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Coated Controlled-Release Fertilizers: Potential Solution for Sustainable Agriculture

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ABSTRACT

The use of fertilizer in the agricultural field is essential for plant growth but an excess amount of pure chemical contents in fertilizers becomes harmful to every living being. To reduce this chemical exposure, the use of materials coated with Controlled Release Fertilizers (CRFs) are being used. The coating of materials outside the fertilizer does not allow the chemicals to spread completely within one application of fertilizer but its spread can be extended as will be done in 2-3 applications of fertilizer. The features of the undercoating material are thus vital to attain this delayed or slow release of the nutrients present in the fertilizer. The longevity of CRFs depends upon the width of the material coating surrounding the fertilizer, temperature, and moisture. The review focuses on the consequences of conventional fertilizers, the need to control the release of fertilizers and types of coatings used, and their application in sustainable agriculture.

INTRODUCTION

The steady increase in population growth and food demand and the continuous reduction in cultivated land per capita induce steady intensification of fertilizer application worldwide (Shaviv 2001). For the cultivation of a healthy plant, it is necessary to provide nutrients and water from time to time. For this, fertilizers are being used in almost every part of the world. The nutrients in fertilizer act as plant building blocks, allowing the crop to grow to its full potential while remaining healthy and disease-free. Fertilizers are significant for the harvest development, yield, maintenance quality parameters, and the well-being of the soil when applied in ideal suggested doses or judiciously. Fertilizers improve the supplement status and nature of soil by enhancing it with supplements that it needs. Crop plants require nitrogen, phosphorous, and potassium to maintain the typical physiological capacity of the cell (Lawrencia et al. 2021). The absence of nitrogen brings about poor development, yet the abundant utilization of nitrogen brings about delayed maturity and low quality of the leaf. Concentrated Fertilizer application causes genuine ecological issues, like eutrophication of waters, loss of biodiversity, unnatural weather change, stratospheric ozone exhaustion, reduction in soil fertility, and destruction of microorganisms and friendly insects. Certain fertilizers additionally contain substantial metals, overabundance utilization of which drives fertilizers to enter the natural way of life by means of retention from the soil. Consequently, fertilization prompts water, soil, and air contamination (Paraskar et al. 2010, Ravisankar & Poongothai 2007)

The excessive use of synthetic fertilizers has adversely affected the ecosystem (Patil et al. 2007, Nandini et al. 2009). Although the plant extracts nutrients from the soil, low nutrient content in the soil affects plant growth and thus leads to low cultivation. Every plant requires a specific amount of nutrients, and the remainder is wasted and released directly into the environment (Pandey 2018). A plant uses only 30-40% of the fertilizer sprayed on it and the rest of the fertilizer (60-70%) gets exposed to the environment in the form of the following factors:

Nitrogen leaching: In most cultivated land, under the ordinary, aerated environment, nitrate is the major form of 'N' used by plants. Nitrogen is oxidized to nitrate by various microbial activities taking place in the soil. As an outcome, comparatively high doses of the applied Nitrogen may leach from the root of the plant into the surface and groundwater. Increased concentration of nitrate is related to methemoglobinemia in infants, gastric cancer, and other diseases such as goiter, birth defects, and heart disease (Barker & Sawyer 2005).

Volatilization of ammonia: Surface-applied ammonium and urea fertilizers are a probable cause of ammonia volatilization, predominantly causing calcareous and alkaline soils due to which soil is unable to sustain the growth of crops. The NH_3 released may be oxidized and transformed into nitric acid (HNO_3), which, in coupling with sulfuric acid (H_2SO_4)

(from industrial activities), forms acid rain. Thus, causes severe damage to the vegetation and eco-system respectively (Schepers & Fox 1986).

Eutrophication: The excessive amount of nutrients gets washed off into water streams like ponds and rivers nearby. This causes eutrophication due to which the water body is overly enriched with minerals and nutrients which persuade extreme growth of algae. This results in depletion of dissolved oxygen in the water body and forms algal bloom and a great rise of phytoplankton in the water body thereby affecting the aquatic life harshly (Shaviv & Mikkelson 1993).

This exposure of remaining fertilizer directly into the environment causes hazardous effects leading to global warming as the chemical components in the fertilizer mix with other greenhouse gases present in the environment (Karibasappa et al. 2009).

CONTROL-RELEASE FERTILIZERS

Despite upgrades in the acts of supplement application, the utilization efficiency (UE) of fundamental components, for example, N and P are not satisfactory, bringing about an expansion of ecological issues. The utilization of controlled-release fertilizers (CRFs) has a promising future in contributing in an amazing way to improving the management of supplement application thereby diminishing altogether natural dangers while keeping up high harvest yields of good quality. Controlled-release fertilizers are normally coated with organic or inorganic materials which control the rate, pattern, and release of plant nutrients into the soil. Polymer-covered urea best represents CRFs (Du et al. 2006, Loper & Shober 2012). The release of nutrients in these fertilizers is due to semi-permeable coating or other chemical means by hydrolysis of water-soluble compounds (Trenkel 2010).

Need for Controlled-Release Fertilizer

Nutrient fertilization plays a vital character in upholding soil lushness and refining crop yield and quality. Specific nutrient organization of crops is a foremost challenge worldwide as it relies primarily on chemical fertilizers (Zulfiqar et al. 2019). To overcome the ill effects of common fertilizer a new technology aroused known as controlled release fertilizer. The Nano-science provided a new method to develop a new coated fertilizer that was less hazardous compared to the common fertilizer. Nanotechnology deals with nanomaterials (NMs) which have at least one dimension ranging from 1 to 100 nm (He et al. 2018). The nano-particles of the fertilizer are made in the combination with coatings of organic/inorganic elements. Nano-science is solitary of the utmost significant study and expansion frontlines in the present science. The usage of Nanoparticles has several benefits because of their exclusive structure and corporal properties. Due to their minor mass, nanoparticles display unique chemical, physical and electrical properties that are diverse from those of majority resources, and could be used to make innovative and better compounds. So, nanoparticles have emerged as the most promising class of modified particles being highly attractive because of their biodegradable and hydrophilic nature which is being exploited in a lot of applications (Hasaneen et al. 2014).

Also, the conventionally coated granules of fertilizers contain a small amount of active material coated with a polymer or other substances due to which the amount of total needful nutrient or active content which comes in contact with the soil and thereby to plant gets reduced significantly. The aforesaid limitation led to the formulation of nanoparticles which offer a large area of active component to be in contact with the plant and hence help in better and controlled release characters of the nutrients (Pereira et al. 2015). Nano fertilizers are nanomaterials that are both nutrients themselves (micro-nutrients or macro-nutrients) or otherwise act as transferors for the nutrients. Nano-fertilizers could equally be advanced by coating nutrients into the nanomaterials. They recover entire crop production and superiority with developed nutrient use efficiency (NUE) however dropping the rate of fabrication and therefore, subsidizing agrarian sustainability (Usman et al. 2020).

The nano-fertilizers are categorized into four clusters: macronutrient nano fertilizers, micronutrient nano fertilizers, nano material-enhanced fertilizers plant growth-stimulating nanomaterials (Marchiol et al. 2020).

All the CRFs must contain three norms: A smaller quantity i.e. lesser than 15% of the nutrients must be out in 24 hrs, Less than 75% ought to be free in one month (28 days), Minimum of 75% has to be free by the specified release interval (42–358 days) (Wei et al. 2020).

CRFs grab more attention than traditional fertilizers because the frequent discharge of Nitrogen from CRFs certifies adequate nutrient supply for plant uptake during the growing season of crops and prevents all the problems being caused to the environment (Wei et al. 2018). CRFs are entirely used for refining soil productivity. Yet, the stability of micronutrients such as Fe, Zn, Cu, and Mn in the soil is also very essential (Li et al. 2017). In total approx. 16 nutrients are very necessary for the plants out of which 13 are frequently taken up by the soil. Nitrogen (N), phosphorus (P), and potassium (K) are categorized as primary nutrients as they are mandatory in larger quantities (Tripathi et al. 2020). K, Ca, and Mg in soil emerge from the disintegration of bedrock and minerals that hold these elements (Cole et al.

2016). Nano fertilizers have facilitated the establishment of these essential nutrients in the soil based on the slow release. This steady release encourages the improved distribution of nutrients to the plants which promotes early germination and high nutritional content (Lateef et al. 2016). CRFs have been mostly considered under altered temperature and soil moisture systems (Nardi et al. 2018).

FERTILIZER WITH EXTERNAL COATINGS

Currently, diverse polymeric and non-polymeric resources have been verified for controlled-release fertilizer coatings (Naz & Sulaiman 2016). In general, the preparation of CRFs, needs a support material, such as natural polymers chitosan, cellulose, alginate, starch, synthetic polymers polydopamine-graft-PAA, polydopamine-co-N, N-dimethyl amino ethyl polymethacrylate, etc. (Qi et al. 2020). To enhance the CRFs, coatings are being developed as outer covering on the fertilizer. The diffusion of nutrients happens at a considerably gentler rate than the normal fertilizer. This is for the reason that the layer becomes the physical fence which inhibits the transportation of nutrients present inside the coating. It was also found that the CRFs, containing functional groups like hydroxyl, phosphate, or amino groups contain the empathy for metal cations consisting of microelements which result in the formation of metal complexes. This creates the tie of micronutrient cations to bio-based constituents by biosorption. Such types of fertilizers would result in greater bioavailability and reduced nutrient discharge to the soil. The usage of normal constituents as fertilizer coverings causes lesser ecological contamination and killing energy, therefore, the obtained products are even called environment-friendly fertilizers. Biodegradability is an essential characteristic when bearing in mind the various environmental concerns, and is a perilous asset for the application of fertilizer coating (Cui et al. 2020).

Types of Coating

Controlled release fertilizers are mainly prepared by the coatings including the least solvable elements like Sulphur, polymers, or grouping of both (Products which consist the mixture of sulfur-coating as well as polymer-coating to occur. Usually, such products comprise urea, covered using a layer of sulfur, which is in turn coated with a layer of polymer. Respectively, every coating layer is normally fewer than the standard thickness for the discrete procedures.) These coatings release the urea when they come in contact with water or moisture. Of all materials, natural polymers and their derivatives have fascinated more consideration due to the benefits of low cost, non-toxicity, easy accessibility, biodegradability, and modifiability (Qi et al. 2020).

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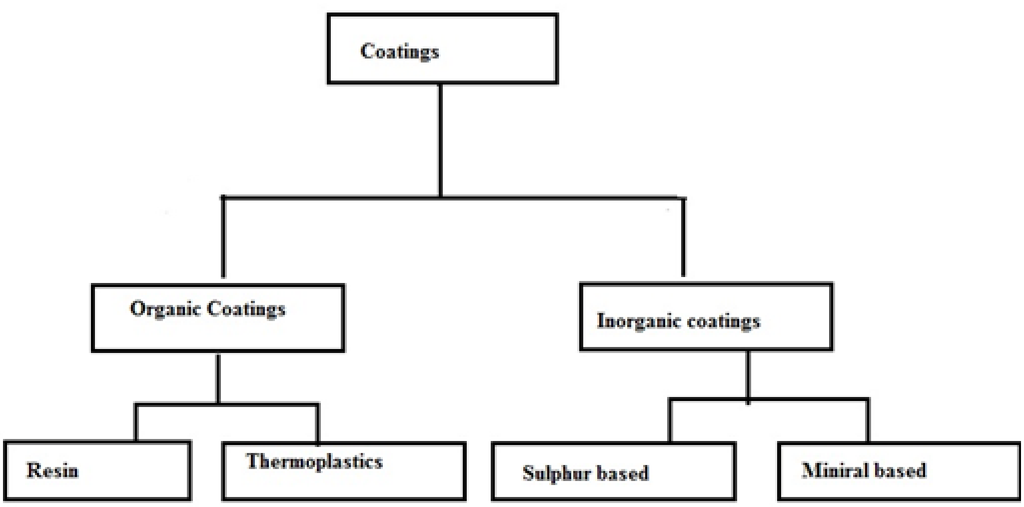

Fig.1: Types of coating.

Organic Coatings

The naturally occurring coated materials are being specified as organic coatings. It includes **Chitosan:** Naturally ample, nontoxic and biodegradable, and biocompatible, minus immunogenic, much extremely less toxicity level, and insoluble in water with high swelling capacity (Pandey et al. 2019).

Starch: Easily altered material, low-cost, non-toxic, and biodegradable.

Cellulose: Renewable, degradable, and film-establishing ability.

Agricultural residues: Copiously available, economically effective, biodegradable, and renewable.

Lignin: cost-effective, freely available from plant sources and its derivatives (Chen et al. 2018).

Thermoplastics: (Polymer Coated urea (PCU) is established as a substitute for SCU to recover the restrictions of sulfur-coated urea. The solicitation of a polymer-film coated fertilizer can raise the nutrient utilization efficiency (NUE) and diminish various environmental contaminations, and polymer latex is an environmentally responsive coating material with an encouraging future (An et al. 2017). Certain biodegradable polymers are being used as the coating material for normal fertilizer but super absorbent polymers are the theme of major emphasis due to their outstanding water absorption & retaining capabilities as CRFs in agronomy applications (Ni et al. 2011). These super absorbent polymers are frequently applied in the form of gel beads, which have low mechanical strength for fighting exterior forces (Zhou et al. 2018).

All coated materials have been established using numerous polymers from non-environmentally degradable polymers (like polyolefin, polyurethane (PU), polysulfonate, etc.) to degradable polymers (like polysaccharides, aliphatic polyesters, etc.) (Mikula et al. 2019). Although the non-degradable polymers are currently in more experimental cases, considerable attention is being shifted to the degradable polymers, to evade tainting of the environment caused by the gathering of coated materials (Ye et al. 2019).

Polyurethane: PU is normally applied as a covering material for the manufacture of film-coated fertilizers. PU generally has a great asset due to the tough polar force and hydrogen bond among the urethane bonds (Dai et al. 2020). PU coated fertilizers are economical, decomposable & environment friendly which makes them a high potential coated fertilizer (Liu et al. 2018).

Polyacrylate: A study was carried out to investigate the interface between PA coating on CRFs and soil in wheat-rice rotation fields Liang et al. 2019. Although the use of PA as a coating on CRF is widely used the effects of PA coating on the soil becomes a serious concern. But according to this study, scientists confirmed that the PA coatings were decomposable and eco-friendly in the field of wheat & rice when used as CRFs. This study involves the formation of PA by polymerization of MMA (monomer). They concluded that the erosion of coating happened in both wheat &rice land. This changes the surface appearance & micro-morphologies because the soil and microbes might abide by the surface of PA coating (Liang et al. 2019).

Inorganic Coatings

The coated substances that do not occur naturally and are synthesized artificially are considered inorganic coatings.

Sulfur-based inorganic coating: One of the firstly invented Controlled Release Fertilizers was prepared by coating Sulphur on it. The sulfur coating is one of the historical coating materials as it's economical and is a substrate for all the soil microbes which are chemoautotrophs and uses sulfur in generating sulphuric acid which dissolves insoluble phosphate existing in the soil. (Cui et al. 2020). sulfur coatings on CRFs are subtle to topsoil assets, and the nutrient discharge from SCU is extremely flexible. Because of all such aspects, the usage of sulfur in coating for SRFs had reduced courtesy of polymeric coatings (Irfan et al. 2018).

Mineral-based inorganic coating: These are the naturally occurring inorganic solids like Zeolite which consist of a crystalline structure and a definite chemical composition. Zeolite is used widely as coated mineral CRF because it is cost-effective and its inherent cation exchange property treats efficiently the control of the release rate of nutrients. zeolite-based CRF proves to be the best in strength and structural stability. As compared to other coated CRFs, zeolite CRF with an acyclic polymer binder can control the release of nitrogen by 54% (Dubey & Mailapalli 2019).

FACTORS AFFECTING CRFS

The important factors which affect the release of CRF include temperature pH and size coating thickness. The availability of nutrients in the soil influences the release mechanism of nutrients from CRF. The shape of fertilizer is another important factor on which the release rate of CRF depends. Only granulated fertilizers are used for the coating process to produce controlled-release fertilizers. As it is difficult to coat the irregular granules uniformly and which can affect their releasing efficiency (Salman & Handslow 2006). The release rate of CRF also depends on the properties of the soil. pH, moisture content, temperature soil composition, and microbial activity. (Fan & Li 2010) An increase in temperature increases the rate of release of nutrients from CRF as the temperature has increased the solubility of nutrients in the soil increases (Du et al. 2006).

The pH of the medium has a significant effect on the release of nutrients of CRFs. pH in the acidic range (2-5) decreases the swelling capacity and thus reduces the rate of release, while pH in the alkaline range (>pH 9) increases the selling capacity (Salimi et al. 2020).

ADVANTAGES OF CONTROL RELEASE FERTILIZERS

- **Excellent plant development:** CRFs provide the plant with balanced nutrient value according to its needs throughout the entire growing season of that particular plant. This ensures the optimal development and highest quality yields (Franca et al. 2019).
- **The number of applications of fertilizer reduced:** A slow release of nutrients is observed in CRFs, so the nutrient release is according to a rate that matches plant uptake. This minimizes the no. of fertilizer application required in growth season (Keeney & Follett 1991).
- **Environment friendly:** Any product being used in agriculture should firstly be eco-friendly so that nature does not suffer from it. The coatings being applied on CRFs are biodegradable and thus, it is environment friendly since it doesn't cause any harm to the surrounding environment.
- CRFs empower standard dosing of supplements in a nonstop way, which suggests that there's no need to fertilize many times. The issue of misfortunes of supplements and root loss caused by increased concentration of salts is reduced (Franca et al. 2019).
- Unlike conventional fertilizers in CRF fertilizers, a solitary application is adequate and the components are discharged all through the developing season (Lubkowski 2016).
- The application of sulfur-coated urea decreases the soil pH which is considered to be useful for the bioavailability of nutrients (Liu & Hanlon 2012).
- **Saves labor and time:** Approx. a single application of CRF is enough for covering the crop's nutritional requirement throughout its growing season. This in turn saves labor, and time and is highly cost-effective.

LIMITATIONS OF CONTROLLED-RELEASE FERTILIZERS

Despite several advantages of controlled-release fertilizers over conventional fertilizers, CRF has not always been considered to be the best fertilizers. The use of sulfur-coated urea in high concentrations can increase soil acidity. While there are problems associated with the degradation of polymer coated control release fertilizers which can lead to another environmental problem. Another problem associated with CRF is the continuous release of nutrients even in the absence of crops in the field as a result of the tailing effect (Shaviv 2001).

The lack of a standardized procedure to determine the release rate of nutrients in a promising way is one of the major limitations of CRFs. Furthermore, the Manufacturing cost of control-release fertilizers is much higher in comparison with conventional fertilizers (Trenkel 2010).

CONCLUSION

Fertilizers, whether inorganic or organic foundations, will be endlessly used to proliferate and withstand the overall crop production to fulfill the ever-increasing demand of the rising population worldwide. So, owing to the very high demand for fertilizer, environmental health has been one of the most important issues because the Ineffective use of fertilizer has caused severe environmental hitches and unsustainable growth of agricultural science**.** The use of Nano-fertilizers with coating with biodegradable elements is worth using. It protects nature from various traditional fertilizer issues like leaching, and denitrification, and is even labor/time saving enhances productivity, and provides resistance to abiotic stresses**.**

Various research is being carried out to notice the future aspects of CRFs. Several technologies for rising CRFs are progressing, transitioning from sulfur-coating to polymer-coating technologies. Through the advancement in nanotechnology, upcoming CRFs may need to assimilate these technologies for enhancing controlled-release features. Also, scientists are developing new techniques by using natural coating material to come up with different types of coated CRFs that are harmless to the environment. The new coated CRFs match up with the plant nutrient uptake in the entire season of plant cultivation within the single application of fertilizer. This instead makes the CRFs cost-effective and environment friendly.

Certain measures can be taken to draw attention to the use of CRFs like a better evaluation of estimated benefits, achievement of improved technologies to produce more competent and cost-effective CRFs, etc. New studies on CRFs would take agricultural science to a new better level.

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