Predicting future US crop phenology dynamics under climate change using an integrated remote sensing and machine learning method: A case study in Kentucky cropping systems

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1 Background

Crop phenology provides essential information for monitoring and modeling crop growth dynamics and productivity. A warming climate has been widely reported in most regions worldwide over the past decades. Climate projections suggest that this changing trend would even accelerate in the future. The impact of historical climate change on crop phenology has been well investigated using multiple methods, such as crop/ecosystem models, climate observations, and remote sensing imagery, from site to global scales. However, it remains uncertain how crop phenology shifts would respond to changing climate conditions under various climate scenarios.

This study proposed an innovative approach, which combines machine learning (eXtreme Gradient Boosting), remote sensing-based crop phenology detecting, and climate projections, to quantify potential shifts in crop phenology dynamics. The overarching objectives are to (1) analyze future changes in temperature and precipitation from GFDL-ESM2M model under the RCP 4.5 and 8.5 scenarios in the contiguous United States during 2021-2099; (2) predict four future corn phenological stages (planting, silking, maturity, and harvesting dates); (3) evaluate the potential impacts of climate variability/change on crop phenology under various scenarios; and (4) analyze the potential vulnerability of Kentucky crops considering predicted phenology dynamics.

2 Datasets and Methodology

2.1 Datasets

The datasets in this study include 1) North America crop phenology product (annual, 500m, 2008-2016) (Yang et al., 2020); 2) Crop Distribution Data: Cropland Data Layer (CDL, annual, 30m, 2008-2019); and 3) USDA survey datasets (2008-2019); 4) GFDL-ESM2M coupled climate model (CMIP5) (daily, 1/24 degree, 2008-2099)

2.2 Methodology

Xtreme Gradient Boost (XGBoost) is a machine learning algorithm that implements an optimized gradient boost technique over decision or regression trees. In this study, we used the regression model to predict crop phenological stages. During the gradient boosting ensemble model processing, regression trees were trained iteratively to predict residual errors of previous trees and are then added together. A set of predictor features and the corresponding target labels were used to drive the XGBoost algorithm. We extracted three temperatures (maximum, minimum, and average temperature) and precipitation variable as the features. The target labels are the four corn phenological stages (planting, silking, maturity, and harvesting dates).

2.3 Flow work

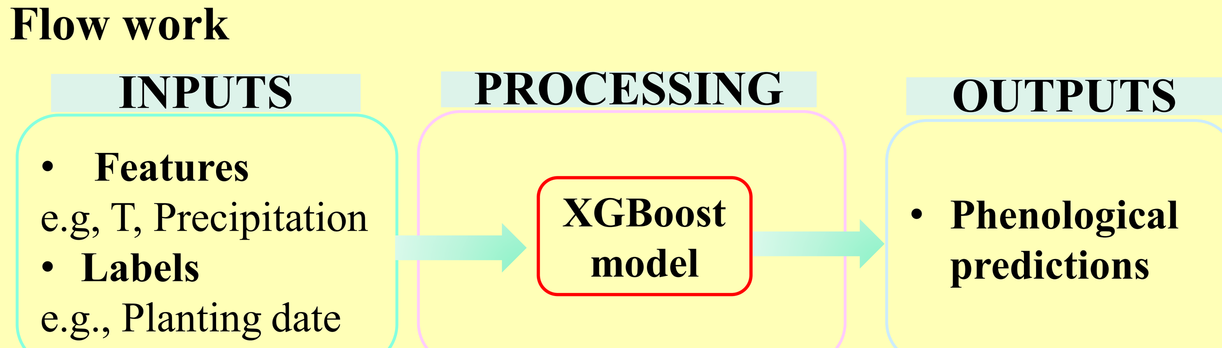

Figure 1. Schematic diagram of the method to predict future crop phenology

3 Preliminary results

3.1 Future climate change under RCP 8.5 during 2021-2099

Future average air temperature and accumulated precipitation during corn growing season were analyzed from 2021 to 2099.

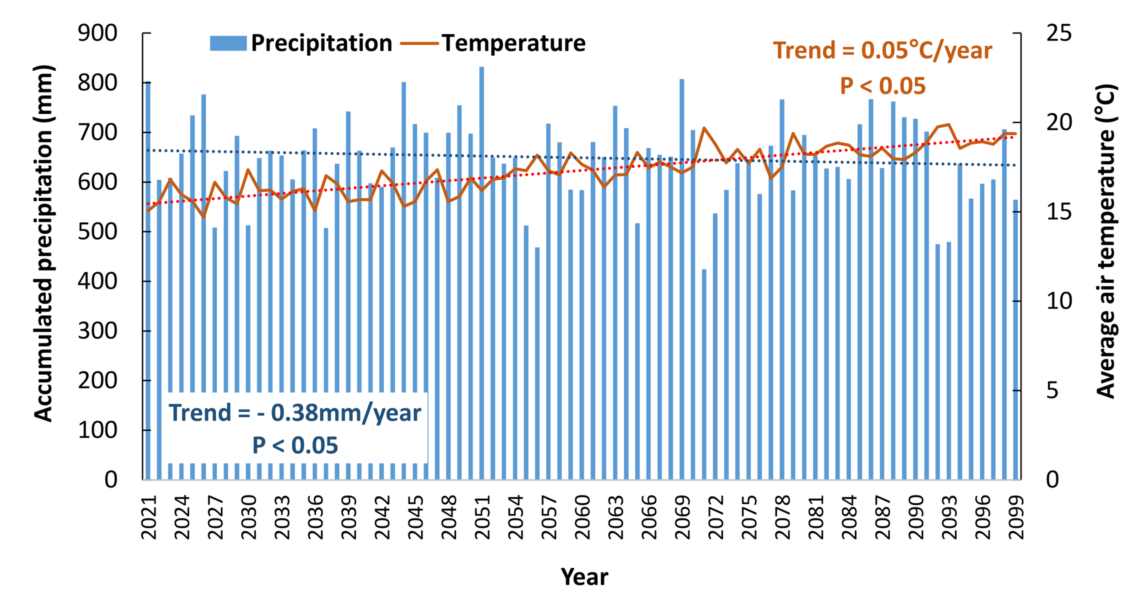

Figure 2. Average temperature and accumulated precipitation during corn growing season in the US from 2021 to 2099

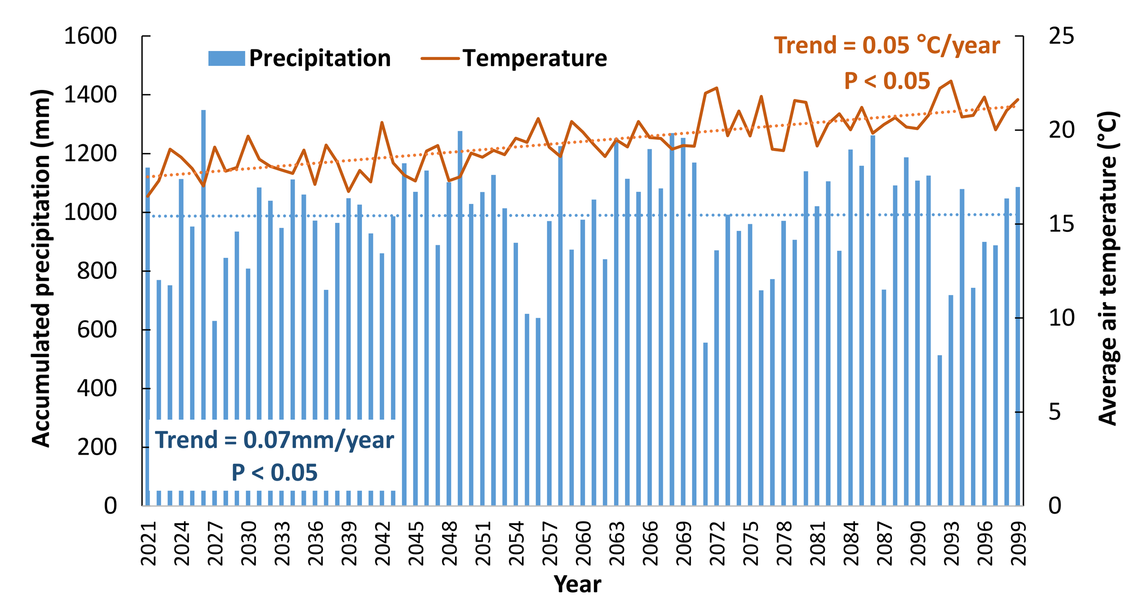

Figure 3. Average temperature and accumulated precipitation during corn growing season in Kentucky from 2021 to 2099

3.2 Evaluation of predicted phenological stages at the pixel level

We evaluated the predicted corn phenological stages against a remote sensing-based approach at the pixel level.

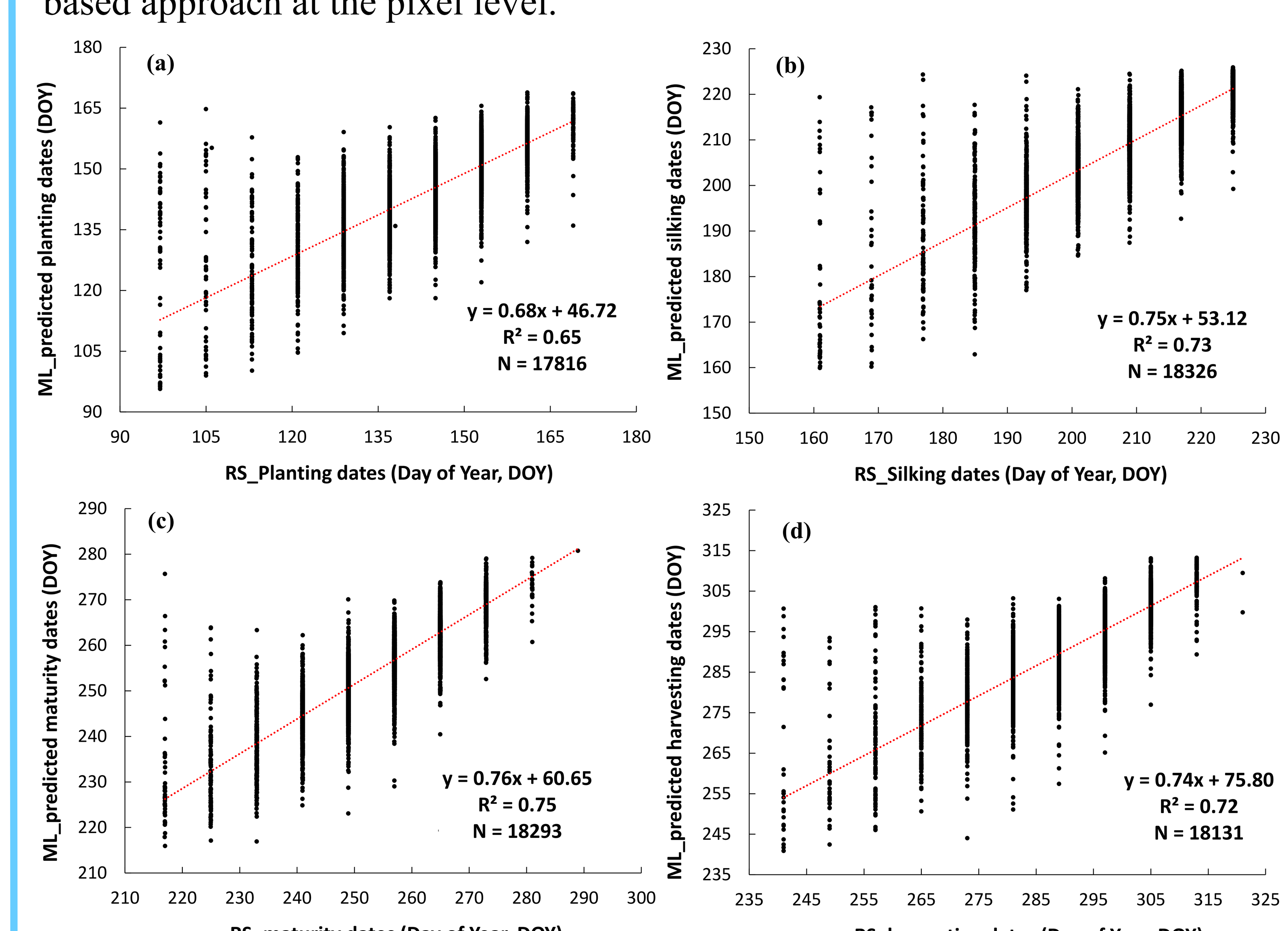

Figure 4. Evaluation for predicted corn phenological stages at the pixel level

3.3 Evaluation of predicted phenological stages at the state level and in the US during 2017 - 2020

Stages	Planting dates	Silking dates	Maturity dates	Harvesting dates
RMSE (days)	4.33	5.94	19.84	18.79
MAE (days)	3.30	4.28	17.71	17.24
r	0.54	0.63	0.20	0.49
N (States)	60	60	60	60
Mean values (DOY) US _report	139	212	269	302
Mean values (DOY) ML_prediction	137	206	251	284

3.4 Changing trends of corn phenological stages in the US and Kentucky

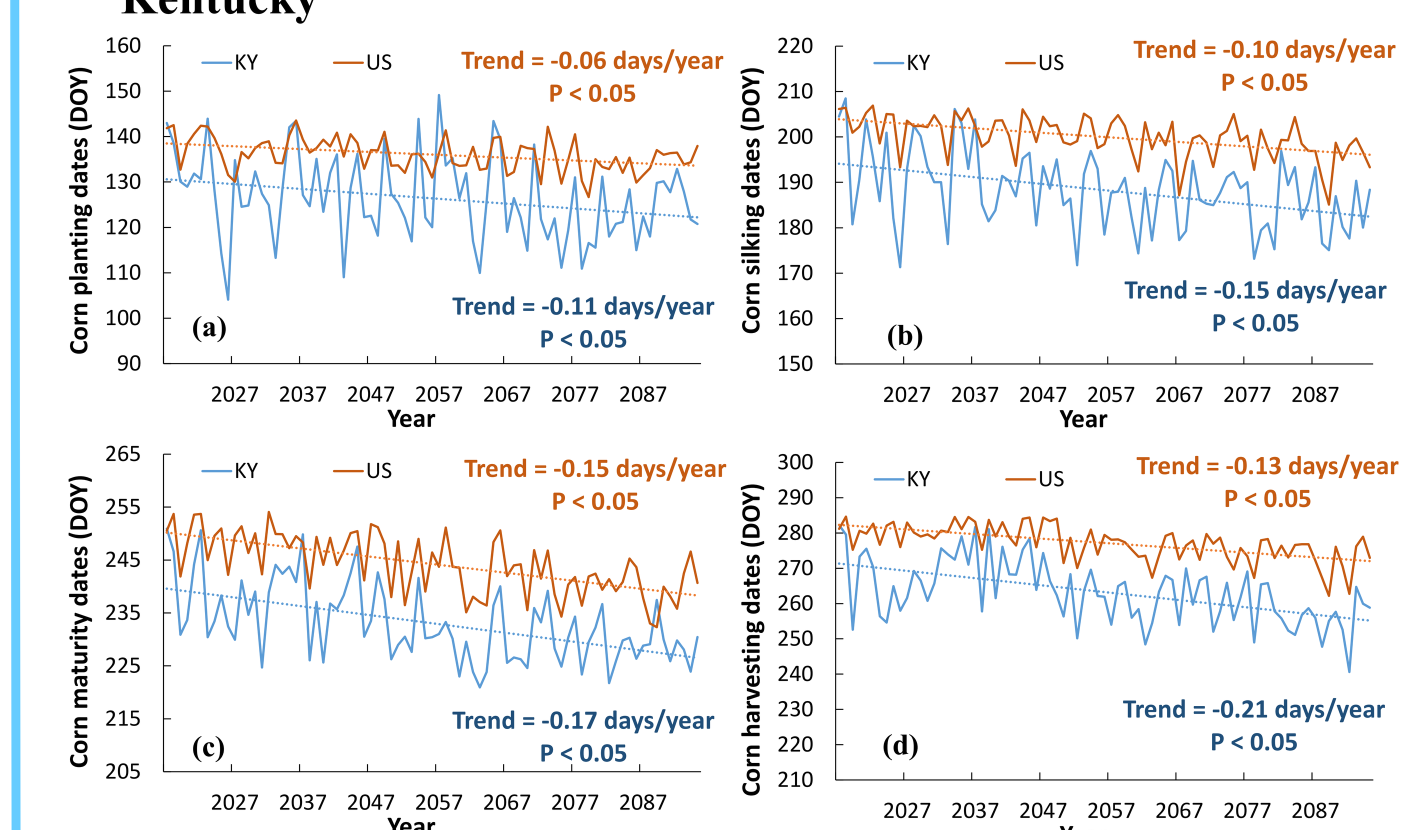

Figure 5. Changing trends of corn phenological stages in the US and Kentucky during 2021 - 2099

4 Summary

- An improved approach that incorporates remote sensing data and a machine learning algorithm was evaluated by comparing with RS-based phenology and USDA crop reports.
- Future climate scenario (RCP8.5) shows that over the corn growing season from 2021 to 2099, the mean air temperature would increase at a rate of 0.05 ºC/year in the US and Kentucky. The accumulated precipitation would increase (0.07mm/year) in Kentucky but decrease (-0.38mm/year) in the US.
- The predicted future corn phenology dynamics in the US and Kentucky show that all four corn phenological stages might advance during 2021 to 2099. The changing trends of corn phenology would be more evident in Kentucky than in the US.

References:

Yang, Y., et al.(2020). Characterizing spatiotemporal patterns of crop phenology across North America during 2000–2016 using satellite imagery and agricultural survey data. ISPRS Journal of Photogrammetry and Remote Sensing, 170, 156-173.

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