Integrating Traditional Jeevamrit into Modern Vertical Hydroponics for Sustainable Crop Production

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Abstract:

The integration of sustainable bio-inputs into hydroponic systems represents a promising approach for reducing dependence on synthetic fertilizers in controlled-environment agriculture. This study evaluated the feasibility of applying filtered cow- and buffalo-derived Jeevamrit, a traditional fermented organic formulation, in a vertical hydroponic system cultivated with spinach (*Spinacia oleracea* L.). Physicochemical parameters of Jeevamrit and hydroponic tray water, including pH, electrical conductivity (EC), total dissolved solids (TDS), and salinity, were monitored throughout the experimental period. Plant growth responses were assessed through measurements of root length and shoot length. Microbial communities associated with Jeevamrit-treated hydroponic systems were investigated through culture-based isolation and Matrix-Assisted Laser Desorption/Ionization Time-of-Flight Mass Spectrometry (MALDI-TOF MS) identification. Physicochemical analyses indicated that Jeevamrit application altered nutrient solution characteristics while maintaining hydroponic system stability. MALDI-TOF analysis revealed the presence of several bacterial taxa, including *Bacillus cereus*, *Acinetobacter tandoii*, *Acinetobacter johnsonii*, *Solibacillus silvestris*, and *Comamonas testosteroni*, demonstrating the establishment of diverse culturable microbial populations within the hydroponic environment. Plant growth observations showed treatment-associated differences, with cow-derived Jeevamrit exhibiting greater shoot growth than buffalo-derived Jeevamrit and control treatments. Overall, the findings demonstrate the feasibility of incorporating filtered Jeevamrit into hydroponic spinach cultivation and provide preliminary insights into its physicochemical and microbial dynamics. Further replicated studies with statistical validation and functional characterization of microbial communities are required to confirm the observed responses and assess their agronomic significance.

Introduction:

Agriculture is facing major challenges due to rapid population growth, declining arable land, environmental degradation, and increasing demand for sustainable food production. Conventional agricultural practices relying heavily on synthetic fertilizers and chemical inputs have improved crop yields but have also contributed to soil degradation, nutrient imbalance, environmental pollution, and disruption of beneficial microbial ecosystems (Tilman et al., 2002; Foley et al., 2011). In addition, rapid urbanization and shrinking agricultural land have accelerated the need for innovative cultivation systems capable of producing higher yields within limited spaces. Controlled environment agriculture, particularly hydroponics and vertical farming, has emerged as a promising solution for efficient resource utilization and year-round crop production (Despommier, 2010).

Hydroponic systems enable precise control over nutrient supply, water use, and environmental conditions, resulting in enhanced productivity and reduced water consumption (Resh, 2013; Sharma et al., 2018). However, these systems primarily depend on synthetic nutrient solutions and lack the beneficial microbial interactions naturally present in soil ecosystems (Lee & Lee, 2015). This limitation has encouraged interest in integrating biological and organic inputs into hydroponic cultivation systems to improve sustainability and plant health.

Natural farming approaches emphasize the use of locally available organic bio-inputs to maintain ecological balance and reduce dependency on synthetic chemicals (Palekar, 2016). Among these, Jeevamrit has gained significant attention as a microbial-rich fermented bio-fertilizer prepared using cow or buffalo dung, urine, jaggery, pulse flour, and soil. Jeevamrit contains diverse beneficial microorganisms involved in nutrient cycling, nitrogen fixation, phosphorus solubilization, and production of plant growth-promoting substances (Sreenivasa et al., 2010; Glick, 2012). Its application has been associated with enhanced nutrient availability, improved plant growth, and increased microbial activity in agricultural systems (Lal, 2015).

Despite its proven benefits in soil-based agriculture, limited research has explored the application of Jeevamrit in hydroponic and vertical farming systems. Integrating traditional bio-inputs with modern hydroponics offers a potential strategy to combine the efficiency of soilless cultivation with the ecological benefits of microbial-based nutrient management. Beneficial microorganisms present in Jeevamrit may improve nutrient dynamics, stimulate root development, and enhance plant growth in hydroponic environments. However, understanding their influence on physicochemical stability, microbial diversity, and plant performance within aqueous systems remains essential.

Therefore, the present study investigated the feasibility of applying filtered cow- and buffalo-derived Jeevamrit in a hydroponic cultivation system using spinach (Spinacia oleracea L.) as a model crop. The study evaluated physicochemical changes in Jeevamrit formulations and hydroponic tray water, assessed spinach seedling growth responses, and characterized culturable microbial communities associated with Jeevamrit-treated systems using MALDI-TOF mass spectrometry. The objective was to generate preliminary insights into the physicochemical and microbial dynamics associated with the integration of traditional fermented bio-inputs into hydroponic cultivation systems.

Materials and Methods

Collection of Samples

Fresh dung and urine samples from Dangi cows were collected from Dang district near Saputara, Gujarat, India, while fresh dung and urine samples from Surati buffaloes were collected from Navsari, Gujarat, India, for the preparation of Jeevamrit. Samples were collected aseptically in sterile containers and transported to the laboratory for immediate processing to minimize external contamination.

Jeevamrit Preparation

Cow- and buffalo-derived Jeevamrit were prepared using fresh dung, urine, gram flour, jaggery, rhizosphere soil, and water following a modified protocol described by Devakumar et al. (2014). The composition of ingredients used for preparation is presented in Table 1. The mixture was maintained under aerobic conditions through regular aeration during the fermentation period to facilitate microbial proliferation and organic matter decomposition.

Physicochemical parameters, including pH, electrical conductivity (EC), total dissolved solids (TDS), and salinity, were monitored throughout the 15-day fermentation period to assess changes associated with microbial activity and nutrient release. After fermentation, the Jeevamrit preparations were subjected to multi-stage filtration to obtain a liquid fraction suitable for hydroponic application and to minimize clogging of the hydroponic system. The filtered formulations were subsequently used for hydroponic experiments and microbial isolation studies.

Table 1. Composition of Jeevamrit used in the study

Ingredient	Quantity
Cow/Buffalo dung	100 g
Cow/Buffalo urine	100 mL
Gram flour	20 g
Jaggery	20 g
Rhizosphere soil	5 g
Water	1800 mL

Isolation of Microorganisms from Jeevamrit

Samples collected on fermentation days 0, 4, 8, and 12 were used for microbial isolation. Isolation was performed using both direct inoculation and enrichment approaches. Briefly, samples were serially diluted in sterile distilled water and spread onto nutrient agar plates. For enrichment, aliquots of Jeevamrit were incubated in nutrient broth prior to serial dilution and plating. The inoculated plates were incubated at 37°C for 48 h, and morphologically distinct colonies were selected and purified by repeated streaking on nutrient agar using the four-flame streaking technique.

Purified isolates were initially differentiated based on colony morphology and subsequently identified using Matrix-Assisted Laser Desorption/Ionization Time-of-Flight Mass Spectrometry (MALDI-TOF MS) according to standard procedures. The identified taxa were used to assess the microbial diversity associated with the Jeevamrit formulations during the fermentation process (Devakumar et al., 2014; Mukherjee et al., 2022).

Hydroponic System and Experimental Design

A tray-based hydroponic system was established to evaluate the feasibility of incorporating filtered Jeevamrit into a soilless cultivation environment. Healthy spinach (Spinacia oleracea L.) seedlings were grown in cups containing moist cocopeat, which served as an inert support medium due to its high water-holding capacity and aeration properties. The cups were placed in thermocol sheets fitted over hydroponic trays, ensuring that the roots remained in contact with the nutrient solution.

The hydroponic system was maintained under controlled conditions, and the nutrient solution was monitored regularly to maintain pH values between 5.5 and 6.5 and electrical conductivity (EC) between 1.2 and 2.0 mS cm^{-1} (Resh, 2013; Sharma et al., 2018). Three treatment groups were evaluated: (i) cow-derived Jeevamrit (0.5%), (ii) buffalo-derived Jeevamrit (0.5%), and (iii) untreated control. The selected Jeevamrit concentration was applied as a supplement to the hydroponic nutrient solution following filtration to facilitate its use in the hydroponic system. Physicochemical parameters of the tray water, including pH, electrical conductivity (EC), total dissolved solids (TDS), and salinity, were measured periodically using digital meters to assess nutrient solution dynamics during cultivation (Pradeep and Sreenivasa, 2012). Plant growth responses were evaluated through measurements of root length and shoot length at designated observation intervals. Comparative observations among treatments were used to assess the compatibility of filtered Jeevamrit with hydroponic cultivation and its potential influence on spinach seedling growth.

Microbial Isolation from Hydroponic Tray Water

Hydroponic tray water samples associated with Jeevamrit-treated spinach cultivation systems were collected on days 0, 4, 8, and 12 for microbial isolation. Bacterial isolation was performed using two approaches: (i) direct inoculation following serial dilution of tray water samples, and (ii) enrichment culture by inoculating 10% (v/v) filtered Jeevamrit into nutrient broth, followed by incubation for 24–48 h prior to serial dilution. For each sample, 100 µL of the diluted suspension or enriched broth culture was spread onto sterile nutrient agar plates using the spread plate technique. The inoculated plates were incubated at 37°C for 48 h, after which morphologically distinct colonies were selected and purified through repeated streaking on nutrient agar using the four-flame streaking method.

The isolation procedure was repeated throughout the experimental period to monitor culturable bacterial populations within the hydroponic environment. Purified isolates were initially differentiated based on colony morphology and subsequently identified using Matrix-Assisted Laser Desorption/Ionization Time-of-Flight Mass Spectrometry (MALDI-TOF MS) according to standard protocols (Devakumar et al., 2014; Mukherjee et al., 2022).The identified bacterial taxa were used to assess the diversity of culturable microorganisms associated with Jeevamrit-amended hydroponic systems.

Results and Discussion

Physicochemical Characteristics of Cow- and Buffalo-Derived Jeevamrit

The physicochemical properties of cow- and buffalo-derived Jeevamrit underwent dynamic changes throughout the 15-day fermentation period (Table 2). Both formulations exhibited a similar fermentation pattern characterized by an initial decline in pH followed by gradual stabilization during the later stages of fermentation. In cow Jeevamrit, the pH decreased from 7.5 on day 0 to 4.0 by day 4 and subsequently increased to 6.5 on day 15. A comparable trend was observed in buffalo Jeevamrit, where the pH declined from 7.5 to 3.5 between days 5 and 7 before recovering to 6.5 at the end of the fermentation period.

Electrical conductivity (EC) increased during the early stages of fermentation in both formulations, indicating the release of soluble ions and nutrients into the liquid phase. Cow Jeevamrit exhibited consistently higher EC values than buffalo Jeevamrit throughout the fermentation period, reaching a maximum value of 7.68 mS cm^{-1} on day 7, whereas buffalo Jeevamrit reached a maximum EC of 4.92 mS cm^{-1} on days 7–8. Similar trends were observed for total dissolved solids (TDS) and salinity. Cow Jeevamrit recorded peak TDS and salinity values of 5.03 and 3.87, respectively, while buffalo Jeevamrit attained maximum values of 3.15 and 2.45.

Following the initial increase, EC, TDS, and salinity values either stabilized or gradually declined towards the end of the fermentation period in both formulations. These changes suggest active microbial metabolism and decomposition of organic substrates during fermentation, resulting in the release of soluble constituents into the medium. The subsequent stabilization of physicochemical parameters during the later stages indicates the maturation of the fermented formulations.

Overall, both cow- and buffalo-derived Jeevamrit displayed characteristic fermentation-associated changes in pH, EC, TDS, and salinity. The higher EC, TDS, and salinity values observed in cow Jeevamrit suggest differences in nutrient release patterns between the two formulations; however, further replicated studies are required to determine the significance and practical implications of these observations.

Table 2. Physicochemical Properties of Cow- and Buffalo-Derived Jeevamrit During the 15-Day Fermentation Period

Fermentation Day	Cow pH	Cow EC (mS/cm)	Cow TDS	Cow Salinity	Buffalo pH	Buffalo EC (mS/cm)	Buffalo TDS	Buffalo Salinity
0	7.5	5.84	3.75	2.92	7.5	4.49	2.91	2.24
1	5.5	7.36	4.78	3.68	4.0	4.49	2.91	2.24
2	4.5	7.36	4.78	3.68	4.0	4.50	2.92	2.25
3	4.5	7.59	4.93	3.79	4.0	4.64	3.01	2.32
4	4.0	7.74	5.03	3.87	4.0	4.65	3.02	2.32
5	4.0	7.64	4.96	3.82	3.5	4.75	3.08	2.37
6	4.0	7.67	4.98	3.83	3.5	4.76	3.09	2.38
7	4.5	7.68	4.99	3.84	3.5	4.92	3.09	2.45
8	5.0	7.60	4.94	3.80	4.0	4.92	3.15	2.45
9	5.0	7.18	4.80	3.59	4.0	4.68	3.15	2.34
10	5.0	7.26	4.72	3.63	4.0	4.85	3.15	2.42
11	5.5	7.35	4.80	3.68	4.5	4.80	3.12	2.40
12	5.5	7.39	4.80	3.69	4.5	4.83	3.14	2.42
13	5.5	7.02	4.56	3.51	5.0	4.80	3.12	2.40
14	6.0	6.82	4.43	3.41	5.0	4.78	3.10	2.39
15	6.5	6.56	4.26	3.28	6.5	4.81	3.13	2.40

MALDI-TOF Identification of Bacterial Isolates Recovered from Hydroponic Tray Water

Microbial isolation from hydroponic tray water associated with Jeevamrit-treated spinach cultivation systems resulted in the recovery of several bacterial taxa that were subsequently identified using Matrix-Assisted Laser Desorption/Ionization Time-of-Flight Mass Spectrometry (MALDI-TOF MS). The identified isolates included Bacillus cereus, Acinetobacter tandoii, Acinetobacter johnsonii, Solibacillus silvestris, and Comamonas testosteroni. MALDI scores ranging from 1.87 to 2.32 indicated reliable identification for most isolates and demonstrated the presence of diverse culturable bacterial populations within the hydroponic environment.

Among the recovered taxa, Acinetobacter tandoii and Acinetobacter johnsonii were isolated repeatedly, suggesting their persistence under the hydroponic conditions employed in this study. Similarly, repeated recovery of Bacillus cereus indicates its ability to survive and establish within Jeevamrit-amended hydroponic systems. Previous studies have reported that members of the genera Bacillus, Acinetobacter, and Comamonas are frequently associated with plant and soil environments and may participate in nutrient cycling and plant–microbe interactions (Dhawi, 2023; White and Chiaranunt, 2023; Li et al., 2021).

The detection of these bacterial taxa demonstrates that microorganisms originating from fermented Jeevamrit formulations can persist within hydroponic systems following application. However, the present study was limited to culture-based isolation and taxonomic identification. Functional characterization of the isolates, including assays for indole-3-acetic acid production, phosphate solubilization, siderophore production, nitrogen fixation, or other plant growth-promoting activities, was not performed. Therefore, the ecological roles and potential contributions of these microorganisms within the hydroponic environment remain to be experimentally validated.

The occurrence of Bacillus cereus warrants particular attention because certain strains of this species have been associated with foodborne illness and opportunistic pathogenicity. Although B. cereus has also been reported from agricultural and rhizosphere environments, its detection in hydroponic systems intended for edible crop production highlights the need for future biosafety assessments and microbial risk evaluation prior to large-scale application of traditionally fermented bio-inputs.

Overall, MALDI-TOF MS analysis provided evidence for the establishment of a diverse culturable microbial community in Jeevamrit-treated hydroponic tray water. These findings contribute to understanding the microbial dynamics associated with the integration of traditional fermented bio-inputs into controlled-environment hydroponic cultivation systems.

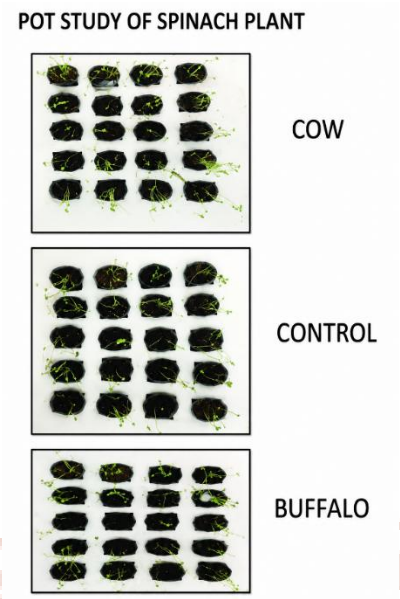

Figure 1. Representative growth response of spinach seedlings under cow Jeevamrit, buffalo Jeevamrit, and control treatments after 25 days of cultivation.

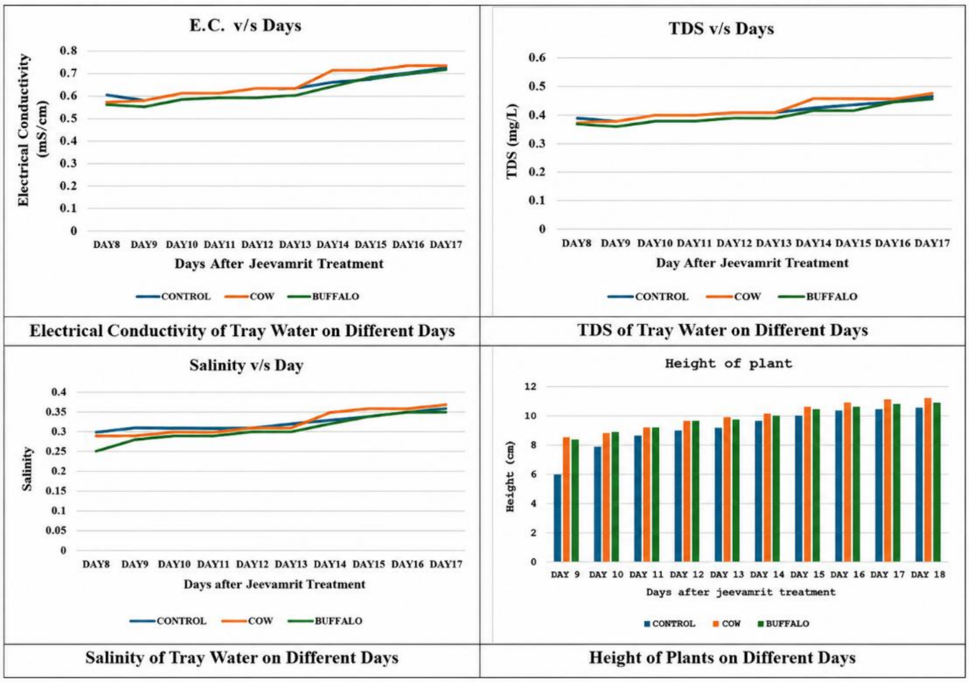

Figure 2. Temporal changes in electrical conductivity (EC), total dissolved solids (TDS), salinity, and plant growth characteristics of spinach cultivated under cow Jeevamrit, buffalo Jeevamrit, and control treatments.

Physicochemical Characteristics of Tray Water and Growth Observations in Spinach

The physicochemical characteristics of hydroponic tray water, including electrical conductivity (EC), total dissolved solids (TDS), and salinity, exhibited gradual variations throughout the cultivation period under cow Jeevamrit, buffalo Jeevamrit, and control treatments (Figure 2). Differences among treatments were observed during the experimental period, with Jeevamrit-amended systems generally maintaining higher EC, TDS, and salinity values than the control. These observations suggest that the addition of filtered Jeevamrit altered the physicochemical profile of the hydroponic solution.

The temporal changes in EC and TDS may reflect the presence of soluble constituents released during fermentation and their subsequent dynamics within the hydroponic environment. Similar trends have been reported in studies investigating the incorporation of organic amendments and microbial bio-inputs into hydroponic systems (Trevisan et al., 2019). The relatively stable physicochemical conditions observed throughout the cultivation period indicate that the addition of filtered Jeevamrit did not adversely affect the operational stability of the hydroponic system.

Visual assessment of spinach seedlings revealed observable differences among cow Jeevamrit, buffalo Jeevamrit, and control treatments. Seedlings grown in Jeevamrit-amended systems exhibited healthy establishment and normal development throughout the cultivation period. Treatment-associated differences were observed in shoot development, root architecture, and overall seedling vigour, suggesting that filtered Jeevamrit was compatible with hydroponic spinach cultivation.

The observed differences among treatments may be associated with variations in nutrient availability, microbial composition, or physicochemical characteristics of the fermented formulations. Previous studies have reported that fermented organic bio-inputs and microbial inoculants can influence plant growth and rhizosphere processes in hydroponic and soilless cultivation systems (Trevisan et al., 2019; Glick, 2012). However, the present study did not include functional microbial characterization or replicated statistical analyses; therefore, direct relationships between the identified microorganisms and plant growth responses cannot be established.

Overall, the findings provide preliminary evidence that filtered Jeevamrit can be incorporated into hydroponic spinach cultivation without negatively affecting nutrient solution stability or seedling establishment. Further replicated experiments incorporating statistical analyses and functional assessment of microbial communities are required to validate the observed trends and evaluate their agronomic significance.

Overall, the findings demonstrate that filtered Jeevamrit can be incorporated into hydroponic tomato cultivation without causing major disruptions to nutrient solution stability, while providing preliminary evidence of treatment-associated differences in plant growth and physicochemical characteristics.

Root and Shoot Growth Responses of Spinach Seedlings

Root and shoot measurements of spinach seedlings grown under cow Jeevamrit, buffalo Jeevamrit, and control treatments are presented in Table 3. Observable differences in seedling growth were recorded among the treatments during the cultivation period.

Cow Jeevamrit-treated seedlings exhibited the greatest shoot length (9.24 cm), followed by the control (8.56 cm) and buffalo Jeevamrit (8.10 cm). Root length was comparable among treatments, with buffalo Jeevamrit recording the highest value (3.70 cm), while cow Jeevamrit and control treatments showed identical root lengths (3.64 cm).

The observed differences may be associated with variations in nutrient composition, physicochemical characteristics, or microbial populations present in the Jeevamrit formulations. However, because the present study was conducted as a preliminary evaluation and did not include replicated statistical analyses, the observed differences should be interpreted as descriptive trends rather than statistically validated treatment effects.

Overall, the results demonstrate that filtered Jeevamrit supported normal spinach seedling establishment and growth under hydroponic conditions. Further replicated studies are required to validate the observed responses and determine their agronomic significance.

Table 3. Root and shoot length of spinach (Spinacia oleracea L.) seedlings grown under cow Jeevamrit, buffalo Jeevamrit, and control treatments.

Treatment	Root Length (cm)	Shoot Length (cm)
Cow Jeevamrit	3.64	9.24
Buffalo Jeevamrit	3.70	8.10
Control	3.64	8.56

Conclusion

The present study demonstrated the feasibility of incorporating filtered cow- and buffalo-derived Jeevamrit into a hydroponic spinach (Spinacia oleracea L.) cultivation system. Fermentation of both formulations resulted in characteristic changes in pH, electrical conductivity (EC), total dissolved solids (TDS), and salinity, indicating active physicochemical and microbial processes during the fermentation period. Furthermore, the application of filtered Jeevamrit did not adversely affect the stability of the hydroponic nutrient solution under the conditions evaluated.

Microbial isolation and MALDI-TOF MS analysis revealed the presence of diverse culturable bacterial taxa, including Bacillus cereus, Acinetobacter johnsonii, Acinetobacter tandoii, Solibacillus silvestris, and Comamonas testosteroni, demonstrating that microorganisms associated with fermented Jeevamrit formulations can persist within hydroponic environments. However, the ecological roles and functional significance of these microorganisms within the hydroponic system remain to be experimentally validated.

Plant growth observations indicated normal establishment and development of spinach seedlings in Jeevamrit-amended hydroponic systems, with treatment-associated differences observed in root and shoot growth parameters. Nevertheless, as the present study was exploratory in nature and did not include replicated statistical analyses or functional characterization of microbial isolates, the observed responses should be interpreted as preliminary trends rather than definitive treatment effects.

Overall, the findings suggest that filtered Jeevamrit can be integrated into hydroponic spinach cultivation without adversely affecting system stability. The study provides preliminary insights into the physicochemical and microbial dynamics associated with the use of traditional fermented bio-inputs in controlled-environment agriculture. Future investigations employing replicated experimental designs, statistical validation, biosafety assessments, and functional microbial analyses are required to evaluate the agronomic potential and practical applicability of Jeevamrit in hydroponic production systems.

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