Phosphorus Fertilizers

Subjects: Agriculture, Dairy & Animal Science

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Phosphorus fertilizers from sewage sludge ash are fertilizers the raw material of which is waste of municipal origin, i.e. sewage sludge ash (SSA). SSA is the by-product produced during the combustion of dewatered sewage sludge in an incinerator and P-rich secondary raw material. The P content in dry matter of SSA ranges from less than 10% to less than 20%. Phosphorus solubilizing microorganisms can be added to SSA-fertilizers to enhance P compounds availability. SSA-fertilizers have a potential to substitute or supplement commercial P fertilizers in times of non-renewable raw material shortage. Their yield-enhancing efficiency of SSA-fertilizers is promising, yet long-term field research concerning the impact on environment are necessary.

secondary raw materials | recycling | phosphorus solubilizing microorganisms | biofertilizers

1. Introduction

Phosphorus (P) fertilizers from sewage sludge ash are fertilizers, i.e. products designed to provide P to plants or to increase the P abundance in soils, the raw material of which is waste of municipal origin, i.e. sewage sludge ash (SSA). SSA is the by-product produced during the combustion of dewatered sewage sludge in an incinerator [1].

The idea of recycling phosphorus (P) from waste for fertilization purposes is justified by the issues of phosphate rock scarcity, growing food requirements and pollution problems with P-containing waste.

Phosphorus is an element of great biological importance [2]. The availability of P for crops ensures the proper growth of plant roots, good condition of the stem, adequate formation of flowers and fruits, timely ripening, appropriate volume and quality of yields, intensive N2 fixation by leguminous plants and a stronger resistance of all plants to biotic and abiotic stress factors [3]. The natural resources of available P in arable soils do not fully satisfy the nutritional needs of field plants [3], which must therefore receive some amounts of this element from fertilizers, mostly mineral [4]. Mogollón et al. [5] forecast that the global P input by fertilizers in croplands will increase from 14.5 million tons per year in 2005 to 22–27 million tons per year in 2050, and 4–12 million tons per year would be needed in 2050 for global intensively managed grasslands to maintain fertility.

2. Production

The production of commercial mineral P fertilizers almost completely relies on primery sources, i.e. phosphate rock [6]. Although the P resources and stocks in the world are still relatively large (recent estimates of global geological phosphate rock resources are over 300 billion tons, and their reserves are about 70 billion tons [7], it is not disputed that they are limited and non-renewable. Li et al. [8] emphasize that without proper management, phosphate rock will be depleted within the next 70~140 years. In addition, phosphate rock resources are unevenly distributed across the globe: most are located in Africa (more than 70% of the P resources are controlled by Morocco and Western Sahara) [7]. This makes some coutries, e.g. the European Union (EU), dependent on imported raw materials. Phosphate rock was included on the EU list of 20 critical resources in 2014 [9] and is still indicated on the updated list in 2017 [10].

The limited P resources can be compensated for by recycling waste materials [11]. It is indicated by some authors that waste recovery at approximately 50% may defer the phosphate rock depletion time by 50 years. A major step in this direction has been taken in Switzerland, Germany and Austria, which have made the recycling of P from sewage sludge and slaughterhouse waste mandatory [12]. In recent years, many scientific centers have been involved in searching suitable P substitutes among secondary raw materials and developing new methods of P recovery for fertilizer industry purposes [13][14][15][16][17].

Sewage sludge ash (SSA) is considerated to link the most promising P source and recovery technologies [18]. Direct application of sewage sludge in agriculture is no longer accepted due to the potential presence of harmful pathogens, as well as organic and inorganic contaminants in the biomass. Methods based on sewage sludge biomass incineration eliminate organic pollutants, microorganisms and pathogens. The problem of toxic elements residues in SSA is also proving to be solvable when using the right P recovery technologies. The P content in dry matter of mineral ash (SSA) ranges from less than 10% to less than 20% , which is comparable to the content of this element in commercial phosphate rock (10.9–16.13% P) as reported by the International Fertilizer Development Centre. According to recent estimates, the annual global production of SSA is about 1.7 million tons and is expected to increase in the future. Since the treatment of wastewater and management of by-products are now a major global issue, the use of SSA as a fertilizer may also moderate this problem. The direct application of SSA into the soil would be the simplest and cheapest recycling method, but the raw material may contain significant amounts of heavy metals or other toxic elements. European Directive 87/278/CEE establishes limit values for the concentration and annual load for specific elements, which are often exceeded in SSA. Moreover, some countries have even stricter limits which hinder the reuse of SSA without pre-treatment [18][19][20][21][22].

In numerous scientific centers, research on the use of SSA as a raw material for fertilizer production has been conducted. Many products were tested for their agronomic utility [23]. Although the results regarding the yield-enhancing efficiency appear promising, some weak points of SSA-based fertilizers, e.g., low solubility of P compounds, were also reported [23]. Solubility issues can be overcome by making use of phosphorus solubilizing microbes (PSM), which transform phosphorus compounds from hardly available to bioavailable forms for plants [24]. Being natural biota in many environments, PSM are also abundantly found in agricultural soils. Thanks to phosphate-solubilizing ability, as well as other mechanisms, both direct (e.g., production of plant hormones, acceleration of mineralization processes) and indirect (e.g., control of morbid factors through the release of antibiotics and antifungal metabolites), PSM may serve as plant growth promoting microorganisms (PGPM) [25].

An innovative technology for producing phosphorus fertilizers from SSA activated by PSM have been recently developed in Poland. As they contain a biological agent, they can be called biofertilizers. The production of SSA-biofertilizers in suspension or granules forms has been practiced, and the possibilities of SSA enrichment with the addition of other waste materials, such as animal bones and animal blood, have also been examined. Different kinds of microorganisms, such as: *Acidithiobacillus ferrooxidans*, *Bacillus megaterium*, *Bacillus cereus* and *Bacillus subtilis*, have been tested as microbial agents [26]. PSM activity is driven by mechanisms producing organic as well as inorganic acids. Solubilizing exudates produced by *Bacillus* spp. are composed of the organic acids: gluconic, lactic, acetic, succinic, and propionic (*B. megaterium* did not produce propionic acid). *A. ferrooxidans* produce sulfuric acid. Under field conditions, the problem may be the stabilization of bacteria in the soil and the adverse effects of weather and agrotechnical treatments (e.g. pesticide application) on them [27]. Stabilizing *A. ferrooxidans* in the soil is problematic, as the soil pH preferred by *A. ferrooxidans* (the optimum pH for the activity of this strain is 2.5, and the upper pH tolerance limit is 4.5 [28]) is unsuitable for most agricultural crops.

Field experiments done for verifying the agronomic utility of SSA-fertilizers and SSA-biofertilizers proved that they were not inferior to the commercial fertilizer in terms of yield-enhancing efficiency [29][30][31][32]. The use of them is also expected to provide satisfactory yields in terms of quality and also not to cause negative changes in the soil environment. Studies to date showed that SSA-fertilizers and SSA-biofertilizers did not pose a hazard to plant yield consumers [33], did not affect the moisture, temperature or pH of the soil in the presence of the test plant, did not increase the content of toxic elements in the soil and did not alter the abundance of heterotrophic bacteria, fungi or earthworms in the soil, when applied in recommended doses [34][35][36]. It therefore appears that these fertilizers have a great potential to substitute or supplement commercial P fertilizers. However, taking into account the consequences of recycled fertilizer use may be invisible in a short term, long-term field ones are postulated.

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