Environmental and economic assessment of nitrogen-fixing *Nostoc* sp. as a sustainable alternative to synthetic urea fertilization

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Abstract

This study investigated the environmental impact and discussed the economic aspects of substituting synthetic urea (S1) with nitrogen-fixing *Nostoc* sp. in two agricultural systems: slow-release fertilization (S2) and external nutrient extraction in the form of biogas digestate (S3), which allows for more efficient use of nutrients by plants. The carbon dioxide (CO_2) sequestration rate was determined experimentally, while actual outdoor productivity data were obtained from the literature and analyzed for uncertainty. The results showed that replacing one ton of traditional synthetic urea with microalgae-based alternatives (S2 and S3) significantly mitigated global warming potential from 5.4 to 2.3 tons CO_2-eq in S2 and achieved net carbon sequestration of - 1.1 tons CO_2-eq in S3 when using biogas in anthropogenic activities. Furthermore, S2 and S3 mitigated the impact of human noncarcinogenic toxicity by 51.0 % and 48.1 %, respectively. However, these alternatives consumed higher water amounts and increased land use significantly. The current cost of equivalent microalgal biomass production is approximately five times higher than the price of urea. Therefore, substituting chemical fertilizer of urea with a natural alternative based on N-fixing *Nostoc* sp. is not economically feasible at present, despite its positive environmental benefits

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ABSTRACT

This study investigated the environmental impact and discussed the economic aspects of substituting synthetic urea (S1) with nitrogen-fixing *Nostoc* sp. in two agricultural systems: slow-release fertilization (S2) and external nutrient extraction in the form of biogas digestate (S3), which allows for more efficient use of nutrients by plants. The carbon dioxide (CO_2) sequestration rate was determined experimentally, while actual outdoor productivity data were obtained from the literature and analyzed for uncertainty. The results showed that replacing one ton of traditional synthetic urea with microalgae-based alternatives (S2 and S3) significantly mitigated global warming potential from 5.4 to 2.3 tons CO_{2-eq} in S2 and achieved net carbon sequestration of −1.1 tons CO_{2-eq} in S3 when using biogas in anthropogenic activities. Furthermore, S2 and S3 mitigated the impact of human non-carcinogenic toxicity by 51.0 % and 48.1 %, respectively. However, these alternatives consumed higher water amounts and increased land use significantly. The current cost of equivalent microalgal biomass production is approximately five times higher than the price of urea. Therefore, substituting chemical fertilizer of urea with a natural alternative based on N-fixing *Nostoc* sp. is not economically feasible at present, despite its positive environmental benefits.

1. Introduction

Haber-Bosch process is one of the greatest achievements of the 20th century that significantly contributes to the global increase in food and feed production and maintains global population growth (Rouwenhorst et al., 2021). Currently nitrogen fertilizers originated from the Haber-Bosch process contributes 80 % of the nitrogen in animal protein (Nascimento et al., 2019). However, it is among the top four chemical processes that contribute to CO_2 emissions alongside cement, steel, and ethylene (Spatolisano and Pellegrini, 2023). It consumes approximately 1.8 % of global energy annually and generates around 500 Mton of CO_2 that contributes significantly to global warming. As reported by Copernicus Climate Change Service (CCCS (CCCS (Copernicus Climate Change Service)), 2023), Climate change phenomenon threatens human life in the 21st century, where the average temperature of the Earth was recorded for the first time at 17.08°C on July 7th, 2023, which temporarily exceeded the 1.5 °C limit of global warming. It raised concerns about the habitability of our planet in the future. This limit was established in the Paris Agreement and approved by 195 countries at the Climate Change Conference in December 2015. The Paris Climate Agreement also recommended immediate actions to mitigate global warming and keep it below 1.5°C (FAO, 2019).

Accordingly, several countries have started efforts to reduce the utilization of N synthetic fertilizers, such as China, one of the main producers of synthetic fertilizers. China developed its Action Plan for Zero Growth of Fertilizer Use. China aimed to avoid the expansion of

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