Global Food Security 38 (2023) 100710

Contents lists available at ScienceDirect

Global Food Security

journal homepage: www.elsevier.com/locate/gfs

Scientific agenda for climate risk and impact assessment of West African cropping systems

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ABSTRACT

Rainfed agriculture is at the centre of many West African economies and a key livelihood strategy in the region. Highly variable rainfall patterns lead to a situation in which farmers' investments to increase productivity are very risky and will become more risky with climate change. Process-based cropping system models are a key tool to assess the impact of weather variability and climate change, as well as the effect of crop management options on crop yields, soil fertility and farming system resilience and widely used by the West African scientific community. Challenges to use are related to their consideration of the prevailing systems and conditions of West African farms, as well as limited data availability for calibration. We outline here a number of factors need to be considered if they are to contribute to the scientific basis underlying transformation of farming systems towards sustainability. These include: capacity building, improved models, FAIR data, research partnerships and using models in co-development settings.

Rainfed agriculture forms the basis of West African economies and is the main source of livelihood for many inhabitants of the region. While the commercialization of smallholder farming is widely promoted by national governments to drive regional economic growth, farm incomes remain low, constrained by a complex mix of factors including poverty, poor market infrastructure, unequal global trade relations, low external input use, low soil fertility and climate change and variability. Highly variable seasonal and interannual rainfall patterns, together with acute vulnerability to food price shocks, lead to a situation in which farmers' investments to increase crop productivity are very risky. Climate change projections suggest droughts and floods will become more frequent and severe in West Africa. As such, climate extremes not only pose an immediate threat to livelihoods through crop yield failures, but also limit farmers' ability to invest in long-term soil improvement and sustainability. Improving the scientific capacity to assess risks and likely damages of climatic extremes on cropping systems, can support building resilience of local farming communities and contribute to achieving longer-term development goals.

Process-based cropping systems models are a key tool to assess the impact of climate variability and change, as well as the effect of crop management options on crop yields, soil fertility and cropping systems resilience (Boote et al., 2013; Jones et al., 2003; Rosenzweig et al., 2014). When correctly parameterized, they provide valuable insights into the contributions of the various factors determining crop responses to weather and climate change. Simply put, when capturing the relevant plant and soil processes and calibrated to local crops and crop management, they are an affordable alternative and complement to traditional field experimentation (Whitbread et al., 2010). This is particularly true for weather extremes which can occur in countless combinations and times in the growing season. Coupled with climate model

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https://doi.org/10.1016/j.gfs.2023.100710
Received 13 March 2023; Received in revised form 11 July 2023; Accepted 12 July 2023
Available online 18 July 2023

projections, outputs from cropping systems models can inform adaptations to climate risk and change. Finally, when combined with whole-farm economic models, cropping systems models can allow participatory scenario analysis of farm management strategies and help to inform policy interventions around affordable and feasible measures to enable and incentivize farmers' investments under highly variable and risky weather conditions (Ricome et al., 2017).

Cropping systems models are increasingly used by the West African scientific community (Amouzou et al., 2019; Rezaei et al., 2014; Guan et al., 2017; Sultan et al., 2013; Traore et al., 2017) supported by efforts in the past decade such as the Agricultural Model Intercomparison and Improvement Project (AgMIP), the training programs of the West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL) and the Consortium of International Agricultural Research Centers (CGIAR). Studies from these and other initiatives and projects in the region (Faye et al., 2018; Traore et al., 2017) have provided evidence of climate change impact and crop-level adaptations that have been considered by the Intergovernmental Panel on Climate Change.

Yet, several challenges preclude cropping systems models from providing robust evidence to support more climate resilient cropping and farming systems. In particular, models differ in their description and representation of the complex and dynamic processes of crop growth, soil nutrient availability, and soil water balances, as well as in the appropriate level of parametrization for specific agro-ecological conditions (Akinseye et al., 2017). This remains problematic for West African cropping systems, as a robust calibration and testing of models that were developed for other parts of the world is often not possible due to limited data availability. This can generate unacceptably large uncertainties in model outputs (Saltelli et al., 2019). At the same time, there has been limited testing of cropping systems models for the management practices(MacCarthy et al., 2017; Tittonell et al., 2008), crops (Tui et al., 2021), soils and weather conditions which predominate in the region (Sultan et al., 2013). Given the urgency of finding solutions for sustainable agricultural development in the face of increasing climate risks, a robust scientific basis needs to be built to support the desired transformation of cropping systems in West Africa. This requires a focus on the following action points: i) capacity building in crop modelling, ii) improving crop models for the conditions of West Africa, iii) implementing FAIR data principles, iv) enhancing research partnerships in crop modelling, and v) using crop models in co-development approaches (Fig. 1).

1. Capacity building

Skilled human resources to develop and apply cropping systems models are critical. Building the capacity of young West African researchers in crop modelling are therefore a key action in which policy makers should invest. In this context, university curricula should increasingly include courses like cropping systems and agroecosystems analysis, systems modeling in general and crop model development in particular. Besides, creating opportunities for graduates in applied mathematics and physics like from the African Institute for Mathematical Sciences (AIMS), to work together with agronomists and scientists from related disciplines such as environmental scientists and socio-economists, can support strengthening interdisciplinary expertise, and, more specifically, will enable them to utilize their advanced analytical skills for the development and improvement of cropping systems models for West Africa. In fact, bringing together experts from these different disciplines will lead to a more comprehensive understanding of the complex processes and their interactions occurring within the West African farming systems. This will allow the development and improvement of context-specific crop models. Therefore, research programs like WASCAL should further promote model development and improvement as a key pillar of their training component. Furthermore, targeted training programs, such as the Crop Models for Risk Assessment (CMRA) 2022 Summer School (here), on assessing climate risks in cropping systems should be organized on a regular basis. Such schools create an opportunity for the exchange of knowledge, expertise and lessons learnt between practitioners and could lead to a community of practice at the regional and global scale. Finally, supporting the capabilities associated with crop modeling are best achieved through institutionalization (e.g., permanent crop modelling positions in the relevant departments of local universities and national agricultural research institutes) allowing the expertise and associated models and datasets to reside and grow in the region.

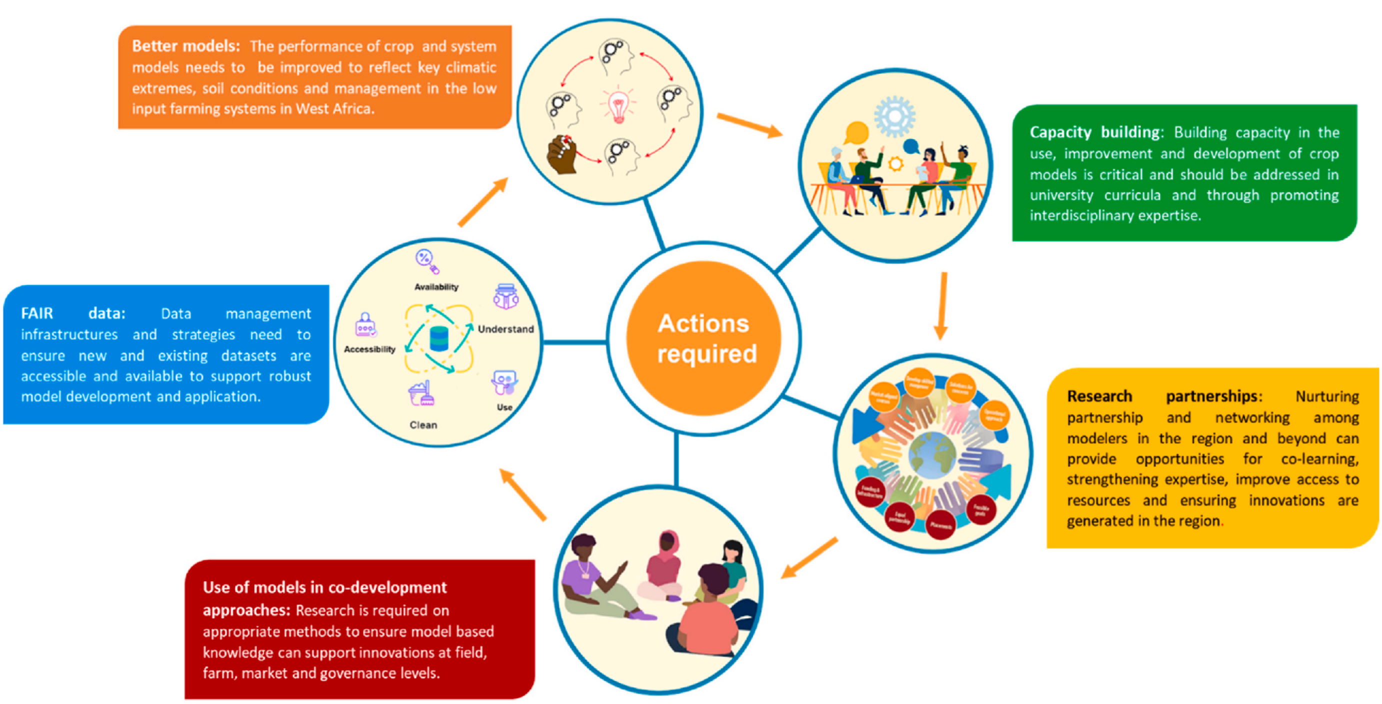

Fig. 1. Required actions for impact through cropping systems modelling.

2. Better models

Cropping systems in West Africa are characterized by complex and heterogeneous agricultural landscape structures, such as intercropping, agroforestry systems (e.g. parklands), frequently degraded soils, commonly high weed pressure and diverse soil conditions together with generally low levels of nutrient inputs. All of these characteristics can have a significant influence on the soil water and nutrient balances and on crop productivity. Currently, most of these characteristics and related processes are not well represented in existing cropping systems models. In fact, models should be able to better capture the heterogeneity of production factors. Therefore, further experimental research efforts are needed to adequately understand the full complexity of these factors and their interactions. Additionally, key staple crops of West Africa, such as pearl millet (Pennisetum glaucum (L.) R. Br.), sorghum (Sorghum bicolor (L.) Moench) and cassava (Manihot esculenta Crantz, Euphorbiaceae), are still underrepresented in standard model releases (e.g. LINTUL-Cassava by Adiele et al. (2022), DSSAT-millet/sorghum by Sanon et al. (2014), APSIM-sorghum by Akinseye et al. (2017), STICS-sorghum by Traoré et al. (2022)), and orphan crops like, yam, Bambara groundnut (Karunaratne et al., 2010) and fonio, are also not well or at all represented. While efforts to improve currently available cropping systems models should intensify, we believe that now is an opportune moment to develop a regional modeling framework that effectively captures the diverse cropping systems in the region. This endeavor will not only contribute to improved understanding of climate impacts on crop production but also aligns with capacity building objectives in crop modelling. Importantly, this regional modeling framework should integrate the interactions between soil nutrient deficiency (i.e., nitrogen (N), phosphorus (P), potassium (K), and micronutrients) and climate conditions. About 75% of sub-Saharan African soils are reported to show plant nutrient deficiency (IFDC, 2006; Leiser et al., 2012). For instance, the limited availability of P was reported by Buerkert et al. (2000) as one of the major constraints to cereal production in West Africa. Therefore, it will be important to better simulate the impact of P stress (and that of other nutrients) on crop growth under changing climate. Besides, accurate simulation of the effect of changes in temperature and water supply on N mineralization, nitrate leaching and N uptake by the crops is crucial given rise in the number of extreme weather events (Falconnier et al., 2020). Finally, as pest and disease stresses on crop growth are expected to increase with climate change, the modeling framework should also account for these (Brévault et al., 2014).

3. FAIR cropping system data

Availability and accessibility of high-quality experimental data have been identified as a major factor that limits the usefulness of crop model applications in West Africa. Here, high-quality experimental data refer to FAIR (Findable, Accessible, Interoperable, and Reusable) data obtained on one or more variables from a particular field experiment conducted using standard research protocols. These variables include weather, crop, soil, and crop management data collected at the required details and frequencies. As an immediate response to data constraints, national agricultural research centers need improved data storage and management systems for the already existing data. Besides, future datasets from advanced research infrastructure and experimental approaches will better support climate risk assessments, for example soil moisture monitoring networks or vegetation and drought-related indices from remote-sensing imagery (Leroux et al., 2019). Standard operating procedures (SOPs) are needed for describing the steps of data collection, methods of collection and ways to safely store the collected data. Novel data collection methods, such as the use of smartphone applications to e.g. monitor crop growth, must be demystified and promoted, ensuring appropriate legal frameworks are in place to protect privacy of citizens. Lastly, there is also the need to encourage allocation of donor funds to include the collection, management, and reuse of primary data as an integral part of research projects.

4. Research partnerships

Nurturing partnership and networking among crop modelers of the region can provide opportunities for co-learning and exchange of ideas, thereby accessing a broader range of resources and expertise. These will contribute to the overall development of modeling competencies and skills. A starting point is to raise awareness about the importance of crop models in building resilient farming systems in West Africa. This can be done through workshops that facilitate meaningful interactions among participants from across the region who share common research interests. The resulting network of crop modelers or community of practitioners should hereby seek for targeted support (e.g., capacity building in model application and improvement) from external experts. The established community can then elaborate a list of required model improvements (e.g., models' ability to accurately simulate crop responses to macro-nutrients in low-input cropping systems) or specify missing expertise (e.g., software engineering techniques), that are required to better simulate West African cropping systems, and at the same time identify opportunities for collaboration. Universities, their scientists from various disciplines, and policy makers should support this network to collaboratively address issues related to crop production and climate risk and change. These research partnerships will allow actors to bring the complementary skills and expertise necessary to thrive impactful and transformative outcomes.

5. Using models in co-development approaches

It is clear that models and their outputs are particularly valuable if the new scientific insights on climate risk and impact lead to cropping innovations that are co-created with farmers and other value chain actors and policy makers. In this context, further research is required on appropriate methods to ensure model-based knowledge can support innovations at field, farm and governance levels. An approach using participatory processes like proposed by (Schmitt et al., 2017) can be used as an initial attempt; in this approach stakeholders co-develop scenarios of crop management adaptation strategies to climate change and evaluate the results of the modelling from their perspectives. This will ensure that model outputs are suitable for the intended use. Thus, it is key that alongside formal cooperation between universities and research organizations, other key private and public partners engage in using knowledge derived from crop modelling to enhance value addition and offer new products and services.

By addressing the above action points, it will be possible to design more sustainable and climate resilient agricultural systems that can support the needs of local communities for generations to come.

6. Conclusion

In our view, the actions we propose are highly interdependent and of equal importance, as they are closely related and must be considered conjointly. Investments in this proposed agenda is needed if science, and in particular cropping systems modelling, is to support solutions to sustainable crop production in the face of climate change and risk, and strengthen the scientific excellence and capacity in crop modelling of the agricultural research institutions and universities in West Africa.

Author contributions

All authors listed in this paper have made a considerable and knowledgeable contribution to this work, and approved it for publication.

Funding

This study resulted from a summer school organized by the Leibniz Centre for Agricultural Landscape Research (ZALF) in collaboration with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) that was funded by the Volkswagen Foundation and the Accelerating the Impact of CGIAR Climate Research for Africa (AICCRA).

Declaration of competing interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.

Data availability

No data was used for the research described in the article.

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