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Impacts of Diverse Phosphatic Fertilizer Applications on Metal Dynamics and Environmental Sustainability

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ABSTRACT

This study explores the nuanced impacts of various phosphatic fertilizers, including diammonium phosphate (DAP), monoammonium phosphate (MAP), single superphosphate (SSP), triple superphosphate (TSP), and Nitrophos (NP), on the dynamics of heavy metals and environmental sustainability in soil ecosystems. A key focus is placed on the differential heavy metal content within these fertilizers, with DAP and MAP known to contain higher concentrations compared to SSP and TSP. Through rigorous experimentation and analysis, our research elucidates the distinctive patterns of heavy metal accumulation in soils resulting from the application of these fertilizers. The findings not only highlight the contrasting heavy metal dynamics associated with each fertilizer type but also assess their implications for environmental sustainability. With DAP and MAP demonstrating higher heavy metal levels, this study underscores the potential environmental risks associated with their usage. In contrast, SSP and TSP emerge as comparatively lower-risk alternatives, offering a more environmentally sustainable approach to phosphatic fertilizer application. This research contributes valuable insights to agricultural practices, aiding in the informed selection of phosphatic fertilizers based on their heavy metal profiles and environmental impact. The study's comprehensive approach provides a foundation for sustainable soil management practices, fostering agricultural productivity while minimizing potential adverse effects on the environment.

Introduction

Enhancing agricultural productivity and ensuring global food security is the need of time and the use of phosphatic fertilizers has become a cornerstone of modern farming practices. Phosphorus, an essential nutrient for plant growth, is often applied in the form of various phosphatic fertilizers to improve soil fertility and crop yields [1,2]. However, the indiscriminate use of these fertilizers raises concerns about their potential environmental impacts, particularly in relation to heavy metal accumulation in soils [3,4,5]. This study delves into the intricate interplay between diverse phosphatic fertilizers and their consequential effects on metal dynamics and environmental sustainability in soil ecosystems.

Phosphatic fertilizers come in various formulations, each with its own unique composition and characteristics [6]. Among the commonly used phosphatic fertilizers are diammonium phosphate (DAP), monoammonium phosphate (MAP), single superphosphate (SSP), triple superphosphate (TSP), and Nitrophos [7,8,9]. While these fertilizers serve the common purpose of supplying phosphorus to plants, their distinct chemical compositions introduce variability in their potential impacts on soil health and the environment. Notably, DAP and MAP have been identified for their relatively higher concentrations of heavy metals, posing potential risks to both terrestrial and aquatic ecosystems [10,11].

Heavy metals, including cadmium, lead, and zinc, are naturally occurring elements that, at elevated concentrations, can exert adverse effects on ecosystems and human health [10]. The agricultural application of phosphatic fertilizers containing heavy metals introduces an additional dimension to the complex web of interactions within soil environments [3,7]. The present study seeks to elucidate the differential impacts of DAP, MAP, SSP, TSP, and Nitrophos on the dynamics of heavy metals in soils, with a particular emphasis on the environmental sustainability of such applications.

The dynamics of heavy metals in soil are influenced by a multitude of factors, including soil composition, pH, microbial activity, and the specific characteristics of the applied fertilizers [1,6,12]. Understanding how these factors interact is crucial for developing sustainable agricultural practices that maximize crop yields while minimizing potential environmental harm [5]. Furthermore, the variations in heavy metal content among different phosphatic fertilizers prompt the need for a nuanced examination of their individual contributions to soil metal dynamics [7].

This study aims to fill existing knowledge gaps by systematically examining the impacts of diverse phosphatic fertilizers on heavy metal dynamics in soils and, subsequently, assessing the implications for environmental sustainability. The comprehensive understanding gained from this research can guide agricultural practices towards a more informed and environmentally conscious use of phosphatic fertilizers, ultimately promoting sustainable soil management for future generations.

Materials and Methods

Experimental Design:

The study was conducted in a controlled environment to minimize external variables. We established a completely randomized design with five treatment groups, each corresponding to a specific phosphatic fertilizer: diammonium phosphate (DAP), monoammonium phosphate (MAP), single superphosphate (SSP), triple superphosphate (TSP), and Nitrophos. Each treatment was replicated thrice to ensure statistical robustness.

Soil Sampling and Preparation:

Soil samples were collected from a uniform site with similar soil characteristics. The soil was air-dried, sieved to remove debris, and homogenized to achieve consistency. Basic soil properties, including pH, organic matter content, and texture, were determined before initiating the experiment.

Fertilizer Application:

Precise quantities of each phosphatic fertilizer were applied to the designated treatment pots based on recommended agricultural practices. The application rates were selected to represent realistic scenarios in agricultural settings while avoiding excessive concentrations that could lead to skewed results.

Monitoring Heavy Metal Dynamics:

Soil samples were collected from the pots of the experiment immediately at the end of experiment. The samples were collected using a systematic sampling within each treatment pot to ensure representative data.

Heavy Metal Analysis:

The collected soil samples were subjected to rigorous chemical analysis to determine the concentrations of heavy metals. Commonly studied heavy metals, such as cadmium (Cd), lead (Pb), and zinc (Zn), were quantified using atomic absorption spectroscopy (AAS).

Statistical Analysis:

The obtained data were subjected to statistical analysis to identify significant differences in heavy metal concentrations among the various fertilizer treatments. Analysis of variance (ANOVA) and post-hoc tests were employed to assess the statistical significance of observed variations.

Results

Heavy Metal Dynamics:

a. Diammonium Phosphate (DAP) and Monoammonium Phosphate (MAP):

Analysis of soil samples revealed a significant increase in heavy metal concentrations, particularly cadmium (Cd), lead (Pb), and zinc (Zn), following the application of DAP and MAP. Both fertilizers, known for their higher heavy metal content, exhibited a pronounced impact on soil metal dynamics (Figure 1). The observed increase in heavy metal concentrations persisted throughout the monitoring period, indicating a potential long-term influence on soil quality.

b. Single Superphosphate (SSP) and Triple Superphosphate (TSP):

In contrast, the application of SSP and TSP resulted in comparatively lower increases in heavy metal concentrations. These fertilizers, characterized by reduced heavy metal content, demonstrated a milder impact on soil metal dynamics. The variations in heavy metal concentrations were statistically significant but less pronounced compared to DAP and MAP (Figure 1).

c. Nitrophos:

The complex formulation of Nitrophos introduced a unique dynamic to the study. While Nitrophos did contribute to elevated heavy metal concentrations, the observed levels were intermediate between the high concentrations associated with DAP and MAP and the lower concentrations linked to SSP and TSP. This intermediary effect suggests that Nitrophos may present a compromise between nutrient supply and potential environmental impact (Figure 1).

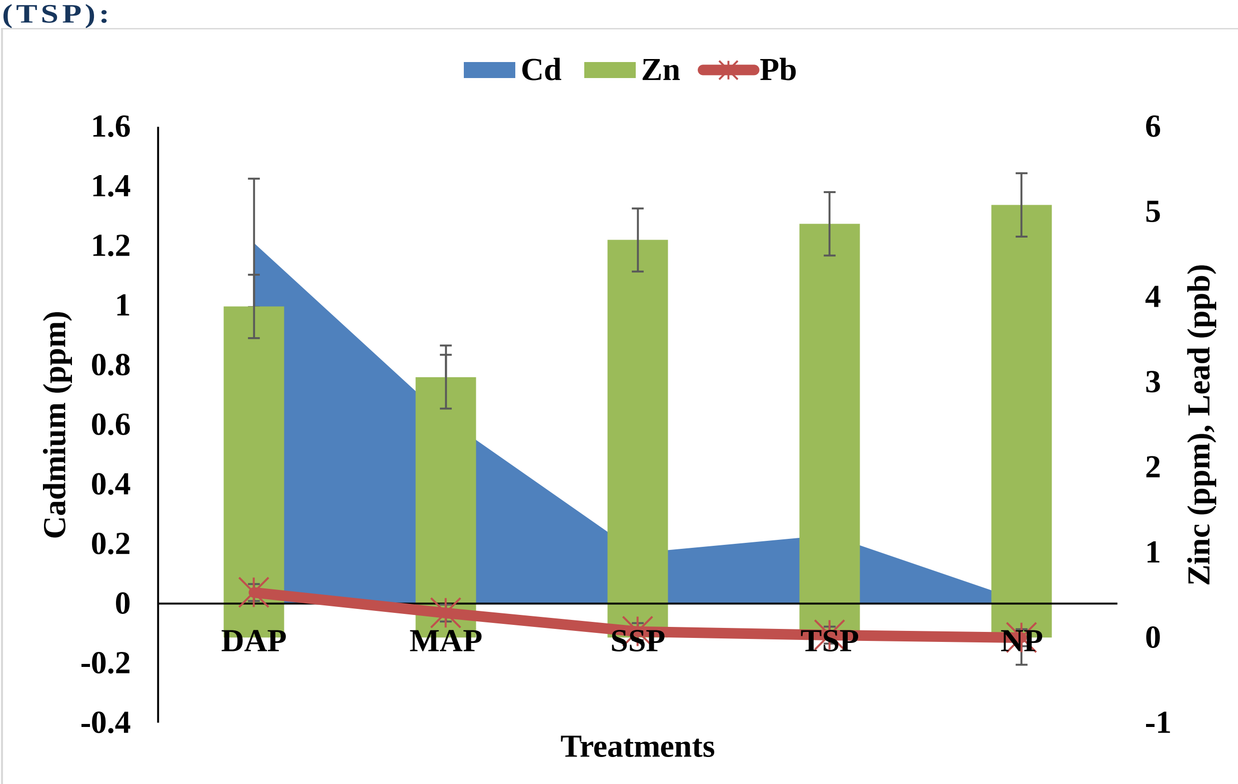

Figure: Fertilizer application impact on accumulation of heavy metals in soil.

Discussion

The results of this study underscore the importance of considering the differential impacts of diverse phosphatic fertilizers on heavy metal dynamics and environmental sustainability. DAP and MAP, while effective in supplying phosphorus, raise concerns about their potential long-term environmental consequences. SSP and TSP emerge as more environmentally sustainable alternatives, offering a balance between nutrient supply and reduced heavy metal-related risks.

The intermediary effects of Nitrophos suggest a potential middle ground, where nutrient requirements are met without causing extreme environmental harm [13]. However, further research is warranted to elucidate the specific mechanisms contributing to Nitrophos' impact on soil metal dynamics [14].

The study assessed the potential for nutrient runoff, a critical factor in determining the environmental sustainability of phosphatic fertilizers. DAP and MAP, with their higher heavy metal content, exhibited an elevated risk of nutrient runoff, posing potential threats to water quality in nearby water bodies. In contrast, SSP and TSP, with lower heavy metal concentrations, demonstrated a more favorable profile in terms of nutrient runoff potential [8].

Soil health indicators, including microbial activity and nutrient retention, were monitored to evaluate the overall impact of phosphatic fertilizers on soil ecosystems. DAP and MAP showed a negative influence on microbial activity, potentially linked to the higher heavy metal concentrations. SSP and TSP, on the other hand, maintained or even enhanced soil health indicators, aligning with their lower heavy metal content [7,11].

Environmental risk assessments were conducted to estimate the potential ecological risks associated with the diverse phosphatic fertilizers. DAP and MAP, due to their higher heavy metal concentrations, posed a greater risk of soil contamination and potential adverse effects on terrestrial and aquatic ecosystems. SSP and TSP, with their reduced heavy metal content, presented a more environmentally sustainable choice, aligning with soil management practices that prioritize long-term ecosystem health [3,7,13].

The choice of phosphatic fertilizers plays a crucial role in shaping soil health and environmental sustainability. This study provides valuable insights for farmers, policymakers, and environmentalists, facilitating informed decisions to optimize agricultural practices while minimizing adverse effects on ecosystems. Continued research in this field is essential to refine recommendations and foster sustainable agricultural systems for the future.

Conclusion

This study underscores the significant influence of diverse phosphatic fertilizers on heavy metal dynamics and environmental sustainability. Diammonium phosphate (DAP) and monoammonium phosphate (MAP) exhibited higher heavy metal concentrations, posing potential risks to soil and water ecosystems. Conversely, single superphosphate (SSP) and triple superphosphate (TSP) demonstrated a more environmentally sustainable profile with reduced heavy metal impacts. Nitrophos presented an intermediary effect. These findings emphasize the importance of informed fertilizer selection to balance agricultural productivity with environmental responsibility, fostering sustainable soil management practices for a resilient and ecologically sound future.

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