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Research review paper

Phosphorus from wastewater to crops: An alternative path involving microalgae

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A B S T R A C T

Phosphorus (P) is a non-renewable resource, a major plant nutrient that is essential for modern agriculture. Currently, global food and feed production depends on P extracted from finite phosphate rock reserves mainly confined to a small number of countries. P limitation and its potential socio-economic impact may well exceed the potential effects of fossil fuel scarcity.

The efficiency of P usage today barely reaches 20%, with the remaining 80% ending up in wastewater or in surface waters as runoff from fields. When recovered from wastewater, either chemically or biologically, P is often present in a form that does not meet specifications for agricultural use. As an alternative, the potential of microalgae to accumulate large quantities of P can be a way to direct this resource back to crop plants. Algae can acquire and store P through luxury uptake, and the P enriched algal biomass can be used as bio-fertilizer.

Technology of large-scale algae cultivation has made tremendous progress in the last decades, stimulated by perspectives of obtaining third generation biofuels without requiring arable land or fresh water. These new cultivation technologies can be used for solar-driven recycling of P and other nutrients from wastewater into algae-based bio-fertilizers.

In this paper, we review the specifics of P uptake from nutrient-rich waste streams, paying special attention to luxury uptake by microalgal cells and the potential application of P-enriched algal biomass to fertilize crop soils.

Contents

Abbreviations: AISP, acid insoluble polyphosphate; ASP, acid soluble pholyphosphate; DW, dry weight; EBPR, enhanced biological phosphate removal; PBR, photobioreactor; P, phosphorus; P_i, inorganic phosphate; WSP, wastewater stabilization pond.

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1. Introduction

Phosphorus (P) is a finite, non-renewable resource and a foundation of modern agriculture (Elser, 2012). After nitrogen, P is the second most frequent macronutrient that limits plant growth. It is an essential component of key molecules such as nucleic acids, phospholipids and ATP, and consequently, plants cannot grow without a reliable supply of this nutrient.

Currently, agriculture depends almost exclusively on P extracted from phosphate rock (Cordell et al., 2009, 2011), which is not distributed uniformly over the globe. Morocco, China, Algeria, United States, South Africa, and Jordan possess the majority of the world's minable P rock, which is expected to be largely exhausted within this century (Jasinski, 2012; Bennett and Elser, 2011; Cordell et al., 2009; Obersteiner et al., 2013; Cordell and White, 2014). In a few of the production countries, the P rock reserves may last longer (Fixen and Johnston, 2012) and changes in demand and other dynamic factors can influence the supply (Scholz and Wellmer, 2013). However, from a global perspective, the need to close the anthropogenic P-loop is urgent. The limited availability of phosphate rock contrasts with eutrophication (nutrient pollution) of natural waters by P washouts from fields and by pollution from animal manure and other waste streams (Fig. 1; see also Anderson et al. (2002)).

Global P and food security as well as the reduction of excessive nutrients of natural waters can only be achieved by synergistic measures that combine increased P use efficiency, changing diets, and the re-use of manure, human excreta, crop residues, and other waste (Cordell and White, 2014). Phosphorus recovery from wastewater and its reuse is particularly attractive (Carpenter and Bennett, 2011; Cordell et al., 2009, 2011; Shilton et al., 2012). The chemical precipitation of P with Al, Fe, or Ca compounds is already widely applied (Mulbry et al., 2005). However, P from chemically precipitated sludge is not readily bioavailable and is typically lost in landfills (de-Bashan and Bashan, 2004) although biological systems can mobilize chemically bound P to a certain extent (Desmidt et al., 2015; Wilfert et al., 2015). Among alternative strategies currently in use, "enhanced biological phosphorus removal" (EBPR) stands out; in this process, P is removed from wastewater through accumulation in heterotrophic sludge bacteria

Fig. 1. An image acquired by the Envisat satellite (Full Resolution, MERIS_FR) showing Lake Erie, USA in 2011. Phosphorus from farms, sewage, and industry facilitated a harmful algae bloom that threatened public health due to hepatotoxin microcystin. The figure demonstrates the negative environmental impact of algae grown on P in runoff waters as well the positive potential of algae to take up large quantities of P if handled properly. Adopted from https://earth.esa.int/web/earth-watching/environmental-hazards/content/-/article/algal-blooms-in-lake-erie-north-america- with permission from the European Space Agency.