World Academy of Science, Engineering and Technology
International Journal of Biotechnology and Bioengineering
Vol:15, No:03, 2021

Algae Biofertilizers Promote Sustainable Food Production and Nutrient Efficiency: An Integrated Empirical-Modeling Study

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Abstract : Agriculture has radically changed the global biogeochemical cycle of nitrogen (N). Fossil fuel-enabled synthetic N-fertiliser is a foundation of modern agriculture but applied to soil crops only use about half of it. To address N-pollution from cropping and the large carbon and energy footprint of N-fertiliser synthesis, new technologies delivering enhanced energy efficiency, decarbonisation, and a circular nutrient economy are needed. We characterised algae fertiliser (AF) as an alternative to synthetic N-fertiliser (SF) using empirical and modelling approaches. We cultivated microalgae in nutrient solution and modelled up-scaled production in nutrient-rich wastewater. Over four weeks, AF released 63.5% of N as ammonium and nitrate, and 25% of phosphorous (P) as phosphate to the growth substrate, while SF released 100% N and 20% P. To maximise crop N-use and minimise N-leaching, we explored AF and SF dose-response-curves with spinach in glasshouse conditions. AF-grown spinach produced 36% less biomass than SF-grown plants due to AF's slower and linear N-release, while SF resulted in 5-times higher N-leaching loss than AF. Optimised blends of AF and SF boosted crop yield and minimised N-loss due to greater synchrony of N-release and crop uptake. Additional benefits of AF included greener leaves, lower leaf nitrate concentration, and higher microbial diversity and water holding capacity in the growth substrate. Life-cycle-analysis showed that replacing the most effective SF dosage with AF lowered the carbon footprint of fertiliser production from 2.02 g CO_2 (C-producing) to -4.62 g CO_2 (C-sequestering), with a further 12% reduction when AF is produced on wastewater. Embodied energy was lowest for AF-SF blends and could be reduced by 32% when cultivating algae on wastewater. We conclude that (i) microalgae offer a sustainable alternative to synthetic N-fertiliser in spinach production and potentially other crop systems, and (ii) microalgae biofertilisers support the circular nutrient economy and several sustainable development goals.

Keywords : bioeconomy, decarbonisation, energy footprint, microalgae
Conference Title : ICABB 2021 : International Conference on Algae Biotechnology and Biofuels
Conference Location : Sydney, Australia
Conference Dates : March 29-30, 2021