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Bio-Polymer Based Slow Release / Control Release Fertilizer

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Abstract

SRF/CRF systems based on biopolymers have various benefits over traditional fertilizers. For starters, they increase fertilizer usage efficiency by lowering nutrient losses, which reduces the need for frequent applications. Second, they improve sustained nutrient availability, which ensures a constant supply of nutrients to plants, hence improving crop development, yield, and quality. Third, by decreasing nutrient runoff, leaching, and related water pollution, these formulations reduce environmental impact. Food demand is increasing at an exponential rate as the human population grows. Fertilizers are a critical component in meeting this rising demand and ensuring global food security. Many high-efficiency fertilizers have been created, including controlled-release fertilizers (CRFs). Although these fertilizers have several benefits over previous generations, their high manufacturing costs, as well as undesirable Their use has been restricted due to environmental and soil quality concerns. CRFs based on biopolymers are a new generation of fertilizers made by coating granules with biopolymers to solve these challenges. These compounds, in addition to controlling the rate of nitrogen release, improve soil quality and offset the detrimental effects of standard fertilizers. This article discusses recent advances in biopolymers and biopolymer-derived biopolymers used in coating technologies, as well as the parameters influencing release behavior through organic coating materials and the impact of coated CRFs on soil and plant development. This paper details the creation of a renewable and biodegradable biopolymer-based hydrogel for use as a soil conditioning agent and for the release of a nutrient or fertilizer in agriculture and horticulture. Hydrogels based on cellulose, which include several organic biopolymers such as cellulose, chitin, and chitosan, are hydrophilic materials that can absorb and hold a high quantity of water in their interstitial sites.

***Key words*: Fertilizer, Soil, Plant, Biopolymer, Coating**

Bio-polymers and nutrients are included in the polymer matrix of bio-polymer-based slow-release fertilizers. Both synthetic and natural bio-polymers can be utilized to make these fertilizers. It is preferable to use natural bio-polymers such starch, cellulose, and chitosan since they are biocompatible and biodegradable. Several variables, including the kind of bio-polymer utilized, the amount of nutrients present, and the environmental circumstances, influence how quickly nutrients are released from bio-polymer-based slow-release fertilizers. By altering the polymer matrix's composition or the particles' size and shape, the release rate may be changed. Studies have demonstrated that bio-polymer-based slow-release fertilizers offer a number of benefits over traditional fertilizers. These fertilizers increase crop yields, decrease nutrient losses, and promote nutrient usage. Additionally, bio-polymer-based slow-release fertilizers can cut down on the quantity of fertilizer applications necessary, which can save a lot of money. The creation of slow-release fertilizers based on biopolymers is not without its difficulties, though. The production of these fertilizers can be costly, and environmental factors like moisture and temperature may have an impact on how well they work. The pH and soil type can also have an impact on how quickly nutrients are released from these fertilizers. To sum up, bio-polymer-based slow-release fertilizers have the potential to change the agricultural industry by minimizing nutrient losses and enhancing crop yields. However, further investigation is required to maximize the production and effectiveness of these fertilizers in various agronomic settings and soil types. The paper also explores the processes of nutrient release from bio-polymer-based delayed release fertilizers, which may be influenced by elements including pH, temperature, and soil moisture. The benefits and drawbacks of these fertilizers are also covered by the writers, as well as how they may be used in organic farming and precision farming. Overall, the study offers an in-depth and instructive summary of the state of bio-polymer-based slow-release fertilizers today and is an invaluable tool for academics, scientists, and industry professionals interested in this subject [1].

The advantages of employing bio-based polymers as a matrix for controlled-release fertilizers, such as starch, cellulose, chitosan, and alginate, are covered by the authors. They also look at the processes used to make these fertilizers,

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such as coating, mixing, and encapsulation. The review also emphasizes how crucial it is to take into account the environmental effect, bio-polymer degradation rate, and nutrient release mechanism while designing slow-release fertilizers.

The usage of starch-based bio-polymer materials in CRFs was the subject of a different investigation by [2]. Comparing starch-based CRFs to traditional fertilizers, the study concluded that they had better controlled-release qualities, increased nutrient usage efficiency, and had less of an impact on the environment.

In conclusion, bio-polymer-based controlled release or slow-release fertilizers have several advantages over conventional fertilizers. The efficacy of nutrient use is improved, nutrient losses are reduced, and environmental consequences are lessened. Employing bio-polymer materials in CRFs has two additional benefits, including using waste as a source of nutrients and reducing the carbon footprint of fertilizer manufacturing [3].

Bio-polymers can be created artificially or naturally from microbes or biomass. They can be used in fertilizers because of their distinct qualities. Bio-polymers have the ability to encapsulate nutrients and slowly release them over time, decreasing nutrient loss and enhancing crop absorption. Additionally, they may be adjusted to certain environmental factors like pH and temperature to guarantee ideal nutrient delivery.

An overview of bio-polymer-based controlled-release or slow-release fertilizers, including their characteristics, advantages, and disadvantages, will be given in this review. It will also go over a few current works in this field and offer recommendations for further research [4]. Cellulose-based biopolymers are used to create porous materials, medications, and functional paper and wood products, among other things [5-7]. They can be used in agriculture as hydrogels for the controlled release of nutrients, the reclamation of sandy soils, and wastewater purification. Two methods—dispersing common fertilizers across a matrix and encasing them inside a bigger compound—have been described in the literature for regulating nutrient release by diffusion. The major polymer-based coating films used to deliver controlled release fertilizers are applied to the surface of fertilizer granules [8]. The majority of synthetic polymers, such as rubber, polyvinyl alcohol, polyacrylic acid, and polyacrylamide, as well as polyurethane-like coatings (such as Polyon, Plantacote, and Multicote), enabled better-coated hydrogels to regulate fertilizer delivery. The two main variables that affect the rate at which nutrients are released are thickness and temperature [9-11]. Regarding biopolymers, chitosan, wheat gluten, and starch are utilized singly or in combinations as biodegradable coating materials.

The development of SRFs has been significantly hampered by a variety of problems associated with these coating materials, including their non-sustainability, non-biodegradability, difficult production techniques, expensive pricing, and negative environmental consequences [12-13]. Many studies on natural/bio-based materials have focused on chitosan, sodium alginate, starch and its derivatives, cellulose and its derivatives, and lignin as coating layers for SRFs because they exhibit great biocompatibility, degradability, and renewability [14-15]. Lignin has been regarded as a viable coating material for SRFs are included among these bio-based compounds since they are the second most abundant component in nature. Because of the current expansion of biomass-based biorefinery firms, the production of lignin as a cheap product has substantially grown. Because of its capacity to break down into humus when subjected to microbial activity in soil, lignin has the potential to be used as an SRF nature. Which are define in blow (Fig) [16].

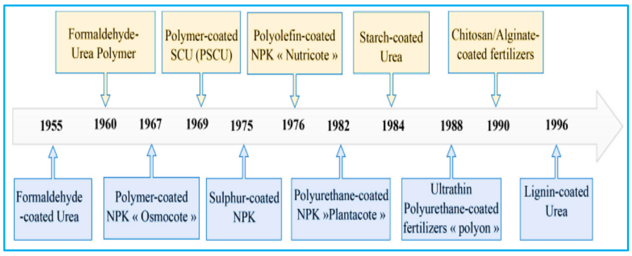

fig 1 chorological development of crfs/sfrs

By giving plants vital nutrients, fertilizers play a significant part in increasing agricultural output. The traditional fertilizers, such urea and ammonium nitrate, release nutrients slowly, which causes nutrition losses through leaching and volatilization. To get over these restrictions and give plants nutrients for a long time, slow-release and controlled-release fertilizers have been created. Due to their biodegradability, low toxicity, and capacity to regulate nutrient delivery, bio-polymers such chitosan, alginate, starch, and cellulose have been employed as a matrix for these fertilizers.

MATERIALS AND METHODS

Slow-release fertilizers are made to supply nutrients to plants over a longer period of time, improving nutrient efficiency and minimizing environmental effect. Utilizing bio-polymers in the fertilizer formulation is one way to achieve slow-release qualities. This article describes the components and procedures required to create a fertilizer based on bio-polymers that releases nutrients gradually.

Biopolymers: Pick biopolymers that might allow for regulated nutrition release. Chitosan, alginate, starch, cellulose derivatives, and poly (lactic-co-glycolic acid) (PLGA) are a few examples of frequently used bio-polymers. Nutrients for fertilizer: Based on the particular needs of the target plants, choose the right nutrients for fertilizer. These might consist of micronutrients like potassium (K), phosphorus (P), nitrogen (N), and other crucial ones. Use coating materials that can effectively encapsulate the fertilizer's nutrients and bio-polymers. Both natural and manufactured polymers, such as gelatin or shellac, are frequently employed as coating materials. Pick the right solvents to dissolve the bio-polymers and coating components. The solubility of the chosen bio-polymers and coating components influences the solvent choice [17].

Shandong Yankuang Lunan Fertilizer Factory (Shandong, China) supplied urea. Cellulose (Mw: 36000), Ethyl cellulose (EC, Mw: 22800), acrylic acid (AA), acrylamide (AM), ammonium persulfate (APS), aluminum hydroxide (AH), polyvinyl pyrrolidone (PVP-K30, Mw: 44000-54000), cetyltrimethylammonium bromide (CTAB), dicyandiamide (DCD), thiourea and so on were all applied by Sinopharm Chemical Reagent (Shanghai, China). All reagents were chemically pure grade and utilized exactly as they were given to us [18].

Inner coating material preparation

The inner coating material was prepared by the following procedure. EC (1 g) was dissolved into alcohol (20 g), and the solution was stirred at room temperature for 3 hours on a magnetic stirrer, until all the EC dissolved, then, PVP (0.01 g) was added to the system stirred constantly until it has dissolved. The resulting product was kept the standby [18].

Outer coating material preparation

Acid-pretreated cellulose (APC) preparation

Acid pretreatment of cellulose can weaken the hydrogen bonding between molecules, making it simpler to react with monomers. Cellulose (2 g) and 0.18 wt% HCl (40 mL) were combined in a reactor at 100 C for 24 hours. The obtained samples were cleaned and dried in a 60 C oven to produce the final goods [18].

CTAB modified bentonite (CMB) manufacturing

Bentonite (5 g) and CTAB (2 g) were combined in 50 mL of distilled water and swirled continuously at 80 C for 3 hours. The obtained CMB was then rinsed with deionized water until it was clear of bromide ions. It was then dried and sieved through a 65-lm size sieve, with samples taken from under the sieve and dried in an oven at 60 C for 24 hours before use [18].

Making of cellulose-SAP

The following process was used to make the cellulose-SAP. In a four-neck flask, AA (22.5 g) was neutralized with 40 mL of NaOH (6 mol/L) in an ice bath. Following that, AM (7.5 g), APC (7.5 g), CMB (0.68 g), APS (0.35 g), and AH (0.05 g) were added to the partly neutralized AA solution in order. The four-neck flask with a stirrer, thermometer, condenser pipe, and nitrogen intake tube were then placed in a water bath, gently heated to 75 C, and kept at this temperature for 3 hours under nitrogen atmosphere and vigorous stirring. The resulting polymer was dried at 60°C. The dry product was milled and screened for further use. Fertilizers [18].

RESULTS AND DISCUSSION

Coating application

Cellulose-based coatings

Slow-release fertilizers (SRF) are a common method for lowering nitrogen losses. The purpose of SRF is to always maintain an acceptable dosage within the soil, minimizing fertilization costs and frequency, gradually releasing it into the soil, and improving fertilizer efficiency [19]. The most frequent kind of SRF is coated fertilizer [20]. Polymers were widely used for coatings in general. Initially, the sulfur-based coating formed on the surface of the fertilizer particles was extremely fragile and susceptible to fractures and holes [21]. making it sensitive to soil microorganisms. Cellulose-based coatings are extensively utilized as bio-polymer coatings for slow-release fertilizers. These coatings allow regulated release of nutrients over time, boosting fertilizer efficiency and lowering environmental consequences. Here is some information about cellulose-based coatings for slow-release.

Starch based coatings

Agriculture is essential for the evolution of human civilization since it provides food, clothing, and other requirements to the world's fast rising population [22]. To meet the growing demand for meals and other agro-products, large quantities of various fertilizers (nitrogen, phosphorous, and potassium) have been employed to improve crop yields during the previous several decades. However, when applied directly, the efficiency of most fertilizers, particularly nitrogen forms, is greatly reduced due to nutrient volatilization and leaching. This also contributes to environmental degradation and health issues owing to water eutrophication and toxic emissions (NH3, N2O, and so on). The goal of this research was to create a unique dual-layer nitrogen-containing slow-release fertilizer by covering urea granules with EC as the first layer and starch-SAP as the second layer. The starch-SAPs (starch-gpolyacrylamides) were synthesized in a twin-roll mixer with acrylamide (AM) and starches derived from three botanical sources (maize, potato, and cassava) as the initiator and N,N'-methylenebisacrylamide (N-MBA) as the cross-linker. The effect of botanical sources on the structure and properties of starch-SAP was investigated. The slow-release fertilizer was then created (urea particles in situ coated with EC first and starch-SAP second) and its release properties in soil were investigated.

Chitosan-based coatings

Chitosan is chitin that has been deacetylated. It is the world's second most prevalent biopolymer [23]. Chitosan is composed of N-acetyl glucosamine and glucosamine residues [24]. Chitin and chitosan are commercially significant polymers because they can be extracted from marine debris such as crustaceans, crabs, shrimp, arthropod waste exoskeletons, and fungi [25]. Thermal, morphological, structural, crystallinity, degree of acetylation, and other physicochemical properties may be examined using various analytical instruments such as TGA, SEM, DSC, XRD, 1 H liquid-state NMR, and elemental analysis are some of the techniques used [26]. Chitosan is available in a wide range of molecular weights (MW) and degrees of de-acetylation (DA). Chitosan may be extracted from the solution in a variety of forms after de-acetylation, including powder, fiber, and sponges [27]. The solubility of chitosan is greatly influenced by MW, DA, ionic concentration, pH, the type of the acid, and the distribution of acetyl groups together with the main chain. Chitosan is often dissolved in mild acids, primarily acetic acid (1%, 0.1 M). In addition, a water-soluble version of chitosan that is extremely suitable for plant applications has been developed. This type of chitosan may be dissolved in water at neutral pH in the presence of glycerol 2-phosphate [28]. Although a stable solution may be created at room temperature, reversible gel formation occurs at temperatures over 40 degrees Celsius. Chitosan has a high complex-forming capacity when compared to chitin, which may be attributed mostly to the presence of free $-NH_2$ groups dispersed along the chitosan main chain [29-30].

Chitosan-based coatings provide various advantages for slow-release fertilizers, including biocompatibility, biodegradability, and nutrient release control. Chitosan coatings can act as a protective barrier around fertilizer particles, limiting nutrient release and reducing nutrient leaching or volatilization. There are various processes involved in the chitosan coating process. To make a chitosan solution, chitosan is first dissolved in a suitable solvent, generally acetic acid. After that, the fertilizer particles are submerged or sprayed with the chitosan solution, which allows the coating to attach to the surface. The chitosan film is cured after coating, providing a protective covering around the fertilizer particles. Nutrient release from chitosan-based coatings can be regulated by a number of parameters, including chitosan content, coating thickness, pH, and environmental conditions. Chitosan coatings can enable regulated nutrient release by diffusion or progressive dissolution of the chitosan matrix, allowing for long-term nutrient availability to plants. More information on chitosan-based coatings for slow-release fertilizers may be found in this reference [31].

Alginate-based coatings

Slow-release or controlled-release fertilizer coatings based on alginate have been widely employed. Alginate is a natural polymer formed from brown seaweeds that is good for encapsulating fertilizers and gradually releasing nutrients. Here's some background on alginate-based coatings for slow-release fertilizers [32].

Alginate is a biodegradable and biocompatible polymer with good film formation capabilities. When divalent cations such as calcium are present, it can form gel-like structures, allowing for the regulated release of nutrients over time. The fertilizer is mixed with an alginate solution before being cross linked with divalent cations during the coating process. This crosslinking process creates a semi-permeable barrier around the fertilizer particles, regulating nutrient delivery.

Nutrients are released from alginate-based coatings through diffusion and ion exchange mechanisms. Water penetrates the coating, dissolves the nutrients, and diffuses through the alginate matrix. As the nutrients diffuse out, ions from the surrounding medium, such as soil or water, replace them, preserving charge balance and continuing the release. The release rate of alginate-based coatings can be regulated by a number of parameters, including alginate content, crosslinking density, coating thickness, and environmental conditions such as temperature and pH. Alginate-based coatings have been shown to improve fertilizer consumption, reduce leaching losses, and provide a regulated nutrient release profile. They have been employed in a variety of agricultural purposes, including crop production, greenhouse culture, and landscaping [32].

Lignin-based coatings

Lignin-based fertilizers are classified into three types: physically coated, chemically reactive, and chelates [33]. In lignin SRFs, chemical procedures such as ammoxidation and the Mannich reaction are employed to directly increase the nitrogen content of lignin. This, however, results in either a low nitrogen content, an unpredictable and unstable nutrition loading rate, or a difficult and dangerous preparation technique. Examined the properties of 15N-labeled ammonia-oxidized pure sulfate lignin, which contained just 13 wt% nitrogen under ideal circumstances [34]. ethylenediamine was employed as a solvent in the Mannich process to fix nitrogen on lignin formed by biorefining processes. When the mixture was heated to 80°C for three hours, nitrogen-containing lignin with a nitrogen content of 10.13 wt% was formed [35]. Coatings based with lignin for delayed or controlled release fertilizers have gained popularity in recent years due to their biodegradability and promise for sustainable farming practices. Lignin, a complex polymer present in plant cell walls, may be derived from renewable sources such as wood or agricultural waste. Here's a quick rundown of how lignin-based coatings may be utilized in slow-release fertilizers. Lignin may be extracted from lingocellulosic materials using various methods such as alkaline or organosolv processing. These techniques remove hemicellulose and cellulose, leaving lignin as a byproduct.

The extracted lignin can be changed to improve its coating characteristics. Its solubility, reactivity, and film-forming characteristics may all be altered chemically. Esterification or cross-linking processes, for example, can be used to increase coating stability and manage nutrient delivery. Lignin, once changed, can be formed into a coating material. Spraying, fluidized bed coating, or pan coating are common methods for applying this lignin-based coating on fertilizer grains or prills. The coating binds to the surface of the fertilizer granules and provides a barrier that regulates nutrient release. The lignin-based coating functions as a semi-permeable barrier, enabling water to pass through but limiting nutrient diffusion. Nutrient release happens by a mixture of diffusion and osmosis, which is affected by environmental conditions such as soil moisture, temperature, and microbial activity.

Sugarcane bagasse-based coatings

Sugarcane bagasse-based coatings have been examined as a viable alternative for slow-release fertilizers due to their availability and biodegradability. The bio-polymer-based coating generated from sugarcane bagasse can assist manage nutrient release and improve the effectiveness of fertilizer applications. The development of sugarcane bagasse-based coatings for slow-release fertilizers generally entails Sugarcane bagasse, the fibrous waste left after sugarcane juice extraction, is collected and processed to produce cellulose or lignocellulosic materials. Various chemical treatments are used to remove contaminants, lignin, and hemicellulose from sugarcane bagasse, leaving behind cellulose-rich material. A bio-polymer covering is created by processing the cellulose-rich substance from sugarcane bagasse. To improve the coating qualities, procedures such as chemical modification, mixing with other polymers, or the application of particular additives may be used. The sugarcane bagasse-based bio-polymer coats the slow-release fertilizer particles. This can be accomplished by fluidized bed coating, spray coating, or other encapsulating processes. The physical and chemical features of coated slow-release fertilizers are investigated, including coating thickness, release kinetics, nutrient release patterns, and stability under various environmental circumstances.

Types of bio-polymers used in CRFs

- Natural polymers
- Biodegradable polymers

Natural polymers

Renewable sources of natural biopolymers include plants, animals, and microorganisms. They have benefits such as biocompatibility, biodegradability, and sustainability. Here are some examples of common natural biopolymers:

Cellulose

Cellulose is the most common natural polymer on the planet, found in plant cell walls. It is made up of glucose units and has a robust, fibrous structure. Cellulose and its derivatives are widely employed in a variety of applications, including medicine delivery, tissue engineering, and food packaging [36].

Chitosan

Chitosan is generated from chitin, a naturally occurring polymer found in crustacean exoskeletons and fungal cell walls. It is a biodegradable and biocompatible polymer with antibacterial and mucoadhesive characteristics. Chitosan is utilized in wound healing, medication delivery systems, and tissue engineering [37].

Gelatin

Gelatin usually a protein that is produced by the dehydration of collagen, which is found in connective tissues of animals such as skin, bones, and tendons. It's common in medications, food, and cosmetics. Gelatin-based materials are employed in drug delivery systems, tissue engineering scaffolds, and bioactive chemical encapsulation [38].

Starch

A carbohydrate polymer consisting of glucose units, starch is frequently derived from corn, potatoes, and wheat. It is biodegradable, plentiful, and cheap. Starch and its derivatives are employed in a wide range of applications, including medication administration, wound healing, and bio plastics [39].

Alginate

Alginate is made from brown seaweed and is made up of alginic acid and its salts. When divalent cations such as calcium are present, it forms a gel-like structure. Because of its biocompatibility and gel-forming capabilities, alginate is frequently utilized in medicines, wound dressings, and tissue engineering [40].

Biodegradable polymers

Biodegradable polymers, also known as biopolymers, are a form of polymer material that degrades by biological processes such as enzyme activity, microbe action, or natural environmental conditions. In comparison to standard non-biodegradable polymers manufactured from fossil fuels, these polymers are intended to be more ecologically friendly and sustainable. Here are some biodegradable polymer samples and references:

Polylactic acid (PLA)

PLA is a biodegradable polymer generated from renewable resources like maize starch or sugarcane. It is used in packaging, textiles, medical gadgets, and other areas [41]

Polyhydroxyalkanoates (PHAs)

PHAs are a class of biodegradable polymers generated by a variety of microorganisms via fermentation of renewable feedstocks. They have a diverse set of features and can be employed in packaging, agriculture, and biomedicine [42].

Background information about (controlled-release and slow-release fertilizers)

Defined release and slow-release for example: - Release the transformation of a chemical compound into a plant-available form. - Gradual release: The fertilizer's rate of nutrient release must be slower than the rate of nutrient release from a fertilizer when the nutrient is readily available for plant uptake. [34]. a fertilizer may be labeled as slow-release if the nutrient or nutrients stated as slow-release satisfy three requirements in soil at specified conditions, including a temperature of 25 degrees Celsius

- Maximum of 15% (m/m) released in 24 hours.
- In 28 days, no more than 75% (m/m) must be discharged.
- At least 75% (m/m) supplied by the deadline.

SRFs are fertilizers that release or converted plant nutrients to a plant-available form more slowly than a comparable reference soluble product. Under specific situations, CRFs are designed to give nutrients at a predictable pace throughout time. Coatings for urea fertilizers. According to the Web of Science database, 795 indexed research articles have been published since 2000 with the title keywords polymer coated fertilizers, controlled-releasing fertilizers, and slow-release fertilizers.

Synthesis methods

Physical mixing, coating, encapsulation, and ionotropic gelation are all processes used in the manufacture of bio-polymer-based slow-release and controlled-release fertilizers. Physical mixing includes combining the fertilizer with a bio-polymer matrix, whereas coating and encapsulation require coating the fertilizer particles with a bio-polymer film or encapsulating them within a bio-polymer shell. Ionotropic gelation is the process of crosslinking a biopolymer with a crosslinking agent, such as calcium ions, to generate a gel-like structure [43].

Synthesis of bio-polymer-based coatings

Biopolymer-based coatings may be made using a number of processes, including solvent casting, spray drying, and electrostatic spraying. Chitosan, a biopolymer produced from chitin, is a popular coating material due to its biodegradability and film-forming ability [44]. Chitosan coatings have been found to promote fertilizer release and prevent nutrient leaching in a variety of crops. Other biopolymers, such as starch and cellulose, have also been employed as coating materials for slow-release fertilizers [45-46].

Synthesis of bio-polymer-based matrices

Biopolymer-based matrices may be created using a variety of techniques, including solution casting, freeze-drying, and extrusion. Because of its gel-forming capabilities and biodegradability, alginate, a biopolymer produced from brown seaweed, is a typical matrix material. In many crops, alginate matrices have been proven to promote nutrient release and minimize nutrient leaching. Chitosan and starch are two more biopolymers that have been employed as matrix materials for slow-release fertilizers [45].

Properties of bio-polymer based slow-release/control-release fertilizers

Regulated nutrient release: Bio-polymer-based slow-release/control-release fertilizers release nutrients at a regulated rate, ensuring long-term nutrient delivery to plants. The rate of release may be regulated by altering the kind of polymer, its molecular weight, and its breakdown rate [47].

Increased nutrient-use efficiency: Slow-release fertilizers assist to increase nutrient-use efficiency by reducing nutrient losses owing to leaching, volatilization, and denitrification. This results in greater nutrient absorption by plants, which results in improved plant growth and development [48].

Reduced environmental pollution: Bio-polymer-based slow-release/control-release fertilizers reduce environmental pollution by releasing nutrients at a regulated rate, decreasing nutrient losses to the environment. This helps to safeguard soil and water quality while also lowering greenhouse gas emissions [49].

Biodegradability: Biopolymer-based slow-release/control-release fertilizers are biodegradable and may be broken down by soil microbes. This decreases the danger of soil contamination and the buildup of non-biodegradable contaminants [50].

Improved soil characteristics: Slow-release fertilizers improve soil qualities by providing plants with a consistent nitrogen supply, resulting in increased soil organic matter, microbial activity, and soil fertility. This can result in enhanced agricultural yields and better plant health [51].

Bio-polymer-based slow-release or controlled-release fertilizers limitation

Slow-release or controlled-release fertilizers based on biopolymers have gained popularity as sustainable alternatives to traditional fertilizers owing to their capacity to give nutrients to plants over a prolonged period of time while decreasing nutrient leaching and boosting nutrient usage efficiency. These fertilizers, however, have significant limits. With references, below are a few drawbacks of bio-polymer-based slow-release fertilizers:

Inadequate nutrient release control: The rate of nutrient release from bio-polymer-based slow-release fertilizers may be inconsistent, resulting in unequal nutrient availability for plants. Temperature, soil moisture, and microbial activity can all impact release kinetics, resulting in nutrient variations [52].

Cost: Slow-release fertilizers based on biopolymers might be more expensive to create than traditional fertilizers. The cost of raw materials and the complexity of production processes contribute to their greater price, restricting their wider adoption, particularly in low-income countries [53].

Environmental concerns: Although bio-polymer-based slow-release fertilizers are meant to decrease nutrient leaching, there is still a danger of nutrient runoff during high rainfall events or over-application. Nutrient runoff can contribute to eutrophication in bodies of water, causing biological imbalances and water quality problems [54].

A restricted nutritional range: Slow-release fertilizers based on biopolymers may be ineffective for supplying nutrients that need certain release mechanisms or pH conditions. Some nutrients, such as micronutrients and trace elements, may not be properly integrated into these fertilizers, limiting their usage in situations requiring a diverse range of nutrients [55].

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