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Impact of Fermented Organic Manure (FOM) on Soil Health and Microbial Diversity in Sustainable Agriculture

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Abstract. Organic amendments are being increasingly applied to agricultural soils as alternatives or complements to inorganic fertilizers. Fermented Organic Manure (FOM) has emerged as a sustainable alternative to synthetic fertilizers, significantly influencing soil health and microbial diversity. FOM amendments can increase the content of organic matter, which directly promotes the amount of organic carbon in soil, concomitantly improving soil physical, chemical and biological properties. The effect of the application of commercial or farm-made FOM amendments on crop yield and nutritional status, as well as on soil physicochemical and microbial properties as indicators of soil quality. Additionally, it supports plant growth by facilitating nutrient cycling and suppressing soil-borne pathogens. The integration of FOM into sustainable agricultural systems aligns with eco-friendly practices, reducing chemical input dependency while maintaining productivity. However, the effectiveness of FOM depends on fermentation processes, raw materials, and environmental conditions. However, the effectiveness of FOM depends on fermentation processes, raw materials, and environmental conditions. Future research should focus on optimizing production techniques and assessing long-term impacts on different soil types and cropping systems. Overall, the strategic application of FOM at the optimal dose (according to the NPK requirements of the crop) can be a beneficial agronomic practice for agricultural soil quality, posing a suitable alternative to mineral fertilization.

KEYWORDS: Fermented Organic Manure, Soil Health, Microbial Diversity, Soil Fertility.

1. INTRODUCTION

Globally, the development of agriculture in the last century has led to a substantial increase in agricultural output, one important approach is chemical fertilization [1]. The increased fertilizer input and intensive land use result in multiple environmental problems, including the pollution in the watersheds caused by nitrogen (N) loss [2]. Sustainable agriculture is increasingly coming up as a response to the alarming soil degradation and falling productivity levels at the same time as such practices have had damaging effects on the environment. Agriculture has made the need for sustainable agriculture increasingly felt within India. As per the Ministry of Agriculture & Farmers' Welfare [3], more than 30% of India's net cultivable area suffers from moderate to severe degradation, with nutrient imbalance and loss of organic carbon as major causative factors [4].

The current trend indicates a shift towards organic amendments and biologically enriched manures, the most important of which is Fermented Organic Manure (FOM). The fermented organic fertilizer has attracted wide attention due to its environmental friendliness [5]. Microbial organic fertilizer not only provides various nutrients needed by crops, but improves the crop growth environment and activates the soil intrinsic nutrients through a large number of beneficial microorganisms and active enzymes [6]. Fermented organic manure refers to organic materials, like plant and animal waste, that have been processed through fermentation to enhance their nutrient content and improve their effectiveness as a fertilizer. Examples include compost, vermicompost, poultry manure, and liquid formulations like Jeevamrutha, Panchagavya, and Bejamrutha [7].

FOM has received a lot of attention for its ability to improve soil fertility, as well as to restore biological health in the soil. It is prepared by fermenting organic matter, such as farmyard manure, crop residues, green leaves, and many other biodegradable inputs, using an inoculum of beneficial microbial cultures. In addition to the stabilization of organic content, this fermentation process promotes the enhancement of microbial diversity and the availability of plant-accessible nutrients. There has been Flat research sponsored by the National Centre of Organic Farming (NCOF), under the Paramparagat Krishi Vikas Yojana

(PKVY), proving that the application of FOM makes the nutrient use efficiency better, improves soil structure, and attracts more resident soil microbes considered beneficial, such as nitrogen fixing and phosphate solubilizing bacteria [8].

2. Role of Fermented Organic Manure (FOM) on Soil Health and Microbial Diversity

Traditionally, organic manures such as FYM, compost, green manure, and crop residues were used in Indian agriculture to improve soil fertility along with organic matter. However, traditional manure efficiency is also lower due to their slow decomposition rates and erratic nutrient release. Under this scenario, the Fermented Organic Manure (FOM) has come up as a much superior alternative for futuristic climate-resilient low-input agriculture [9]. FOM is produced by fermenting organic matter like FYM (Farm Yard Manure), biomass, green leaves, or agricultural residues with a specific microbial culture. The fermentation process enriches the manure with beneficial microorganisms such as *Bacillus*, *Azotobacter*, and *Pseudomonas* and phosphate-solubilizing bacteria that help mineralize nutrients and suppress diseases. Various studies have reported positive effects of Fermented Organic Manure (FOM) on various soil properties and Microbial Diversity.

2.1 Enhancements in Soil Fertility through FOM

The utilization of Fermented Organic Manure (FOM) has resulted in substantial improvements toward better soil fertility markers, including soil organic carbon (SOC), nitrogen (N), phosphorus (P), potassium (K) and soil physical properties, including pH balance and water-holding capacity. During fermentation, microbes transform basic organic substances into accessible nutrients, which leads to higher agricultural productivity with increased soil sustainability. The increased P availability in soil following fermented organic manure is primarily attributed to the release of inorganic P from added organics, as well as the expedition of P absorption by organic compounds secreted by the organics. Because of the presence of higher amounts of microorganisms, when compared to other organic amendments, the soils that were enriched with Panchgavya significantly allowed improved basal respiration. The usage of VM (Vermicompost Manure), PM (Poultry Manure), and FYM in conjunction with PGPR (Plant Growth Promoting Rhizobacteria) increased the availability of micronutrients, possibly due to chelating agents being released during organic matter decomposition, which may have prevented micronutrient precipitation, oxidation and leaching. The fermented formulation of Panchagavya, Jeevamruth, and Beejamruth contain high concentrations of beneficial microorganisms such as *actinomycetes*, fungi, methylotrophs, lactic acid bacteria, *Pseudomonas*, *Azospirillum*, *Azotobacter*, and *Phosphbacteria*, as these are made from cow products. The fermented organic inputs also increase the activity of soil enzymes. Soil enzyme activity increases are indicators of soil fertility, though are affected by the climate, conditioners, cultivation practices, crop type, and edaphic properties. The application of FYM, Beejamrut, Jeevamrut, and Panchagavya in chili resulted in a significant increment in dehydrogenase activity in the soil. As a result of the cumulative effect of the amendments, the soil microbial biomass, a living component of the soil organic matter, acts as a labile reservoir for plant-available N, P, and S (sulfur), affecting the soil's ability to supply nutrients to plants via soil organic matter turnover.

2.2 Effect on Microbial Populations and Diversity through addition of FOM

Application of organic amendments has been shown to impose a marked influence on the structure and diversity of microbial communities in the soil. As per, long-term organic farming practices increase the beneficial population of microorganisms and decrease that of pathogenic ones. The application of fermented liquid bio-formulations such as *Panchagavya, Jeevamrut, Amritpani,* Humic acid, Seaweed, and Vermiwash promotes soil microorganisms, promotes plant growth, and increases root biomass. These formulations play a critical role in preserving and boosting the soil's microflora population, which in turn increases the soil fertility and nutrient availability. Fermented manures promote the growth of beneficial microbes due to the availability of partially decomposed organic substrates and readily available sources of carbon and nitrogen. In a case study by Tamil Nadu Agricultural University (TNAU) on banana cultivation, it was found that FOM application significantly increased the population of phosphate-solubilizing bacteria and *actinomycetes* in the rhizosphere, improving nutrient uptake and disease resistance. Further evidence through molecular methods such as 16S rRNA gene sequencing and phospholipid fatty acid (PLFA) profiling conclude that fermented amendments generate richer and more diverse microbial community composition, most notably in functional groups associated with carbon and nitrogen cycling. Shifts within such populations are reputedly important to maintain long-term soil fertility and resilience of agroecosystem structure and functions. Field-level evidence from multiple agroclimatic zones of India provides testimony to the beneficial effect of FOM on crop yields and soil health. A trial run at the Punjab Agricultural University (PAU) reported a 12–18% increase in wheat yield with the application of FOM and reduced doses of chemical fertilizers.

Some research works have further certified the increase in crop yield and soil health due to the application of FOM in several agroclimatic regions of India. In a study by, both Jeevamrut and Beejamrit exhibited high levels of microbial activity and growth hormones, which may have boosted soil biomass and promoted the availability and absorption of both added and naturally occurring nutrients, resulting in the highest crop growth and production. In another instance, fermented organic liquid inputs had significant effects on microbial populations in maize, paddy, soybean, and field bean crops. The microbial activity of the soil was enhanced as a result of the application of varied concentrations of *Panchagavya* to the seeds of legumes and cereals, including pea, gramme, green gram, black gram, dry bean, lentil, moth bean, and soybean. *Jeevamrut* contains a high microbial load that proliferates in the soil and functions as a tonic to boost microbial activity.

Application of FOM enables increased microbial diversity which functions as a key factor for controlling nutrient cycling processes. The slow release of nutrients throughout the crop cycle occurs through essential microbial actions of *Azotobacter* and phosphate-solubilizing bacteria (PSB) and *Trichoderma* spp. mineralizing organic compounds. The combined action between different microorganisms provides better nutrient efficiency and prevents nutrient drain through both leaching and volatilization.

Research on Soil Biodiversity and Biofertiliser demonstrated FOM treatment produces microbial biomass carbon that rises 2–3 times higher than synthetic fertilizers or conventional farmyard manure. The utilization of FOM material has generated substantial constructive effects on soil physical and chemical properties. Soil organic carbon increased by 20% while porosity improved as FOM application resulted in better water infiltration according to the Indian Institute of Soil Science field trials. Soil pH stabilization occurs while bulk density drops and aggregate stability improves due to FOM treatment, which supports root growth and air circulation in the soil.

Organic materials containing fulvic acid and humic structures serve as an excellent substrate for microbial growth which increases microbial biomass carbon levels and functional diversity. Research conducted through the All India Network Project on Soil Biodiversity-Biofertilisers [11] demonstrates that FOM treated soils contain higher levels of phosphate dehydrogenase and urease activities which imply better soil metabolic function.

The microbial communities present in FOM-amended soils contain stable compositions characterized by beneficial microorganisms. Neutralization of nutrients together with disease management operates as a vital process that sustains both cycles. The regular application of FOM in Punjab and Uttar Pradesh fields reduced root-borne diseases by 15–25% as *Trichoderma* and *Bacillus subtilis* populations increased through the microbial activity of FOM. The microbial processes present in FOM help protect against soil-based pathogens by simultaneously developing symbiotic relationships that boost both drought resistance. The soil ecosystem becomes better regulated on its own through this process which decreases dependence on chemical farming.

3. Preparation and Mechanisms of Fermented Organic Manure (FOM)

Fermented Organic Manure (FOM) represents a nutritious organic substrate that develops as micro-organisms ferment different biodegradable components including farmyard manure and crop residues and green leaves and press mud and various bio-wastes. The fermentation development includes adding beneficial microbes such as *Azotobacter* and phosphate solubilizing bacteria (PSB) as well as

Trichoderma and lactic acid bacteria to materials in anaerobic or semi-aerobic conditions during a time frame ranging from 15 to 30 days depending on substrate properties and environmental conditions. The fermentation process transforms hard to digest compounds into basic nutrients that plants can use most effectively. The process particularly benefits the availability of nitrogen, phosphorus and potassium in the soil.

Soil health benefits tremendously from FOM because it strengthens pH stability together with cation exchange capacity and better water management. The environment supports beneficial macro as well as micronutrient availability levels [12].

3.1 Fermentation Method and Ingredients for FOM

Fermented Organic Manure (FOM) represents an enhanced bio-organic input that results from fermenting organic waste products through the use of helpful microbial consortia. The preparation of microbial fermentation requires organic materials like farmyard manure, green leaves, agro waste, kitchen waste, and oil cakes which decompose under controlled conditions with selected microbial cultures. The selected microbial cultures used for fermentation consist of *Azotobacter* and *Azospirillum* as nitrogen fixers and *Pseudomonas* alongside *Bacillus* spp. as phosphate-solubilising bacteria together with *actinomycetes* and fungi (*Trichoderma* spp.) and lactic acid bacteria.

To start the process, one mixes dried leaves or straw with cow dung or urine before adding microbial slurry. The appropriate moisture level of 60–65% allows the material to stay in either anaerobic or semi-aerobic fermentation pits or in piles for a 20–30-day period. The microbial cohort works to break down complex organic substances during this period as well as produce multiplication and beneficial organic acids and enzymes, and antibiotic substances [10].

Regular measurement of temperature along with pH value and smell detects quality, along with the monitoring of odor and pH value. The quality indicators for properly fermented manure include an earthy smell, together with pH levels within 6.5 to 7.5, and elevated content of humic compounds and vitamins and microflora.

3.2 Mechanisms Involved in Soil Replenishment through FOM

The soil receives beneficial effects from FOM as it operates across various biochemical and ecological mechanisms. Organic carbon within FOM enables soil organic matter development that enhances both water retention and soil structure and cation exchange capacity (CEC). The microbial metabolites alongside enzymes work to turn nutrients like nitrogen phosphorus and potassium used by plants through mineralization processes. Fermented manure also contributes to the introduction of various beneficial microbes which occupy root zone areas through mutualistic relationships. The microbes introduced by fermentation compete against pathogens to decrease disease occurrences and simultaneously produce growth-promoting substances including indole acetic acid (IAA), gibberellins, and siderophores.

Biologically active manure enhances degraded soil conditions by rebuilding nutrient relationships along with microbial food systems. Soils become better buffered when organic acids and humic substances that occur during fermentation stabilize pH levels. Saline and acidic soils recover through time as FOM fertigation leads to continuous improvements of general soil health [13].

4. Impact of FOM on Soil Chemical Properties: pH, EC, SOC and NPK Levels

The delivery of both short-term crop production and sustained soil health depends heavily on four crucial chemical soil elements that include soil pH levels and electrical conductivity (EC) and soil organic carbon (SOC) and NPK nutrient levels. The continuous excessive application of synthetic fertilizers has resulted in major soil degeneration throughout Indian agricultural regions manifesting through acidified soil, increased salinity levels, reduced organic carbon quantities along with deteriorated micronutrient profiles. The Soil Health Card Scheme shows that more than 30% of Indian agricultural soil indicates low soil organic carbon content along with pH and electrical conductivity imbalances which reduce nutrient availability and damage microbial activity. Integrated and organic nutrient management approaches are gaining recognition due to which

Fermented Organic Manure (FOM) has become an attractive and sustainable alternative.

4.1 Soil pH Stabilization

The pH of the soil frequently changes following excessive use of urea and DAP due to their effects on nutrient solubility and the activity of soil microbes. The continued usage of chemical fertilizers across India has produced opposite effects among different regions because it simultaneously makes soil acidic while making other areas alkaline leading to restricted nutrients and diminished biological activity in the soil. FOM enables the correction of soil acidity to a favorable pH level between 6.5–7.5 so microbes can thrive, and plants can absorb nutrients effectively. The fermented organic manure (FOM) contains an abundant population of beneficial microorganisms which include *Lactobacillus spp*., *Actinomycetes*, photosynthetic bacteria, and yeasts. This substance holds important amounts of intermediary products which include organic acids together with amino acids. The ammonium form makes up most of the 0.1% nitrogen content alongside an available phosphorus percentage of 1.0%. A proper FOM sample contains approximately 10:1 relation between carbon and nitrogen compounds. The quality standard of FOM is influenced substantially by the amount of moisture in raw materials and molasses sugar addition and the selected microbial strain for fermentation. The reliability of evaluating fermentation efficiency and progression depends mainly on the pH quality indicator. Such fermented manure provides beneficial effects to both soil health and plant growth through its organic materials combined with the introduced microbes' beneficial activities as well as bioactive compounds created during microbial metabolic processes.

4.2 Electrical Conductivity (EC) Reduction

The application of constant chemical fertilizers results in soil salinization, which causes elevated EC values in the soil system. The plant growth is negatively affected by elevated EC because it causes osmotic stress and ion toxicity. The application of FOM enables superior microbial performance and better soil structure, thus promoting salt leaching from the soil. The All India Coordinated Research Project on Long-Term Fertiliser Experiments through field testing noted that FOM-treated plots lowered soil EC by 12–20% more than urea-DAP-fed plots, especially within arid and semi-arid zones].

4.3 Enhancement of Soil Organic Carbon (SOC)

Soil Organic Carbon stands as a vital indicator for evaluating soil health because it directly shapes the valley of soil fertility together with water management and microbial activity performance. The continuous decline of SOC found across India poses a growing problem which stems from excessive agricultural activities combined with widespread mechanical burning of agricultural residues as well as high usage of chemical fertilizers. FOM represents a successful method to rebuild SOC levels in the soil. Soil enriched with FOM contains decomposed organic matter and advantageous microbial communities that execute dual carbon delivery functions to the earth while enhancing microbial activation. The microbial activity within the soil produces humified carbon while enhancing the carbon stability in the long run. The fermentation breakdown of organic matter in FOM through microbial activity produces durable humic substances that persist in the soils for extended periods. Agricultural lands maintain higher carbon storage levels because these resistant compounds help decrease carbon losses while building up SOC stock. Molasses, together with specified microbial inoculants, helps develop useful soil microorganisms during FOM preparation, which sustains organic matter breakdown and carbon cycling mechanisms. The regular use of FOM creates better soil structure, thus it retains water, which ultimately maintains higher organic carbon concentrations in soils. The microbial biomass and their produced metabolites function together with existing soil microbes to improve carbon mineralization and immobilization processes, which transform into increased SOC levels [7].

Soil organic carbon replenishment benefits strongly from FOM because it contains both humic substances and microbial metabolites. The use of FOM as a soil organic matter during two successive cropping seasons resulted in SOC increases between 0.2% and 0.4% within different soil types according to the data from [14]. This enhancement of nutrient retention capacity, together with carbon sequestration capabilities, creates a vital method for building climate adaptation systems in agricultural operations.

4.4 Nutrient Enrichment: Nitrogen, Phosphorus, Potassium (NPK)

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The research conducted by ICAR- Krishi Vigyan Kendra's demonstrated that FOM-treated land exhibited higher available N levels increase of 18–22%, and P levels increase of 12–15%, and K levels increase 15–20%, than untreated and chemical-treated areas. The enriched soil composition and phytic acid production during fermentation resulted in observed enhancements, according to studies. The nutrient-mineralizing process from FOM persists after its application because of microbial activity, which provides extended fertility benefits.

5. CONCLUSION

The use of Fermented Organic Manure (FOM) emerges as an influential bio-input in the field of sustainable agriculture, offering multidimensional advantages to soil health and microbial diversity. Through the combination of organic substrates along with microbial inoculation and fermentation process, not only enhances the availability of macro nutrients such as nitrogen, phosphorus, and potassium but also improves soil physicochemical properties, including both pH balance and electrical conductivity as well as Soil Organic Carbon (SOC) content. Through FOM the soil ecosystem develops better microbial communities composed of phosphorus solubilizers, nitrogen fixing bacteria, and *actinomycetes* which creates diverse and resilient microbial functions. Soil nutrient cycling and humification receive support from the slow-release nutrient characteristics and microbial metabolite elements, which also lead to sustained fertility improvements. Antifungal composition stability exists due to fermentation methods that boost microbial activity while decreasing environmental waste. The cumulative effects of FOM impact both crop yields along the sustainability of soils and the agroecology balance. Strategic FOM implementation fulfills the requirements of conventional farming fertilizers, while supporting soil management efforts towards regeneratively managed agricultural systems that face climate change. Standardizing FOM research methods will enhance their widespread adoption in various agricultural areas of India.

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16