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Combined use of biostimulants and chabazite in the sustainable management of Lettuce

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The integration of biostimulants and soil amendments represents a critical advancement in sustainable agricultural practices. There is a sustained research interest in understanding the mechanistic effects of biostimulants on soil characteristics and crop development. Similarly, the ongoing exploration of zeolites in agriculture underscores their potential to enhance soil quality and crop performance, particularly through improvements in soil structure and increased resilience to environmental stressors. While the individual benefits of seaweed extract biostimulants and zeolites on plant growth are well-documented, their synergistic effects warrant further investigation. This study investigates the potential advantages of co-applying a *Ascophyllum nodosum*-based seaweed extract biostimulant (Acadian MPE) with chabazite as a soil amendment for the sustainable cultivation of lettuce. Under controlled conditions, we assessed the impacts of chabazite and seaweed extract on lettuce water relations, physiological behaviour and growth. Lettuce plants were grown in pots containing sandy-loam soil, subjected to four distinct treatments: (1) soil amended with 2% chabazite (Chabazite); (2) soil treated with seaweed extract (Acadian); soil incorporating both 2% chabazite and seaweed extract (Chabazite + Acadian); and (4) an untreated control soil. Soil water retention curves (SWRCs) were characterized for the Chabazite treatment. Key physiological parameters including soil moisture, gas exchange, leaf water potential, and various growth indicators were systematically measured. Physical soil and plant growth parameters of the four treatments were analyzed by an ANOVA and multivariate analysis using principal component analysis (PCA). Our findings indicate that both seaweed extract and chabazite independently enhance photosynthesis and water use efficiency, suggesting that their combined application could synergistically amplify these parameters in lettuce. Seaweed extracts are known to ameliorate abiotic stresses such as drought by optimizing physiological responses. Concurrently, chabazite improves water retention, collectively bolstering crop resilience and gas exchange efficiency. The combined Chabazite + Acadian treatment demonstrated a significant positive impact on lettuce plant growth, evidenced by increased fresh weight and leaf area. This suggests that the co-application of chabazite and seaweed extract biostimulants offers tangible benefits for lettuce cultivation. Notably, the

seaweed extract appeared to mitigate any potential negative effects of chabazite on water uptake by enhancing the physiological responses of the lettuce plants. Ultimately, both amendments possess distinct mechanisms for positively influencing crop growth parameters, and their combined deployment holds promise for synergistic outcomes, improving lettuce water relations, gas exchange, and overall plant development.