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APSIM-based optimisation of maize-soybean intercropping in Malawi: Calibration, simulation, and sensitivity analysis

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Abstract

Maize-soybean intercropping is a key strategy for sustainable intensification and food security in sub-Saharan Africa, yet optimising management under variable climates remains challenging. This study applied the Agricultural Production Systems Simulator (APSIM) to calibrate the model, simulate planting windows and nitrogen management, and conduct sensitivity analysis to evaluate system performance and identify key drivers of maize–soybean intercropping in Malawi.

APSIM was calibrated and validated using observed data and subsequently applied to long-term simulations (2005–2024). The model reproduced treatment variability with high accuracy for maize ($R^2 \leq 0.82$; Nash–Sutcliffe Efficiency (NSE) ≤ 0.77) and strong agreement for soybean ($R^2 \leq 0.92$). Simulation results indicated that optimal productivity occurred when crops were sown between mid-December and mid-January, with maize yields of 5.5–9 t ha^{-1} and soybean yields of 0.7–1.2 t ha^{-1}. Simulated nitrogen responses showed that 50–75 kg N ha^{-1} optimised maize productivity and agronomic efficiency, with yields plateauing beyond 100 kg N ha^{-1}, indicating limited responsiveness to higher fertiliser inputs and suggesting potential economic advantages of moderate application rates. Soybean relied largely on biological nitrogen fixation. The simulated trends were consistent with observed data, with early and medium planting resulting in significantly higher yields than late planting.

Sensitivity analysis using the Morris method (μ^* and δ) identified plant population, rainfall, and sowing date as main drivers of yield variability, while strip configuration had minor effects. Soil fertility variables showed low direct influence but strong interactions, and runoff (used as a proxy for soil structural effects linked to tillage and rooting conditions) exerted a stronger influence than other soil-related factors.

Overall, APSIM effectively simulated maize-soybean intercropping systems and highlighted how management choices shape system resilience to rainfall variability and seasonal drought risk for smallholder farmers in Malawi. Importantly, the simulated optimal planting window broadly aligns with current farmer sowing practices in some regions but also suggests that a proportion of farmers planting earlier or later than this window could potentially gain yield benefits by adjusting planting timing and plant population management.

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