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Integrating *azolla,* pruning, and ratoon systems within circular agricultural bioeconomy for sustainable, climate-adaptive rice farming

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Abstract

Circular agricultural bioeconomy is increasingly recognised as a strategic framework for enhancing soil and food security in sustainable, climate-resilient rice production systems. By optimising biological resource use and nutrient recycling, it sustains productivity while minimising environmental impacts. However, rice production remains constrained by soil degradation, inefficient resource utilisation, and rising greenhouse gas emissions under climate change. These challenges underscore the need for low-emission, regenerative practices that maintain soil functions, improve resource-use efficiency, and stabilise productivity under variable climatic conditions. This study evaluates the integration of *Azolla,* strategic canopy pruning, and ratoon rice systems within a circular agricultural bioeconomy framework to strengthen soil and food security while improving productivity and reducing environmental impacts. The study was conducted using a Climate Field Farmers School (CFS)-based approach in Pangandaran, Indonesia, promoting participatory learning and accelerating farmer adoption of sustainable innovations. *Azolla,* an aquatic fern symbiotically associated with *Anabaena* cyanobacteria, functions as green manure, biofertiliser, and a carbon sequestration agent. It enhances nutrient cycling, supports biological nitrogen fixation, and increases soil carbon accumulation. Field observations indicate that *Azolla* incorporation supplies 40–60 kg N ha ^{1}, reduces synthetic nitrogen fertiliser use by 25–40 %, and increases soil organic carbon by 10–20 %, contributing to yield gains of 10–15 %. Strategic canopy pruning improves plant architecture and light interception, increasing effective tiller formation by 15–25 %. The ratoon rice system enables regrowth after harvest, producing 30–60 % of the main crop yield with 20–40 % lower inputs. Collectively, these practices enhance carbon sequestration by 15–25 %, improve fertiliser-use efficiency by 20–30 %, and increase annual rice productivity by 20–40 %. This integrated system supports low-emission, climate-resilient rice production while strengthening long-term soil and food security

Keywords: Biofertiliser, carbon capture, circular agriculture, green manure, net-zero farming (NFZ), soil ameliorants

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