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Microbial consortium-induced changes: A comprehensive study on the physical and chemical properties of sewage sludge

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Abstract
Researchers investigate sewage sludge for sustainable agriculture, aiming to boost soil fertility. Challenges arise from potential contaminants, necessitating responsible use through safety standards, risk assessments, and microbial enrichment. The ongoing study assesses sewage sludge before and after microbial enrichment, aligning with environmental stewardship.
A modest increase in water-holding capacity and a slight post-enrichment decline in pH, ultimately stabilizing. The elevated soluble salt content implies heightened electrical conductivity linked to organic matter decomposition. Initial organic carbon (OC) decreases, indicating carbon loss, with the C: N ratio suggesting mineralization and increased nitrogen content post-enrichment.
Elevated levels of phosphorus (P) and potassium (K) suggest microbial activity, while calcium (Ca) and magnesium (Mg) remain largely unchanged, sulfur (S) constant, and micronutrients show a slight increase after enrichment. Heavy metal assessments reveal no cadmium, and concentrations of Ni, Pb, and Cr remain stable, meeting municipal solid waste compost standards. This holistic exploration demonstrates the potential of sewage sludge in sustainable agriculture, emphasizing careful management practices for environmental and agricultural benefits.

Keywords: C: N ratio, phosphorus (P), potassium (K), sulphur (S)

Introduction
In exploring sustainable and environmentally conscious agricultural practices, myriad innovative solutions are being investigated to tackle challenges in traditional waste management and soil enhancement. A particularly noteworthy avenue in this endeavor involves harnessing the potential benefits of sewage sludge for agriculture. Derived as a by-product of wastewater treatment, sewage sludge comprises a rich array of organic and inorganic compounds that can significantly bolster soil fertility and crop yields. The adoption of sewage sludge as a resource for agricultural purposes presents a fresh perspective in addressing waste disposal issues, concurrently providing transformative opportunities to enhance agricultural sustainability.
Sewage sludge unfolds as a dual prospect in agriculture, offering both opportunities and challenges. With its richness in organic matter and nutrients, sewage sludge emerges as a potential boon for soil enhancement, fortifying fertility, and supporting crop growth. However, this promise is accompanied by inherent risks. The sludge may harbor contaminants like heavy metals, pathogens, and pollutants, posing threats to both soil quality and human health if not diligently treated or managed.
The responsible and regulated incorporation of sewage sludge in agriculture demands meticulous adherence to safety standards, comprehensive risk assessments, and effective treatment processes to address potential environmental and health implications. Achieving a nuanced equilibrium between leveraging the nutrient-rich attributes of sewage sludge and mitigating associated risks becomes imperative for optimizing its agricultural benefits while safeguarding environmental sustainability and human well-being.
Enhancing sewage sludge with a microbial consortium is imperative to maximize its positive influence on agriculture. Despite its richness in organic matter and nutrients, sewage sludge often contains intricate compounds and potential contaminants.

Introducing a diverse microbial consortium, including beneficial bacteria and fungi, serves as a catalyst, effectively breaking down these compounds. This enrichment process accelerates the decomposition of organic matter, facilitating the conversion of nutrients into forms readily available to plants.

Moreover, specific microbes contribute to remediating contaminants and stabilizing potentially harmful substances in the sludge. The microbial consortium enhances the overall quality of the sludge by promoting a more balanced and sustainable nutrient composition. By fortifying sewage sludge with a diverse and well-balanced microbial community, harness natural decomposition processes and establish a sustainable and efficient solution for converting organic waste into a valuable resource for soil enrichment in agriculture. This approach aligns seamlessly with the principles of environmental stewardship. The current investigation is undertaken to examine the physical and chemical characteristics of sewage sludge both prior to and following enrichment with a microbial consortium.

Material and Methods

The present experiment was conducted at the Department of Soil Science and Agricultural Chemistry, GKVK campus, UAS, Bangalore, in 2022, this investigation focuses on the enrichment process applied to sewage sludge. The procedure involves combining 2ml of a liquid microbial consortium with 100 ml of water for each kilogram of sewage sludge. The resultant mixture undergoes thorough blending and is regularly watered twice a week to maintain a moisture content range of 60-70%. Placed under shade, the mixture is granted a 15-day period to facilitate the proliferation of the microbial population. Standard protocols (Table 1) were employed to assess various physical and chemical aspects of both enriched and unenriched sewage sludge. The microbial consortium *includes Azotobacter chroococcum*, *Bacillus megaterium*, *Frateuria aurantia*, *Pseudomonas fluorescens*, and *Trichoderma viride*.

Table 1: Methods followed for analysis of sewage sludge before and after enrichment

Parameter	Method	Reference
Physical properties		
MWHC (%)	Keen Raczkowski Cup	Piper, 1966 [6]
Chemical properties		
pH (1:10)	Potentiometry	Jackson, 1973 [2]
EC (dS m^{-1})	Conductometry	Jackson, 1973 [2]
Organic carbon (%)	Wet oxidation	Walkley and Black, 1934 [8]
Total Nitrogen (%)	Kjeldahl distillation method	Piper,1966 [6]
Total Phosphorus (%)	Spectrophotometry	Piper,1966 [6]
Total Potassium (%)	Flame photometery	Piper, 1966 [6]
Total Calcium (%)	Versenate titrimetry	Jackson, 1973 [2]
Total Magnesium (%)	Versenate titrimetry	Jackson, 1973 [2]
Total Sulphur (%)	Turbidometry	Jackson,1973 [2]
Total Fe, Mn, Zn and Cu (ppm)	Atomic Absorption Spectrophotometry	Lindsay and Norvell, 1978 [3]
Total B (ppm)	Azomethane-H	Page *et al*., 1982 [5]
Total heavy metals (ppm)	Atomic Absorption	Lindsay and Norvell, 1978 [3]

Results and Discussion

The findings from the experiment are elucidated in Table 2, where the water-holding capacity reveals a modest increase in moisture content within enriched Sewage Sludge (SS) (44.18%) compared to its initial state before enrichment (46.66%). The pH of SS, initially recorded at 6.74, experienced a slight decline to 6.72 post-enrichment, likely due to the generation of organic acids and phenolic compounds during incubation. However, the pH subsequently stabilized over time, a phenomenon possibly influenced by the buffering characteristics of humic substances.

The soluble salt content in SS increased from 1.24 dSm-1 before enrichment to 1.27 dSm-1 post-enrichment, indicating a rise in electrical conductivity associated with an increased salt concentration, potentially originating from the decomposition of organic matter. The initial organic carbon (OC) content in SS was 9.83%, decreasing to 8.59% after enrichment, suggesting an overall decline attributed to carbon loss in the form of carbon dioxide (CO_2) (Adani *et al*., 1997) [1].

Table 2: Physical and chemical composition of Sewage sludge (SS) before and after enrichment

Parameters	Before Enrichment	After Enrichment
	SS	SS
MWHC (%)	44.18	46.66
pH (1:10)	6.74	6.72
EC (dSm-1)	1.24	1.27
OC (%)	9.83	8.59
C:N ratio	7.80	5.84
N (%)	1.26	1.47
P (%)	1.18	1.29
K (%)	0.31	0.45
Ca (%)	0.64	0.64
Mg (%)	0.27	0.27
S (%)	1.19	1.21

B (mg kg-1)	9.12	11.16
Cu (mg kg1)	55.80	58.13
Mn (mg kg1)	284.60	286.13
Zn (mg kg-1)	140.53	163.65
Fe (mg kg-1)	216.80	231.20
Ni (mg kg-1)	13.05	13.05
Cd (mg kg-1)	ND	ND
Pb (mg kg-1)	16.13	16.14
Cr (mg kg-1)	10.27	10.27

The carbon-to-nitrogen (C: N) ratio decreased from 7.80 before enrichment to 5.84 after 15 days, indicating a reduction in organic carbon content and an increase in nitrogen due to mineralization. The nitrogen content in SS increased from 1.26% to 1.47% after enrichment, associated with the breakdown of labile organic carbon compounds.

Before enrichment, phosphorus (P) content in SS was 1.18%, rising to 1.29% post-enrichment, likely due to the introduction of a microbial consortium facilitating an efficient mineralization process. Potassium (K) content increased from 0.31% to 0.64% after enrichment, possibly linked to swift microbial activity.

Calcium (Ca) and magnesium (Mg) content in SS remained nearly unchanged post-enrichment (0.64% and 0.27%, respectively), while sulfur (S) content remained constant at 1.21%. Micronutrient concentrations exhibited a slight increase after enrichment, likely owing to organic chelation.

The assessment of heavy metals revealed no detection of cadmium. Concentrations of Ni, Pb, and Cr remained almost unchanged before and after enrichment, aligning with observations of lower heavy metal concentrations in compost derived from municipal solid waste. This consistency with standards was noted by Stillwell and David (1993) [7] and Manju *et al*. (2013) [4].

Conclusion

Sewage sludge has potential in sustainable agriculture, but responsible management and the present study are paramount to harness its benefits while minimizing risks. This approach promotes environmentally friendly agricultural practices and resource efficiency.

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