Application of Super Absorbent Polymer in the Research of Water-retaining and Slow-release Fertilizer

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Abstract. Super absorbent polymer is a new type of functional polymer material that has been researched in recent decades. Due to its special structure and water-absorbing and water-retaining properties, it has a broad field of drought resistance, soil improvement and crop protection. It is a new type of soil conditioner and agricultural drought-resistant and water-saving materials. Combining it with fertilizers to prepare agricultural and forestry slow-release fertilizers with water-absorbing and water-retaining functions, it is very good in improving fertilizer utilization and saving water resources. This article summarizes the literature, expounds the research status, existing problems, and future research directions and hot spots of super absorbent resins.

1. Introduction

China is a large agricultural country. Agriculture, as the foundation of the national economy, is China’s basic national conditions and is an irreplaceable primary industry. In order to increase crop yields, supplement food supplies, and meet the growing demand for food, the input of chemical fertilizers and water resources in agricultural production has increased year by year. However, due to the rapid dissolution rate of existing chemical fertilizers, when fertilizers are applied to the soil, a large number of nutrients are easily lost to the natural environment through gaseous volatilization, leaching and surface runoff, and only a small part of the nutrients can be plant absorption and full utilization, resulting in low fertilizer utilization [1]. According to reports, the seasonal utilization rate of nitrogen fertilizer in China is 30-35%, phosphate fertilizer is 10-25%, and potash fertilizer is 30-45%. High fertilizer losses and unreasonable fertilization methods have not only caused huge economic losses and energy waste, but also brought many serious environmental problems, such as groundwater pollution, water eutrophication, soil degradation, air pollution, etc [2].

Water is another important factor restricting agricultural development. China is a country with a very shortage of water resources. The per capita water resources are only 1/4 of the world average. It is also the country with the most serious soil erosion and the largest desertification area in the world. Moreover, my country has a large population. How to effectively use the limited land and Water
resources to feed such a large population is one of the major problems facing the sustainable development of agriculture in my country [3].

Super absorbent resin is a new type of functional polymer material developed in recent decades [4]. Due to its special chemical composition, physical structure and water absorption and water retention properties, it can resist drought, improve soil, and maintain fertilizer efficiency in farmland. It is a new type of soil conditioner and agricultural drought-resistant and water-saving material. Combining it with fertilizers to prepare agricultural and forestry slow-release fertilizers with water absorption and water retention functions will surely cause a new upsurge in the field of fertilizer research [5]. However, slow-release fertilizers are expensive and their application is not universal. In addition, most of the super absorbent resin materials used in the production of slow-release fertilizers are synthetic polymer materials of polyolefins, which are not biodegradable. Large amounts of application will make the soil sandy and the land is difficult to sustainably use. The materials pollute the soil environment, and it is necessary to develop biodegradable coating materials [6].

2. Water retention and slow release mechanism

2.1. Water retention mechanism

Super absorbent polymer (SAP) usually refers to a new type of functional polymer material containing-COOH, -NH2, -OH and other hydrophilic groups. When the super absorbent resin is in contact with water, because the crosslinked network structure contains a large number of strong hydrophilic groups such as carboxyl (-COOH) and hydroxyl (-OH), the hydrophilic groups on the molecular surface ionize and interact with Water molecules combine to form hydrogen bonds, in this way SAP can absorb a large amount of water. At the same time, in the process of water absorption by the SAP, the electrolyte on the molecular network chain causes the penetration potential difference between the electrolyte solution in the network and the external water.

Under the action of the difference in penetration potential, water continuously enters the interior of the polymer molecules, and the ions on the molecular network meet water to produce electrolysis. The positive ions are in a free state, while the negative ion groups are still fixed on the network chain, and the adjacent negative ions generate repulsion. It causes the expansion of the polymer network structure, and a large amount of water enters the mesh of the molecular network structure [7]. Traditional irrigation methods consume huge amounts of water by evaporation and leakage, and the effective utilization rate of water is low. SAP can absorb deionized water hundreds to thousands times its own mass or physiological saline tens to nearly a hundred times its own mass, and keep most of its water from being lost for a long period of time [8]. Adding it to the soil can increase the effective absorption of irrigation water and rainfall by the soil, and increase the water holding capacity of the soil.

After the super absorbent resin is applied to the soil, the absorbed water will be gradually released for plants to absorb and utilize as the moisture content of the external environment decreases. The results of the study show that the absorption power of SAP to water is mainly maintained in the low suction range of 10-50 KPa, and 98% of the water absorbed is free water, which is most easily absorbed by plants. In addition, the maximum water absorption capacity of SAP is in the range of 13-14 Kg/cm², while the water absorption capacity of plant roots is generally in the range of 17-18 Kg/cm², so there will be no backflow of water from the root system. Therefore, in the drought period, the irrigation cycle is extended, thereby enhancing the drought resistance of plants.

2.2. Slow-release mechanism

SAP can absorb water and swell into gel after contact with soil solution. The fertilizer is soluble in the water in the hydrogel, and the swollen gel has an obstructive effect on the diffusion of the coated or combined fertilizer, which slows down the release rate of fertilizer nutrients, thereby improving the utilization rate of the fertilizer. Under certain conditions, these adsorbed nutrients can slowly diffuse from the hydrogel through the network system to the soil for crop absorption and utilization, thereby promoting plant growth.
3. Research status

3.1. Organically synthesized polymers

3.1.1. Polyacrylates. Li An et al. [9, 10] used cheap sodium humate and acrylic acid to prepare a water-retaining agent with better performance. The sodium humate can be slowly released and used as plant nutrients for crops to absorb. Liu Mingzhu et al. [11] prepared a water-absorbing and water-retaining slow-release nitrogen fertilizer by reacting sodium acrylate and urea with a water absorption rate of 680 g/g.

3.1.2. Polyacrylamides. Bajpai et al. [12] first prepared a carboxymethyl cellulose grafted polyacrylamide super absorbent polymer, then swelled the resin in a 1% potassium nitrate solution, and then dried to prepare a water-absorbing and water-retaining polymer fertilizers. And discussed the effects of carboxymethyl cellulose, acrylamide and crosslinking agent dosage on potassium nitrate release.

3.1.3. Copolymer of acrylic acid and acrylamide. Japan’s Norio et al. [13] used water-absorbent polyacrylamide and acrylamide-acrylic acid copolymer to adsorb fertilizers to prepare water-absorbing and water-retaining slow-release fertilizers. Wen [14] et al. used acrylic acid, acrylamide, bentonite, and urea as raw materials to synthesize a poly (acrylic acid-co-acrylamide)/bentonite/urea water-retaining release nitrogen fertilizer with a nitrogen content of 14.98% by inverse suspension polymerization. The water absorption of the product in distilled water is as high as 1527.8 g/g, and in different salt solutions (NaCl, MgCl₂, CaCl₂, BaCl₂, FeCl₃) at 0.05-0.25 mol/L, the water absorption range is as high as 62-205.6 g/g. It has good water absorption and salt tolerance.

3.2. Biodegradable polymers

3.2.1. Natural polymers. Prafulla [15] et al. used starch and ethyl methacrylate as the main raw materials to obtain super absorbent resin by graft copolymerization. Degradation experiments were carried out in activated sludge. As shown in Figure 1, it was found that compared with starch and PEMA, the prepared SAP had much more degraded quality within 28 days, and the quality loss was about 70%. This is because the composite material holds more water than a single starch, so it is easier to biodegrade. Yoshimura [16] et al. prepared SAP from cotton fiber and succinic anhydride, with a water absorption rate of 400 g/g, and good degradability, which can be completely degraded within 25 days.

![Degradation in activated sludge at [EMA] = 0.563 mol dm⁻³](image)

**Figure 1.** Degradation in activated sludge at [EMA] = 0.563 mol dm⁻³ [15]
3.2.2. Polylactic acid. Calabria L. [17] et al. reported a slow-release fertilizer, using soybean protein isolate/polylactic acid blend (SPI/PLA-TA) as a matrix and adding triacetin (NPK) fertilizer. After melt processing, this composite material formed a highly ordered SPI porous matrix, and the PLA structure and NPK salt were uniformly dispersed. The dynamic conductivity measurement shows that compared with the pure NPK sample, the cumulative amount grows slowly over time, and it has a good release performance. Biodegradation is performed by detecting weight loss and surface morphology as a function of incubation time in the soil.

3.2.3. Polyamino acids. Zhang [18] et al. used ethylene glycol glycidyl ether as crosslinking agent to synthesize polyglutamic acid super absorbent resin by chemical crosslinking method. The effects of polymer concentration, crosslinking agent, pH value, and reaction time on the water absorption performance of the gel were studied. The results show that the suitable reaction conditions are polyglutamic acid 12%, the amount of crosslinking agent is 18.75% of the polyglutamic acid, the pH is about 5, the constant temperature shaking reaction in 40°C water area for 48 hours, the highest water absorption rate of the obtained resin can reach 1600g/g.

3.2.4. Polysaccharide compound. Although SAPs such as natural polymers and polylactic acids that have been developed have a certain degree of biodegradability, after their components are degraded by microorganisms, the organic synthetic polymers (such as polyacrylic acid) will remain, and it is difficult to achieve complete degradation [19]. In recent years, in order to improve the biodegradability of SAP, there have been more and more studies on the preparation of water-absorbent resins by compounding different kinds of polysaccharides. Although the water absorption capacity of such materials is not high, they can be completely degraded in soil. And it has a certain slow-release performance for fertilizers, so it has important research significance. Zhang [20] et al. used acrylic acid (AA), acrylamide (AM) and 2-acrylamido-2-methylpropanesulfonic acid (AMPS) as monomers, added a variety of natural clays and polysaccharides, and prepared a series of composite water retention agents and several water retention slow release fertilizers by conventional polymerization. The three aspects of its water absorption and water holding capacity, soil physical properties and effects on plant growth were studied. Figure 2 shows the effect of polysaccharide types on the water absorption of P(AM-AMPS)/VMT/polysaccharide samples. The polysaccharides added to it are: CS (chitosan), CMC (carboxymethyl cellulose) and SA (sodium alginate). It can be seen that the product with CMC added has the best water absorption performance (286 g/g), followed by SA with 258 g/g, and finally CS with a water absorption rate of 209 g/g.

![Figure 2. The effect of polysaccharide types on water absorption (VMT=25 wt%, polysaccharide=10 wt %) [20]](image-url)
4. Current problems in research
With the continuous development of the chemical fertilizer industry, research reports on water-retaining slow-release fertilizers have increased, but the technology is not yet mature, and there are still some problems in product performance and promotion, mainly in the following aspects [21, 22]: (1) The cost is high and it is difficult to promote. From the current point of view, the price of SAP for general crops is obviously high, and its production cost needs to be reduced; (2) Because of its water absorption and water retention, it is difficult to store for a long time; (3) The water retention time needs to be scientific. At present, the release rate of water retention agent is difficult to achieve scientific control, which can lead to plant diseases and nutritional insufficiency. In addition, the water retention time is relatively short, and it is difficult to ensure the rooting and survival of plants when applied to desert areas. (4) Poor salt tolerance. Soil particles and salt ions can greatly reduce the water absorption rate of the water retaining agent. In addition, in high-salt soils, it is difficult for water-retaining agents to improve the soil, but it causes soil compaction, so the salt tolerance of SAP needs to be greatly improved. (5) The product will absorb water in the soil to form a gel, which greatly reduces its mechanical strength, and cracks are prone to appear on the surface of the product, causing a "burst release" phenomenon, making the nutrient release performance uneven and not achieving the desired effect. (6) There is a lack of systematic combination research on the application of water retention agent. In the actual use of the water-retaining agent, the types and application conditions of the water-retaining agent should be combined to systematically study the effect of various factors such as soil texture, water and fertilizer conditions, climatic conditions, application amount, application time, and application method of water retention agent in the effect of water retention agent. Study the influences of various factors such as soil texture, water and fertilizer conditions, climatic conditions, application amount, application time, and application method of water retention agent in the effect of water retention agent. At the same time, the water retention agent should be comprehensively evaluated in terms of water absorption and water retention, fertilizer retention and efficiency, soil improvement, antibacterial and disease resistance and environmental impact. (7) There is a lack of theoretical and practical research on nutrient release mechanism and release kinetics, fertilizer performance and quality inspection methods. (8) Poor degradability in soil. Most of the water-retaining agents are synthetic high molecular polymers, which are difficult to degrade or only partially degrade in the soil, and the polymers remaining in the soil are likely to cause soil environmental pollution.

5. Outlook
Water-absorbing and water-retaining slow-release fertilizer is not only a soil water-absorbing and water-retaining conditioner, but also slow release of fertilizer nutrients. It has the comprehensive excellent performance of super absorbent resin and slow-release fertilizer. Therefore, its research, production, and promotion and application will definitely bring a new revolution in the field of fertilizer, its development trends and research directions can be summarized as follows: (1) Non-ionic agricultural materials such as urea, pesticides, trace elements and herbicides are compounded with super absorbent resin to diversify the types and functions of slow-release fertilizers. (2) By changing the composition of the super absorbent resin and its combination with fertilizers, the nutrient release mode is further optimized to meet the needs of crops, and at the same time the degradability and salt tolerance of the absorbent resin are improved. (3) The development of slow-release fertilizers in China should focus on field crops, and through independent innovation of materials, processes and equipment, focus on solving the key technical problems of complex processes, low production capacity, high energy consumption and high costs, and promote the industrial development of slow-release fertilizers. (4) Slow-release fertilizer is a new type of product, which cannot be made mature only by the research of scientific research unit. It needs government encouragement and policy support, and cooperate with agricultural extension department to make it practical.
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