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Organic nutrient management and bioformulations for climate-resilient and sustainable turmeric production

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Abstract

Turmeric (*Curcuma longa* L.) is an economically important spice and medicinal crop widely recognized for its curcumin-rich rhizomes and diverse therapeutic properties. The increasing demand for residue-free produce and the challenges posed by climate change have intensified the need for sustainable nutrient management strategies in turmeric cultivation. This review critically examines national and international research on the role of organic nutrient management and bioformulations in enhancing turmeric growth, productivity, quality, and soil health. Evidence from numerous studies demonstrates that organic nutrient sources, including farmyard manure, vermicompost, poultry manure, neem cake, and other oilseed cakes, significantly improve vegetative growth, rhizome development, and fresh as well as cured rhizome yield by enhancing nutrient availability and improving soil physical, chemical, and biological properties. Bioformulations such as Jeevamrut, Panchagavya, Vermiwash, Effective Microorganisms (EM), cow urine, and humic acid further stimulate microbial activity, nutrient cycling, physiological processes, and biochemical quality, thereby increasing productivity of crops under organic production systems. Their combined application with organic manures has been consistently reported to produce synergistic effects by promoting beneficial soil microorganisms, improving nutrient-use efficiency, and enhancing resilience against environmental stresses. In addition, these practices contribute to long-term soil fertility, biodiversity conservation, and reduced dependence on synthetic inputs, supporting climate-smart and environmentally sustainable agriculture. Overall, the available evidence indicates that integrating sources of organic nutrient with bioformulations represents a promising strategy for achieving resilient, productive, and high-quality turmeric cultivation while ensuring ecological sustainability and economic viability for farmers.

Keywords: Organic nutrient management, review, growth, soil health, organic formulations agronomy of turmeric, etc.

Introduction

Sustainable agricultural practices are increasingly essential to address climate change, declining soil fertility, and the growing demand for safe, residue-free agricultural products. In this context, organic nutrient management has emerged as an effective approach to sustain crop productivity while improving soil health and environmental quality. The combined use of organic manures and bioformulations enhances nutrient availability, stimulates soil microbial activity, improves nutrient cycling, and strengthens crop resilience to climatic stresses, making it particularly relevant for high-value spice crops such as turmeric.

Turmeric (*Curcuma longa* L.), a perennial herb of the family Zingiberaceae, is one of the world's most important spice, medicinal, and industrial crops. Native to Southeast Asia, it is cultivated widely in tropical and subtropical regions for its curcumin-rich rhizomes, which possess significant culinary, pharmaceutical, cosmetic, and nutraceutical value. The crop grows best under warm, humid conditions with temperatures of 18–28 °C, annual rainfall of around 1500 mm, and well-drained sandy loam soils having a pH of 6.5–7.5 (Devi and Sanghamitra, 2011) [13]. India is the leading producer, consumer, and exporter of turmeric, and its produce is internationally recognized for superior quality and high curcumin content (Anonymous, 2025) [3].

Being an exhaustive crop with a growth duration of 8–9 months, turmeric requires a continuous and balanced nutrient supply for optimum rhizome development and quality.

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Although synthetic fertilizers can enhance productivity, their indiscriminate use has contributed to soil degradation, nutrient imbalance, and environmental concerns. Organic nutrient management provides a sustainable alternative by improving soil fertility, enhancing nutrient-use efficiency, and producing high-quality rhizomes. Organically grown turmeric has also been reported to contain higher levels of desirable quality constituents, including vitamins, carbohydrates, proteins, amino acids, minerals, and organic acids (Woese *et al.*, 1997) ^[65].

Organic manures such as farmyard manure (FYM), vermicompost, poultry manure, and neem cake play a vital role in improving soil physical, chemical, and biological properties. These inputs enrich the soil with essential nutrients, increase organic carbon, improve moisture retention and cation exchange capacity, and promote beneficial microbial populations, resulting in enhanced plant growth, yield, and long-term soil fertility (Sangashetty and Babalad, 2011; Gupta, 2022) ^[49, 17].

Complementing organic manures, bioformulations such as Jeevamrut, Vermiwash, Panchagavya, Effective Microorganisms (EM), cow urine (Gomutra), and humic acid have gained importance in sustainable crop production. These biologically active formulations supply beneficial microorganisms, enzymes, plant growth regulators, vitamins, and organic compounds that accelerate nutrient mineralization, improve soil enzyme activity, enhance nutrient uptake, and stimulate plant growth (Khaled and Fawy, 2011; Kumar *et al.*, 2021) ^[27, 30]. Their integrated application with organic nutrient sources has consistently demonstrated synergistic effects on crop productivity, rhizome quality, soil fertility, and microbial diversity.

Although numerous studies have documented the individual benefits of organic manures and bioformulations, comprehensive information on their combined role in turmeric production remains fragmented. This review synthesizes current national and international research on organic nutrient management and bioformulations, with emphasis on their effects on crop growth, yield, quality, soil health, and climate resilience. It also identifies research gaps and highlights sustainable nutrient management strategies for enhancing the productivity, profitability, and environmental sustainability of turmeric cultivation.

Materials and Methods

I) Literature Collection and Data Sources

A comprehensive literature survey was conducted to examine the influence of organic nutrient management and bioformulations on the growth, yield, quality, and soil health of turmeric. Relevant information was gathered from peer-reviewed research articles, review papers, books, theses, conference proceedings, and technical publications available in both national and international literature. Preference was given to recent publications, while important earlier studies with significant scientific contributions were also considered. The information presented in this review is based on the critical synthesis of published findings. Literature was accessed through the Department of Agronomy and the Central Library of Mahatma Phule Krishi Vidyapeeth, Rahuri, using electronic resources such as CeRA, J-Gate, and other institutional e-library facilities.

II) Literature Screening and Data Management

The collected literature was systematically identified, screened, and evaluated using internationally recognized scientific databases and online search platforms, including Scopus, Web of Science, ScienceDirect, SpringerLink, Google Scholar, PubMed, Wiley Online Library, Semantic Scholar, and other relevant academic databases. Reference management tools, namely EndNote, Zotero, and Mendeley, were utilized to organize bibliographic information, eliminate duplicate records, and maintain consistency in citations. The selected studies were critically reviewed, classified according to the objectives of the review, and synthesized to provide a comprehensive understanding of the role of organic nutrient management and bioformulations in sustainable turmeric production.

Results and Discussions

I) Effect of organic nutrient management

a) Effect of organic nutrient management on growth parameters and growth of turmeric

Studies have demonstrated that the application of organic manures in combination with inorganic fertilizers significantly improved the growth and quality attributes of turmeric compared with the recommended fertilizer dose (RFD) alone. The combined use of Neem cake, farmyard manure (FYM), and RFD enhanced nutrient uptake, dry rhizome recovery, plant height, dry matter accumulation, number of leaves, and leaf area index (LAI). This integrated nutrient management approach also resulted in significantly greater dry matter production and higher curcumin content in turmeric, indicating the beneficial effect of combining organic amendments with recommended inorganic fertilization (Rao *et al.*, 2005) ^[43]. Application of farmyard manure (FYM) at 18 t ha⁻¹ and poultry manure at 10 t ha⁻¹ produced comparable results and significantly outperformed both the control and the treatment receiving 100% NPK. These organic manure treatments enhanced the number of side suckers, leaves per plant, and rhizome yield of turmeric, demonstrating their effectiveness in improving crop growth and productivity (Sanwal *et al.*, 2007) ^[50]. The combined application of farmyard manure (FYM) along with *Azospirillum*, *Phosphobacteria*, and vesicular arbuscular mycorrhiza (VAM) resulted in the most pronounced improvement in turmeric growth. This treatment recorded the maximum plant height (95.12 cm), number of leaves per plant (20.62), and number of tillers per plant (4.32), indicating the synergistic effect of organic manure and beneficial microbial inoculants on crop growth (Velmurugan *et al.*, 2008) ^[62]. The study indicated that turmeric responded favorably to the application of organic manures, with neem cake proving particularly effective. Application of neem cake at 2 t ha⁻¹ resulted in the highest plant height (79.30 cm), number of tillers per plant (5.40), and number of leaves (5.40), along with greater leaf area (44.09 dm²) and leaf area index (0.429), compared with the other organic manure treatments (Kamal and Yousuf, 2012) ^[25]. Application of vermicompost at the full recommended rate of 25.0 t ha⁻¹ resulted in significantly superior plant height, leaf area, rhizome development, and root characteristics compared with the other nutrient treatments. The performance of this treatment was followed by the application of neem cake at the full rate of 6.0 t ha⁻¹, which also showed a favorable response in turmeric growth and development (Bhende *et al.*, 2013) ^[6]. Among the organic manure treatments, neem cake applied at 1.75 t ha⁻¹ was found to be the most

effective in promoting turmeric growth. This treatment resulted in superior plant height, tiller production, number of leaves, leaf area, and leaf area index compared with the other organic manure sources (Kumar *et al.*, 2013) [32]. The findings indicated that the integrated application of farmyard manure (FYM), vermicompost, and neem cake promoted vegetative growth in turmeric, as evidenced by increased plant height and leaf production. In contrast, the lowest values for these growth parameters were recorded under the absolute control treatment (Sarma *et al.*, 2015) [51]. Integrated application of FYM (15 t ha⁻¹) + vermicompost (3.8 t ha⁻¹) + neem cake (1.5 t ha⁻¹) significantly improved plant height, tiller production, leaf area, and stem girth of turmeric (*Curcuma longa* L.) cv. Roma. This treatment was followed in effectiveness by vermicompost (7.5 t ha⁻¹) + FYM (7.5 t ha⁻¹) + neem cake (1.5 t ha⁻¹), and neem cake (3 t ha⁻¹) + FYM (7.5 t ha⁻¹) + vermicompost (3.8 t ha⁻¹), indicating the beneficial role of combined organic nutrient sources in enhancing vegetative growth and stem development of turmeric (Kumar *et al.*, 2016) [31]. The results demonstrated that application of 125% of the recommended organic manure dose in combination with biofertilizers produced the highest plant height, dry matter accumulation, and tiller number in turmeric. However, these values remained statistically comparable with those obtained under 100% of the recommended organic manure dose, applied either alone or together with biofertilizers. The findings further indicated that the inclusion of biofertilizers provided an additional beneficial effect on the growth and yield performance of turmeric (Singh *et al.*, 2017) [53]. Application of the recommended fertilizer dose resulted in the highest plant height (95.37 cm), number of leaves per tiller (12.28), and tiller production per plant (4.76). These growth attributes were statistically comparable with those recorded under vermicompost application, which produced a plant height of 90.17 cm, 10.70 leaves per tiller, and 3.72 tillers per plant, respectively. The findings suggest that vermicompost could provide growth performance comparable to the recommended fertilizer treatment in turmeric (Kadam and Kamble, 2020) [24]. The combined application of 50% of the recommended dose of fertilizer (RDF) with 50% nitrogen supplied through neem cake (NC) significantly enhanced plant height, number of leaves per plant, leaf width, leaf area index, and number of clumps per plant in turmeric (*Curcuma longa* L.). These growth parameters progressively increased with crop age and attained their maximum values at 150 days after planting (DAP), demonstrating the beneficial effect of integrated nutrient management on turmeric growth (Lohar and Hase, 2021) [34].

b) Effect of organic nutrient management on yield parameters and yield of turmeric

The combined application of FYM at 12 t acre⁻¹ and vermicompost at 1 t acre⁻¹ resulted in the highest weights of mother, primary, and secondary rhizomes, as well as greater rhizome yield per plant and overall rhizome productivity in turmeric. Under this treatment, rhizome yield reached 48.8 t ha⁻¹, compared with only 19.53 t ha⁻¹ under the control, demonstrating the substantial contribution of organic nutrient inputs to turmeric yield enhancement (Rajamani *et al.*, 2007) [41]. The application of FYM in combination with poultry manure markedly improved important yield attributes of turmeric, including mother rhizome weight,

number of fingers per plant, and the weights of primary and secondary fingers and total rhizomes per plant. The improvement in these yield components contributed to a higher rhizome yield compared with the other nutrient treatments. Overall, the use of different organic nutrient sources resulted in a 16% increase in rhizome yield over the untreated control, highlighting their potential for enhancing turmeric productivity (Sanwal *et al.*, 2007) [50]. The integrated application of farmyard manure (FYM) with *Azospirillum*, *Phosphobacteria*, and vesicular arbuscular mycorrhiza (VAM) (M: S₇) resulted in superior turmeric yield attributes. This treatment produced greater number, length, girth, and weight of mother, primary, and secondary rhizomes, which ultimately contributed to the highest rhizome yield per plant (0.838 kg) and estimated productivity of 33,313 kg ha⁻¹. The results highlight the effectiveness of combining organic manure with beneficial microbial inoculants for improving rhizome development and yield in turmeric (Velmurugan *et al.*, 2007) [63]. Application of vermicompost at 25 t ha⁻¹ and neem cake at 6 t ha⁻¹ significantly outperformed the other treatments with respect to rhizome spread, rhizome thickness, root spread, root length, root weight, and number of fingers in turmeric. Among these treatments, vermicompost at 25 t ha⁻¹ was particularly effective, producing the highest fresh rhizome yield in Kasthuri turmeric. The corresponding yield reached 364.95 g plant⁻¹ during the first year and increased to 396.33 g plant⁻¹ in the second year, demonstrating the consistent productivity-enhancing effect of vermicompost application (Nirmalatha *et al.*, 2010) [36]. The application of organic nutrient sources in combination with inorganic fertilizers significantly improved rhizome finger length, finger diameter, and both fresh and cured ginger yields compared with the untreated control. Among the nutrient combinations, 50% NPK supplemented with 50% pig manure produced the highest fresh and cured rhizome yields. However, its performance was statistically comparable with that of 50% NPK + 50% FYM and 50% NPK + 50% vermicompost, indicating the effectiveness of integrated nutrient management in enhancing ginger productivity (Yanthan *et al.*, 2010) [66]. Neem cake application at 2 t ha⁻¹ markedly enhanced the yield-contributing attributes of turmeric, resulting in 1.75 mother rhizomes, 5.19 primary rhizomes, 18.03 secondary rhizomes, and 7.69 tertiary rhizomes per plant. The treatment also produced greater rhizome size, with mother, primary, and secondary rhizomes measuring 7.69, 21.86, and 7.05 cm, respectively. The cumulative improvement in these yield components resulted in the highest fresh and cured rhizome yields of 29.48 and 5.59 t ha⁻¹, respectively, demonstrating the effectiveness of neem cake in enhancing rhizome development and productivity (Kamal and Yousuf, 2012) [25]. Among the organic nutrient sources, application of farmyard manure (FYM) at 10 t ha⁻¹ resulted in superior growth and yield attributes of turmeric compared with the other treatments. This treatment also produced the highest fresh rhizome yield, reaching 103.81 q ha⁻¹, which was substantially greater than that recorded under the control, demonstrating the positive effect of FYM on turmeric productivity (Pandey *et al.*, 2012) [38]. The treatment T₁₆, comprising the recommended dose (RD) of nitrogen through poultry manure along with the recommended doses of phosphorus, potassium, and other nutrients, resulted in superior yield attributes of turmeric. It recorded the highest

number of mother rhizomes per plant (2.78), fingers per rhizome (12.10), rhizome volume per plant (164.38 cc), fresh rhizome weight per plant (189.89 g), fresh rhizome yield per plot (5.700 kg), and fresh rhizome productivity (40.25 t ha⁻¹). The performance of T₁₆ was followed by T₁₅, consisting of the recommended dose of nitrogen through poultry manure + recommended doses of P and K + recommended dose of Fe, and T₁₄, comprising the recommended dose of nitrogen through poultry manure + recommended doses of P and K + recommended dose of Zn. (Patel *et al.*, 2012) ^[39]. Vermicompost applied at the full recommended rate of 25.0 t ha⁻¹ resulted in superior rhizome and root growth characteristics, followed by neem cake at 6.0 t ha⁻¹. The highest fresh as well as dry rhizome yields were also obtained with the application of vermicompost at 25.0 t ha⁻¹, highlighting its effectiveness in improving rhizome development and productivity of turmeric (Bhende *et al.*, 2013) ^[6]. The combined application of farmyard manure (FYM), vermicompost, and neem cake resulted in the highest rhizome productivity, with a yield of 20.48 t ha⁻¹. In contrast, the untreated control recorded the lowest rhizome yield of 12.50 t ha⁻¹, demonstrating the positive influence of integrated organic nutrient management on turmeric yield (Sarma *et al.*, 2015) ^[51]. Application of poultry manure at 5 t ha⁻¹ resulted in superior yield attributes compared with the control. The treatment enhanced the weight of primary and secondary rhizomes per plant, fresh rhizome weight per plant, dry matter recovery, leaf area index, leaf area duration, dry leaf biomass, and fresh rhizome yield per plot as well as per hectare. These results demonstrate the beneficial role of poultry manure in improving growth, biomass accumulation, and yield performance of turmeric (Singh *et al.*, 2015) ^[54]. The combined application of vermicompost at 7.5 t ha⁻¹ + FYM at 15 t ha⁻¹ along with *Azophos* at 5 kg ha⁻¹ resulted in superior growth and yield performance of turmeric compared with the conventional nutrient management system. A similar trend was observed for quality attributes; however, the variation in quality parameters was predominantly associated with differences among the cultivars (Basak and Jana, 2016) ^[4]. Treatment T₄, comprising FYM at 15 t ha⁻¹ + vermicompost at 3.8 t ha⁻¹ + neem cake at 1.5 t ha⁻¹, significantly enhanced turmeric productivity. This treatment recorded the highest fresh rhizome yield of 606.54 g plant⁻¹, along with a projected dry rhizome yield of 7.6 t ha⁻¹ and a curing percentage of 25.25%, demonstrating the effectiveness of integrated organic nutrient management in improving rhizome yield and curing recovery (Kumar *et al.*, 2016) ^[31]. Application of farmyard manure (FYM) positively influenced the growth, yield attributes, and productivity of turmeric. The highest rhizome yield (204.4 q ha⁻¹) was obtained with 125% of the recommended organic manure dose combined with biofertilizers. However, this treatment was statistically comparable with 100% of the recommended organic manure dose applied either alone or in conjunction with biofertilizers. The results further indicated that the inclusion of biofertilizers provided an additional improvement in turmeric growth and yield, highlighting their potential role in integrated organic nutrient management (Singh *et al.*, 2017) ^[53]. An integrated nutrient management treatment comprising 75% of the recommended NPK dose + FYM at 25 t ha⁻¹ + vermicompost at 5 t ha⁻¹ + neem cake at 500 kg ha⁻¹ + *Azotobacter* at 2 kg ha⁻¹ + phosphorus-solubilizing

bacteria (PSB) at 2 kg ha⁻¹ (T₆) enhanced fresh rhizome productivity, recording 29.69 t ha⁻¹ with a curing percentage of 24% (Amala *et al.*, 2019). In another study, application of neem cake at 4 t ha⁻¹ in combination with *Azotobacter* (10 kg ha⁻¹), PSB (10 kg ha⁻¹), and VAM (65 kg ha⁻¹) proved superior to the other nutrient treatments in terms of processed finger yield. These findings emphasize the potential of combining organic nutrient sources with beneficial microbial inoculants for improving turmeric productivity and processing recovery. (Bondre *et al.*, 2019) ^[7]. Application of the recommended fertilizer dose (RDF) resulted in the highest dry rhizome yield of turmeric (62.42 q ha⁻¹), which was statistically comparable with vermicompost application (55.45 q ha⁻¹). Similarly, the fresh rhizome yield was significantly higher under RDF (312.12 q ha⁻¹), followed by vermicompost treatment (264.24 q ha⁻¹). These findings indicate that vermicompost can provide a comparatively effective alternative nutrient source for maintaining rhizome productivity in turmeric (Kadam and Kamble, 2020) ^[24]. The integrated application of 50% of the recommended dose of fertilizer (RDF) with 50% nitrogen supplied through neem cake significantly improved the yield attributes of turmeric. This treatment recorded higher fresh weights of primary and secondary rhizomes (46.5 and 55.5 g, respectively) and produced a greater marketable rhizome yield of 251.2 q ha⁻¹ compared with the control. The fresh rhizome yield per plot was also comparatively higher under this treatment (418.5 g) than the control (308.1 g) and the other nutrient treatments, indicating the effectiveness of combining inorganic fertilizer with neem cake for enhancing turmeric productivity (Lohar and Hase, 2021) ^[34]. Rhizome length is an important yield-contributing trait in turmeric, and its improvement through integrated organic nutrient management can enhance crop productivity. The experimental findings demonstrated that supplying 100% of the recommended nitrogen through organic sources, comprising 50% vermicompost + 50% neem cake in combination with biofertilizers, significantly increased the length of mother, primary, and secondary rhizomes compared with the other bio-manuring treatments. This treatment consistently exhibited superior rhizome length during both years of experimentation, indicating its effectiveness in promoting rhizome development and yield formation in turmeric (Darekar *et al.*, 2022) ^[11].

II) Effect of organic formulations on growth parameters and growth of turmeric

a) Effect of organic formulations on growth parameters and growth of turmeric

The application of organic nutrient inputs significantly improved the growth and productivity attributes of pigeonpea compared with the untreated control. Among the treatments, FYM at 2.5 t ha⁻¹ + vermicompost at 1 t ha⁻¹ + two applications of Jeevamrut at 500 L ha⁻¹ (30 and 45 DAS) produced significantly superior plant height, branches per plant, compound leaf number, leaf area, seed yield, and stalk yield. These findings demonstrate the potential of combining organic manures with liquid bio-inputs such as Jeevamrut for enhancing growth and yield performance in pigeonpea (Janbhare, 2010) ^[22]. The combined use of FYM with liquid organic formulations, namely Jeevamrutha and Panchagavya, significantly improved the growth and yield attributes of French bean. Soil application of Jeevamrutha at 1000 L ha⁻¹ resulted in higher plant height (26.7 cm),

number of branches (6.93), leaf area (1325 cm²), pods per plant (15.89), pod weight per plant (81.58 g), and green pod yield (141.7 q ha⁻¹). Similarly, foliar application of Panchagavya at 3% produced superior values for these parameters, recording plant height of 26.6 cm, 6.89 branches per plant, leaf area of 1263 cm², 15.40 pods per plant, pod weight of 79.42 g plant⁻¹, and green pod yield of 138.7 q ha⁻¹. Both treatments performed significantly better than their respective treatments without Jeevamrutha or Panchagavya application, demonstrating the potential of liquid organic inputs in enhancing crop growth and productivity (Basavaraj *et al.*, 2015) [5]. The application of Jeevamrutha at 1000 L ha⁻¹ and Panchagavya at 7.5% significantly enhanced the vegetative growth of the crop. These organic liquid formulations positively influenced key growth parameters, including plant height, number of branches and leaves per plant, leaf area, and leaf area index, demonstrating their potential for improving crop growth under organic nutrient management (Sutar *et al.*, 2017) [57]. The influence of EM microorganisms on growth and nitrate content on pepper and chilli plants. In all the experiments carried out, the pepper and chilli plants treated with EM were significantly higher yield than those treated with water. The fresh weight of the pepper and chilli berries has significantly increased in the EM-treated theses compared to those irrigated with water, 138.56 g compared to 121.90 g in pepper and 33.93 g compared to 26.02 g in chilli (Domenico Prisa, 2019) [14]. Increase in cow urine concentrations increased the performance of all phenotypic characters of fenugreek and okra such as plant height, shoot and root length, number of leaf, leaf length and breadth were increased with increased concentration of urine as compared to control (Jandaik *et al.*, 2015) [23]. The growth rate among the treated group was high in the mixture of vermicompost and vermiwash treated plants than untreated plants. The maximum range of some plant parameters, such as number of leaves (33.1 ± 0.21), leaf length (4.1 ± 0.03 cm), plant height (9.5 ± 0.42 cm) and root length of plant (7.1 ± 0.10cm) were recorded in the vermicompost and vermiwash mixture (Tharmaraj *et al.*, 2010) [58]. Shoot length and number of leaves were maximum when treated with soil+ vermicompost (S+VC) (21.65 cm and 66.80) respectively, followed by soil + vermiwash (S+VW) (19.72 cm) with respect to shoot length and the number of leaves in S+VC+VW treated plants compared to the control (soil + cow dung), shoot length (17.92 cm) and the number of leaves (63.95) in tomato (Samadhiya *et al.*, 2013) [48]. Application of vermiwash at 100% ha⁻¹ resulted in significantly superior vegetative growth compared with the other treatments. The treatment recorded the highest plant height, number of primary and secondary branches, leaf area index, and dry matter accumulation, indicating the beneficial effect of vermiwash application on crop growth and biomass production (Verma *et al.*, 2017) [64]. The integrated application of organic nutrient sources, comprising 50% N through FYM + 25% N through neem cake + 25% N through vermicompost, supplemented with *Azospirillum* at 5 kg ha⁻¹ and Panchagavya at 3%, resulted in superior vegetative growth. Plants receiving this treatment exhibited greater plant height, leaf production, tiller number, and leaf area, indicating the effectiveness of combining organic nutrient sources with microbial inoculants and liquid bioformulations in promoting crop growth (Chitra and Vinothini, 2020) [10].

b) Effect of organic formulations on yield parameters and yield of turmeric

The combined application of Beejamrutha, Jeevamrutha, and Panchagavya enhanced chilli productivity compared with the treatment comprising Beejamrutha and Jeevamrutha alone. Dry fruit yield increased to 8.52 and 8.01 q ha⁻¹, respectively, demonstrating the beneficial contribution of Panchagavya when integrated with other natural farming formulations (Chandrakala *et al.*, 2007) [9]. Beejamrutha, Jeevamrutha, and Panchagavya contain considerable populations of beneficial microorganisms, including bacteria, fungi, actinomycetes, nitrogen-fixing microorganisms, and phosphate-solubilizing microorganisms. Their application has been reported to enhance crop productivity in several crops, including paddy, field bean, maize, and soybean, indicating their potential role in improving microbial activity and nutrient availability under organic and natural farming systems. (Devakumar *et al.*, 2008) [12]. Application of Jeevamrutha at 2500 L ha⁻¹, owing to its relatively higher nutrient status, promoted vigorous crop growth, as reflected by greater dry matter accumulation and improved yield-contributing attributes. The results indicate that Jeevamrutha can enhance crop performance by supporting nutrient availability and biomass production. (Kasbe *et al.*, 2009) [26]. Application of Jeevamrutha significantly improved the productivity of groundnut compared with the untreated control. The treated plots recorded a groundnut yield of 2,050 kg ha⁻¹, whereas the control treatment produced only 986 kg ha⁻¹. The substantial increase in yield indicates the potential of Jeevamrutha as an effective liquid organic formulation for enhancing crop productivity (Upperi *et al.*, 2009) [60]. The results demonstrated that Jeevamrutha application enhanced rice productivity, with grain yields of 2.775 t acre⁻¹ in the Masura variety and 2.625 t acre⁻¹ in the Hamsa variety. The variation in yield between the two cultivars indicates that varietal response may influence the effectiveness of Jeevamrutha application under organic nutrient management. (Uma Amareshwari and Sujathamma, 2014) [59]. Soil application of Jeevamrutha at 1000 L ha⁻¹ and foliar application of Panchagavya at 3% significantly enhanced the yield attributes and productivity of French bean. Jeevamrutha application increased the number of pods plant⁻¹ (15.89), pod weight plant⁻¹ (81.58 g), and green pod yield (141.7 q ha⁻¹), compared with 13.18 pods plant⁻¹, 67.30 g pod weight plant⁻¹, and 117.0 q ha⁻¹, respectively, in the absence of Jeevamrutha. Similarly, Panchagavya application resulted in 15.40 pods plant⁻¹, 79.42 g pod weight plant⁻¹, and 138.7 q ha⁻¹ green pod yield, compared with 13.67 pods plant⁻¹, 69.56 g pod weight plant⁻¹, and 120.0 q ha⁻¹, respectively, without Panchagavya. These findings demonstrate the beneficial effects of Jeevamrutha and Panchagavya in improving yield formation and productivity of French bean (Basavaraj *et al.*, 2015) [5]. Application of Jeevamrutha at 600 L ha⁻¹ (L₁) significantly improved plant height, cob weight per plant, green cob yield, fodder yield, and total non-reducing sugar content. The treatment recorded green cob and fodder yields of 16,145 and 20,068 kg ha⁻¹, respectively, along with a higher harvest index. The performance of Jeevamrutha was statistically comparable with that of Panchagavya (L₃) and Sanjeevak (L₄), each applied at 600 L ha⁻¹, indicating the effectiveness of these liquid organic formulations in improving growth, yield, and quality attributes of the crop

(Safiullah *et al.*, 2018) ^[46]. The combined application of vermicompost at 7 t ha⁻¹ with Jeevamrut through drenching and foliar application significantly improved yield performance and soil nutrient status. This treatment also enhanced nutrient uptake and recorded the highest fruit weight (59.33 g), number of fruits plant⁻¹ (29.13), fruit yield plot⁻¹ (24.73 kg), and fruit productivity (366.42 q ha⁻¹). The results indicate that integrating vermicompost with Jeevamrut can effectively improve nutrient availability, plant nutrient uptake, and overall crop productivity. (Hameedi *et al.*, 2018) ^[19]. Effective Microorganisms (EM) improve soil health and enhance crop growth, yield, and quality across diverse agroecological conditions (Higa and Parr, 1994) ^[20]. EM promotes beneficial indigenous microbial activity, including mycorrhizal associations, thereby improving nutrient availability and reducing dependence on synthetic fertilizers and pesticides. Improved soil fertility consequently supports better flowering, fruit development, and crop maturity (Levai *et al.*, 2006) ^[33]. Application of compost enriched with Effective Microorganisms (EM) significantly increased wheat biomass and grain production compared with compost without EM and the untreated control, demonstrating the beneficial role of EM in improving crop productivity. (Hu and Qi, 2013) ^[21]. Seed inoculation and foliar application of Effective Microorganisms (EM) significantly enhanced tomato productivity, increasing overall yield by 40% compared with the control. Seed treatment with EM alone improved marketable yield by approximately 44.6%, demonstrating its potential for enhancing commercial tomato production (Kleiber *et al.*, 2014) ^[28]. Farmyard manure (FYM) and activated Effective Microorganism (EM) solution supplied both macro- and micronutrients in varying amounts. Rice yield increased from 1.35 t ha⁻¹ under control to 3.31 t ha⁻¹ with FYM, 3.03 t ha⁻¹ with activated EM solution, and 3.33 t ha⁻¹ when FYM and activated EM were applied in combination, indicating the advantage of their integrated use (Saidia and Mrema, 2017) ^[47]. Cow urine application enhanced lettuce productivity, with the highest yield obtained at 1.25% concentration as a foliar spray and 1.0% concentration through soil application. These concentrations were identified as effective rates for improving lettuce yield (Oliveira *et al.*, 2009) ^[37]. Application of FYM at 12.5 t ha⁻¹ in combination with cattle urine at 34,300 L ha⁻¹ significantly improved the yield attributes of the crop. The treatment resulted in higher numbers of seeds per cob, test weight, number of rows per cob, grain yield, and stover yield, demonstrating the beneficial effect of integrating organic manure with cattle urine for enhancing crop productivity (Veeresha *et al.*, 2014) ^[61]. Application of vermicompost, either alone or in combination with 5 or 10% vermiwash as a foliar spray, significantly improved yield attributes compared with the untreated control. The treatments enhanced the number of pods plant⁻¹ and seeds pod⁻¹, indicating the beneficial effect of integrating vermicompost with vermiwash on reproductive development and crop productivity (Mahto and Yadav, 2005) ^[35]. Weekly foliar application of vermiwash enhanced dry chilli productivity, resulting in a 7.3% increase in yield compared with the untreated crop. This indicates the potential of vermiwash as a foliar bio-input for improving chilli yield. (George *et al.*, 2007) ^[16]. Application of vermicompost and vermiwash significantly improved the growth and productivity of black gram compared with the

untreated control. Plants receiving these vermi-based inputs exhibited enhanced growth rates and greater productivity, demonstrating their potential as effective organic nutrient sources (Tharmaraj *et al.*, 2010) ^[58]. At 90 days after planting, foliar application of vermiwash at 50% concentration produced the highest number of flowers (37.4) and fruits (31.6) in brinjal, followed by the 25% concentration, which recorded 36.6 flowers and 27.2 fruits, respectively (Sundararasu and Jeyasankar, 2014) ^[56]. Application of 50% of the recommended NPK through drip fertigation in combination with liquid biofertilizers and humic substances performed better than the other treatments and was statistically comparable with the superior treatments. The findings indicated that fertigation with microbial inoculants and humic substances can complement mineral fertilizers in improving cowpea yield and quality under sandy soil conditions. Such integrated nutrient management may also help reduce the dependence on chemical fertilizers and minimize environmental pollution and associated risks to human and animal health (Abdehamid *et al.*, 2011) ^[1]. Humic acid application improved photosynthetic efficiency, water-use efficiency (WUE), plant nutritional status, seed and lint yields, and fibre quality of cotton under salinity stress. In contrast, its soil application reduced leaf Na concentration, total soluble sugars, and free proline. Overall, humic acid exerted a positive influence on growth, productivity, fibre quality, and WUE of salt-stressed cotton (Rady *et al.*, 2016) ^[40]. Integrated application of 50% N through FYM, 25% N through neem cake, and 25% N through vermicompost, along with *Azospirillum* at 5 kg ha⁻¹ and Panchagavya at 3%, significantly improved the growth and yield attributes of ginger. This treatment recorded the highest green rhizome yield of 23.55 t ha⁻¹, demonstrating the effectiveness of integrating organic nutrient sources with biofertilizers and liquid organic formulations for enhancing ginger productivity (Chitra and Vinothini, 2020) ^[10].

III) Effect of organic nutrient mangement and organic formulations on biological properties of soil

Application of different organic nitrogen sources markedly enhanced the populations of beneficial soil microorganisms, including bacteria, fungi, and actinomycetes, compared with the control. Among the organic nutrient sources, the combined application of FYM and neem cake resulted in the highest microbial populations, recording 38.6 CFU g⁻¹ of bacteria, 15.2 CFU g⁻¹ of fungi, and 12.2 CFU g⁻¹ of actinomycetes (Krishnakumar *et al.*, 2005) ^[29]. In capsicum, the combined application of FYM with Beejamrutha, Jeevamrut, and Panchagavya significantly enhanced soil dehydrogenase activity, reaching 30.00 and 25.67 mg TPF g⁻¹ soil day⁻¹ at 120 and 160 DAT, respectively. This improvement indicates greater microbial activity and biological functioning of the soil under integrated organic nutrient management (Chandrakala *et al.*, 2007) ^[9]. The addition of a handful of soil during Jeevamrut preparation acts as an initial inoculum of beneficial microorganisms, including bacteria, fungi, actinomycetes, nitrogen-fixing microorganisms, and phosphate-solubilizing microorganisms. Consequently, Jeevamrut and other organic liquid manure formulations may contain substantial populations of beneficial microbes, contributing to improved soil biological activity and nutrient cycling. (Devakumar *et al.*, 2008) ^[12]. Integrated application of

fermented organic formulations, namely Beejamrutha, Jeevamrut, and Panchagavya, together with compost, vermicompost, and green leaf manure, substantially enhanced soil biological activity. Dehydrogenase activity was greater under combined organic and fermented organic treatments than with their individual application or conventional RDF + FYM. The highest dehydrogenase activity ($34.84 \mu\text{g TPF g}^{-1} \text{ soil day}^{-1}$) was recorded with compost + vermicompost + green leaf manure + Jeevamrut + Beejamrutha, which was statistically comparable with vermicompost + green leaf manure + Jeevamrut + Beejamrutha + Panchagavya. In contrast, the lowest activity ($24.27 \mu\text{g TPF g}^{-1} \text{ soil day}^{-1}$) was observed under RDF + FYM at 60 DAS in soybean grown in a soybean–wheat cropping system (Shwetha and Babalad, 2008) [52]. At 180 DAP, the combined application of compost + *Azospirillum* sp. + *Glomus* sp. recorded the highest soil microbial population ($117.94 \times 10^5 \text{ CFU g}^{-1} \text{ soil}$), significantly exceeding the other treatments. The same treatment maintained a significantly higher microbial population ($105.25 \times 10^5 \text{ CFU g}^{-1} \text{ soil}$) even after harvest. At 60 DAP, its performance was statistically comparable, whereas at 120 DAP, vermicompost + *Azospirillum* sp. + *Glomus* sp. recorded a superior microbial population (Roy and Hore, 2011) [45]. The findings revealed that organic nutrient management significantly enhanced soil microbial biomass. The treatment comprising FYM at 30 t ha^{-1} + neem cake at 2.0 t ha^{-1} + ash at 1.0 t ha^{-1} + vermicompost at 4.0 t ha^{-1} , along with rhizome treatment using biofertilizers, recorded significantly higher microbial biomass than the other nutrient management treatments (Srinivasan *et al.*, 2016) [13]. Microbial analysis of bio-enhancers revealed that Panchagavya contained highest number of total bacteria ($6.25 \times 10^9 \text{ cfu ml}^{-1}$) as compared to Jeevamrita ($3.24 \times 10^9 \text{ cfu ml}^{-1}$), Biodynamic liquid pesticide ($2.27 \times 10^9 \text{ cfu ml}^{-1}$) and Amritpani ($5.49 \times 10^8 \text{ cfu ml}^{-1}$). Fungi population was highest in Jeevamrita ($1.20 \times 10^7 \text{ cfu ml}^{-1}$) as compared to Biodynamic liquid pesticide ($2.64 \times 10^6 \text{ cfu ml}^{-1}$), Amritpani ($0.46 \times 10^5 \text{ cfu ml}^{-1}$) and Panchagavya ($0.20 \times 10^5 \text{ cfu ml}^{-1}$). Similarly, gram positive bacteria, gram negative bacteria and Rhizobium were highest in Jeevamrita (1.60×10^8 , 2.20×10^8 , $7.51 \times 10^7 \text{ cfu ml}^{-1}$) (Ram *et al.*, 2018) [42]. The results showed that soil application of jeevamrutha 1000 l ha^{-1} + panchagavya @ 7.5 % gave higher bacteria, fungi and actinomycetes population (50.33×10^5 , 32.33×10^4 and $20.33 \times 10^3 \text{ cfu g}^{-1}$ of soil, respectively) (Rao *et al.*, (2018) [42]. Significantly more bacterial population with application of jeevamrutha (28.27×10^5 and $31.59 \times 10^5 \text{ cfu g}^{-1}$ of soil) as compared to NCOF- decomposer (21.54 and $23.73 \times 10^5 \text{ cfu g}^{-1}$ of soil) (Gangadhar *et al.*, 2020) [15]. In aerobic rice, microbial biomass carbon ranged from $234.4 \text{ mg C kg}^{-1}$ in the control to $381.88 \text{ mg C kg}^{-1}$ in jeevamrutha @ 2000 l ha^{-1} (applied twice) + NPK75 (Alemayehu *et al.*, 2022) [2]. Application of 30 tons of FYM recorded significantly higher bacterial population ($264.58 \text{ CFU} \times 10^5 \text{ g}^{-1} \text{ soil}$), fungal population ($85.75 \text{ CFU} \times 10^2 \text{ g}^{-1} \text{ soil}$) and actinomycetes population ($88.00 \times 10^3 \text{ g}^{-1} \text{ soil}$) compared to the NPK and control treatments (Chandra *et al.*, 2022) [8]. Application of jeevamrutha, panchagavya and ghanajeevamrutha in black pepper recorded the highest microbial population viz., bacteria ($70.48 \times 10^6 \text{ CFU soil}^{-1}$), fungi ($17.49 \times 10^3 \text{ CFU soil}^{-1}$), actinomycetes ($39.34 \times 10^4 \text{ CFU soil}^{-1}$), free living nitrogen fixers ($27.65 \times 10^4 \text{ CFU soil}^{-1}$) and P-solubilizers

population ($22.64 \times 10^4 \text{ CFU soil}^{-1}$) (Gurumurthy *et al.*, 2022) [18].

Conclusion

The findings compiled in this review clearly demonstrate that organic nutrient management and bioformulations are effective and sustainable approaches for enhancing turmeric productivity, rhizome quality, and soil health. Organic nutrient sources such as farmyard manure, vermicompost, poultry manure, and neem cake improve soil physical, chemical, and biological properties, resulting in better nutrient availability, vigorous vegetative growth, superior rhizome development, and increased fresh and cured rhizome yields. Bioformulations, including Jeevamrut, Panchagavya, Vermiwash, Effective Microorganisms (EM), cow urine, and humic acid, further stimulate soil microbial activity, nutrient mineralization, enzyme activity, and physiological processes that contribute to improved crop performance. The integrated application of organic manures and bioformulations consistently produces synergistic effects by enhancing nutrient-use efficiency, promoting beneficial microbial populations, and sustaining long-term soil fertility. Such integrated organic nutrient management practices also reduce dependence on synthetic fertilizers, conserve natural resources, and improve the resilience of turmeric cultivation under changing climatic conditions. Although substantial progress has been made, further long-term, multi-location studies are required to standardize nutrient schedules, optimize bioformulation application methods, and evaluate their economic feasibility under diverse agro-climatic conditions. Overall, integrating organic nutrient sources with bioformulations offers a practical and climate-resilient strategy for achieving productive, environmentally sustainable, and economically viable turmeric cultivation.

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