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ORGANIC LIQUID FORMULATIONS IN HORTICULTURAL CROPS: A COMPREHENSIVE REVIEW ON GROWTH, QUALITY, AND SOIL HEALTH

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ABSTRACT

In recent years, organic farming has gained global significance as a sustainable alternative to chemical-intensive agriculture. Among various organic practices, the application of Organic Liquid Formulations (OLFs) has emerged as a promising strategy for improving crop productivity, soil fertility, and environmental health. This review provides a comprehensive overview of the role and impact of traditional and indigenous OLFs such as Panchagavya, Jeevamrutha, Beejamrutha, Amritpani, Vermiwash, and others on horticultural crop production. These bio-inputs are rich in plant growth-promoting microorganisms (PGPMs), essential nutrients, phytohormones, and bioactive compounds that enhance plant growth, yield, stress tolerance, and produce quality. The review highlights how OLFs contribute to soil microbial diversity, enzymatic activity, nutrient cycling, and the suppression of soil-borne pathogens. Studies demonstrate significant improvements in vegetative growth, flowering, fruit set, biochemical parameters, and soil organic carbon levels under OLF treatments across various horticultural crops. Furthermore, OLFs play a vital role in maintaining ecological balance by reducing synthetic agrochemical dependency, minimizing environmental contamination, and enhancing biodiversity. However, challenges such as inconsistent formulation quality, limited awareness, and nutrient variability must be addressed through research, training, and policy support. This review underscores the potential of OLFs in transforming horticultural practices and advocates for their integration into sustainable and climate-resilient agricultural systems.

***Keywords*:** Organic liquid formulations, horticultural crops, soil fertility, plant growth promotion, sustainable agriculture

Introduction

In response to the long-term environmental and health impacts of the Green Revolution, organic farming has emerged as a sustainable alternative to conventional agricultural practices. Unlike chemical-intensive farming systems, organic agriculture promotes ecological balance, reduces environmental hazards, and is widely recognized as a safer, eco-friendly method of food production. India's rich agro-climatic diversity provides substantial potential for cultivating a wide range of organic products, supported by traditional knowledge and long-standing organic practices in various regions. This combination of natural advantage and indigenous expertise presents significant opportunities for organic producers to meet the growing demand in both domestic and international markets.

India has established itself as a global leader in organic farming, ranking fourth in certified organic agricultural area. Among 188 countries engaged in organic agriculture, India contributes nearly 2.4 million of the global 4.3 million organic producers. The country has witnessed remarkable growth in its organic farming area from approximately 5 million hectares in FY 2012 to 10.17 million hectares in FY 2023. The share of organic farming in India's total agricultural land increased from 0.97% in FY 2016 to 4.43% in FY 2023, with significant momentum observed post-FY 2021. Madhya Pradesh leads in certified organic area, followed by Maharashtra, Rajasthan, Gujarat, Odisha, and others. In FY 2023–24, India produced 3.6 million metric tons of certified organic produce, including oilseeds, cereals, pulses, cotton, tea, spices, fruits, vegetables, and more. Exports reached 261,029 MT, earning over INR 4007.91 Crore (USD 494.8 million), with key markets including the USA, EU, Canada, UK, Japan, and others (APEDA, 2025; FiBL & IFOAM, 2025).

Organic and natural farming systems are holistic production models designed to enhance agroecosystem health, including biodiversity, nutrient cycles, and soil microbial activity. Vegetables and fruits, being integral to human diets, are valued for their rich micronutrient and antioxidant content (Abadias *et al.,* 2008). However, the widespread and prolonged use of synthetic fertilizers and pesticides for yield maximization has severely impacted crop quality, environmental health, and human well-being (Prajakta *et al*., 2013). Chemical residues not only degrade the nutritional value of horticultural crops but also contribute to long-term soil and ecosystem degradation. To address these concerns, emphasis has shifted toward organic formulations such as panchagavya, plant-based extracts, vermicompost, Trichoderma, and rhizobacteria that enhance crop resilience, productivity, and quality without harmful side effects (Lelde *et al.,* 2017). These biogenic inputs provide a sustainable path to replace synthetic agrochemicals, reduce soil pollution, and rejuvenate soil fertility.

In line with this shift, practices such as zero budget natural farming (ZBNF) and the application of organic amendments like panchagavya, jeevamruth, and beejamruth are being increasingly adopted. These methods involve the inoculation of beneficial microorganisms that serve as biofertilizers and biocontrol agents, supporting plant growth while maintaining ecological integrity (Khadse *et al*., 2018; Shyamsunder *et al*., 2021). Organic liquid formulations embody the core principles of sustainable agriculture, emphasizing soil fertility, environmental protection, and ecosystem vitality. By relying on biodegradable, natural compounds, these inputs reduce contamination of soil, water, and crops (Pretty, 2008). They promote the direct availability of nutrients, resulting in better root development, plant vigour, and crop yield and quality (Nayak *et al.,* 2025). Moreover, they contribute to improved soil structure, moisture retention, and microbial diversity, creating a resilient soil ecosystem capable of supporting long-term production (Bengtsson *et al*., 2005).

Compared to solid manures, liquid organic manures (LOMs) are more efficient, offering quicker nutrient delivery and easier application through existing irrigation systems (Magdoff & Weil, 2005; Rajanand, 2018). They are particularly effective in addressing nutrient deficiencies rapidly and safely, as their filtration processes reduce the risk of pathogen and weed seed contamination (Hiremath & Hosamath, 2024). While solid manures provide slow-release nutrients, LOMs offer fast-acting, bioavailable nutrients that promote immediate growth responses (Nyalemegbe *et al*., 2011). This review aims to provide a systematic and comprehensive assessment of the role of organic liquid formulations in improving plant growth, yield, nutrient uptake, and soil health, with a focus on horticultural crops. It explores a range of organic liquid inputs like panchagavya, amritpani, jeevamruth, beejamruth, fish amino acid, egg amino acid, five-leaf extract, and kunapajala etc. The review further evaluates their impact on microbial diversity, enzymatic activity, and the overall sustainability of the soil ecosystem.

Organic Liquid Formulations: An Overview

Organic liquid formulations are carbon-based solutions derived from organic materials such as plant residues, animal waste products, or their derivatives. These formulations are typically created by combining various organic substances to achieve specific agronomic functions, including plant growth promotion, pest suppression, and enhanced nutrient availability. The composition and preparation methods of these formulations vary depending on the availability of local organic resources and regional agricultural practices. Different countries adopt unique formulations suited to their agroecological zones and traditional knowledge systems. Among the widely recognized traditional liquid organic inputs are Panchagavya, Amritpani, Jeevamrutha, Beejamrutha, Fish Amino Acid, Egg Amino Acid, Five Leaf Extract, Kunapajala, Sanjivak, Dashparni Ark, Neemhastra, and Brahmastra (Nandhini and Somasundharam 2023; Biswas *et al*., 2023; Deng *et al*., 2019). Each of these plays a distinctive role in enhancing plant health, productivity, and resilience under sustainable farming systems.

The composition and preparation methods of various organic formulations differ based on the type of components used and traditional practices. According to Nandhini and Somasundharam (2023), stirring the mixtures in a clockwise direction is essential during preparation, as it is believed to impart positive energy and enhance the efficacy of the formulation. A comprehensive overview of different types of organic formulations, along with their specific uses and applications, is presented in Table 1.

Table 1: Organic formulations – preparation, application, and benefits

Organic Formulation	Method of Preparation	Application Method	Advantages	References
Panchagavya	Combine 5 kg cow dung, 3 L cow urine, 2 L milk, 2 L curd, 1 L ghee, 3 L coconut water, bananas, and ½ kg jaggery. Mix and ferment for 7 days, stirring twice daily.	Apply 3% as foliar/seed treatment; 50 L/ha for irrigation.	Promotes plant vigor and enhances resilience against stress.	Kumar *et al.,* 2021; Nandhini and Somasundaram, 2023
Jeevamrutham	Mix 10 kg cow dung, 10 L cow urine, 2 kg jaggery, 2 kg pulse flour, and garden soil in water to make 200 L. Ferment for 7 days, stirring 3 times daily.	Apply 500 L/ha via irrigation.	Enhances soil fertility and health.	Nandhini and Somasundaram, 2023; Bhowate *et al*., 2023
Beejamurtha	Mix 50 g cow dung, 50 mL each of cow milk and cow urine, 3 g lime, 1 L water, and a handful of soil. Keep the solution in shade for 24 hours.	Apply 50% as foliar spray; use undiluted for seed treatment and root dipping.	Supplies nutrients and helps manage soil and seed-borne diseases.	Shyamsunder and Menon, 2021
Neemasthra	Mix 5 kg neem leaves, 5 L cow urine, and 2 kg cow dung. Let ferment for 24 hours.	Use as a 3–6% foliar spray.	Natural pesticide targeting sap-sucking insects.	Nandhini and Somasundaram, 2023
Agniastra	Boil 1 kg of Ipomea leaves, 5 kg of neem leaves, 500 g of chili, and 500 g of garlic in 10 L of cow urine until the volume reduces by half. Filter the extract.	Use as a 2–3% foliar spray.	Effective natural pesticide against sap-sucking insects, rollers, and borers.	Nandhini and Somasundaram, 2023
Brahmasthra	Boil 2 kg each of neem, custard apple, papaya, pomegranate, and guava leaves in 10 L of cow urine until reduced to half. Ferment for 24 hours.	Apply via 100 L/acre using irrigation.	Acts as a general-purpose natural pesticide.	Anonymous, 2018
Amritpani	Combine ¼ liter ghee, ½ liter honey, and 10 kg cow dung in 200 liters of water. Stir the mixture thoroughly.	Apply via 500 L/ha irrigation or 3% foliar spray.	Enhances tolerance to biotic and abiotic stress, promoting overall crop yield.	Bhowate *et al*., 2023
Dashparni	Combine crushed leaves of various plants including neem, papaya, castor, and others with chili and garlic paste, 2 kg cow dung, 20 L cow urine, and 200 L water. Ferment in shade for a month, stirring periodically.	Use as a 5–10% foliar spray or 2 L/acre via irrigation.	Improves pest resistance and supports plant nutrition.	Nandhini and Somasundaram, 2023

Fish Amino Acid	Blend fish waste with jaggery (1:1 ratio), fill 2/3 of a container, top with jaggery, and ferment for 2 months.	Spray at 6% dilution.	Serves as a rich source of plant nutrients.	Nandhini and Somasundaram, 2023
Five Leaves Extract	Prepare a paste from neem, nochi, physic nut, milkweed, and karanj leaves. Mix with 5 L cow urine and 5 L water, ferment for 5 days, boil for 30 minutes, and allow it to settle for 12 hours.	Apply at 10% concentration as foliar spray.	Controls sucking pests effectively.	Nandhini and Somasundaram, 2023
Matka Khad	Combine 5 kg cow dung, 5 L cow urine, 5 L water, and 250 g jaggery. Transfer to a 20 L pitcher, bury partially, cover, and let ferment for 8–12 days.	Apply twice—15 days before and 15 days after sowing—diluted with 7–8 L water, using a pump or broom.		Kaith and Dadhich, 2024
Sanjivak	Blend 10–20 kg cow dung, 10 L cow urine, and 50 g jaggery in 30 L water. Ferment for 10 days.	Dilute 20x and apply in three stages: before sowing, 20 DAS, and 45 DAS via soil or irrigation.	Stimulates growth and stress resistance.	Chandra *et al*., 2019
Vermiwash	Assemble materials: 3 pitchers, 2 lids, 4 m rope, 1.5 m pipe, 4 kg cow dung, 2 kg biomass, and 200–300 earthworms. Set up a layered system with sand, biomass, manure, and worms in a pitcher with drainage to collect the vermiwash.	Dilute 1:10 with water; apply every 15–20 days during crop stages.	It increases therate of photosynthesis in crops/plants, number of micro-organisms in the soil, crop yield, resistance to pestsand diseases,	Nandini and Venmathi, 2017

Microbial and Metabolic Roles of Traditional Organic formulations in Enhancing Crop Growth and Resilience

Traditional organic formulations play a vital role in promoting crop growth through their rich microbial and metabolic profiles. For instance, formulations like Panchagavya, Amritpani and Sanjivak, are rich in plant growth-promoting bacteria such as *Bacillus*, *Enterobacter*, *Pseudomonas*, *Azospirillum*, *Agrobacterium*, and *Rhizobium*. These microbes produce indole-3-acetic acid (IAA), which enhances cell division, stimulates root development, and activates the plant's defense systems (Kumar *et al.,* 2021; Nandhini and Somasundharam, 2023)

Similarly, Kunapajala, and Sanjivak, microbial species like *Herbaspirillum*, *Acetobacter*, *Azospirillum*, and *Bacillus*, which contribute to the production of gibberellins. These phytohormones play a crucial role in promoting flowering and fruit setting (Mathukia *et al*., 2023; Chandra *et al.,* 2019). Moreover, combinations such as Panchagavya, Amritpani, and Bokashi support the growth of *Pseudomonas* and *Methylobacterium* spp., known for synthesizing cytokinins, which are essential for cell expansion and division (Kumar *et al.,* 2021; Nandhini and Somasundharam, 2023)

In stress management, Panchagavya and Jeevamrutha provide beneficial strains of *Proteobacteria* and *Actinobacteria* that produce ACC deaminase, an enzyme that lowers ethylene levels by converting ACC into α-ketobutyrate and ammonia. This mechanism is vital for sustaining plant growth under abiotic stress (Suman *et al*., 2016; Nandhini and Somasundharam, 2023).

To improve soil fertility and water retention, organic formulations such as Jeevamrutha, Fish Amino Acids and Egg Amino Acids, contain plant-growth-promoting rhizobacteria (PGPR) that secrete exopolysaccharides. These compounds enhance soil structure, nutrient uptake, and plant biomass accumulation (Deng *et al*., 2019).

Disease resistance is also strengthened through the use of microbial consortia. Inputs like Five-Leaf Extract and Beejamurtha are rich in lactic acid bacteria and yeasts, which produce antimicrobial agents that suppress pathogenic microorganisms (Shyamsunder *et al.,* 2021). Furthermore, a range of bio-inputs including

Panchagavya, Amritpani, Dashparni, Neemastra, and Agneyastra support species such as *Bacillus*, *Pseudomonas*, and *Streptomyces*. These produce secondary metabolites like salicylic acid, jasmonic acid, ethylene, and reactive oxygen species (ROS), which contribute to enhanced systemic resistance against biotic and abiotic stress (Chandra *et al.*, 2019; Nandhini and Somasundharam, 2023).

In addition, Amritpani, Dashparni, and Neemastra are known to support *Bacillus*, and *Pseudomonas* spp., which produce lipopolysaccharides, siderophores, and flagellin. These compounds are known to activate systemic resistance pathways in plants Chandra *et al.,* 2019; Yu *et al*., 2022). The same formulations also encourage microbial populations such as *Bacillus*, *Pseudomonas*, and *Azospirillum*, which emit volatile organic compounds (VOCs) that boost photosynthesis and enhance the production of various phytohormones (Chandra *et al*., 2019).

Patel *et al*. (2017) reported that Brahmastra at 20% concentration was the most effective among traditional formulations in controlling sucking pests (aphids, thrips, leafhoppers, and whiteflies) when compared to Agniastra and Neemastra at the same concentration.

Impact of Organic Liquid Formulations on Crop Growth, Yield of Horticultural Crops

Application of liquid organic manures such as Panchagavya, Jeevamruth etc. has shown significant potential in enhancing crop growth and yield (Table 2). These formulations are rich in beneficial microbial populations including bacteria, fungi, actinomycetes, phosphate solubilizers, fluorescent *Pseudomonas*, and nitrifiers, all of which contribute to improved soil nutrient dynamics and plant health (Leo *et al.,* 2013). In cauliflower, a 10% foliar spray of Panchagavya resulted in noticeable improvements in crop growth and yield, likely due to enhanced nutrient mineralization and solubilization driven by the microbial activity present in the formulation (Chawla *et al*., 2023). Additionally, both Panchagavya and Jeevamruth have proven to be effective seed priming agents, particularly under salinity stress conditions. Their use in bitter gourd cultivation led to the development of healthier seedlings, suggesting their role in stress mitigation and early-stage vigor enhancement (Patil *et al*., 2021).

The application of organic liquid manures such as Vermiwash and Panchagavya has been found to significantly promote plant growth by enhancing early vegetative development and root-shoot architecture. For instance, *Capsicum frutescens* treated with Vermiwash exhibited greater root and shoot lengths and a higher number of leaves after 30 days compared to untreated plants (Subha and Lakshmi, 2014). Similarly, a combination of Vermiwash and gibberellic acid was effectively used to promote seed germination and seedling growth in *Hibiscus sabdariffa* and *Phaseolus vulgaris* (Fathima and Malathy, 2014). Foliar applications of vermiwash prepared from animal dung and municipal solid waste (MSW) either alone or in combination with improved neem (*Azadirachta indica*) oil and aqueous extracts of its leaf and bark resulted in significant improvements in tomato crop productivity, early flowering, and plant growth, along with a notable reduction in pest infestation (Tiwari and Singh, 2016).

These growth-enhancing effects can be attributed to the presence of naturally occurring growth regulators such as indole-3-acetic acid (IAA), gibberellic acid (GA), and cytokinins in Vermiwash and Panchagavya. Along with these hormones, these bio-inputs contain essential plant nutrients and beneficial microbial populations, including *Acetobacter*, *Azospirillum*, and *Phosphobacterium*, which function as biofertilizers (Esakkiammal *et al*., 2015).

Amritpani, often referred to as the essence of dead soil, enhances soil's biological and physical health, thereby improving plant growth, yield, and quality (Biswas & Das, 2022). Prepared using cow dung, ghee, and honey, it is rich in micronutrients, plant hormones, and beneficial microbes including actinomycetes, P-solubilizers, and UV-resistant bacteria (Gupta & Pathak, 2021). It also exhibits antimicrobial activity and gains pesticidal properties when combined with neem (*Azadirachta indica*).

Table 2: Impact of organic liquid formulations on crop growth and yield

Crop	Findings	Reference
Okra	Vermiwash and vermicompost significantly increased okra yield by 64.27%, with higher fat (23.86%) and protein (19.86%) content compared to chemical fertilizers.	Ansari and Sukhraj (2010)
Tomato	Combined application of fertilizers, beejamruth, jeevamruth, and panchagavya resulted in maximum plant height (143.20 cm), root length (19.8 cm), and number of fruits per plant (19.65).	Gore and Sreenivasa (2011)

Onion, French Bean, Knol-Khol, Cauliflower	Vermiwash (1:10 v/v) application resulted in 10% higher yield in onion, 26% in French bean, 27% in knol-khol, and 65% in cauliflower. Panchagavya (3%) was effective in controlling cauliflower stalk rot (88.9%).	Chadha *et al*. (2012)
Okra	3% Panchagavya concentration improved all growth and yield parameters, recommending it for use after proper dilution.	Rajesh and Jayakumar (2013)
French Bean	RDF + Jeevamrutha (2000 l/acre at 15, 30, 45 DAS) improved the parameters like plant height (34.97 cm), leaves/plant (26.40), pods/plant (10.67), pod yield (13.33 t/ha)	Biradar (2016)
Capsicum	Application of Jeevamrutha, Cow Urine, Panchagavya had resulted higher fruit yield at multiple stages (32.26 to 121.20 q/ha) vs control (26.54 to 104.16 q/ha)	Boraiah *et al.* (2017)
Capsicum	Application of Jeevamrut (5% drench + 3% foliar spray), FYM (10–20 t/ha), Vermicompost (1.75–7 t/ha) had found max plant height (66 cm), branches (3.2), leaf area (85.39 cm²), fruit yield (366.42 q/ha); highest TSS (6.2°Brix), ascorbic acid (181.33 mg/100g); 82.4% yield increase.	Atal (2017)
Withania somnifera	Application of Kunapa Jala showed superior growth, photosynthetic traits, and yield, including highest leaf area, chlorophyll content, and dry root yield. Panchagavya recorded the highest leaf area ratio and root diameter.	Ankad *et al*., 2017
Okra	3% Panchagavya concentration resulted in maximum plant height (74.68 cm), fruit weight (30.67 mg/fruit), and fruit number (19).	Rakesh *et al*. (2017)
Bell Pepper	Vermicompost (7 t/ha) + jeevamrut resulted in maximum fruit weight (59.33 g), number of fruits per plant (29.13), and fruit yield (366.42 q/ha).	Hameedi *et al*. (2018)
Okra	Vermiwash concentrations (0.25%, 0.5%, 0.75%, and 1%) resulted in 100% seed germination, with highest shoot length (2.1 cm) at 0.75% and maximum root length (2.9 cm) at 0.25%.	Senthilmurugan *et al.* (2018)
Tomato	12.5 t/ha farmyard manure, 5 t/ha vermicompost, and 3% panchagavya resulted in maximum fruits per plant (20.30) and fruit yield (998.93 g).	Arivazhagan *et al.* (2019)
Cowpea	Application of Jeevamrutha (1000 l/resulted in maximum plant height (65.60 cm), branches (8.89), leaves (26.50), leaf area (1039.56 cm²), LAI (1.54)	Sutar *et al.* (2019)
Brinjal	RDN 100% + 5% panchagavya + 5% jeevamrut increased plant height (84.12 cm), spread (84.81 cm), number of fruits (20.38), and fruit yield (441.84 q/ha).	Inderjeet *et al.* (2023)
Papaya (Taiwan Red Lady)	Application of RDF + Jeevamrutha resulted in maximum plant height, trunk girth, early flowering & fruit maturity, fruit weight, pulp thickness, fruit number & yield	Jhade *et al.* (2020)

Impact of Organic Liquid Formulations on Quality of Horticultural Crops

The application of indigenous liquid organic formulations such as Panchagavya, Jeevamrutha, Vermiwash, etc., plays a significant role in improving fruit quality by enhancing metabolic activities and nutrient assimilation. These inputs contribute to various physiological and biochemical processes that directly influence fruit sweetness, acidity, texture, and retention. Cytokinins present in Panchagavya stimulate carbohydrate metabolism and help establish new source-sink relationships, thereby increasing the total soluble solids (TSS) concentration in fruits (ShM *et al*., 2017). Similarly, the application of Jeevamrutha accelerates the conversion of starch and pectin into soluble sugars, facilitating their rapid translocation from leaves to developing fruits (Sahana *et al.,* 2020). Vermiwash has also been shown to enhance the movement of photosynthetic byproducts, leading to increased sugar accumulation in fruits (Rajkumar *et al*., 2019). This enhancement in sugar content is further supported by the application of humic acid, which plays a crucial role in carbohydrate synthesis and breakdown, protein synthesis, and nutrient availability. It also stimulates pigment accumulation, resulting in greener leaves with higher photosynthetic efficiency. The increased production of assimilates through enhanced photosynthesis ultimately raises the TSS levels in fruits (Maha and Abdel Salam, 2016). Additionally, higher potassium availability from these formulations supports sugar biosynthesis and translocation, contributing to improved sweetness as seen in crops like peaches (Karam *et al*., 2003; Javana *et al.,* 2012).

With an increase in TSS, a concurrent decrease in titratable acidity has also been observed in berries treated with Panchagavya and Jeevamrutha. This reduction may be attributed to the roles of micronutrients like boron and zinc, which aid in converting acids into sugars or their derivatives through glycolytic pathways or their utilization in respiration (Jhade *et al*., 2020). Vermiwash, rich in easily assimilable nutrients, similarly contributes to lower acidity and better fruit quality (Khachi *et al.,* 2015). As TSS increases and acidity decreases, a higher TSS-to-acidity ratio is typically achieved, which is a key indicator of improved taste and market quality. These bio-inputs also influence fruit firmness and structural integrity. Panchagavya has been reported to enhance calcium uptake, an essential nutrient for maintaining cell wall stability and contributing to firmer fruit texture (Sau *et al.*, 2017). Jeevamrutha stimulates the production of secondary metabolites like phenolics and lignin, which reinforce cell walls and improve fruit firmness. Vermiwash, which contains a variety of nutrients including calcium, supports overall vine health and enhances berry development, contributing further to fruit firmness. Humic acid improves root conditions and nutrient uptake, particularly calcium, leading to stronger cell walls and firmer fruits (El-Razek *et al.*, 2012). The presence of natural plant hormones such as auxins, gibberellins, and cytokinins in Panchagavya and Jeevamrutha helps regulate fruit development, set, and reduce premature shedding. These hormones also exhibit antioxidant properties, which protect grapevines from oxidative stress, thereby supporting fruit retention (Sugha, 2005). Vermiwash contributes to stress mitigation by providing beneficial compounds and microbes that help plants cope with water stress and disease pressure, ultimately reducing berry drop (Rajkumar *et al.,* 2019). Humic acid further enhances the plant's ability to absorb and utilize essential nutrients like calcium and magnesium, which are vital for fruit attachment and stress resilience. Altogether, Panchagavya, Jeevamrutha, Vermiwash, and humic acid serve as potent plant growth stimulants. They enhance the biological efficiency of crops, boost soil microbial activity, improve nutrient availability, and elevate the physical and biochemical characteristics of fruits making them invaluable in sustainable horticultural practices (Devi and Singh, 2023). Their influence extends beyond sweetness and acidity, contributing to overall fruit firmness, appearance, and stress resistance, as supported by studies like Michael (2010), which reported enhanced taste and appearance in red lettuce following organic fertilization. El-Shaieny *et al.* (2022) reported that vermicompost tea significantly improved relative chlorophyll content (SPAD values) and enhanced onion bulb quality, with the lowest weight loss percentage observed under 100% vermicompost tea application.

Table 3: Impact of organic liquid formulations on quality

Crop	Findings	Reference
Tomato	Foliar application Beejamruth +Jeevamruth + Panchagavya increased the lycopene content	Gore (2009)
Okra	Vermiwash + vermicompost increased protein and fat content in fruits by 23.86% and 19.86%, respectively, compared to chemical fertilizers.	Abdullah and Kumar (2010)
Bitter Gourd	Application of vermicompost (5 t/ha) + FYM (25 t/ha) + panchagavya (3%) resulted in maximum TSS (4.22 °Brix) and increased ascorbic acid content (121 mg/100g).	Anuja and Archana (2012)
Banana	Maximum potassium content (4095 ppm) in banana fruit with treatment farm residue @ 10 t/ha+ 2% jeevamrut @ 400 l/ha and higher content of Mn (3.10 mg/kg), Cu (1.77 mg/kg) and Zn (1.88 mg/kg) in fruit with treatment of farm residue @ 10 t/ha + 2% panchgavya @ 400 l/h	Kaswala *et al.* (2017b)
Okra	0.5% Vermiwash resulted in the highest chlorophyll content (4.91 mg/l), while 0.75% vermiwash had the highest protein content (9.50 mg/g) compared to control.	Senthilmurugan *et al.* (2018)
Tomato	Application of 25 t/ha farm yard manure, 5 t/ha vermicompost, and 3% panchagavya resulted in maximum TSS (6.70 °Brix), ascorbic acid (23.2 mg/100g), and acidity in tomato.	Arivazhagan *et al.* (2019)
Okra	Application of liquid organic nutrient formulations (LONBFs) like jeevamrutha and fish amino acids resulted in higher chlorophyll content (0.40 mg/100g), carbohydrate (89.5 mg/g), and protein content (3.45 mg/g) in okra.	Krishnamoorthy *et al.* (2019)
Papaya (cv. Taiwan Red Lady)	Application of RDF + Jeevamrutha resulted in the highest Fruit diameter (24.27 cm), TSS (9.83 °Brix), ascorbic acid (23.80 mg/100g), minimum acidity (0.016%)	Jhade *et al.* (2020)
Strawberry	Application of Vermicompost + Jeevamrutha (500 ml/pot) + Beejamrutha (seedling treatment) resulted in higher TSS (8.03 °Brix), ascorbic acid (58.749 mg/100g), total sugars (7.57%), shelf life (3.52 days), fruit growth rate (0.19 cm/day), minimum acidity (0.82%)	Sahana *et al.* (2020)
Chilli (*Capsicum annuum* L.)	Application of Jeevamrut was found maximum ascorbic acid (129.08 mg), capsaicin (11.7%), oleoresin (69.66%) content in fruit.	Gangadhar *et al.* (2020)

Microbial Dynamics and Soil Fertility Improvement through Organic Liquid Formulations' (OLFs')

Healthy soils are foundational to sustainable agricultural production. However, in conventional farming systems, soil health continues to deteriorate, negatively impacting crop productivity and the environment. Organic farming offers a comprehensive and eco-friendly strategy to restore soil vitality and promote plant growth (Bhattacharyya and Jha, 2012). One such key component in organic farming systems is the use of Organic Liquid Formulations (OLFs), which are natural bio-inputs designed to enhance plant development, soil fertility, and overall ecosystem resilience.

The use of indigenous fermented organic formulations, particularly Jeevamrit, Panchagavya, Beejamrit, and Ghanjeevamrit, has shown substantial promise in improving soil health and crop productivity. These bio-inputs, made using cow dung, urine, jaggery, gram flour, milk, and small quantities of local soil, are rich in nutrients and act as a favorable medium for microbial growth (Sharma *et al.,* 2021; Bindushree *et al.*, 2023). The incorporation of these ingredients, especially from the indigenous cow *Bos indicus*, provides a balanced carbon-to-nitrogen ratio and acts as an inoculum, facilitating the growth of a wide range of beneficial microbes (Gangadhar *et al.,* 2020). Microbial diversity in these formulations includes nitrogen-fixing bacteria (*Azospirillum*, *Azotobacter*), phosphorus-solubilizing bacteria, actinomycetes, fungi, *Pseudomonas*, lactobacteria, and methylotrophs (Sreenivasa *et al.*, 2009; Gore and Sreenivasa, 2011; Mukherjee *et al.*, 2022). Many OLFs include microbial inoculants, compost, and plant-based extracts that increase soil organic matter. Higher organic matter content enhances soil structure, promotes soil aggregation, and improves porosity and aeration, resulting in better nutrient availability and root development (Eghball and Power, 2019; Ghosh *et al.,* 2020). The presence of easily degradable organic compounds such as simple sugars contributes to high enzymatic and microbial activity, making these formulations potent catalysts in soil biochemical processes (Bonilla *et al.*, 2012). These microbes secrete proteins, antioxidants, organic acids, and plant growth-promoting substances like indole-3-acetic acid (IAA) and gibberellic acid (GA_3), further boosting nutrient availability and plant vigor (Mukherjee *et al.*, 2022).

Application of these fermented bio-formulations increases the population and diversity of soil microorganisms, directly enhancing soil fertility and plant nutrient uptake (Chatterjee *et al.,* 2014; Sharma *et al.,* 2021). Jeevamrit, in particular, stimulates the soil microbial ecosystem, multiplying beneficial microbial groups with its regular use (Palekar, 2006). It has been shown to significantly structure soil microbial communities, supporting both bacterial and fungal populations that play essential roles in ecosystem functioning and plant health (Saharan *et al.,* 2023). The use of Jeevamrit also enhances soil enzyme activities, which are crucial for organic matter decomposition, nutrient mineralization, and maintaining soil physicochemical balance (Chatterjee *et al.*, 2014). These enzymes reflect microbial functionality and act as indicators of a healthy soil ecosystem. Moreover, the rise in microbial activity catalyzes these enzyme functions, reinforcing the feedback loop between organic inputs and soil biochemical cycling.

One of the additional ecological benefits of Jeevamrit and similar formulations is the stimulation of earthworm populations. Earthworms improve aeration, increase soil porosity, and bring up minerals from deeper layers, thereby improving nutrient dynamics and root development (Ribeiro *et al.,* 2022). Scientific studies support the role of beneficial soil microbes in promoting plant growth, nutrient recycling, and improving soil structure by secreting a variety of primary and secondary metabolites (Ray *et al.,* 2020). These microbes not only aid in organic matter transformation and nutrient solubilization but also serve as a reservoir of plant-available nutrients (Mohite *et al.,* 2013). A high microbial diversity index in soil is often correlated with improved ecosystem stability, resilience, and higher crop yields (Bargaz *et al.,* 2018).

Hartman *et al.* (2015) demonstrated that organic manure-based products not only increased bacterial populations but also enhanced soil nutrient levels. Jeevamrit has been found to support the proliferation of proteobacteria and actinobacteria, which play critical roles in nitrogen fixation, phosphate solubilization, carbon cycling, and suppression of soil-borne pathogens (Sharma *et al.*, 2022). These microbial functions contribute directly or indirectly to plant growth and soil sustainability. Furthermore, the application of Jeevamrit has been reported to enhance soil organic carbon, improve soil structure, and increase water-holding capacity, offering notable improvements over conventional chemical fertilizers such as NPK (Han *et al.,* 2016; Sharma, 2022). Cultural diversity assessments of Ghanjeevamrit also confirmed high microbial loads, with total bacteria (183×10^5 cfu g^{-1}), fungi (20×10^4), actinomycetes (56×10^3), nitrogen-fixers (42×10^4), and phosphorus solubilizers (28 × 10^4) (Mukherjee *et al.*, 2022). The abundance of heterotrophic microbial populations was highest under Beejamrit and Jeevamrit treatments, where microbes in the presence of organic matter secreted bioactive substances and converted nutrients into plant-available forms (Bindushree *et al.,* 2023). These biological transformations enhance nutrient uptake efficiency and overall soil fertility. Collectively, these findings establish that the integration of organic formulations into agricultural practices not only improves the microbial ecosystem and soil chemistry but also enhances plant health, nutrient use efficiency, and long-term soil sustainability. By utilizing locally available inputs and promoting microbial richness, these formulations offer an environmentally sound and economically viable alternative to synthetic agrochemicals.

Table 4: Impact of organic liquid formulations on nutrient uptake and soil health

Crop	Findings	Study
Bell Pepper	Combined application of vermicompost (7 t/ha) + jeevamrut increased nitrogen (164.71 kg/ha), phosphorus (26.44 kg/ha), and potassium (125.39 kg/ha) uptake in bell pepper.	Hameedi *et al.* (2018)
Okra	Vermicompost + poultry manure with panchagavya (5%) and jeevamrut (5%) increased available N, P, K (5%, 7%, 9%) and improved microbial count, biomass, and soil enzyme activities.	Lalkhumliana (2018)
Capsicum	Application of 90% recommended nutrients with PGPR and liquid manures (panchagavya, jeevamruth, amritpani) resulted in maximum NPK uptake (13.76, 1.79, 13.34 kg/ha) and improved organic carbon (1.30%) and NPK content in soil.	Brar *et al.* (2020)
French Bean	Conjunctive use of beejamrutha, jeevamrutha, 100% recommended nitrogen from vermicompost, and 3% panchagavya spray resulted in higher nitrogen (86.87 kg/ha), phosphorus (14.32 kg/ha), and potassium (75.93 kg/ha) uptake.	Gowthamchand *et al.* (2020)
Okra	Jeevamruth (100% N equivalence) + farmyard manure (10 t/ha) resulted in highest residual soil organic carbon (12.00 g/kg), microbial counts, and maximum available nutrients in soil (N, P, K, S, Fe, Cu, Mn, Zn).	Rakesh and Shivani (2022)
Broccoli	Treatment with 90% RDN + 5% jeevamrit foliar spray increased organic carbon (20.93 g/kg), available N (375.13 kg/ha), P (48.46 kg/ha), K (260.53 kg/ha) and nutrient uptake (N: 60.58 kg/ha, P: 7.25 kg/ha, K: 37.88 kg/ha).	Shraddha *et al.* (2023)

Effects of Organic Liquid Formulations on The Environment

In agriculture, organic liquid formulations offer a sustainable substitute for synthetic chemicals with a number of advantages in terms of the environment, human health, and the economy. By lowering the runoff of dangerous substances like synthetic fertilisers and pesticides, they protect water bodies and aquatic ecosystems by mitigating pollution in terms of water quality (Reganold and Wachter, 2016). Additionally, they promote biodiversity by fostering beneficial insects and a variety of microbial communities, which strengthens ecosystem resilience. Additionally, by reducing greenhouse gas emissions and volatile organic compounds linked to the manufacture and use of synthetic chemicals, these formulations enhance air quality. Additionally, they have a lower carbon footprint than synthetic compounds since they depend less on energy-intensive production processes, transportation, and inputs derived from fossil fuels. On the other hand, synthetic chemicals have a negative effect on biodiversity, air and water quality, climate change, and human health. All things considered, organic liquid formulations provide an environmentally responsible and sustainable method of farming that improves biodiversity, soil health, water quality, air quality, and carbon footprint reduction (Reganold and Wachter, 2016).

Challenges and Limitations

Organic farmers face several challenges while using organic liquid formulations, including limited availability, high costs, lack of technical knowledge, inconsistent quality, regulatory compliance, and integration into existing farming systems. To address these issues, many farmers prepare their own formulations using locally available materials or collaborate with nearby suppliers to improve access. They adopt cost-effective methods like composting and bulk purchasing to make inputs more affordable. Training programs and workshops help them gain the necessary skills for proper application. To ensure consistency and quality, farmers follow best practices, conduct regular inspections, and adjust formulations as needed. They also stay informed about certification requirements, maintain detailed records, and integrate these formulations into their systems through sustainable practices like crop diversification and conservation techniques.

There are a number of significant restrictions on the use of organic liquid formulations in organic farming, as research like those by Dharmakeerthi *et al.* (2021) and Ghosh *et al.* (2020) have shown. Their lower nutrient concentrations when compared to synthetic fertilisers are a major drawback, as this might result in slower growth rates and lower yields, particularly for crops with high nutrient requirements. During crucial growth stages, their slow-release methods might not always match the urgent nutritional requirements of rapidly growing crops, which could result in nutrient shortages and lower production. By affecting microbial activity and nutrient availability, environmental factors including as temperature, humidity, and soil conditions might further impact their effectiveness. Furthermore, because various batches have varying nutrient contents, they must be applied more frequently than synthetic fertilisers, which raises expenses and labour for farmers. Despite the general advantages of organic liquid formulations, these limits underscore the need for careful control and thought when incorporating them into organic farming operations.

Research and Innovation Opportunities in Sustainable Agriculture

Opportunities for research and innovation are abundant in the field of organic liquid formulations for sustainable agriculture, providing encouraging paths to improve crop production, soil fertility, and environmental sustainability (Kumar *et al.,* 2021). First, in order to create highly effective formulations, optimising formulation composition entails investigating the synergistic interactions between microbial inoculants and organic inputs such as composts, manures, and plant extracts. Enhancing nutrient stability, shelf life, and bioavailability is the goal of this study. Identifying advantageous microbial strains and their modes of action to support plant development, soil health, and crop resilience is a major field of research into the potential of microbial biostimulants and biofertilizers in organic liquid formulations (Berg *et al.,* 2017). Furthermore, in order to address nutritional inadequacies and enhance human health outcomes, biofortification initiatives seek to enrich crops with vital nutrients and bioactive substances (Malik *et al.,* 2021). To further reduce environmental effects and optimise formulation application for optimal efficacy and resource efficiency, digital agriculture technologies and the development of biodegradable carriers are being integrated (Turan *et al.,* 2021). Stakeholders in sustainable agriculture may fully realise the potential of organic liquid formulations and promote constructive changes in agricultural systems by seizing these research and innovation opportunities globally.

Future Directions and Innovations

The future of organic farming with liquid formulations depends on strong government support through well-designed policies, financial incentives, and clear regulatory frameworks. Prioritizing research and innovation is essential to develop more efficient and accessible organic inputs. Education and training, especially through farmer field schools and capacity-building initiatives, will help farmers adopt and refine these practices. Strengthening infrastructure, certification systems, consumer awareness, and market access will further boost the organic sector. Environmental sustainability should remain a core focus, with policies aimed at preserving biodiversity, reducing ecological impact, and enhancing resilience. Aligning these efforts with climate goals can create a more sustainable, equitable, and climate-resilient food system.

Conclusion

There are several advantages to using organic liquid formulations in agriculture. First, by promoting microbial activity, enhancing structure, and aiding in nutrient cycling, they improve soil health and raise fertility and production. These formulations enable appropriate plant nutrition, minimise losses, and offer easily accessible nutrients. Additionally, by improving biodiversity and lowering dependency on chemicals, they support environmental sustainability. Farmers see advantages in crop performance, such as increased yield potential and stress tolerance, which results in better-quality food and financial gains. By lowering input prices and decreasing reliance on synthetics, long-term cost-effectiveness is attained despite upfront investment. Because they contain natural ingredients that control pests while protecting ecosystems and beneficial creatures, organic liquid formulations are also essential for pest control. For adoption to be successful, knowledge exchange, capacity building, and regulatory compliance are necessary. Farmers improve organic farming systems' resilience, productivity, and sustainability through strategic integration.

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