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Phytoremediation of Municipal Wastewater Using *Eichhornia crassipes* at Different Sewage Concentrations

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Abstract:

Rapid urbanization has escalated municipal wastewater generation, necessitating cost-effective and sustainable treatment alternatives. This study investigates the phytoremediation potential of Eichhornia crassipes (water hyacinth) for treating municipal sewage. Sewage samples were formulated into five treatment sets with varying concentrations (ranging from 20% to 100%) and treated with acclimatized plants. Initial and final physicochemical parameters-including pH, solids (TSS, TDS), organic load (BOD, COD), and nutrients-were analyzed to evaluate the plant's removal efficiency. The results demonstrated substantial pollutant reductions across all concentrations. In the undiluted (100%) sewage, E. crassipes achieved remarkable remediation, reducing BOD by 72.2%, COD by 64.0%, and TSS by 78.8%. Furthermore, the plant successfully removed over 50% of critical eutrophication-inducing nutrients, such as nitrates and phosphates. However, chloride concentrations remained largely unaffected, highlighting a biological limitation of the macrophyte. These findings confirm that E. crassipes provides a highly effective, eco-friendly, and economically viable biological filtration system for municipal wastewater management. This approach is particularly beneficial for developing regions seeking sustainable alternatives to conventional, energy-intensive treatment facilities.

Keywords: Constructed Wetlands, Eichhornia Crassipes, Municipal Sewage, Phytoremediation, Nutrient Removal, Wastewater Treatment.

Introduction:

Rapid urbanization and population growth have led to a substantial increase in municipal wastewater generation worldwide. Municipal sewage is typically characterized by high concentrations of organic matter, suspended solids, pathogenic microorganisms, and nutrients such as nitrogen and phosphorus. If discharged untreated, these pollutants degrade aquatic ecosystems, trigger severe eutrophication, and pose serious public health risks (Tchobanoglous et al., 2014; World Health Organization [WHO], 2017). While conventional wastewater treatment systems are highly effective, they require significant capital investment, continuous energy supplies, and specialized technical expertise. These barriers make them difficult to implement in many developing regions, where untreated sewage frequently contaminates surface and groundwater sources relied upon for drinking and irrigation (United Nations Environment Programme [UNEP], 2016).

To address these challenges, phytoremediation has emerged as a sustainable, low-cost, and eco-friendly alternative for wastewater treatment. This biological method utilizes aquatic macrophytes to remove pollutants through mechanisms such as phytoaccumulation,

phytodegradation, rhizofiltration, and synergistic microbial interactions within the rhizosphere (*Phytoremediation of Contaminated Soil and Water*, 2003). Beyond improving water quality, this sustainable technology produces useful biomass that can be harvested for composting, biogas production, and animal feed (Food and Agriculture Organization [FAO], 2013).

Among aquatic plants, *Eichhornia crassipes* (water hyacinth) is widely recognized as one of the most efficient phytoremediators. Its rapid growth rate, massive biomass production, and extensive fibrous root system provide a vast surface area that enhances both direct nutrient uptake and rhizosphere microbial activity (Reddy & Smith, 1987; Rezania et al., 2015). Studies have consistently shown that *E. crassipes* effectively reduces biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids, and nutrient loads in municipal wastewater.

Building upon these findings, the present study evaluates the phytoremediation efficiency of *E. crassipes* under varying sewage concentrations. Municipal sewage was diluted using distilled water to prepare treatment sets ranging from 20% to 100% concentration. By analyzing the initial and final physicochemical parameters across these sets, this research aims to systematically assess the plant's capacity to remove organic loads and nutrients from municipal wastewater, providing insights into its optimal application for sustainable water management.

Materials and Methods:

1. Sample Collection and Treatment Preparation:

Municipal sewage samples were collected from the influent channel of a local sewage treatment facility using clean polyethylene containers. To minimize microbial alterations prior to experimentation, the samples were transported to the laboratory and stored at low temperatures. Five treatment sets were then prepared to establish a range of wastewater concentrations suitable for phytoremediation analysis. The collected sewage was carefully diluted with measured volumes of distilled water to yield solutions of 20%, 40%, 60%, 80%, and 100% (undiluted) municipal sewage. All treatment solutions were prepared in identical, thoroughly pre-cleaned plastic containers, and equal volumes were maintained across all sets to ensure consistent and comparable experimental conditions.

2. Plant Acclimatization and Experimental Setup:

Healthy *Eichhornia crassipes* plants were harvested from a freshwater pond and washed thoroughly with tap water, followed by distilled water, to remove attached debris and epiphytes. Prior to the experiment, the plants were acclimatized in clean water for 5 to 7 days to stabilize their physiological conditions. Following acclimatization, an equal biomass of the plant was introduced into each of the five treatment containers. Corresponding control sets, containing the wastewater dilutions but no plants, were also maintained to establish baseline degradation rates. The experiment was conducted under natural light conditions at room temperature, with water levels actively maintained throughout the fixed 10-to-15-day treatment duration.

3. Physicochemical Analysis:

To evaluate the phytoremediation efficiency and pollutant removal, water samples from each treatment set were analyzed both initially and at the conclusion of the experimental period. All analyses strictly followed the standardized procedures outlined in the *Standard Methods for the Examination of Water and Wastewater*, 23rd edition (APHA, AWWA, & WEF, 2017). The physicochemical parameters

measured included pH, electrical conductivity (EC), total suspended solids (TSS), total dissolved solids (TDS), total solids (TS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrate, phosphate, sulphate, chloride, ammoniacal nitrogen, and total nitrogen. These parameters were selected to provide a comprehensive assessment of the wastewater's organic load, ionic concentration, and eutrophication-inducing nutrient levels (Metcalf & Eddy, Inc. et al., 2014). To ensure accuracy and minimize experimental error, standard calibration procedures were followed, and all measurements were performed in triplicate with the average values recorded.

4. Data Analysis:

To evaluate the overall effectiveness of the phytoremediation process, the removal efficiency for each physicochemical parameter was quantified. The percentage of pollutant reduction was calculated using the following equation:

Removal Efficiency (%) = {[Initial Value - Final Value]/Initial Value}x 100

The calculated results were then systematically compared across the five treatment concentrations. This comparative analysis allowed for a thorough assessment of the plant's varying capacity for pollutant uptake and helped identify the optimal sewage concentration for effective phytoremediation.

Results and Discussion:

The efficiency of *Eichhornia crassipes* in remediating municipal wastewater was systematically evaluated by comparing the physicochemical parameters of the water before and after the experimental treatment period. To establish an accurate baseline, **Table 1** presents the initial and final characteristics of the dilution water treated with the macrophytes in the absence of municipal sewage (the control set). The core experimental data for the wastewater dilutions are detailed in the subsequent tables. **Table 2** outlines the initial physicochemical profiles of the five formulated treatment sets (ranging from 20% to 100% sewage concentration) prior to biological intervention. Following the phytoremediation process, the final characteristics of these respective sets were recorded and are displayed in **Table 3**, illustrating the plant's capacity for pollutant reduction across the different dilution gradients.

Table 1: Before and after characteristics of water used for dilution and in control set with *Eichhornia crassipes* without municipal sewage.

Parameter	Unit	Measured Initial Value	Measured Final Value
pH	–	7.2	7.0
EC (Electrical Conductivity)	µS/cm	305	265
TSS (Total Suspended Solids)	mg/L	7	2.5
TDS (Total Dissolved Solids)	mg/L	152	141
TS (Total Solids)	mg/L	163	143
BOD (Biochemical Oxygen Demand)	mg/L	1.1	0.4
COD (Chemical	mg/L	2.5	1.5

Oxygen Demand)			
NO_3 (Nitrates)	mg/L	6.1	3.1
PO_4 (Phosphates)	mg/L	0.2	0.9
SO_4 (Sulphates)	mg/L	22	19
Cl^- (Chlorides)	mg/L	N/A	N/A
Ammoniacal Nitrogen	mg/L	0.05	0.01
Total Nitrogen	mg/L	0.34	0.14

Table 2: Initial physicochemical characteristics of Municipal Sewage influent and Treatment sets prepared with dilution water.

Parameter	**Unit**	**Set I (20%)**	**Set II (40%)**	**Set III (60%)**	**Set IV (80%)**	**Set V (100%)**
pH	–	7.2	7.4	7.6	7.9	8.1
EC	µS/cm	15	15	17	18	19
TSS	mg/L	72	99	137	221	331
TDS	mg/L	322	465	576	621	846
TS	mg/L	394	564	713	842	1177
BOD	mg/L	19	37	54	74	90
COD	mg/L	58	110	161	210	264
NO_3	mg/L	6	11	15	21	26
PO_4	mg/L	4	9	12	14	20
SO_4	mg/L	15	38	62	77	98
Cl^-	mg/L	48	72	110	221	335
Amm. Nitrogen	mg/L	10	13	16	19	22
Total Nitrogen	mg/L	23	54	77	97	124
Parameter	**Unit**	**Set I (20%)**	**Set II (40%)**	**Set III (60%)**	**Set IV (80%)**	**Set V (100%)**

Table 3: Final physicochemical characteristics of Municipal Sewage influent and Treatment sets prepared with dilution water.

Parameter	**Unit**	**Set I (20%)**	**Set II (40%)**	**Set III (60%)**	**Set IV (80%)**	**Set V (100%)**
pH	–	6.8	6.9	7.1	7.3	7.4
EC	µS/cm	11	10	11	12	13
TSS	mg/L	12	18	25	45	70
TDS	mg/L	260	360	440	480	650
TS	mg/L	272	378	465	525	720
BOD	mg/L	3.5	8.0	12.5	18.0	25.0
COD	mg/L	15.0	30.0	48.0	70.0	95.0
NO_3	mg/L	1.8	3.5	5.0	8.5	11.0
PO_4	mg/L	0.8	2.2	3.5	5.5	9.0
SO_4	mg/L	11.5	28.0	48.0	62.0	80.0
Cl^-	mg/L	44	68	105	215	328

Amm. Nitrogen	mg/L	1.5	2.5	4.0	6.5	9.0
Total Nitrogen	mg/L	6.0	16.0	28.0	42.0	58.0

Table 4: Before and After characteristics at a glance in the treatment sets

Parameter (Unit)	**Set I (20%)**		**Set II (40%)**		**Set III (60%)**		**Set IV (80%)**		**Set V (100%)**	
Parameter	Before	After	Before	After	Before	After	Before	After	Before	After
pH	7.2	6.8	7.4	6.9	7.6	7.1	7.9	7.3	8.1	7.4
EC (µS/cm)	15	11	15	10	17	11	18	12	19	13
TSS (mg/L)	72	12	99	18	137	25	221	45	331	70
TDS (mg/L)	322	260	465	360	576	440	621	480	846	650
TS (mg/L)	394	272	564	378	713	465	842	525	1177	720
BOD (mg/L)	19	3.5	37	8.0	54	12.5	74	18.0	90	25.0
COD (mg/L)	58	15.0	110	30.0	161	48.0	210	70.0	264	95.0
NO_3 (mg/L)	6	1.8	11	3.5	15	5.0	21	8.5	26	11.0
PO_4 (mg/L)	4	0.8	9	2.2	12	3.5	14	5.5	20	9.0
SO_4 (mg/L)	15	11.5	38	28.0	62	48.0	77	62.0	98	80.0
Cl^- (mg/L)	48	44	72	68	110	105	221	215	335	328
Amm. Nitrogen (mg/L)	10	1.5	13	2.5	16	4.0	19	6.5	22	9.0
Total Nitrogen (mg/L)	23	6.0	54	16.0	77	28.0	97	42.0	124	58.0

1. Control Set and Baseline Activity:

The initial and final characteristics of the dilution water treated with *Eichhornia crassipes* (Table 1) demonstrated the baseline metabolic activity of the plants in the absence of municipal sewage. Minor reductions in baseline parameters, such as a drop in Total Dissolved Solids (TDS) from 152 mg/L to 141 mg/L and Chemical Oxygen Demand (COD) from 2.5 mg/L to 1.5 mg/L, indicate that the acclimatized plants were actively filtering the water and taking up trace nutrients prior to heavy pollutant exposure. The **characteristics of water used for dilution & control set was analyzed before and after the experimental study and results are graphically presented in Fig. 1.**

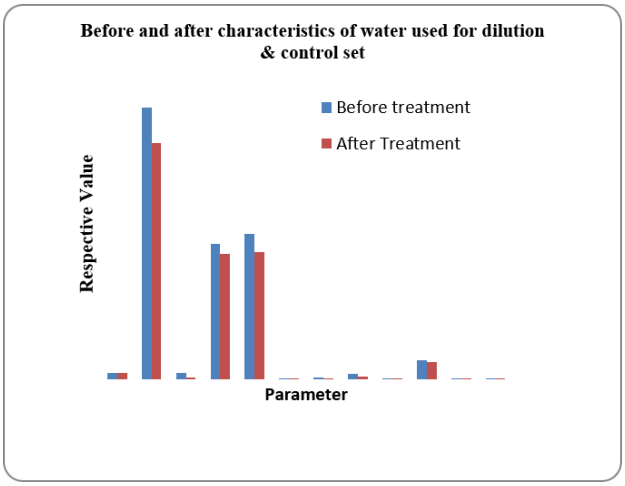


Fig. 1: Before and after characteristics of water used for dilution & control set

2. Changes in pH and Electrical Conductivity (EC):

The initial pH of the municipal sewage sets ranged from 7.2 (Set I) to 8.1 (Set V). Following the phytoremediation period, the pH levels in all treatments trended toward neutrality, ranging from 6.8 to 7.4 (Table 3). This neutralization is a well-documented effect of phytoremediation, attributed to the release of organic exudates from the plant roots and the absorption of nutrient ions, which buffer the aquatic environment (Mahmood et al., 2005). Electrical conductivity also exhibited a reduction across all sets, reflecting the active uptake of dissolved ionized solutes by the extensive root system of *E. crassipes*.

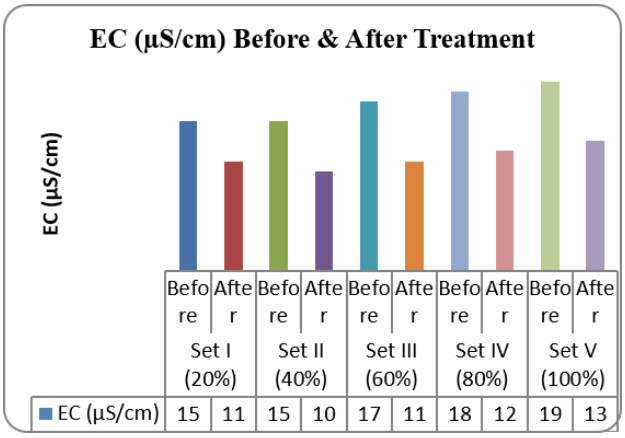


Fig. 2: Comparison of Electrical Conductivity (EC) in µS/cm before and after treatment across different concentration sets.

3. Reduction of Suspended and Dissolved Solids:

E. crassipes demonstrated a profound capacity for physical filtration and root-assisted sedimentation. In the undiluted sewage (Set V), Total Suspended Solids (TSS) were reduced from 331 mg/L to 70 mg/L, achieving a highly effective removal efficiency of 78.8%. TDS and Total Solids (TS) were also substantially reduced. The massive, fibrous root system of the water hyacinth acts as a mechanical filter that traps suspended matter while simultaneously absorbing dissolved organic and inorganic solids (Maine et al., 2001).

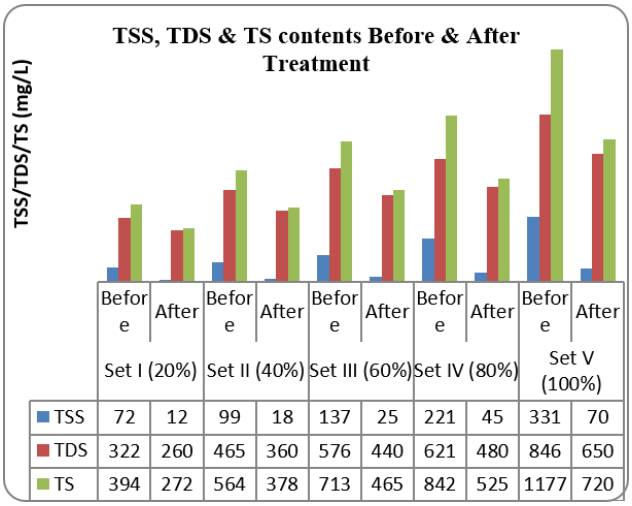


Fig. 3: Comparison of Total Suspended Solids (TSS), Total Dissolved Solids (TDS), and Total Solids (TS) contents in mg/L before and after treatment across different concentration sets.

4. Organic Load Removal (BOD and COD):

The initial Biochemical Oxygen Demand (BOD) and COD for the 100% sewage concentration (Set V) were 90 mg/L and 264 mg/L, respectively. After treatment, these values plummeted to 25 mg/L and 95 mg/L, representing a removal efficiency of 72.2% for BOD and 64.0% for COD. Similar high-efficiency trends were observed across the diluted sets (Sets I - IV). This significant depletion of the organic load is primarily driven by the symbiotic relationship between the aquatic macrophyte and the

microbial communities residing in its rhizosphere. The plant roots release oxygen and carbon exudates, establishing an aerobic micro-zone that rapidly accelerates the microbial degradation of complex organic pollutants (Brix, 1997; Rezania et al., 2015).

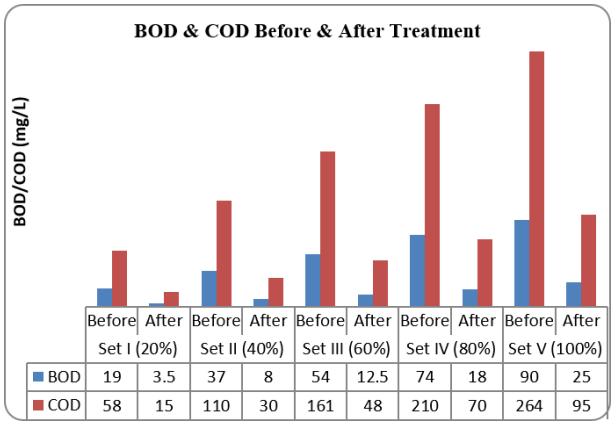


Fig. 4: Comparison of Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) in mg/L before and after treatment across different concentration sets.

5. Nutrient Uptake (Nitrogen and Phosphorus):

Nutrient removal is one of the primary advantages of utilizing *E. crassipes*. In Set V, nitrate (NO_3) decreased from 26 mg/L to 11 mg/L (57.6% removal), while phosphates (PO_4) were reduced from 20 mg/L to 9.0 mg/L (55.0% removal). Furthermore, total nitrogen was reduced by more than 53% in the undiluted set. Water hyacinths have exceptionally high nutrient demands to support their rapid biomass proliferation. The removal of nitrogen and phosphorus occurs largely through direct plant assimilation and subsequent conversion into plant tissue, alongside coupled microbial nitrification-denitrification processes in the root zone (Reddy & DeBusk, 1987).

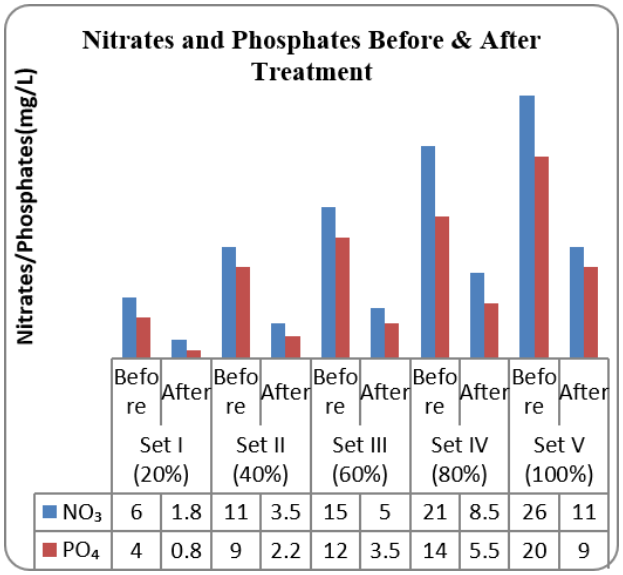


Fig. 5: Comparison of Nitrates (NO3) and Phosphates (PO4) concentrations in mg/L before and after treatment across different concentration sets.

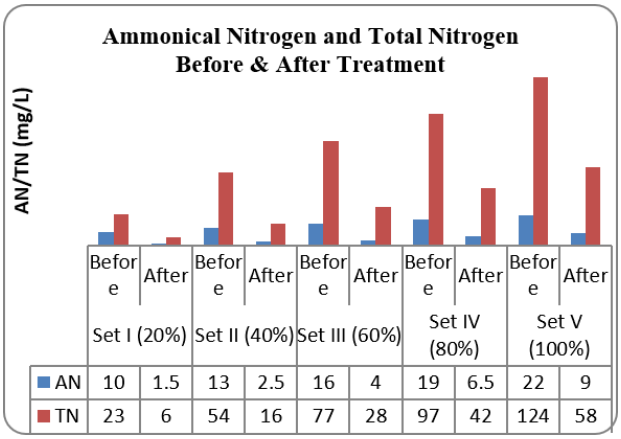


Fig. 6: Comparison of Ammonical Nitrogen (AN) and Total Nitrogen (TN) concentrations in mg/L before and after treatment across different concentration sets.

6. Behavior of Inorganic Ions:

While parameters like sulphates (SO_4) saw moderate reductions (e.g., 98 mg/L to 80 mg/L in Set V), chloride (Cl^-) ions remained largely unaffected. The initial chloride concentration in Set V was 335 mg/L and only decreased slightly to 328 mg/L. This ~2% reduction highlights a known limitation of phytoremediation: macrophytes generally do not biologically metabolize or volatilize chlorides

efficiently. The minor reduction observed is likely due to trace cellular uptake rather than bulk degradation, confirming that alternative treatments may be necessary if high salinity or chloride toxicity is the primary concern in the effluent (Metcalf & Eddy, Inc. et al., 2014).

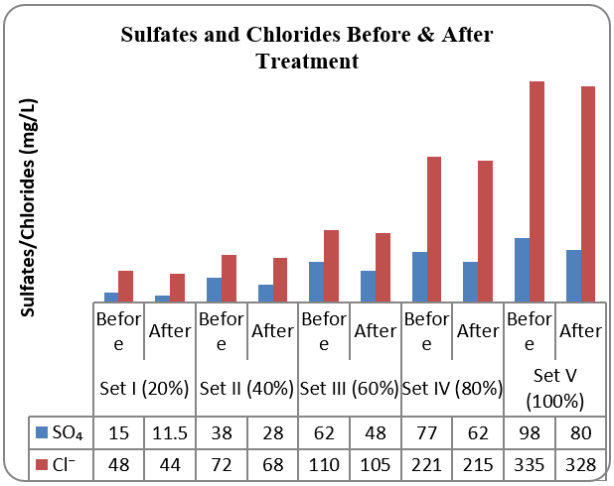


Fig. 7: Comparison of Sulfates (SO4) and Chlorides (Cl-) concentrations in mg/L before and after treatment across different concentration sets

Conclusion:

The present study demonstrates that *Eichhornia crassipes* (water hyacinth) is a highly efficient, sustainable, and eco-friendly biological agent for the remediation of municipal wastewater. The experimental data revealed a profound reduction in major physicochemical pollutants across all sewage concentrations (20% to 100%). Notably, in the undiluted municipal sewage (Set V), the macrophyte achieved significant removal efficiencies for both organic loads-reducing Biochemical Oxygen Demand (BOD) by 72.2% and Chemical Oxygen Demand (COD) by 64.0%—and suspended solids, which were reduced by nearly 79%. These results confirm the plant's robust capacity for physical filtration and its ability to foster an active rhizosphere that accelerates microbial degradation.

Furthermore, *E. crassipes* proved highly effective in mitigating eutrophication-inducing nutrients, successfully removing over 50% of nitrates, phosphates, and total nitrogen from the raw sewage. While the plant showed remarkable overall remediation capabilities, the study also highlighted a known biological limitation: it was largely ineffective at removing chloride ions, indicating that secondary treatments may be required if high salinity is a primary concern.

Ultimately, this research underscores the viability of phytoremediation as a low-cost alternative to conventional, energy-intensive wastewater treatment plants. By utilizing *E. crassipes*, developing regions can effectively manage municipal sewage, prevent the contamination of vital water bodies, and simultaneously generate harvestable plant biomass that can be repurposed for bioenergy or agricultural compost.

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