantage of AMF-assisted intercropping systems. The LER value is always unity in monocropping and if LER is found greater than 1, it means that intercropping is beneficial over sole cropping. Thus, it means that there is yield advantage in intercropping due to efficiently utilization of land in intercropping system. Due to complementary crop interactions and improved nutrient uptake, the higher land equivalent ratio and monetary advantage index found in cauliflower interplanted with fenugreek together with AMF (T_2) imply more effective resource utilisation and higher economic returns. The AMF-assisted cauliflower–carrot and cauliflower–coriander systems' increased production efficiency and cauliflower equivalent yield further demonstrate the contribution of AMF and appropriate intercrops to raising output and system efficiency. from the intercropping systems indicated the suitability, productivity as well as the profitability of the systems over the sole crop cultivation. These results were supported by the findings of [24].

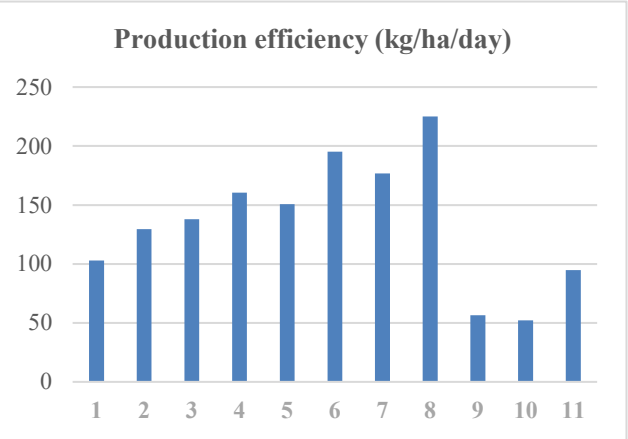


Fig. 2. Production efficiency (kg/ha/day) of cauliflower as sole crop and as influenced by intercropping.

Table 5. Yield advantage in intercropping system

Treatment	Land equivalent ratio (LER)	Monetary advantage index (MAI)	Cauliflower equivalent yield (CEY/q/ha)
T_1	1.00	–	–
T_2	1.00	–	–
T_3	1.56	7.51	126.42
T_4	1.64	8.26	186.23
T_5	1.45	7.58	129.31
T_6	1.93	12.83	164.41
T_7	0.92	8.45	169.11
T_8	0.95	10.78	193.04
SEm (±)	0.19	3.62	7.87
CD (5%)	0.41	1.69	16.89

3.3 Effect of intercropping and arbuscular mycorrhizal fungi on soil microbial properties

The soil microbial population was significantly influenced by intercropping systems and AMF application. The highest bacterial population (57.66 × 10^6 CFU) was recorded in T_8 [cauliflower (with AMF) + carrot], followed by T_2 [cauliflower as sole crop with AMF] (56.00 × 10^6 CFU) (Table 6), indicating a strong positive effect of AMF on bacterial proliferation in the rhizosphere. Similar observations have been reported earlier, where greater bacterial and fungal populations were observed under diversified cropping systems compared to conventional farming, particularly when cauliflower was intercropped with pea or coriander [25]. Enhanced AMF populations under organic nutrient management compared to mineral fertilization have also been reported, suggesting favorable conditions for microbial activity under biologically managed systems [26].

Table 6. Effect of AMF and intercropping on microbial community of cauliflower as sole crop and influenced by intercropping

Treatment	Bacterial count (CFU) 10^6	AM Spore count	Phosphorus Solubilising bacteria (CFU)10^6
T_1	44.33^{cd}	110.00^{c}	2.10^{e}
T_2	56.00^{a}	176.00^{a}	4.99^{c}
T_3	40.00^{e}	116.00^{bc}	2.46^{d}
T_4	47.00^{c}	167.66^{a}	5.26^{b}
T_5	44.66^{cd}	110.00^{c}	2.10^{e}
T_6	44.00^{cd}	173.33^{a}	5.90^{a}
T_7	52.00^{b}	115.33^{bc}	2.06^{e}
T_8	57.66^{a}	188.33	5.80^{a}
T_9	43.66^{d}	119.66^{bc}	2.10^{e}
T_{10}	42.66^{de}	119.66^{bc}	2.10^{e}
T_{11}	43.00^{de}	125.33^{b}	2.100^{e}
SEm (±)	1.48	5.72	0.12
CD(5%)	3.08	11.93	0.26

The maximum arbuscular mycorrhizal (AM) spore count (188.33) was recorded in T_8, followed by T_{10} [coriander as sole crop] and T_{11} [fenugreek as sole crop] (119.66 each). The higher spore density under these treatments may be attributed to suitable host compatibility and favorable soil nutrient status. Under conditions of adequate nitrogen and phosphorus availability, AMF may contribute less to nutrient acquisition and more to improving soil aggregation, water uptake, transport efficiency, and plant resistance to biotic and abiotic stresses, thereby sustaining symbiotic activity [27].

The maximum phosphorus-solubilizing bacterial (PSB) population (5.90 × 10^{-6} CFU) was recorded in T_6 [cauliflower (with AMF) + fenugreek], followed by T_9, T_{10}, T_{11}, T_5, and T_1, which showed comparatively lower but similar populations (~2.10 × 10^{-6} CFU). The enhanced PSB population under AMF-treated and legume-intercropped systems suggests a synergistic interaction between AMF, PSB, and crop roots, facilitating better microbial colonization and survival in the rhizosphere. This indicates that indigenous beneficial microorganisms can effectively proliferate and establish under integrated biological nutrient management practices, leading to improved soil biological health [28-30].

4. Conclusion

The study revealed that cauliflower-based intercropping systems performed better under AMF conditions compared to non-AMF and sole cropping. Among the treatments, Cauliflower (With AMF) + Carrot (T8) was most productive, recording the highest production efficiency (225.11 kg/ha/day) and CEY (193.04 q/ha). Cauliflower (With AMF) + Fenugreek (T6) was significantly superior for gross curd weight, net curd weight, yield per plot, yield per hectare, phosphorus sol-ubilizing bacteria (PSB), land equivalent ratio (1.93), and monetary advantage index (MAI), highlighting its overall efficiency. In contrast, non-AMF combinations, particularly Cauliflower (Without AMF) + Carrot (T7), recorded the lowest performance. Thus, AMF-assisted intercropping of cauliflower with fenugreek or carrot proved to be the most efficient system, ensuring higher productivity, resource-use efficiency, and sustainability compared to sole cropping.

Author Contributions

Author Contributions: OPSTAT software, formal statistical analysis, Hiya Dashora -original draft preparation, Nikhil Malav-review and editing, Dr Shipra Singh Parmar; supervision.

Conflict of Interest

The authors declare that there is no conflict of interest.

Data Availability Statement

The data generated and analyzed during the current study are un-available publicly, where data supporting reported results can be found. Access to the data may be granted by the corresponding author upon reasonable request.

Funding

This research received no external funding

Acknowledgment

We would like to express my sincere gratitude to Dr. S.K. Sharma, Head of the Department, ITM University Gwalior for his invaluable support and encouragement through the course of this work.

References

1. Turan, M., Erenler, S., Ekinci, M., Yildirim, E., and Argin, S. (2022). Intercropping of cauliflower with lettuce is more effective for sustainable fertilizer management and minimizing environmental risks. *Sustainability*, 14(13), 7874.
2. Weih, M., Mínguez, M.I. and Tavoletti, S., 2022. Intercropping systems for sustainable agriculture. *Agriculture*, *12*(2), p.291.
3. Mrnka, L., Frantík, T., Schmidt, C. S., Baldassarre Svecova, E., and Vosatka, M. (2023). Intercropping of *Tagetes patula* with cauliflower and carrot increases yield of cauliflower and tentatively reduces vegetable pests. International Journal of Pest Management, 69(1), 35-45.
4. Chatterjee, B., and Acharya, B. (2016). Intercropping systems for pest control in vegetable crops. *Journal of Sustainable Agriculture*, 28(3), 45-60.
5. Dhull, S. B., Chandak, A., Bamal, P., Malik, A., & Kidwai, M. K. (2021). Fenugreek (*Trigonella foe-num-graecum*): Nutritional, health properties and food use. *In fenugreek: Biology and Applications Singapore: Springer* Singapore (pp. 219-246).
6. Davoud, S. A., Hassandokht, M. R., Kashi, A. K., Amri, A., & Alizadeh, K. H. (2010). Genetic variability of some agronomic traits in the Iranian fenugreek landraces under drought stress and non-stress conditions. *African Journal of Plant Science*, 4(2), 12-20.
7. Susila, E., Chan, S. R. O. S., Achmad, B. S., & Maulina, F. (2022). Exploration and morphology identification of spores asbuscular mycorrhizal fungi from horticultural plantation.

Journal of Applied Agricultural Science and Technology, *6*(1), 20-30.
8. Mugabo, J. P., Bhople, B. S., Kumar, A. K., Singh, V. K., Mahmoud, E. A., Ullah, F., Singh, O. (2024). Insights into the tripartite interaction: Effects of Arbuscular mycorrhizae and Rhizobium on root morphology, soil enzymes, and biochemical properties in pea cultivation in alluvial soils of Punjab, India. Cogent Food & Agriculture, 10(1) 2366384.
9. Selvaganapathi, K., Kumar, K. A., Bhople, B. S., Singh, V. K., Jayanthi, J., Singh, O., Bárek, V., Alshehri, M. A., Gaber, A., & Hossain, A. (2025). Boosting soil nutrients, carbon storage, and wheat yield with co-compost organic fertilizers and growth-promoting microorganisms in Typic Haplustept soils. *Journal of Soil Science and Plant Nutrition*.
10. Trombley, J., Celenza, J. L., Frey, S. D., & Anthony, M. A. (2025). Arbuscular Mycorrhizal Fungi Boost Development of an Invasive Brassicaceae. *Plant, Cell & Environment*.
11. Kumar, V., Mehta, R.S., Rajveer, M.P., Kumar, P. (2022). Growth and yield response of different coriander (*Coriandarum sativum* L.) based intercropping systems under Semi-arid Eastern Plain Zones of Rajasthan. *The Pharma Innovation Journal,*11(7): 913-916.
12. Bewuket, G. and Shewaye, H.2020. Effect of Different Rates of N and Intrarow Spacing on Growth Performance of Lettuce (Lactuca sativa L.) in Gurage Zone, Wolkite University, Ethiopia. *Advances in Agriculture*,1-6.
13. Znidarcic, D., Marsic, N. K., Osvald, J., Pozrl, T., & Trdan, S. (2007). Yield and quality of early cabbage (Bra*ssica oleracea* L. var. capitata) in response to within-row plant spacing. Acta Agriculturae Slovenica, 89(1), 15-23.
14. Guvenc, I., Yildirim, E. (2006). Increasing productivity with intercropping systems in cabbage production. *Journal of Sustainable Agriculture,* 28(4), 29-44.
15. Ananda, A., Devi, A. B., Barik, S. P., Konthoujam, J., & Bairwa, M. K. (2018). Effect of Growth, Physiological Aspects and Yield of Cabbage (Brassica oleracea L. cv Rareball) in Knol khol and Broad Bean Intercropping System under Imphal West Condition. *International Journal of Current Microbiology and Applied Sciences*, *7*(10), 1111-1117.
16. Farahzety, A.M. and Aishah, H.S. (2013). Effects of organic fertilizers on performance of cauliflower (*Brassica oleracea* var. *Botrytis*) grown under protected structure. J. Trop. Agric. Food sci., 41 (1): 15-25.
17. Abd El-Hady, A. M. (2020). Effect of incorporating natural zeolite with or without phytase enzyme into broilers diets on blood constituents and carcass traits. *Egyptian Poultry Science Journal*, *40*(1), 225-242.
18. Gao, X., Guo, H., Zhang, Q., Guo, H., Zhang, L., Zhang, C., & Zeng, F. (2020). Arbuscular mycorrhizal fungi (AMF) enhanced the growth, yield, and fiber quality and phosphorus regulation in upland cotton (*Gossypium hirsutum* L.). Scientific reports, 10(1), 2084.
19. Choudhuri, P. (2016). Intercropping in cabbage (*Brassica Oleracea* L. var. *capitata*) for growth, yield, quality and sustainable soil health under foothills of Eastern himalayan region. *Journal of Applied and Natural Science*, 8(4), 1740-1747.
20. Merentola, M., Kanaujia, S. P., & Singh, V. B. (2012). Effect of integrated nutrient management on growth, yield and quality of cabbage (*Brassica oleracea* var. c*apitata*).
21. Salehi, A., Fallah, S., Neugschwandtner, R. W., Mehdi, B. and Kaul, H. P. (2018). Growth analysis and land equivalent ratio of fenugreek-buckwheat intercrops at different fertilizer types. *Journal of Land Management Food and Environment,* 69(2), 105–119.
22. Shivran, U., *et al.,* (2021). Evaluation of Organic Nutrient Management practices on productivity and quality of Cabbage. *Indian Journal of Fertilisers*, 17(10):1076- 1080.
23. Panda, D., Padhiary, A.K. and Mondal, S. (2020). Effect of Panchagavya and Jeevamrit on growth and yield of tomato (*Solanum lycopersicum* L.). *Annals of Plant and Soil Research*, 22(1): 80-85.
24. Hasan, T., Prodhan, M. Z. H., Islam, A., & Akther, M. A. (2017). Intercropping of banana with potato and vegetables. *Bangladesh Journal of Agricultural Research*, *42*(4), 749-755.
25. Choudhuri, P., and Jana, J.C. 2012. Effect of intercropping on yield and economics of cabbage. *Journal of Crop and Weed*, 8(1): 155-157.
26. Farhad, H., Dunet, V., Bachelard, K., Allenbach, G., Kaufmann, P. A., & Prior, J. O. (2013). Added prognostic value of myocardial blood flow quantitation in rubidium-82 positron emission tomography imaging. *European Heart Journal–Cardiovascular Imaging*, *14*(12), 1203-1210.
27. Wakil A. 2021. Tritrophic Interactions in Cauliflower Under Zero Budget Natural Farming and Conventional Farming Systems. Ph.D. Thesis. Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Solan.72-81p.
28. Zhu, C., Ling, N., Guo, J., Wang, M., Guo, S., & Shen, Q. (2016). Impacts of fertilization regimes on arbuscular mycorrhizal fungal (AMF) community composition were correlated with organic matter composition in maize rhizosphere soil. *Frontiers in Microbiology, 7*, 1840.
29. Delavaux, C. S., Smith-Ramesh, L. M., & Kuebbing, S. E. (2017). Beyond nutrients: a metal analysis of the diverse effects of arbuscular mycorrhizal fungi on plants and soils. Ecology, 98(8), 2111-2119.
30. Minaxi, J. Saxena, S. Chandra and L. Nain. 2013. Synergistic effect of phosphate solubilizing rhizobacteria and arbuscular mycorrhiza on growth and yield of wheat plants*. J. Soil Sci. Plant Nut.,* 13(2): 511-52.