DOCTORAL THESIS

Modeling Framework to Evaluate the Impacts of Climate Change on Crop Productivity over a Diverse Region

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Abstract

Crop productivity is an essential component of food security which is affected by multiple biotic and abiotic parameters, including climate variations. Previous studies have reported variable impacts of climate change on crop productivity depending upon the climatic parameter analyzed or the study region's characteristics. The negative impacts of climate change on crop productivity can be eased by adopting efficient strategies and making the cropping system more resilient towards extreme events. Process-based crop models provide a unique opportunity to study the complex interactions of physiological conditions and agronomic practices from a local to regional scale. Previous large-scale crop model studies have used spatially aggregated biophysical, climatic, and crop management conditions to provide generalized climate change assessments of crop production. The exclusion of regional cropland diversity remains a persistent flaw in large-scale crop model studies that may mislead adaptation strategies at the local scale.

This research aims to design a modeling framework to evaluate climate change impacts on crop productivity over a diverse region. Three aspects of the regional cropland diversity were focused on in this research: (a) existing climate-cropland nexus, (b) spatial variability of cropping system, and (c) spatiotemporal variations of crop management activities. Time-series data from satellite remote sensing were the primary input for the intended methodology. The machine learning algorithms to unearth hidden patterns in multitemporal data and GIS (Geographical Information System) capabilities to handle extensive geospatial data were employed to achieve the research objectives. The Indus River (IR) basin that stretches over four international territories of the developing world and fall under arid and semi-arid climatic zones was the focus of this research.

The outcomes of the first research objective revealed variable existing cropland trends in the region. The climate-cropland nexus analysis pointed out that actual evapotranspiration and evaporative stress index are the primary climate-related parameters that control the IR's cropland trends. The proposed novel approach of mapping the cropping system revealed that wheat-cotton and wheat-rice are the two most crucial crop rotations in the region. The overall accuracy of identifying seasonal primary crop type was 88±3% when assessed against field observations using the error matrix. The remote sensing-based yield of wheat and rice was estimated with an accuracy of achieving the coefficient of determination (R^2) values of 0.75 and 0.68, respectively. The spatiotemporal detection of crop types and their productivity levels were used to assess the diverse crop management practices in the region.

A gridded model approach in the GIS was adopted to integrate cropland diversity in a crop model for future climate impact assessment on crop productivity. The crop model was calibrated and validated against reported wheat and rice yield by achieving a value of R^2 and NSE (Nash–Sutcliffe Efficiency) ≥ 0.50. Future yield simulations revealed that wheat yield might decrease in highly productive regions but improve productivity in various other regions. Similarly, rice yield might severely decrease in southern parts but might increase in the IR basin's northern parts. The overall impact of carbon fertilization was positive on crop water use efficiency; yet a rise in temperature and severe rainfall reduction was the leading cause of a decline in crop productivity in various parts of the study region. Different adaptation and mitigation strategies to overcome projected yield losses for regional food security are also discussed in this dissertation.

Keywords: Cropland diversity, Crop productivity, Remote sensing, Machine learning, Climate change, Food security

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