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Review

Environmentally friendly fertilizers: A review of materials used and their effects on the environment

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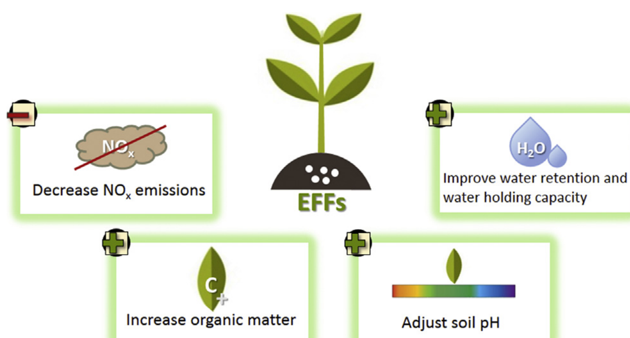
HIGHLIGHTS

- New developments in environmentally friendly fertilizers (EFFs) are discussed.
- EFFs are developed to improve yields without compromising the environment.
- The effects of EFFs on the environment are explored.
- Challenges and perspectives are provided on EFFs production and applications.

GRAPHICAL ABSTRACT



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ABSTRACT

Fertilizer plays an important role in maintaining soil fertility, increasing yields and improving harvest quality. However, a significant portion of fertilizers are lost, increasing agricultural cost, wasting energy and polluting the environment, which are challenges for the sustainability of modern agriculture. To meet the demands of improving yields without compromising the environment, environmentally friendly fertilizers (EFFs) have been developed. EFFs are fertilizers that can reduce environmental pollution from nutrient loss by retarding, or even controlling, the release of nutrients into soil. Most of EFFs are employed in the form of coated fertilizers. The application of degradable natural materials as a coating when amending soils is the focus of EFF research. Here, we review recent studies on materials used in EFFs and their effects on the environment. The major findings covered in this review are as follows: 1) EFF coatings can prevent urea exposure in water and soil by serving as a physical barrier, thereby reducing the urea hydrolysis rate and decreasing nitrogen oxide (NO_x) and dinitrogen (N_2) emissions, 2) EFFs can increase the soil organic matter content, 3) hydrogel/superabsorbent coated EFFs can buffer soil acidity or alkalinity and lead to an optimal pH for plants, and 4) hydrogel/superabsorbent coated EFFs can improve water-retention and water-holding capacity of soil. In conclusion, EFFs play an important role in enhancing nutrients efficiency and reducing environmental pollution.

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Contents

1. Introduction

Greater input of fertilizer, water and pesticides, along with new technologies, have generated immense developments in modern agriculture over the past century. The crop production per unit of land has increased greatly, which has allowed for increased populations and has promoted economic development (Zhang et al., 2015). However, while these developments have been significant, the environmental impacts have typically gone unmeasured. Such costs associated with agricultural development have resulted from the over-application of fertilizers and pesticides, which have led to water eutrophication and toxicity, groundwater pollution, air pollution, soil quality degradation, and even the ecosystems change, raising questions about the sustainability of modern agriculture (Tilman et al., 2002; Khan et al., 2008; Wen et al., 2016).

Increasing crop production without compromising the environment can be achieved by increasing fertilizer and water-use efficiency, minimizing pesticide requirements, and using integrated management of farming systems. This review mainly discusses research about the environmental impacts associated with increasing fertilizer-use efficiency.

Intensive high-yield agriculture is dependent on fertilizer additions. Increased food production cannot be achieved without increased fertilizer inputs. These inputs have helped to keep world crop productivity in step with human population growth and have enhanced rural economic development. However, mismanagement of fertilizer, applied in excess of plant use, in conventional agriculture is a well-known inefficiency that poses a threat to the environment. To avoid the negative environmental consequences, fertilizer efficiency must be greatly increased (Shaviv and Mikkelsen, 1993; Trenkel, 2010).

There are a variety of strategies that are used to increase fertilizer-use efficiency to eliminate their negative impacts on the environment, including improving fertilizer application methods, such as the use of split or localized application, precision fertilization, fertigation-fertilization via irrigation systems, and the use of environmentally friendly fertilizers (EFFs) (Shaviv, 2005; Lü et al., 2016).

EFFs offer an effective way to improve nutrient efficiency, to minimize leaching and volatilization losses of fertilizers, and to reduce environmental hazards. They reduce environmental pollution from nutrient losses by retarding or even controlling the release of nutrients into soil. They are also referred to as "enhanced efficiency fertilizers" (EEFs) (Chalk et al., 2015; Timilsena et al., 2015). Usually, EFFs are formulated in such a way that nutrients are coated with environmentally friendly materials, which can be degraded in soil and converted into carbon dioxide, water, methane, inorganic compounds or microbial biomass. This is the most common and commercially available formulation (Naz and Sulaiman, 2016). However, other technologies have been employed to develop EFFs; for example, using micro/nano networks to entrap nutrients (Zhou et al., 2015a) or preparing nanocomposites with the extrusion of a plastic mixture of polymer and fertilizer (Pereira et al., 2015). This review mainly discusses coated EFFs, including the materials most used in EFFs (Fig. 1) and the effect of EFFs on the environment (Fig. 2).

2. Natural materials used in EFFs

Various materials have been used as coatings to retard nutrient releases and to increase fertilizer-use efficiency. To develop EFFs, concentrated effort has been put into developing environmentally friendly coating materials; most of these coatings derive from natural materials. These natural materials display multiple advantages over synthetic polymers due to their eco-friendly source: a low-cost, easy availability and biodegradability (Wezel et al., 2014; Bao et al., 2015; Schneider Teixeira et al., 2016). Table 1 shows the positive and negative characteristics of the natural materials that are most used in EFFs.

2.1. Chitosan

Chitosan is a polysaccharide derived from the (partial) deacetylation of chitin, which is a major constituent of the exoskeleton of crustaceous water animals such as crab and shrimp (Rinaudo, 2006). This naturally regenerating resource makes chitosan naturally abundant. Furthermore, it is nontoxic and degradable. Due to these properties, chitosan has been extensively used in various applications, including agriculture (Li et al., 1992; Rinaudo, 2006; Harish Prashanth and Tharanathan, 2007; Wang et al., 2014; Xing et al., 2014; Perez and Francois, 2016). It should not generate pollution because it is naturally occurring and degradable; therefore, it has been widely employed in EFFs (Jamnongkan and Kaewpirom, 2010; Rattanamanee et al., 2014; Sabadini et al., 2015).

Chitosan-coated nitrogen, phosphorus and potassium compound fertilizer has been developed (Wu and Liu, 2008). Water-soluble nitrogen, phosphorus and potassium fertilizer granule cores were coated with chitosan as an inner coating, and poly(acrylic acid-*co*-acrylamide) (P(AA-co-AM)) superabsorbent polymer was used as the outer coating. The nutrient content included nitrogen (N) 8.06%, phosphorus (P) 8.14%, and potassium (K) 7.98%. The percentages released were 79, 62, and 69% for N, P, and K on the 30th days, respectively. In addition