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Impact of organic, integrated and inorganic production systems on yield, quality and soil fertility in cumin (*Cuminum cyminum* L.)

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Abstract
In the present scenario, people are health-conscious and need food which are free from synthetic chemicals/pesticides. Due to the over-usage of synthetic inorganic agri-inputs, such as chemical fertilisers/pesticides, the regions have witnessed a reduction in production quality, groundwater contamination, and soil organic matter depletion. To address this, a field study was carried out during two consecutive years (2022-23 and 2023-24) at ICAR-NRCSS, Ajmer, to assess the impact of organic, integrated and inorganic production systems on yield, quality and soil fertility in cumin. Based on nutrition, 12 treatments, including organic, integrated and inorganic, were planned to execute the investigation. It is found that the organic production system, in comparison to integrated and inorganic production systems, was superior in yield, quality and soil fertility. This study also infers that among the various organic treatments, supply of 50% recommended dose of nitrogen through PGPR enriched FYM + 50% recommended dose of nitrogen through castor cake was most effective combination to meet the nutrition requirements of cumin for higher yield of 485 kgha^{-1} (~ 210 % higher in comparison to inorganic), essential oilof 5.55% (~ 96 % higher in comparison to inorganic) and soil N of 127 kg ha^{-1} (~4 % higher in comparison to inorganic).

Keywords: Cumin, organic, integrated, inorganic, quality, soil fertility

Introduction
Cumin (*Cuminum cyminum* L.) is an herbaceous annual plant belonging to the Apiaceae family. In India, it is commonly called *Jeera in the vernacular*. Rajasthan and Gujarat together contribute almost 99per cent of the national area and production of cumin(Spice Board, 2024). Both the total area under cumin cultivation and the quantity of production have increased significantly over the past

twodecades.India is the largest producer, consumer and exporter of cumin in the world. The bulk ofproduction is used for domestic consumption, and around 20 per cent is exported. Cumin is known as an export-oriented crop. China, United States, Vietnam,United Arab Emirates, and Bangladesh are the major destinations for the export of cumin seeds from India (Export Import Data, 2024-25).The by-products of cumin seeds, like oleoresins and cumin oil, are also exportedto the United States of America, Canada and Europe.

In past years, many countries, including the USA and Europe, have set stringent standards and norms for the quality of agricultural produce during import. Under such circumstances, our consignments are often rejected because they do not meet the standards and norms, resulting in significant losses of foreign export earnings. Nowadays, people are health-conscious and need food which are free from synthetic chemicals/pesticides. Due to theover-usage of synthetic inorganic agri-inputs such as chemical fertilizers/pesticides, the regions have witnessed a reduction in production quality, groundwater contamination, soil organic matter depletion, and air pollution (Zambon *et al.*, 2017). Looking at this, there is an urgent need to cultivate cumin without use of synthetic chemicals/pesticides. Recently, organic and regenerative organic agriculture are gaining momentum to address this issue. The overarching aim of organic farming is to enhance long-term soil fertility, minimize dependency on external inputs, maintain or improve crop productivitywhile also fostering climate resilience, ecological restoration, and the health, well-being, and economic stability of farmers.It is practiced by using organic manures, bio-fertilizers, botanicals, plant growth-promotingrhizobacteria (PGPR) etc. Considering the above information, an attempt has been made to compare the yield, quality and soil fertility among organic, integrated and inorganic production systems.

Materials and Methods

A field study was conducted on "Impact of organic, integrated and inorganic production systems on yield, quality and soil fertility in cumin" at ICAR-National Research Centre on Seed Spices, Ajmer, Rajasthan, India during 2022-23 and 2023-24. The Centre lies on 74˚ 35' 39'' E to 74˚ 36' 01'' E longitude and 26˚ 22' 12'' N to 26˚ 22' 31'' N latitude at an altitude of 460.17 m above mean sea level. The rainfall in the area is highly erratic, and more than 90% of the rain is received from July to September, with several intermittent long dry spells. The average rainfall is ~500 mm. The temperature ranges from 2–5˚C during January and 42–45˚C during May. The soil was sandy loam in nature and the site was maintained as per standard organic production requirements.

The experiment consists of three replications of a 3 × 3 m plot size in the randomized block design (RBD).In T_1, the RDF (30: 20: 15 NPK kg ha-1) of cumin was supplied through urea, diammonium phosphate (DAP) and muriate of potash (MOP) and considered an inorganic production system. Treatment T_2 comprised 10 t FYM + RDF (30: 20: 15 NPK kgha^{-1}) through inorganic fertilizers and considered an integrated production system. Treatment T_3 to T_{12}comprises a solo and a combination of organic manures, viz., farm yard manure (FYM), vermicompost (VC), neem cake (NC), castor cake (CC), with or without PGPR and is considered an organic production system. In organic production systems (T_3 to T_{12}), the RDN of cumin was supplied through a combination of organic manures, based on their N content, to meet the crop's N requirement.The N content of FYM, VC, NC and CC was 0.44, 0.24, 2.81 and 4.50 % respectively.In some of the treatments, bulky organic manures,*viz.* FYM and VC were enriched by an indigenous isolate of PGPR (*Pseudomonas aeruginosa*) before sowing every year.The details of treatments, quantity of fertilizers and organic manures applied are given in Table 1.

Sowing of cumin was done during third week of November of each year. Data on growth and yield attributes were recorded periodically on five randomly selected plants from each replication, excluding border plants. Test weight was calculated by weighing 1000 seed counts. Cumin harvesting commenced during the second week of March. The seed yield was recorded plot-wise. Essential oil was extracted from shade-dried cumin seeds (30 g per sample) using hydro-distillation in a Clevenger-type apparatus for 7 hours, following the method of Clevenger (1928). Samples were taken in three replications. The recovered oil was separated, dried over anhydrous sodium sulphate, and expressed as a percentage (v/w) based on the initial dry weight. The resulting oil was pale yellow in colour and free from moisture.

Soil samples were taken using an auger after harvesting of the crop from each replication, ranging in depth from 0 to 15 cm, in accordance with the conventional technique, in order to examine the variations in the soil's fertility level. After being well combined, dried, and run through a 100-mesh (2 mm) filter, the samples were stored in plastic bags for analysis of the organic carbon (Walkey and Black, 1934)and available nitrogen (Alkaline permanganate method), available P (Olsen *et al*., 1954) and available K (Jangir *et al.*, 2019).

The data were subjected to one way analysis of variance (ANOVA) by *AGRI ANALYZE* online software. The least significant difference (LSD) test at a significance level of $p<0.05$ was performed to compare the means if the F-value was significant.

Results and Discussion

Growth and yield attributes

The data presented in Table 2indicate that the treatments significantly influenced growth and yield attributes. Significantly higher values of plant height were noticed in all organic treatments (T_3 to T_{12}) in comparison to inorganic (T_1) and integrated production system (T_2).Among the organic treatments, the tallest plants were recorded in T_6 (35.71 cm) at par with T_8 (35.16 cm). The no. of primary branches recorded a maximum in T_{12} (6.13), which was also statistically on par with T_8 (5.90). Similarly, a significantly higher number of secondary branches was observed in all organic treatments (T3 to T12) comparedto inorganic (T_1) and integrated (T_2). Amidst the organic treatment, the highest no. of secondary branches was recorded in T_8 (17.90). The same trend was followed in the case of the number of umbels/plant and umbellate/umbel when comparing between organic, integrated and inorganic. However, within organic treatmentshighest umbel/plant was recorded in T_8 (20.86) at par with T_{12} (20.40). Umbellate/umbel was maximum in T_{12} (5.33), at par with T_8 (5.26). The test weight was recorded as maximum in T_6 (4.96 g), which was statistically on par with T_8 (4.82 g). Similarly, a significant increment was observed in organic treatments in comparison to integrated and inorganic treatments with respect to seed yield. The lowest seed yield (156 kgha^{-1}) was recorded in inorganic (T_1), followed by integrated (T_2) (190 kgha^{-1}). The variation in seed yield within organic treatments was statistically nonsignificant. Though the maximum was recorded in T8 (485 kg ha-1), receiving 50% RDN through PGPR-enriched FYM + 50% RDN through castor cake, followed by T_{11} (471 kg/ha). The yield improvement in T_8 (organic) was ~ 210% higher than inorganic. Results are in agreement with Chaudhary *et al*. (2025), who found that 50% RDN through FYM could record the highest seed yield of Nigella under an organic production system. Utilizing FYM increases the soil environment, promotes more extensive root growth, improvessoil structure, and improves nutrient cycling by soil microbes (Fageria, 2019). FYM's ability to retain moisture enhancednutrient absorption (Shivran*et al*., 2024). Organic acids generated during the breakdown process become good chelating agents forP (Yu *et al*., 2013). Besides, the PGPR secretes helpful growth-promoting chemicals such as IAA, GA, kinetin, riboflavin, and thiamin, which can result in improved plant development (Malik *et al*., 2005). The PGPR can stimulate plant development by increasing root surface area or root architecture in general (Chattoo*et al*., 2007).Six plant growth-promoting rhizobacteria (PGPR) were applied for the enhancement of growth and yield of coriander crop (Coriandrumsativum L. cv Acr-1), in which the maximum seed yield of 1650.94 kg/ha was recorded with Bacillus aerophilus Cor-15, being at par with Bacillus subtilis strains, and the minimum in the control. Maximum essential oil yield was recorded with *Bacillus megaterium* ISB-28 (5.86 l/ha), followed by B. aerophilus Cor-15 (4.64 l/ha), and the least was observed with the control (3.09 l/ha) (Mishra *et al.*, 2016).

Seed quality (essential oil content)

The data presented (Table 2) indicate that seed quality was significantly influenced by the treatments. The quality of cumin seed is determined by essential oil content. The essential oil content significantly differed between organic, integrated, and inorganic production systems. Significantly higher values of essential oil were found in organic treatments in comparison to integrated and inorganic treatments. Within the organic treatments, T_8had the highest essential oil content

(5.55%), followed by T_6 and T_{10}. The lowest essential oil was recorded in inorganic treatment (T_1). The essential oil in T_8 (organic) was improved by ~ 96 % in comparison to inorganic treatment. This elevated aromatic quality under organic systems is consistent with earlier studies in spices, which suggest that organic nutrient management enhances the biosynthesis of secondary metabolites, including essential oils, due to improved soil biological activity and stress-induced metabolic responses (Singh *et al.*, 2008; Kumari *et al.*, 2017). Organic amendments such as FYM and compost, along with natural bio-inputs like *Jeevamrit* and *Ghanjeevamrit*, improve soil microbial diversity and enzymatic activity, which are known to positively influence the synthesis of volatiles in aromatic crops (Deshmukh *et al.*, 2022). Such conditions may stimulate plant defence-related secondary metabolism, leading to a higher accumulation of essential oil constituents (Ramesh *et al.*, 2010; Meena *et al.*, 2018).

Soil fertility

The perusal of data (Table 3) revealed that soil fertility status was significantly influenced by different production systems. The highest value of organic carbon was observed in T7 (0.39%) compared to T2, T5, and T_9. The lowest value was recorded in T_9. Treatment T_8 recorded the statistically significantly highest value of N (127 kg ha-1) receiving 50% RDN through PGPR-enriched FYM + 50% RDN through castor cake,in comparison to T_7, T_1, T_{11}, T_3 and T_4. The lowest value of N was recorded in T_4. The N content in T_8 was improved by ~ 4% in comparison to inorganic treatment. The highest P content was recorded in T_7 (9.87 kgha^{-1}), receiving 50 % RDN through PGPR-

Table 1. Treatment details, quantity of fertilizers and organic manures used in the study

Treat.	Descriptions	Quantity (kg ha^{-1})
T_1	Inorganic-RDF (30: 20: 15 kg NPK/ha) through inorganic fertilizers	DAP-43.5, urea- 48, MOP_25
T_2	Integrated-10 t/ha FYM + RDF (30:20:15 kg NPK/ha) through inorganic fertilizers	FYM-10 t/ha, DAP - 43.5, urea-48, MOP-25
T_3	100% RDN through farmyard manure (FYM)	6000
T_4	100% RDN through PGPR enriched FYM	6000
T_5	100% RDN through vermicompost (VC)	3000
T_6	100% RDN though PGPR enriched VC	3000
T_7	50% RDN through PGPR enriched FYM + 50% RDN through neem cake (NC)	3000 +1000
T_8	50% RDN through PGPR enriched FYM+ 50% RDN through castor cake (CC)	3000+350
T_9	50% RDN through PGPR enriched VC + 50% RDN through NC	1500+1000
T_{10}	50% RDN through PGPR enriched VC + 50% RDN through CC	1500+350
T_{11}	33.3% RDN through PGPR enriched FYM +33.3 % RDN through CC + 33.3% RDN through NC	2000+233+666
T_{12}	33.3% RDN through PGPR enriched VC+ 33.3% RDN through CC + 33.3% RDN through NC	1000+233+666

RDF-Recommended dose of fertilizers; RDN-Recommended dose of nitrogen

Table 2. Effect of organic, integrated and inorganic production systems on growth, yield and quality of cumin (Pooled over data of two years)

Treatment	Plant height (cm)	Primary branch (no)	Secondary branch (no)	Umbel/ plant (no)	Umbellate/ umbel (no)	Test weight (g)	Seed yield (kg ha^{-1})	Essential oil (%)
T_1	24.2^{c}	4.66^{d}	10.50^{e}	13.66^{d}	4.73^{c}	3.02^{e}	156^{b}	(1.68) 2.83^{d}
T_2	24.13^{c}	5.03^{cd}	10.43^{e}	14.20^{d}	4.73^{c}	3.75^{d}	190^{b}	(1.80) 3.27^{d}
T_3	34.53^{ab}	5.30^{bc}	13.16^{d}	16.16^{c}	5.13^{ab}	4.62^{abc}	352^{a}	(2.19) 4.43^{abc}
T_4	34.9^{ab}	5.16^{cd}	12.43^{d}	18.20^{b}	5.30^{a}	4.61^{abc}	381^{a}	(2.25) 5.10^{abc}
T_5	32.43^{b}	5.10^{cd}	15.70^{bc}	17.86^{bc}	4.93^{bc}	4.33^{c}	456^{a}	(2.10) 4.50^{c}
T_6	35.71^{a}	5.63^{abc}	16.70^{ab}	18.96^{ab}	4.93^{bc}	4.96^{a}	426^{a}	(2.30) 5.33^{ab}
T_7	33.78^{ab}	5.40^{bc}	16.83^{ab}	19.26^{ab}	5.30^{a}	4.73^{abc}	464^{a}	(2.24) 5.11^{abc}
T_8	35.16^{a}	5.90^{ab}	17.90^{a}	20.86^{a}	5.26^{a}	4.82^{ab}	485^{a}	(2.35) 5.55^{a}
T_9	34.37^{ab}	5.80^{ab}	14.86^{c}	19.03^{ab}	5.10^{ab}	4.43^{bc}	432^{a}	(2.18) 4.77^{abc}
T_{10}	34.38^{ab}	5.13^{cd}	12.26^{d}	17.96^{bc}	4.93^{bc}	4.40^{bc}	412^{a}	(2.30) 5.32^{ab}
T_{11}	34.66^{ab}	5.63^{abc}	16.30^{b}	19.33^{ab}	5.06^{ab}	4.68^{abc}	471^{a}	(2.16) 4.77^{bc}
T_{12}	34.94^{ab}	6.13^{a}	14.60^{c}	20.40^{a}	5.33^{a}	4.35^{bc}	402^{a}	(2.11) 4.55^{c}
LSD (5%)	2.68	0.62	1.35	1.94	0.32	0.47	146	0.17

T_1-Inorganic-RDF (30: 20: 15 kg NPK/ha) through inorganic fertilizers; T_2-Integrated-10 t/ha FYM + RDF(30: 20: 15 kg NPK/ha) through inorganic fertilizers; T_3-100% RDN through FYM; T_4-100% RDN through PGPR enriched FYM; T_5 –100% RDN through vermicompost; T_6 –100% RDN through PGPR enriched vermicompost; T_7 -50% RDN through PGPR enriched FYM + 50% RDN through neem cake; T_8 -50% RDN through PGPR enriched FYM + 50% RDN through castor cake; T_9 - 50% RDN through PGPR enriched vermicompost + 50% RDN through neem cake; T_{10} - 50% RDN through PGPR enriched vermicompost + 50% RDN through castor cake; T_{11} -33.3 % RDN through PGPR enriched FYM + 33.3 % RDN through castor cake + 33.3 % RDN through neem cake; T_{12} - 33.3 % RDN through PGPR enriched vermicompost + 33.3 % RDN through castor cake + 33.3 % RDN through neem cake

Means with different letters are significantly different within columns (LSD test, $p < 0.05$).
Figures in parentheses are transformed values.

Table 3. Effect of organic, integrated and inorganic production systems on soil fertility (Pooled over data of two years)

Treatment	Organic carbon (%)	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})
T_1	(1.15) 0.34^{abcd}	122^{cd}	9.41^{bc}	250^{a}
T_2	(1.14) 0.32^{bcd}	124^{abcd}	9.28^{bc}	247^{ab}
T_3	(1.17) 0.37^{abc}	118^{ef}	9.20^{c}	251^{a}
T_4	(1.16) 0.35^{abcd}	115^{f}	9.38^{bc}	248^{ab}
T_5	(1.14) 0.31^{cd}	127^{ab}	9.46^{abc}	245^{ab}
T_6	(1.15) 0.34^{abcd}	125^{abc}	9.30^{bc}	239^{b}
T_7	(1.18) 0.39^{a}	124^{bcd}	9.87^{a}	248^{ab}
T_8	(1.16) 0.35^{abcd}	127^{a}	9.66^{ab}	249^{a}
T_9	(1.13) 0.29^{d}	126^{ab}	9.14^{c}	250^{a}
T_{10}	(1.16) 0.35^{abcd}	125^{abc}	9.31b^{c}	245^{ab}
T_{11}	(1.17) 0.39^{ab}	121de	9.66^{ab}	248^{ab}
T_{12}	(1.16) 0.36^{abcd}	125^{abcd}	9.67^{ab}	244^{ab}
LSD (5%)	0.03	3.60	0.42	9.36

T_1-Inorganic-RDF (30: 20: 15 kg NPK/ha) through inorganic fertilizers; T_2-Integrated-10 t/ha FYM + RDF(30: 20: 15 kg NPK/ha) through inorganic fertilizers; T_3-100% RDN through FYM; T_4-100% RDN through PGPR enriched FYM; T_5 –100% RDN through vermicompost; T_6 –100% RDN through PGPR enriched vermicompost; T_7 -50% RDN through PGPR enriched FYM + 50% RDN through neem cake; T_8 -50% RDN through PGPR enriched FYM + 50% RDN through castor cake; T_9 - 50% RDN through PGPR enriched vermicompost + 50% RDN through neem cake; T_{10} - 50% RDN through PGPR enriched vermicompost + 50% RDN through castor cake; T_{11} -33.3 % RDN through PGPR enriched FYM + 33.3 % RDN through castor cake + 33.3 % RDN through neem cake; T_{12} - 33.3 % RDN through PGPR enriched vermicompost + 33.3 % RDN through castor cake + 33.3 % RDN through neem cake.

Means with different letters are significantly different within columns (LSD test, $p < 0.05$).
Figures in parenthesis are transformed values.

enriched FYM + 50% through neem cake, which was at par with T_{12}, T_{11}, T_8 and T_5. The lowest value of P was recorded in T_9. The statistically significant highest value of K was recorded in T_3, T_1, T_9 and T_8 in comparison to T_6. The highest K content was recorded in T_3 (251 kgha^{-1}) receiving 100 % RDN through FYM, at par with T_1, T_9 and T_8. The lowest value was recorded in T_6.Organic systems improve microbial biomass, which helps convert crop residues into stable organic carbon pools (Kumar *et al.*, 2022).The variations in soil accessible N, P, and K in plots treated with various manures might be related to the variances in their intrinsic potential to deliver these nutrients (Reddy and Reddy, 2011). The addition of organic matter, which raises the population and microbial activity of bacteria capable of converting bound N, P, and K to available forms, is another explanation for the rise in available N, P, and K in soil (Sharma *et al.* 2014).

Conclusion

The organic production system was found to be superior for better yield, quality, and soil fertility compared to inorganic and integrated systems.Among the various organic treatments, the combination of 50% RDN through PGPR-enriched FYM and 50% RDN through castor cake was the most effective in meeting the nutrition requirements of cumin for better productivity, essential oil, and soil fertility. However, a long-term study of microbial populations and ecosystem services may strongly justify the importance of organic farming in future perspectives.

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Conflict of interest

The authors declare that the research was conducted beyond any commercial or financial affairs that could be taken as a potential conflict of interest.

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