1

Dennis J. Timlin
and Saseendran S. Anapalli

Introduction: System Models Integrated with Experiments Can Be Useful Tools to Develop Improved Management Practices for Subsistence Farming to Address Increased Intensification and Climate Change

Semi-arid to sub-humid regions of the world are major producers of food and fiber. Soil, water, and climate resources are becoming major limiting factors for agriculture in these regions, especially in developing countries where subsistence farming is dominant. Driving factors include increased urban and industrial use of land, more frequent droughts, climate warming, and natural limits to precious natural resources. At the same time, there is a need to produce even more food for the growing population, which requires more intensive use of these resources. To obtain the most production from available resources while maintaining environmental quality, we need whole-system based quantitative knowledge and tools to help select appropriate crops and optimally manage water and associated soil inputs at different locations on a site-specific basis under variable and changing climate. Site-specific experimental results are available for limited locations, limited periods of time, and limited management options. Well-tested, process models of cropping systems can extend field research results to long-term weather conditions, other climates, and soils (Beah et al., 2021; Falconnier et al., 2020). This will allow us to explore new management options, and thus provide the whole-system based knowledge and management guides for various locations

---

Enhancing Agricultural Research and Precision Management for Subsistence Farming by Integrating System Models with Experiments, First Edition. Edited by Dennis J. Timlin and Saseendran S. Anapalli.

DOI: 10.1002/9780891183891.ch01

over variable weather and climate. The contributions to this book present various applications of crop system models to help develop management decision tools to optimize the use of limited water and soil nutrients for subsistence farming (low-input agriculture) and explore adaptations and mitigations for climate change under a variety of conditions. Subsistence farming generally involves smaller farms and the use of suboptimal amounts of nitrogen, water, and other inputs. The lower inputs require the models to more rigorously account for soil nitrogen–water–temperature interactions than in the cases where adequate amounts of nitrogen and water are applied.

Chapter 2 (Birnholz et al., 2022) covers the use of models to assess sustainable land management practices in the Central Highlands of Kenya. This multi-faceted study used a whole farm model to investigate impact of farm configurations (such as physiographic location, socio-economics, and crop and livestock choices) on farm performance. The information from this model was used to evaluate the outcomes of various erosion control practices on farm health and erosion. They found that profitability trade-offs existed for erosion control practices. In some cases, labor investment for maintenance of erosion control practices is not always compensated by improved income from the new practice. Also, livestock can sometimes take better advantage of improved land management practices rather than row crops.

There is some uncertainty about the best management practices for wheat (*Triticum aestivum* L.) on the sandy loam soils in Ethiopia, especially in light of potential future climate change. Wheat is a major cereal crop in Ethiopia and yields need to be higher to support a growing population. However, poor soil conditions and biotic stresses limit potential yields. Chapter 3 (Araya et al., 2022) analyzes the power of crop simulation models to better understand what management factors can be used to increase wheat yields in these soils of Ethiopia. Such models can be used to augment more expensive and time consuming field-scale experiments. The simulation results indicate that early planting with a plant density of 300 plants m^{-2} is optimal for this region and that increased nitrogen fertilization to a maximum of 180 $kg\,ha^{-1}$ increases yields. The expected increase in average temperature along with increased CO_2 due to climate change in this region, according to simulations, will increase wheat yields. The analysis did not take short episodes of extreme temperatures into account.

Agro-ecosystem services provide agricultural, societal, and ecological benefits to all humans. These services include recharge of groundwater, climate modification, and maintenance of soil health, among other services. Climate change threatens the sustainability of these services. Chapter 5 (Ali et al., 2022) describes various simulation and numerical methods in detail used to quantify infiltration, aquifer recharge, and soil erosion in India and other nearby countries. These methods are then applied to understand how expected changes in climate will impact ecosystem services. Climate change models predict the wet season to become wetter and the dry season to become drier. Simulations show how water harvesting and storing excess summer water in ponds can increase groundwater recharge and provide additional water during dry periods. Because of increased future rainfall, soil erosion is predicted to increase by 58% and soil organic carbon loss is predicted to increase by 57% over the base period.

Chapter 7 (Ko et al., 2022) reports on a geospatial modeling approach to understand regional and geographical variations in rice (*Oryza sativa* L.) and barley (*Hordeum vulgare* L.) yields in Korea in the present and future environments. The simulations show that rice yields are more negatively affected by rising temperatures than is barley yield. Increased CO_2 has little effect on alleviating the effects of high temperature on rice, whereas it has a larger effect on barley. Because the climate and geography of Korea varies greatly, there is great opportunity to identify areas where climate change could have beneficial effects such as bringing warmer temperatures to higher elevations. This will allow planners to mitigate some effects of climate change by adjusting cropping methods to geography. Here the authors developed statistical methods to divide Korea into regions that similarly respond to climate change. Such a classification will help agricultural planners better target areas for what will respond favorably to climate change.

China is a country with a large population and sizable areas where water is limited during the growing season. Arid areas are especially vulnerable to climate change, and it is important to understand the hydrology and water relations of arid lands. In these arid areas, groundwater can be a significant water source for agriculture. Chapter 6 (Gao et al., 2022) discusses modeling approaches to determine the best use of groundwater that can be supplied by capillary fluxes in the soil. Shallow groundwater can provide large amounts of water via capillary rise but can limit growth due to water logging. If the groundwater is very deep, greater than 3 or 4 m upward capillary flow cannot sustain crop growth. Irrigation with water pumped from groundwater can enhance the contribution of groundwater through capillary flow and increase irrigation water use efficiency. This is because when irrigation is used in areas with a groundwater depth less than 3 m, excess irrigation that percolates to the groundwater table is available for uptake by plants. These kinds of analyses are useful in areas with plentiful groundwater but undeveloped irrigation systems.

Maize (*Zea mays* L.) is an important food crop in Africa. Adequate fertilizer can provide large yields, but there is often insufficient nitrogen fertilizer available or affordable to maintain optimum maize yields. Also, nitrogen uptake and use efficiency depends greatly on water availability, which, in turn, is affected by planting date. Chapter 4 (MacCarthy et al., 2022) explains how the Decision Support System for Agrotechnology (DSSAT) maize model is used to determine yield response to nitrogen fertilizer, variety, and sowing date at multiple locations in Ghana. The results demonstrate the spatial distribution of yield response to these variables in locations throughout Ghana and show that, at the eastern part of the Guinea Savanna, early and late planting best utilizes available rainfall and gives the best yields. Late planting is preferred in the Sudan Savanna area. They also found that, for early and very early varieties, 60 kg N ha^{-1} gave the best yields. Medium and long season varieties respond to higher nitrogen rates (90 kg ha^{-1}), and the medium season variety gives better overall yields for simulations throughout the entire country.

The Fertile Crescent (FC) in the Middle East is considered one of the birthplaces of agriculture and is also in a region where the climate has historically been highly variable and subject to drought and high temperatures. Climate change is expected to result in an increasing frequency of drought and high temperatures in this region. Because of the pressure of increasing population and intensification of agricultural activities, there is a concern of increased soil degradation and decreasing production. Chapter 8 (Jaradat & Timlin, 2022) shows how simulation models and statistical modeling are used to identify the effects of climate change on yield gaps in this area. Under the three climate change scenarios used in the study, Jaradat and Timlin (2022) found annualized crop rotation and rainfed yields were expected to decrease by 34 and 65%, respectively, compared with current conditions. In spite of using crop rotations, soil carbon is also expected to decrease due to limited rainfall and increasing temperatures. This underscores the need to develop new cropping rotations that conserve soil carbon.

Jaradat and Timlin (2022) also look at yield gaps, which is the difference between best potential yield for the area and actual yields measured on farms. They find that three-way relationships between potential yield (Yp), and yield gaps (Yg) under RCP4.5 and RCP8.5 for the major crops separated the seven countries of the FC into three groups: Jordan and Iraq are expected to sustain the largest yield gaps; Turkey, Lebanon and Iran, the lowest; and Syria and Israel intermediate yield gaps. They conclude that closing these yield gaps demands immediate local adaptive research and will inevitably involve the adoption of management practices and inputs that have been developed and used elsewhere in the world during the 1900s.

The simulation studies in this book cover a wide variety of applications. They range from assessment of fertilizer and planting date on wheat and maize yields to studies of climate change impacts on surface and subsurface water resources and erosion. Models are applied to provide insight into geospatial distributions of crop response to different environmental and management variables. We also saw examples of socio-economic analysis tied with model results. Many of the studies investigate the effects of climate change on crop yields using estimated climate data generated by climate change models (Representative Concentration Pathways RCP2.6, RCP4.5, and RCP8.5; and CMIP5 [Coupled Model Intercomparison Project, https://www.wcrp-climate.org/wgcm-cmip/wgcm-cmip5]). The effects on subsistence and low-input agriculture are expected to be severe due to lack of research on alternative management practices and limited resources for farmers. However, most studies show that increased diversification through crop rotations and use of alternative crops can decrease the variability caused by climate change and result in decreased impact of heat and water stress.

References

Ali, S., Islam, A., & Ojasvi, P. R. (2022). Modeling water dynamics for assessing and managing ecosystem services in India. In D. Timlin (Ed.), *Enhancing agricultural research and precision management for subsistence farming by integrating system models with experiments* (pp. 69–103). ASA, CSSA, and SSSA. DOI

Araya, A., Prasad, P. V. V., Ciampitti, I. A., Rice, C. W., & Gowda, P. H. (2022). Using crop simulation models as tools to quantify effects of crop management practices and climate change scenarios on wheat yields in northern Ethiopia. In D. Timlin (Ed.), *Enhancing agricultural research and precision management for subsistence farming by integrating system models with experiments* (pp. 29–47). ASA, CSSA, and SSSA. DOI

Beah, A., Kamara, A. Y., Jibrin, J. M., Akinseye, F. M., Tofa, A. I., & Adam, A. M. (2021). Simulating the response of drought–tolerant maize varieties to nitrogen application in contrasting environments in the Nigeria Savannas using the APSIM model. *Agronomy*, *11*, 76. https://doi.org/10.3390/agronomy11010076

Birnholz, C., Paul, B., Sommer, R., & Nijbroek, R. (2022). Modeling soil erosion impacts and trade-offs of sustainable land management practices in the Upper Tana Region of the Central Highlands in Kenya. In D. Timlin (Ed.), *Enhancing agricultural research and precision management for subsistence farming by integrating system models with experiments* (pp. 6–28). ASA, CSSA, and SSSA. doi 10.1002/9780891183891

Falconnier, G. N., Corbeels, M., Boote, K. J., Affholder, F., Adam, M., MacCarthy, D. S., Ruane, A. C., Nendel, C., Whitbread, A. M., Justes, É., Ahuja, L. R., Akinseye, F. M., Alou, I. N., Amouzou, K. A., Anapalli, S. S., Baron, C., Basso, B., Baudron, F., Bertuzzi, P., . . . Webber, H. (2020). Modelling climate change impacts on maize yields under low nitrogen input conditions in sub-Saharan Africa. *Global Change Biology*, *26*, 5942–5964. https://doi.org/10.1111/gcb.15261

Gao, X., Huo, Z., Qu, Z., & Tang, P. (2022). Modeling agricultural hydrology and water productivity to enhance water management in the Arid Irrigation District of China. In D. Timlin (Ed.), *Enhancing agricultural research and precision management for subsistence farming by integrating system models with experiments* (pp. 104–133). ASA, CSSA, and SSSA. doi 10.1002/9780891183891

Jaradat, A. A., & Timlin, D. (2022). Constraints to productivity of subsistence dryland agroecosystems in the Fertile Crescent: Simulation and statistical modeling. In D. Timlin (Ed.), *Enhancing agricultural research and precision management for subsistence farming by integrating system models with experiments* (pp. 155–189). ASA, CSSA, and SSSA. doi 10.1002/9780891183891

Ko, J., Jeong, S., Kim, H.-Y., & Lee, B. (2022). Use of data and models in simulating regional and geospatial variations in climate change impacts on rice and barley in the Republic of Korea. In D. Timlin (Ed.), *Enhancing agricultural research and precision management for subsistence farming by integrating system models with experiments* (pp. 134–154). ASA, CSSA, and SSSA. doi 10.1002/9780891183891

MacCarthy, D. S., Adiku, S. G. K., Kamara, A. Y., Freduah, B. S., & Kugbe, J. (2022). The role of crop simulation modeling in managing fertilizer use in maize production systems in northern Ghana. In D. Timlin (Ed.), *Enhancing agricultural research and precision management for subsistence farming by integrating system models with experiments* (pp. 48–68). ASA, CSSA, and SSSA. doi 10.1002/9780891183891