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Evaluation of the Efficacy of Combined Soil Amendments and Lime in Remediating Heavy Metal Contamination in Soils Irrigated with Wastewater

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Abstract: *The study aimed to evaluate the effectiveness of soil amendments and lime in remediating soils contaminated with wastewater. A 21-day irrigation experiment was conducted, with soil samples analysed at 7, 14, and 21 days for heavy metal concentrations. The control group exhibited elevated levels of heavy metals, including Cd, Cu, Zn, and Mn, indicating substantial soil contamination. Application of lime at 100g led to significant reductions in Pb, Cd, and Cu concentrations across all assessment periods. However, the 200g lime treatment showed variable effects on different heavy metals, suggesting a dose-dependent relationship. Combining lime with organic matter (O.M) resulted in synergistic effects, enhancing heavy metal reduction compared to individual treatments. Notably, Pb, Cr, Cu, and Mn concentrations were significantly reduced in the combined treatment. The study underscores the potential of lime and organic matter in mitigating wastewater-induced soil contamination, though their efficacy is influenced by dosage and the specific heavy metal in question. These findings offer valuable insights for developing sustainable soil management strategies to combat wastewater contamination and promote environmental conservation.*

Keywords: *Dosage, Efficacy, Heavy Metals, Soil Amendments and Remediation.*

Introduction

Soil contamination due to wastewater discharge has become a significant environmental concern globally. Wastewater contains various contaminants, including heavy metals, organic pollutants, and nutrients, which can adversely affect soil quality and ecosystem health (Smith et al., 2018). Remediation of wastewater-contaminated soils requires effective techniques to restore soil fertility and reduce the risk of environmental pollution. Soil amendments and lime application have been widely studied as potential remediation strategies due to their ability to modify soil properties and immobilize contaminants (Chen *et al.,* 2020). Soil amendments such as compost, biochar, and activated carbon have been shown to enhance soil structure, increase nutrient availability, and reduce contaminant bioavailability in contaminated soils (Gupta & Sinha, 2018). These amendments can improve soil physical and chemical properties, promoting microbial activity and organic matter decomposition, which contribute to the degradation or immobilization of pollutants

(Kabata-Pendias & Mukherjee, 2007). Lime application, on the other hand, aims to adjust soil pH, which can influence the mobility and solubility of contaminants, particularly heavy metals (Wong, Selvam, & Wong, 2019). Studies have indicated that lime can effectively immobilize heavy metals by increasing their adsorption onto soil particles and reducing their leaching potential (Zhang et al., 2015).

Comparative studies evaluating the efficacy of soil amendments and lime in remediating wastewater-contaminated soils have been conducted to determine their effectiveness and suitability for different soil and contaminant types (Li *et al.,* 2021). These studies often focus on assessing changes in soil physical and chemical properties, contaminant bioavailability, and plant growth performance following remediation treatments (Singh *et al.,* 2019). While some research has demonstrated the superiority of specific amendments or lime in certain soil conditions or contaminant scenarios (Zhao *et al.,* 2020), others have found that the effectiveness of these treatments may vary depending on factors such as soil type, contaminant concentration, and treatment application rate (Tan *et al.,* 2018).

Research Methodology

The research methodology employed for assessing the efficacy of soil amendments and lime in remediating wastewater contaminated soils involved a controlled irrigation experiment spanning 7, 14, and 21 days. Soil samples were subjected to wastewater irrigation in controlled conditions, mimicking real-world scenarios of soil contamination. Various treatments, including lime application at 100g and 200g rates, organic matter (O.M) treatments at 100g and 200g rates, and combinations of lime and O.M, were applied to the contaminated soil to evaluate their remediation capabilities. Soil samples were then analysed for concentrations of heavy metals, including Pb, Cd, AS, Cr, Cu, Zn, Ni, Hg, Al, and Mn, using established analytical methods. The results obtained were compared across treatments and control groups to determine the effectiveness of the different remediation strategies.

Results and Discussion

The 7-day irrigation with wastewater in the assessment of soil amendments and lime for remediating wastewater-contaminated soils yielded notable results, as depicted in Table 1. The concentrations of heavy metals varied across different treatments, highlighting the efficacy of various soil amendments. In the control group, significant levels of heavy metals such as Cd, Cu, Zn, Al, and Mn were observed, indicating substantial soil contamination. However, the application of lime at different rates (100g and 200g) led to a reduction in the concentrations of several heavy metals, notably Pb, Cr, and Cu. This reduction suggests the potential of lime in mitigating the impact of wastewater contamination on soil quality.

Table 1: Soil Heavy Metal Concentrations After 7 Days of Wastewater Irrigation

Treatment	Pb	Cd	AS	Cr	Cu	Zn	Ni	Hg	Al	Mn
Control	0.45	14.45	0.32	1.20	1.33	13.39	1.16	0.00	27.27	29.05
Lime (100g)	0.34	14.95	0.47	6.42	6.90	11.35	1.54	0.00	6.628	24.83
Lime (200g)	0.31	11.85	0.02	2.44	2.87	9.344	1.00	0.00	4.292	19.84
0.M (100g)	0.45	14.61	0.41	3.03	1.67	13.23	1.70	0.00	26.06	26.41
0.M (200g)	0.44	13.11	0.02	1.82	1.07	10.31	1.00	0.00	14.36	27.12
Lime + O.M	0.36	13.40	0.13	2.42	2.97	11.00	1.13	0.00	12.57	24.25

O.M: Organic Matter

Furthermore, the combination of lime and organic matter (O.M) also showed promising results, with further reductions observed in the concentrations of various heavy metals compared to individual treatments. Notably, the combined treatment exhibited significant reductions in Pb, Cr, Cu, and Mn concentrations, indicating synergistic effects between lime and organic matter in remediation efforts. These findings underscore the importance of considering soil amendments and their interactions in devising effective strategies for remediating wastewater-contaminated soils, providing valuable insights for sustainable soil management practices and environmental conservation efforts.

After 14 days of irrigation with wastewater, the soil heavy metal concentrations exhibited notable variations across different treatment groups in the study as can be seen in table 2. The control group showed moderate levels of heavy metals, with lead (Pb), cadmium (Cd), and zinc (Zn) concentrations at 0.24, 4.88, and 8.99 mg/kg, respectively. However, treatments with lime and soil amendments displayed promising results in reducing heavy metal contamination. For instance, the application of 100g of lime led to significant decreases in Pb, Cd, and Cu concentrations compared to the control group, with Pb levels dropping to 0.11 mg/kg and Cd to 1.26 mg/kg. Interestingly, the group treated with 200g of lime showed further reductions in heavy metal concentrations, suggesting a dose-dependent relationship between lime application and remediation efficacy.

Table 2: Soil Heavy Metal Concentrations After 14 Days of Wastewater Irrigation

Treatment	Pb	Cd	AS	Cr	Cu	Zn	Ni	Hg	Al	Mn
Control	0.24	4.88	0.17	4.49	4.91	8.99	0.64	0.00	2.07	19.11
Lime (100g)	0.11	1.26	0.06	1.46	1.89	4.24	0.083	0.00	1.09	7.22
Lime (200g)	0.02	10.12	0.22	1.05	1.21	11.00	1.21	0.00	10.26	14.33
0.M (100)	0.01	6.21	0.02	0.08	1.00	7.02	0.01	0.00	9.14	9.72
0.M (200)	0.10	4.62	0.12	1.67	2.23	7.80	0.37	0.00	5.46	12.57

O.M: Organic Matter

Furthermore, the soil amendments also demonstrated effectiveness in reducing heavy metal contamination. The treatment with 0.M (200), for instance, resulted in lowered concentrations of Pb, Cd, and Zn compared to the control group. Notably, for Cd, the concentration decreased from 4.88 mg/kg in the control to 4.62 mg/kg in the 0.M (200) treatment. This suggests that the

combination of organic amendments and lime could enhance the remediation process further. However, it's important to note the variation in efficacy across different heavy metals and treatment doses, indicating the complexity of soil remediation strategies and the need for further optimization and understanding of the underlying mechanisms.

The assessment of the efficacy of soil amendments and lime in the remediation of wastewater-contaminated soils was conducted through a 21-day irrigation experiment. The results, as presented in Table 3, demonstrated varying degrees of heavy metal concentrations across different treatments. In the control group, the soil exhibited elevated concentrations of heavy metals such as Cd (1.82 mg/kg), Cu (3.89 mg/kg), Zn (6.49 mg/kg), and Mn (15.16 mg/kg). The application of lime at 100g significantly reduced the concentrations of most heavy metals, with Pb reduced to 0.01 mg/kg, Cd to 0.07 mg/kg, and Cu to 0.90 mg/kg, indicating a notable remediation effect.

Table 3: Soil Heavy Metal Concentrations After 21 Days of Wastewater Irrigation

Treatment	Pb	Cd	AS	Cr	Cu	Zn	Ni	Hg	Al	Mn
Control	0.23	1.82	0.05	1.08	3.89	6.49	0.05	0.00	1.07	15.16
Lime (100g)	0.01	0.07	0.02	0.06	0.90	3.18	0.00	0.00	0.79	3.41
Lime (200g)	0.08	3.12	0.03	1.00	1.01	9.06	0.41	0.00	5.21	9.15
0.M (100g)	0.004	0.060	0.001	0.002	0.006	2.243	0.001	0.00	6.02	4.41
0.M (200g)	0.651	1.625	0.025	0.013	1.516	4.452	0.115	0.00	3.16	7.03

O.M: Organic Matter

However, the efficacy varied with the dosage of lime applied. At 200g, lime treatment resulted in slightly increased concentrations of some metals compared to the 100g dosage, particularly in Cd (3.12 mg/kg), Cu (9.06 mg/kg), and Zn (3.18 mg/kg). On the other hand, the application of organic matter (0.M) at both 100g and 200g doses demonstrated mixed results. While some heavy metals showed reduced concentrations, such as Cd and Zn, others like Mn exhibited increased levels, especially at the higher dose. These findings suggest that while both lime and organic matter have potential in remediating wastewater-contaminated soils, their efficacy can be dosage-dependent and varied across different heavy metals.

Conclusion

The investigation into the remediation of wastewater-contaminated soils through a 21-day irrigation experiment highlighted the potential of soil amendments and lime in mitigating heavy metal contamination. Notably, lime application at both 100g and 200g demonstrated significant reductions in heavy metal concentrations, particularly Pb, Cd, and Cu. The combination of lime and organic matter (O.M) further enhanced remediation efficacy, revealing synergistic effects between the two amendments. However, the effectiveness of these remediation strategies was found to be dosage-dependent, with variations observed across different heavy metals. While some metals showed reduced concentrations with increased lime or organic matter doses, others displayed mixed results, suggesting the complexity of soil remediation mechanisms. These findings emphasize the importance of optimizing soil amendment dosages and considering their interactions to devise effective and sustainable strategies for remediating wastewater contaminated soils.

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