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"Reconcile land system changes
with planetary health"

The promise and perils of AI and hybrid modelling in agriculture

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Abstract

Agriculture is entering a data-rich era where near-real-time analytics harness petabyte-scale data streams from satellites, proximal sensors, farm machinery, and genomic platforms. Making use of this huge data via Artificial Intelligence (AI) and hybrid modelling is revolutionising agriculture, offering unprecedented opportunities to enhance productivity, sustainability, and resilience in food systems. By integrating vast datasets from satellites, sensors, and genomic platforms, these technologies enable real-time, granular decision-making that can improve fertiliser and water-use efficiency by 10–30 % in precision-farming trials. Predictive maintenance and autonomous field robotics further reduce labour costs and downtime, while market and climate risk analytics enhance supply-chain agility. Additionally, Hybrid modelling, which combines process-based models (PBMs) with AI techniques, offers several advantages such as reduced root mean square error (RMSE) by up to 35 % in yield prediction compared to PBMs alone, maintains mechanistic traceability for policy scenarios, and learns location-specific residuals to boost cross-site transferability and scalable solutions for complex agricultural challenges.

Adopting these technologies faces challenges such as data heterogeneity and interoperability, with farm data often in incompatible formats. Connectivity gaps affect up to 30 % of EU and US farms, and the situation is worse in Africa. Privacy and governance risks, like ownership disputes and weak consent, undermine farmer trust. Additionally, technical debt may arise as AI models retrained on biased data propagate errors when scaled.

To address these challenges, several developments are needed: Edge-cloud architectures can reduce latency and bandwidth, while federated learning ensures privacy. Physics-informed neural networks (PINNs) can better align AI with biological laws. Standardized data commons may offer interoperable benchmarks. Socio-ethical frameworks, including algorithmic transparency and data-sharing cooperatives, are crucial for fair adoption. Finally, green AI metrics should be integrated into model evaluation to balance progress with sustainability.

In conclusion, while AI and hybrid modelling hold transformative potential for agriculture, their success hinges on overcoming technical, ethical, and infrastructural barriers. By fostering collaboration among governments, the private sector, and farmers, and by implementing supportive policies and infrastructure, these technologies can become mainstream pillars of global food-system resilience.

Keywords: Agriculture, artificial Intelligence, food systems, hybrid modelling, sustainability

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