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Editorial: Modelling approaches for climate variability and change mitigation and adaptation in resource constrained farming systems

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Editorial on the Research Topic
Modelling approaches for climate variability and change mitigation and adaptation in resource constrained farming systems

The impacts of climate variability and change are disproportionately experienced in the Global South, particularly within resource-constrained smallholder farming systems (Ngcamu, 2023; Asare-Nuamah, 2021). Smallholder farmers, who play a critical role in local economies and food systems, are increasingly vulnerable to erratic weather patterns, extreme temperatures, and prolonged droughts, which threaten both their food security and livelihoods (Touch et al., 2024). To address these challenges, there is an urgent need to develop, evaluate, and implement low-cost, adaptable climate risk management strategies. The Research Topic, *"Modelling Approaches for Climate Variability and Change Mitigation and Adaptation in Resource-Constrained Farming Systems,"* aimed to leverage modeling tools and approaches, such as crop models, machine learning, and big data analysis to identify and evaluate cost-effective climate risk management and mitigation strategies. These strategies aim to enhance the resilience and decision-making capacity of smallholder farmers in the global South.

Kumi et al. used the Decision Support System for Agro-technology Transfer (DSSAT) model to assess the impacts of variations in rainfall onset on maize yields in Ghana. The study also demonstrated that maize yields could be effectively simulated using a model validated from measured and FAO data and appropriate maize cultivars under different rainfall scenarios, offering invaluable guidance for agricultural decision support in rainfed systems facing climate variability. Similarly, in India, Chandran et al. applied DSSAT coupled with CMIP-5 multi-model ensembles and the TOPSIS decision analysis tool, to evaluate the sustainability of rice-based cropping sequences under projected climate scenarios for the mid-century (2040–2069) and end-century (2070–2099) phases. Their findings identified the rice-lentil-groundnut and the rice-wheat-groundnut sequences as the optimal sequences that improved yields, reduced water use, and enhanced soil nitrogen content under climate change for the mid and end of the century time periods, respectively. It is therefore possible to optimize sustainability of cropping sequences in the face of climate change and variability, allowing for flexible agricultural planning and optimization of scarce resources to ensure food security. In another study, Kumar et al. used DSSAT to simulate the impacts of conservation agriculture and nitrogen management on wheat growth and development, and soil nitrogen dynamics. The results illustrate that modeling can effectively simulate complex interactions between agricultural practices, such as conservation agriculture and nitrogen management, and their impacts on crop growth and soil health. This also demonstrates the value of modeling in evaluating and optimizing agricultural practices, providing evidence-based recommendations that can guide resource-constrained farmers in making informed decisions. In West Africa, Vieira Junior et al. used the APSIM Millet model to assess how temperature and precipitation affect pearl millet production. The study demonstrated the value of modeling to quantify the impacts of climate variability, such as high temperatures and low rainfall, and evaluated alternative management strategies. This highlights the potential of models to not only identify climate impacts but also simulate mitigation strategies, providing crucial insights for improving food security and resilience in resource-constrained farming systems. Collectively, these studies showcase the value of crop models in optimizing agricultural practices under changing climates.

In addition to process-based crop models, empirical modeling through regression analysis, trend evaluation, and machine learning approaches are increasingly used to analyze climate data, identify trends, and different adaptation strategies. Slayi et al. uses logistic regression to analyze factors influencing the willingness of cattle farmers to adopt communally owned feedlots. The model effectively identifies key demographic and awareness variables, such as age and education, that influence farmers' decision-making. This illustrates how statistical modeling can uncover relationships between socio-economic factors and adoption rates of climate adaptation strategies. Al Mamun et al. employs trend analysis (Mann-Kendall method and Sen's slope) and quantile regression to assess the impacts of climate variables (temperature, rainfall, and humidity) on rice yield. The use of trend analysis helps detect temporal changes in climatic variables, while quantile regression shows how these changes affect rice yield across different geographic regions, thereby illustrating how statistical techniques can model climate impacts on agriculture. In another study, Ndiwa et al. utilizes principal component analysis (PCA), multinomial logit regression, and ordered probit models to identify factors affecting the adoption of climate change adaptation strategies. PCA helps reduce the dimensionality of the data, while logit and probit models analyze the intensity of strategy use. This demonstrates how these models can effectively explore and interpret complex relationships between multiple adaptation strategies and socio-economic factors. Noshabadi et al. highlights the value of structural equation modeling (SEM) to test a behavioral model incorporating theories of planned behavior, self-determination, and social cognition. SEM effectively captures the relationships between cognition, motivation, and volition phases in climate smart agriculture (CSA) adoption, highlighting the role of psychological and economic factors in shaping farmer behavior. This illustrates how advanced modeling techniques can integrate behavioral theories to explain CSA technology adoption. Tunio et al. employs the endogenous switching regression (ESR) model to evaluate the effect of CSA practices on food performance while addressing potential biases. The ESR model is suitable for correcting selection bias and assessing the causal impact of CSA adoption on farm outcomes. This illustrates the use of statistical models to provide unbiased estimates and insights into the effectiveness of agricultural practices in response to adverse weather events. Aditya et al. models the greenhouse gas emissions and energy consumption of the tea industry, using emission estimation models to quantify CO_2 emissions. The study then evaluates the potential for renewable energy adoption in tea production. Statistical modeling effectively demonstrates how to quantify emissions and evaluate alternative energy sources for more sustainable production processes. These statistical models complement crop models by providing a broader understanding of climate impacts at different spatial and temporal scales, enabling researchers to predict outcomes, identify risk factors, and inform targeted interventions to support resilience in resource-constrained farming systems. Finally, Mndzebele et al. aimed to enhance agricultural productivity in low-resource farming systems by examining the effects of varying fertilizer applications on cowpea and amaranth. By integrating experimental results with statistical analyses, the study equips farmers and stakeholders with valuable insights for sustainable crop management. The findings emphasize tailored agricultural practices that can improve productivity and resource efficiency, ultimately supporting food security in resource-constrained environments.

Process-based and statistical models are not only useful for simulating adaptation strategies for smallholder farmers in resource-constrained environments but can also quantify the mitigation benefits of alternative agricultural practices. For instance, Kumar et al. used DSSAT to demonstrate how nitrogen management and conservation agriculture can reduce soil nitrogen emissions and enhance carbon retention, highlighting their potential for climate change mitigation. Similarly, Chandran et al. applied DSSAT with CMIP-5 models to evaluate cropping sequences under future climate scenarios. This approach helps optimize crop rotations for reduced water use, improved nitrogen cycling, and lower emissions, offering a framework for both adaptation and mitigation in farming systems. Additionally, empirical models, such as the emission estimation models used by Aditya et al. in the tea industry, can be adapted to model GHG emissions across a range of crops and farming systems. These models provide a means of assessing the broader environmental impact of different agricultural practices, including the potential for integrating renewable energy sources in farming operations, as demonstrated in the tea production system. These studies showcase the ability of modeling techniques to highlight the dual benefits of evaluating modified farming systems for both adaptation and mitigation, an essential step in building resilient and climate-smart agricultural systems in the Global South.

Overall, the articles in this Research Topic underscores the critical role of both process-based crop models and empirical statistical models in addressing the challenges posed by climate variability and change in resource-constrained farming systems, particularly in the Global South. By combining advanced big data analytics and modeling techniques, researchers have not only deepened our understanding of climate impacts on agricultural productivity but also provided actionable insights into adaptation and mitigation strategies. Going forward, integrating modeling tools with localized knowledge and stakeholder engagement will be essential to optimizing resource use, improving food security, and enhancing the adaptive and mitigation capacity of smallholder farmers in the face of increasing climate risks.

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