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Short Communication

Surfactants in Agriculture: A Review of their Impact on Soil Water Repellency and Water Infiltration

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Abstract

The use of surfactants in agriculture has been exponentially increasing in the efforts to alleviate the damaging effects of soil water repellency and improve the efficiency of water infiltration and uniform distribution. This material classes of non-ionic, Alkyl Block Polymers (ABP) and Polyoxyethylene Polymers (PoAP) have immense roles in improving the wettability of the soil while ameliorating the drought stresses resulting from SWR. Nevertheless, their effectiveness and environmental impact are closely linked to factors such as the nature of the soil, the level of organic matter content, and the chemical properties of the surfactants. Further, the present short communication discusses the varied efficacy levels of these surfactants, their environmental implications, and the need for a tailor-made application in sustainable agriculture.

Introduction

Soil water repellency, SWR, is a severe impairment in agriculture. Water can barely infiltrate and move across the soil profile, associated with adverse effects such as the decline of crop yields and the development of drought stress conditions. This condition arises when soil particles become hydrophobic, primarily induced by the accumulation of organic compounds and making the infiltration and distribution of water uniformly challenging. Addressing SWR is vital to retain soil health and for the sustainability of agricultural practices. Surfactants are one of the recent developments that reduce the adverse effects of SWR. These agents increase soil wettability by decreasing the surface tension of water such that it infiltrates quickly over and into hydrophobic soils and promotes more effective water use. Examples of nonionic surfactants among the different types used in agriculture include Alkyl Block Polymers (ABP) and Polyoxyethylene Polymers (PoAP). A great property of nonionic surfactants is that they can interact with soil particles without creating ions and can minimize soil salinity problems. ABPs and PoAPs, on the other hand, are site-specific due to their specific molecular structures that can enhance water movement through soils of varying textures and compositions [1-4].

A number of factors conditions surfactants' potential efficacy and environmental compatibility. All these factors include a class of soil, the organic matter contained in the soil, and all other chemical properties of the surfactant. For instance, surfactant applications are likely to interact with clayey or organic-rich soils opposite to sandy soils with low organic content. Additionally, from an ecological point of view, environmental concerns involve soil-adsorbed chemical residues that could influence soil microorganisms and, hence water quality. From this angle, complete understanding of differences in the efficacy of various surfactants and their environmental consequences is essential when designing sustainable agricultural practices. The following Communication delves into these aspects and has made the requirement of surfactant applications site-specific, considering both soil types and the requirements of sustainable agricultural management. Thus, surfactants can prove very useful for addressing all such requirements about improved soil water management and a greater resilience of farming systems towards varying environmental conditions [5].

Surfactants and their Interaction Mechanism with Effective Means of Soil Management

Understanding surfactants

Surfactants reduce surface tension between two materials, one liquid and the other solid, between each other. What surfactants do in agricultural practices is decrease the surface hydrophobicity of soil to increase the penetration and movement of water within it. It is a modification to soil-water interactions by surfactants that forms an integral use of them in SWR management.

Nonionic surfactants: Among the surfactants, PoAP surfactants are distinct in that they are likely to enhance soil wetting just because of not interacting with soil minerals and organic matter in a way that would reduce their efficacy in most soil environments. They, therefore, have a potential long-term effect to increase soil carbon content and make the soil more hydrophobic, with some SWR impacts tending in one direction, while others grow in another direction.

Alkyl Block Polymers (ABP): ABP increase the soil wettability without significantly decreasing organic soil carbon, which may render them suitable for not disturbing the organic matter balance in soils. This is most relevant to the condition of sandy soil where water retention is the least.

Anionic surfactants: Surfactants, including sodium dodecyl sulfate (SDS), could separate the hydrophobic organic substances from the polluted soil matrix by increasing solubility. However, using anionic surfactants must be monitored since they will result in the loss of vital nutrients and soil amendments due to leaching [6].

Environmental impacts of surfactant usage

Although surfactants can present significant merit in handling soils, their ecological impact introduces apprehension for potential changes in soil chemistry, biology, and hydrology.

Effect on soil microbial populations: Surfactants can affect the activity of the population of soil microorganisms; some reduce the functioning of the microbes where, as others benefit from the activity. For example, some surfactants can suppress microbial activity temporarily, disrupting regular nutrient cycles and organic matter decomposition. In contrast, other agents may stimulate microbial growth with additional carbon sources or change the soil environment.

Preferential flow pathways and leaching: Repeated surfactant use may become preferential flow pathways in the soil; consequently, the potential risk of leaching mobile elements, such as nitrates and pesticides, increases. This is even more distressing with sandy soils where the rapid movement of water and solutes would easily pollute groundwater.

Effect on soil-water distribution: The influence of surfactants on soil-water distribution is a function of the nature of the surfactant and the type of soil. When the soil is hydrophobic, surfactants improve the entry and movement of water, decrease surface runoff, and increase irrigation efficiency while lowering drought stress. However, in hydrophilic soils, they may not show such effectiveness and could even result in increased water retention at high potentials without substantially affecting runoff or erosion.

Tailored applications for sustainable agriculture

A one-size-fits-all application of surfactants is not recommendable due to the diverse effects on the different soil types and potential environmental impacts. There is, therefore, an apparent need for a more nuanced approach that takes specific soil characteristics into account for tailoring of the applications for it to result in outcomes that are required [7,8].

Soil type and texture: The effectiveness of surfactants largely depends on soil type and texture. For example, surfactants that enhance wettability and water distribution function most effectively in sandy soils; they may not benefit clayey soils, and under some circumstances, the latter may suffer adverse effects if the application is ineffective.

Organic matter content: Soil with higher organic matter content would have an increased ability to hold water. Such soils might not require surfactants that enhance water infiltration at the cost of worsening the balance of organic matter in the soil. Soils with lower organic matter content might need surfactants targeting soil organic carbon enhancement to address all soil property conditions and enhance water-holding capacity.

Surfactant chemistry: The chemical nature of surfactants greatly influences performance and environmental implications. Nonionic surfactants like PoAPs are stable and less reactive, hence suitable for several soil types. However, anionic surfactants should be managed carefully to prevent leaching to the potential groundwater.

Case Studies and Uses

Water penetration in hydrophobic soils

The Application of nonionic surfactants in hydrophobic soils has been proven to enhance water penetration and decrease runoff. This is evidence of the efficiency with which these surfactants work to enhance the advancement of water spread and moisture flow through the soil. Proper selection of suitable surfactants based on soil characteristics is a critical factor for the best water use in agriculture.

Overcoming water repellency in sandy soil

Research works conducted on applying alkyl block polymers to sandy soils revealed that these polymers are effective for impeding water into the soil and dispersing it. This helps in reducing water repellency and increasing crop yield. It, therefore, implies that alkyl block polymers can be used to solve water management problems in moisture-deficient soils.

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Reducing environmental impact of agricultural use

Surfactants have been researched on the effect of their chemistry on soil management, especially in an environmental context, which creates the need for surfactant use in agriculture to be formulated. This will, in turn, avert leaching as well as the contamination of water resources. Development of surfactants using guidelines in sustainable agriculture to bring down the adverse effects on the surrounding environment is sought after.

Conclusion

Surfactants play an imperative role in treating water repellency in soils and enhancing the irrigational efficiency of agricultural lands [9,10]. The selection of application should be with careful consideration based on the existing soil condition and should be closely monitored to ensure its long-term effects on the environment. The most dramatic effects of surfactants can be for increasing the penetration and spread of water within repellent soils. Still, there must be consideration of potential influence on soil microbial populations, preferential flow pathways, and consequent nutrient and contaminant leaching. The approach, therefore, needs to be more subtle, relating to the type of soil, the amount of organic matter present, and the chemistry of the surfactant. With this background, as agriculture moves towards much more sustainable practices, the role of surfactants will be a critical area of interest for research and development.

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