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Optimising Nutrient and Water Use Efficiency in Hydroponic and Aquaponic Systems: Recent Advances Across Functional and Horticultural Crops

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Abstract

Increasing pressure on freshwater resources, fertilizer inputs and arable land availability has intensified the need for resource-efficient crop production systems. Hydroponic cultivation offer precise control over nutrient delivery and water management, creating opportunities to improve nutrient use efficiency (NUE) and water use efficiency (WUE) while maintaining high crop productivity and quality. This review evaluates recent advances in soilless cultivation systems with emphasis on resource-use efficiency in functional, medicinal and horticultural crops. Evidence from recent studies demonstrates that optimization of nutrient solution composition significantly improves nutrient uptake, biomass accumulation and water productivity in soilless cultivation systems. In *Portulaca oleracea*, tailored N-P-K management enhanced both nutrient and water use efficiency while maintaining desirable nutritional quality. Similarly, optimization of electrical conductivity and nitrogen concentration in hydroponically cultivated *Scolymus hispanicus* improved plant growth, nutrient uptake and water productivity, highlighting the importance of nutrient solution management for maximizing resource-use efficiency. Comparative evaluations of hydroponic, aquaponic and soil-based systems showed that hydroponically cultivated *Nasturtium officinale* achieved 46.8% greater yield while reducing daily water consumption by 39.0%, whereas aquaponic cultivation increased yield by 81.0% and reduced water use by 34.4% compared with conventional soil cultivation. Water use efficiency was reported to be 2.45- and 2.78-fold higher in hydroponic and aquaponic systems, respectively. Furthermore, functional and medicinal plant species grown in low-energy hydroponic systems exhibited biomass increases ranging from 18.4% to 43.3% relative to soil-based cultivation. These findings demonstrate that soilless cultivation systems can substantially improve resource-use efficiency through precise nutrient management and water re-circulation while maintaining crop productivity and quality.

Keywords: Hydroponics, Aquaponics, Nutrient use efficiency, Water use efficiency, Nutrient management, Medicinal plants, Functional crops

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