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Agroecology as a dual strategy for drought resilience and sustainable N and P management: Mechanisms, evidence, and trade-offs

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Abstract

Global agriculture faces interconnected challenges from climate change-induced drought and unsustainable nitrogen (N) and phosphorus (P) management. Conventional strategies, relying heavily on irrigation and synthetic fertilisers, have historically maximised short-term yields but are increasingly constrained by resource depletion, low nutrient use efficiency, environmental degradation, and economic inefficiencies. This review synthesizes contemporary evidence on how agroecological practices can simultaneously mitigate water scarcity and optimise N and P cycling, offering a holistic alternative to decoupled management approaches. We examine core agroecological strategies, including cover cropping, agroforestry, legume integration, organic amendments, diversified rotations, and conservation tillage. Mechanistically, these practices synergistically enhance soil organic matter, structural integrity, and belowground biodiversity. Consequently, improved soil architecture increases water infiltration and moisture retention, thereby buffering crops against drought stress. Simultaneously, rooting complementarity and stimulated microbial processes – such as biological N fixation, arbuscular mycorrhizal fungal (AMF) colonisation, and microbial P solubilisation – boost overall nutrient use efficiency. These biological pathways reduce reliance on synthetic inputs while mitigating N losses via leaching and nitrous oxide emissions, as well as P losses through surface runoff and erosion. Current evidence indicates that agroecological systems can sustain agricultural productivity and significantly improve long-term yield stability. However, outcomes are inherently context-dependent; the efficacy of these practices varies across climates, soil types, cropping systems, and management histories. Notably, transition periods can introduce complex trade-offs, including short-term yield penalties or delayed ecological benefits prior to realising long-term gains. Furthermore, widespread adoption remains hindered by critical knowledge gaps, technical and financial barriers, and entrenched policy frameworks that disproportionately subsidise conventional, linear nutrient supply chains. Ultimately, agroecology presents a robust, systems-based paradigm for advancing climate-resilient, resource-efficient, and ecologically sound agriculture. To fully operationalize this dual strategy, future research must prioritise long-term, multi-site studies that elucidate the complex, coupled dynamics of water, N, and P under shifting environmental conditions.

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