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Review

Microalgal and cyanobacterial cultivation: The supply of nutrients

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ABSTRACT

Microalgae and cyanobacteria are a promising new source of biomass that may complement agricultural crops to meet the increasing global demand for food, feed, biofuels and chemical production. Microalgae and cyanobacteria cultivation does not interfere directly with food production, but care should be taken to avoid indirect competition for nutrient (fertilizer) supply. Microalgae and cyanobacteria production requires high concentrations of essential nutrients (C,N,P,S,K,Fe, etc.). In the present paper the application of nutrients and their uptake by microalgae and cyanobacteria is reviewed. The main focus is on the three most significant nutrients, i.e. carbon, nitrogen and phosphorus; however other nutrients are also reviewed. Nutrients are generally taken up in the inorganic form, but several organic forms of them are also assimilable. Some nutrients do not display any inhibition effect on microalgal or cyanobacterial growth, while others, such as NO_2 or NH_3 have detrimental effects when present in high concentrations. Nutrients in the gaseous form, such as CO_2 and NO face a major limitation which is related mainly to their mass transfer from the gaseous to the liquid state. Since the cultivation of microalgae and cyanobacteria consumes considerable quantities of nutrients, strategies to improve the nutrient application efficiency are needed. Additionally, a promising strategy to improve microalgal and cyanobacterial production sustainability is the utilization of waste streams by recycling of waste nutrients. However, major constraints of using waste streams are the reduction of the range of the biomass applications due to production of contaminated biomass and the possible low bio-availability of some nutrients.

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1. Introduction

Microalgae and cyanobacteria are photoautotrophic microorganisms, which are presently cultivated to produce numerous high value products, such as vitamins, pigments, proteins, fatty acids, polysaccharides etc. In the near future it is expected that the dedicated market for microalgal high-value compounds will significantly expand (Borowitzka, 2013; Spolaore et al., 2006). Moreover, microalgae are considered as a potential biomass feedstock for the production of biofuels and it is believed that they will play a significant role in the sector of renewable energy (Gouveia, 2011; Schenk et al., 2008). However, to fulfill only the global needs for transportation fuels using microalgal biomass as feedstock, the cultivation of microalgae rises several practical questions and has some significant constraints, such as high land areas use and high consumption of energy, water and nutrients (Borowitzka and Moheimani, 2013; Chisti, 2013). The mass production of microalgae for biofuels production presupposes the application of massive quantities of nutrients (fertilizers) (Borowitzka and Moheimani, 2013). Since microalgae can be cultivated in non-arable land it is believed that microalgal biomass production for biofuels will not compete with food production. However, the competition between biomass for biofuels and food production might be transmitted to the competition for nutrient (fertilizers) availability. Because microalgal biomass has low content of cellulose compared to terrestrial crops, it contains three times the amount of nutrients compared to biomass of terrestrial plants. As a result, the nutrient demand for microalgal biomass production is much higher than that for agricultural crops (Elser et al., 2000).

Microalgae during photosynthesis utilize solar energy and along with several essential nutrients (C, N, P, S, K, Fe etc.) to synthesize their biomass compounds and to multiply their cells. Microalgae need specific quantities of those essential elements in order to be capable to produce biomass. Possible deficiency of one of the elements will cause growth reduction (Liebig's law of the minimum). Considering the universal Redfield C:N:P ratio of 106:16:1 of phytoplankton elemental composition, all of the essential elements have to be present in appropriate ratios, in adequate quantities and in bioavailable chemical form in the cultivation medium so that the growth of microalgae will not be limited (Spaargaren, 1996). Consequently, in the literature the recipes of the cultivation media are frequently considered as fixed. Nevertheless, the experience of cultivating microalgae in various types of wastewater with diverse nutrient compositions and the evidence that phytoplankton stoichiometry diverges from the canonical Redfield ratio under specific conditions (Arrigo, 2005) suggest that the cultivation media could be flexible and could be adapted to the microalgal metabolic needs.

It is very significant in practice and in large-scale cultivation systems to adapt the cultivation medium to the needs of microalgal growth under the specific environmental conditions, in order to achieve high yields per mass of applied nutrient. The knowledge about the nutrient application and the microalgal uptake of the nutrients is of particular significance. The present article aims to review and to present the most important issues about the application of the most essential nutrients for the production of microalgae using either synthetic fertilizers or wastewater streams. The review will focus and discuss not only issues related to the physiology of microalgae/cyanobacteria but also will discuss technical concerns about the application of nutrients for biomass production. The main focus will be on the nutrients carbon, nitrogen and phosphorus; however the minor nutrients potassium, magnesium, sulfur, calcium and iron will also be reviewed.

2. Carbon

Photosynthesis is a complex process through which light energy and inorganic carbon is converted into organic matter.