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Production of rock phosphate-enriched compost: A green approach using leaf litter and *Salvinia molesta*

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Abstract
A study was conducted to investigate the potential use of leaf litter and *Salvinia molesta* as sustainable raw material for the production of RP-enriched compost which helps not only in waste management but also creates value-added agricultural inputs. Three compost formulations were prepared using cattle shed waste, cow dung, *Salvinia molesta* and leaf litter from various tree species. Agricultural-grade RP (18% P_2O_5) was added to enhance phosphorus content. Results showed that composting significantly enhanced nutrient content and improved compost maturity. Organic carbon levels decreased due to microbial activity, while total nitrogen increased, particularly in *Salvinia molesta* compost. Phosphorus content improved markedly in leaf litter compost. Calcium levels increased significantly due to the RP enrichment, enhancing soil amendment properties. Micronutrients such as iron, manganese and zinc also showed notable increases. The findings suggest that RP-enriched composts derived from leaf litter and *Salvinia molesta* are highly effective in improving soil fertility and nutrient availability. The study supports the promotion of enriched organic manures as a viable alternative to synthetic fertilizers, ensuring long-term agricultural sustainability and soil health.

Keywords: *Salvinia molesta*, leaf litter, RP-enriched compost, phosphorus enhancement

Introduction
Agricultural sustainability hinges on the effective utilization of natural resources and the promotion of eco-friendly practices to meet the increasing global demand for food. Conventional farming practices heavily reliant on synthetic fertilizers have contributed significantly to environmental degradation, including soil depletion, water pollution and greenhouse gas emissions (Tal, A., 2018) [23]. In this context, the development of alternative, sustainable fertilizers have become a pressing priority for researchers, policymakers and agricultural practitioners. Among these alternatives, organic manures enriched with essential nutrients such as rock phosphate (RP) offers a promising solution to address nutrient deficiencies in soils while enhancing soil health and promoting sustainable agricultural practices.

Rock phosphate a naturally occurring mineral rich in phosphorus plays a critical role in plant growth and development. However, its direct application to soils often results in low bioavailability due to its insoluble nature in neutral and alkaline pH conditions (Zhu, j. *et al.*, 2018) [27]. To overcome this limitation, integrating RP with organic matter has been proposed as an effective strategy to enhance its solubility and bioavailability. Organic matter, when decomposed releases organic acids that aid in the dissolution of RP, making phosphorus more accessible to plants. This approach not only improves the efficiency of phosphorus utilization but also increase soil organic carbon status, fostering a healthier soil ecosystem (Amarasinghe *et al.*, 2022) [1].

Leaf litter and invasive aquatic plants, such as *Salvinia molesta* are abundant and underutilized organic materials that hold immense potential for sustainable manure production. Leaf litter which is a byproduct of natural leaf shedding from trees is rich in organic carbon and micronutrients, making it a valuable material for composting (Chatterjee *et al.*, 2017) [9]. Similarly, *Salvinia molesta*, a fast-growing invasive weed poses significant ecological challenges by clogging water bodies and disrupting aquatic ecosystems (Madzivanzira, *et al.*, 2023) [18] Harnessing these organic resources for the production of enriched organic manures not only addresses waste management issues but also contributes to the creation of value-added agricultural inputs.

The widespread use of synthetic fertilizers in modern agriculture has led to several challenges, including, a. Soil Degradation; Prolonged use of chemical fertilizers often results in the loss of soil organic matter and microbial diversity, reducing soil fertility over time. b. Nutrient Imbalance; Imbalanced fertilization practices lead to the accumulation of certain nutrients while depleting others, negatively affecting crop yields and soil health. c. Environmental Pollution; Runoff from synthetic fertilizers contributes to eutrophication in water bodies, causing algal blooms and threatening aquatic life. d. High Energy Consumption; The production of synthetic fertilizers is energy-intensive, relying heavily on non-renewable resources such as fossil fuels, which exacerbates carbon emissions (Kumar, R. *et al.*, 2019) [15]. To mitigate these challenges, the adoption of organic fertilizers has gained momentum. Organic manures are renewable, biodegradable and environmentally benign. Enriching these fertilizers with essential nutrients such as phosphorus can further enhance their efficacy, making them a viable alternative to chemical fertilizers.

Phosphorus is a macronutrient essential for various physiological and biochemical processes in plants, including energy transfer, photosynthesis and root development. Despite its significance, phosphorus availability in soils is often limited, necessitating external supplementation. RP with its high phosphorus content has been extensively used as a source of this nutrient in agriculture. However, its application faces several challenges, including low solubility and limited bioavailability in certain soil conditions (Arun *et al.*, 2025) [3]. The incorporation of organic matter, such as leaf litter and *Salvinia molesta* into RP formulations offers a practical solution to these challenges. Organic acids released during the decomposition of organic matter enhance the solubilization of rock phosphate, increasing its availability to plants (Singh and Amberger, 1998) [21]. Furthermore, the integration of organic matter improves overall health of soil.

Leaf litter, a natural byproduct of tree ecosystems which is abundant and rich in carbon, nitrogen and micronutrients, leaf litter provides an ideal substrate for composting and manure production. The decomposition of leaf litter by microbial activity results in the release of humic substances and organic acids, which play a vital role in nutrient cycling and soil fertility enhancement. *Salvinia molesta* commonly known as giant salvinia, is a free-floating aquatic fern that has become a global concern due to its invasive nature. It grows rapidly, forming dense mats on the surface of water bodies, thereby disrupting aquatic ecosystems and impeding water usage for agricultural and domestic purposes. Effective management of *Salvinia molesta* is essential to mitigate its environmental impact. Recent studies have highlighted the potential of *Salvinia molesta* as a resource for composting and organic manure production. Rich in nitrogen and other nutrients, this aquatic weed can serve as an excellent feedstock for the production of nutrient-enriched organic fertilizers. When combined with rock phosphate and leaf litter, *Salvinia molesta* can significantly contribute to the solubilization of phosphorus and the enhancement of manure quality.

The production of organic manures enriched with RP offers several agronomic and environmental benefits like, enhanced nutrient availability, improved soil health, waste management, cost-effectiveness and environmental sustainability. In the view of above facts, a study on production of rock phosphate-enriched compost: a green approach using leaf litter and *Salvinia molesta*" was conducted at ZAHRS Brahmavar, Udupi Karnataka with aim of evaluating the potential of leaf litter and *Salvinia molesta* as feedstocks for composting and their characterization.

Materials and Methods

Preparation of rock phosphate enriched compost and its characterization

The rock phosphate enriched compost preparation was carried out at the compost preparation unit, ZAHRS Brahmavar. Three composts were prepared using different raw materials namely, cattle shed waste, cow dung, *Salvinia molesta* an aquatic weed and leaf litter collected from the local forest area (mainly *Ficus religiosa*, *Murraya koenigii*, *Azadirachta indica*, *Artocarpus heterophyllus*, *Ficus benghalensis*, *F. elastica*, *F. benjamina*, *Caesalpinia pulcherrima*, *Tecoma stans*, *Thespesia populnea*, *Delonix regia and Eucalyptus spp.*). Agricultural grade rock phosphate (P_2O_5 - 18 %) was used for P enrichment during the process of composting as per the procedure outlined by Biswas and Narayanasamy (2006) [7]. Cattle dung served as natural inoculant for faster decomposition to each of the composting mass. The rock phosphate enriched composts were prepared by pit method having size of 3.65 m × 1 m × 1 m. Raw materials (about 30 cm thick layer) were spread as first layers. A layer of rock phosphate was then spread over the raw materials followed by layer of fresh cattle dung spread over the composting mass. After 30 days, first turnover was given and worms were released into the pits which were filled with leaf litter and *Salvinia molesta.* Optimum moisture conditions were maintained throughout the composting period. The composting materials were turned at 30, 60 and 90 days to provide adequate aeration. After complete maturity of composts, they are analyzed for total nutrient compositions and other parameters using standard protocols as given below.

pH and electrical conductivity

The pH and electrical conductivity were determined in 1:10 organic material (powdered) and water suspension (Jackson, 1973) [14] by using digital pH meter and conductivity meter, respectively.

Organic carbon (%)

Organic carbon (OC) in the compost samples was estimated by taking known quantities of dried samples in a pre-weighed silica crucible. The samples were kept in a furnace at a temperature of 600 °C for 2 hours. The crucibles were later transferred to desiccators, cooled and immediately weighed to a constant (ash weight).

Total nitrogen (%)

The ground samples were digested with sulphuric acid and digestion mixture (K_2SO_4 + $CuSO_4$ + Selenium powder). The digested compost sample was analyzed for total nitrogen by transferring to distillation unit with sodium hydroxide and liberated ammonia was trapped in boric acid and mixed indicator distilled using kjeldhal distillation unit. This was further titrated against standard sulphuric acid (Subbaih and Asija, 1956) [22].

Digestion of compost sample

A known quantity of compost sample (0.5 g) was digested in 100 ml conical flask with diacid mixture (HNO_3:$HClO_4$) (9:4) until white residue was developed. The digested sample was used in detecting phosphorus, potassium, secondary nutrients and micronutrients.

Total phosphorus (%)

Total phosphorus content in the digested compost sample was determined by vanadomolybdo phosphoric acid yellow colour method using spectrophotometer (Jackson, 1973) [14].

Total potassium (%)

Total potassium content in the digested compost sample was determined by flame photometer (Jackson, 1973) [14].

Calcium and magnesium (%)

Five ml of the di-acid digest was titrated against standard EDTA after adding necessary reagents required for calcium and calcium plus magnesium as described by Piper (1966) [20].

Total sulphur (%)

Sulphur present in di-acid digest of the compost material was determined by precipitating the sulphate with barium chloride and turbidity was measured at 420 nm using spectrophotometer as described by Black (1965) [8].

Estimation of micronutrients

The micronutrient concentrations in the digested compost sample were determined by using AAS (Lindsay and Norvell 1978) [16].

Results and Discussion

Data regarding nutritional status of organic manures (Table 1), including FYM, leaf litter compost and *Salvinia molesta* compost enriched with rock phosphate was conducted before and after composting process to know the changes in chemical properties that occurred after composting.

The pH of the FYM reduced to 7.21 were as in both leaf litter compost and *Salvinia molesta* compost pH stabilized at 6.20. The change in pH may be due to the organic acid produced during composting (Cheung *et al.*, 2010, Wei *et al.*, 2018) [10, 25]. pH range between 6.0 and 7.5 is ideal for compost maturity and nutrient availability, indicating that the composted materials are within acceptable limits for agricultural applications.

Organic carbon levels decreased slightly after composting, indicating microbial consumption of organic matter and released C in the form of CO_2 during respiration (Fabrizio *et al.*, 2009 and Tognetti *et al.*, 2007) [12, 24]. FYM showed a slight decrease from 35.25 percent to 34.00 percent, leaf litter compost dropped from 46.80 percent to 41.50% and *Salvinia molesta* compost declined from 43.03 percent to 39.45 percent. FYM increased from 0.55 percent to 0.89 percent, leaf litter compost from 0.65 percent to 1.04 percent and *Salvinia molesta* compost showed a notable rise from 1.42 percent to 2.56 percent. The increase in nitrogen is due to the decomposition and mineralization of organic matter, the increment in total N is may be due to higher nitrogen content in raw material and also due to the use of earthworms and cow dung as raw material for composting. The higher nitrogen content in *Salvinia molesta* compost suggests its potential as a rich nitrogenous source for crop production.

Phosphorus concentration increased significantly after composting. FYM increased from 0.20 percent to 1.74 percent, leaf litter compost from 0.14 percent to 3.49 percent and *Salvinia molesta* compost from 0.84 percent to 2.79 percent (Fig. 1). The substantial rise in phosphorus content is due to the breakdown of organic phosphorus compounds and also RP enrichment during composting resulted in increased P content markedly, especially in leaf litter compost, total P increased to 3.49 percent, it is due to higher dissolution of enriched rock-phosphate by organic acids released during the process of composting (Biswas and Narayanasamy, 2006) [7] than the FYM and *Salvinia molesta* compost, that is because time taken for decomposition of leaf litter was more (5 months) comparing with other composts.

Potassium levels increased post-composting, with FYM showing a modest rise from 0.46 percent to 0.50 percent, leaf litter compost from 0.56 percent to 0.87 percent, and *Salvinia molesta* compost from 1.36 percent to 2.00. The increase is attributed to the release of potassium from decomposing organic matter and its relatively stable nature, as it does not volatilize like nitrogen (Haynes, 1986) [13]. The high potassium content in *Salvinia molesta* compost suggests its suitability for potassium-deficient soils. However, calcium levels saw a significant rise due to higher content of calcium (40 %) in the rock phosphate used for enrichment, also which contributes to improved nutrient content, increased compost's fertilizing potential and soil amendment properties.

Iron, manganese, zinc and copper showed varying trends post-composting analysis. Iron content increased in all composts, with *Salvinia molesta* compost showing the highest increase from 3859 mg kg^{-1} to 4420 mg kg^{-1}. Manganese levels also increased significantly, with *Salvinia molesta* compost rising from 1647 mg kg^{-1} to 1988 mg kg^{-1}. Zinc showed minor fluctuations, with FYM decreasing slightly, leaf litter compost increasing marginally and *Salvinia molesta* compost increasing from 45.45 mg kg^{-1} to 49.11 mg kg^{-1}. Copper content showed a declining trend, which could be due to its binding with organic matter or microbial uptake.

The C/N ratio dropped considerably, which is a critical indicator of compost maturity (Ndegwa and Thompson, 2000) [19]. FYM had an initial C/N ratio of 91.56, which decreased to 54.57 after composting. Leaf litter compost reduced from 102.86 to 57.01, while *Salvinia molesta* compost had the most significant decline from 43.29 to 22.02. C/N ratio below 25 indicates compost maturity and stability. *Salvinia molesta* compost reached the most suitable C/N ratio, making it ideal for immediate soil application.

Overall, the slight acidity benefits many crops, as it improves the solubility and availability of essential nutrients like phosphorus and micronutrients. The significant increase in nitrogen content in matured composts, particularly *Salvinia molesta* compost, provides a steady supply of N for crop growth, aiding in vegetative development and overall yield improvement. The enhancement of phosphorus ensures better root development and enhances energy transfer processes in crops, promoting stronger and more productive plants. Though the change in potassium content was minor, it still contributes to improved plant vigor, disease resistance, and better fruit and grain development. Micronutrients like iron, manganese and zinc saw significant increases, especially in *Salvinia molesta* compost, providing essential elements for enzyme activation and chlorophyll production, thereby supporting plant metabolism. Reduction in the C/N ratio, especially in *Salvinia molesta* compost, reflects well-decomposed composts that release nutrients more efficiently, making them highly suitable for rapid nutrient uptake by crops.

These rock phosphate-enriched composts provide an excellent source of macro and micronutrients, improve soil structure and enhance microbial activity, all of which lead to better crop yield, healthier plants and sustainable agricultural practices.

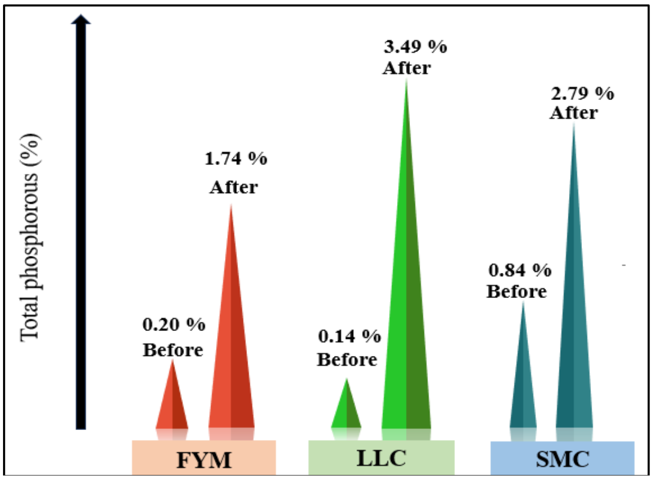

Fig 1: Total P content of organic manures before and after composting process

Table 1: Characterization of farm yard manure, leaf litter compost and *Salvinia molesta* compost

Parameters	Unit	FYM		Leaf litter		*Salvinia molesta*	
		Before composting	After composting	Before composting	After composting	Before composting	After composting
pH	-	7.79	7.21	-	6.20	-	6.20
EC	dS m^{-1}	0.41	0.67	-	0.73	-	0.76
Organic carbon	%	35.25	34.00	46.80	41.50	43.03	39.45
Total carbon		50.36	48.57	66.86	59.29	61.47	56.36
Total N		0.55	0.89	0.65	1.04	1.42	2.56
Total P		0.20	1.74	0.14	3.49	0.84	2.79
Total K		0.46	0.50	0.56	0.87	1.36	2.00
Total Ca		0.31	2.25	0.22	2.50	1.05	2.87
Total Mg		0.15	0.27	0.18	0.45	0.34	0.74
Total S	mg kg^{-1}	0.11	0.09	0.20	0.23	0.12	0.19
Total Fe		824.06	940.27	488.09	588.46	3859	4420
Total Mn		44.02	48.96	58.72	66.62	1647	1988
Total Zn		223.86	216.02	144	149	45.45	49.11
Total Cu		96.16	87.26	16.27	14.01	23.23	19.76
C/N Ratio	-	91.56	54.57	102.86	57.01	43.29	22.02

Conclusion

The study indicates that composting significantly enhances the nutrient profile of FYM, leaf litter and *Salvinia molesta*. The reduction in pH, organic carbon, and C/N ratio, along with an increase in nitrogen, phosphorus, potassium and micronutrient levels, suggests improved compost quality. Among the three compost types, *Salvinia molesta* compost demonstrated the highest nitrogen, potassium and micronutrient content, making it a highly nutrient-rich option for agricultural use. The findings suggest that these composts can be effectively utilized as organic fertilizers to improve soil fertility and crop productivity while promoting sustainable waste management practices. The integration of rock phosphate with organic resources such as leaf litter and *Salvinia molesta* represents a sustainable approach to organic manure production. This strategy not only addresses the limitations of rock phosphate solubility but also contributes to waste management and environmental conservation. By promoting the use of enriched organic manures, this study aims to support sustainable agriculture practices, ensuring food security and environmental health for future generations.

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