Uncertainties in the Prediction of Winter Wheat Response to Climate Change with Crop-climate Models

M. Ahmed[1,2], C.O. Stöckle[1], R.L. Nelson[1], S.Higgins[1]

[1]Biological system Engineering, Washington State University, WA 99164-6120

[2]Department of Agronomy, PMAS Arid Agriculture University Rawalpindi-46300, Pakistan

Abstract

Simulations of crop yield under climate variability are subject to uncertainties, and quantification of such uncertainties is essential for effective use of projected results in adaptation and mitigation strategies. In this study we evaluated the uncertainties related to crop-climate models using five crop growth simulation models (CropSyst, APSIM, DSSAT, STICS and EPIC) and 14 general circulation models (GCMs) for 2 representative concentration pathways (RCP) of atmospheric CO_2 (4.5 and 8.5 W m^{-2}) in the Pacific Northwest (PNW), USA. The aim was to assess how different process-based crop models differed in the estimation of winter wheat growth, development and yield. We concluded that to improve accuracy and consistency in simulating wheat growth dynamics and yield under a changing climate, a multimodel ensemble approach should be used. Results support the concept of using multimodel ensemble analysis to more adequately capture wheat growth dynamics and yield in climate scenarios.

Methodology

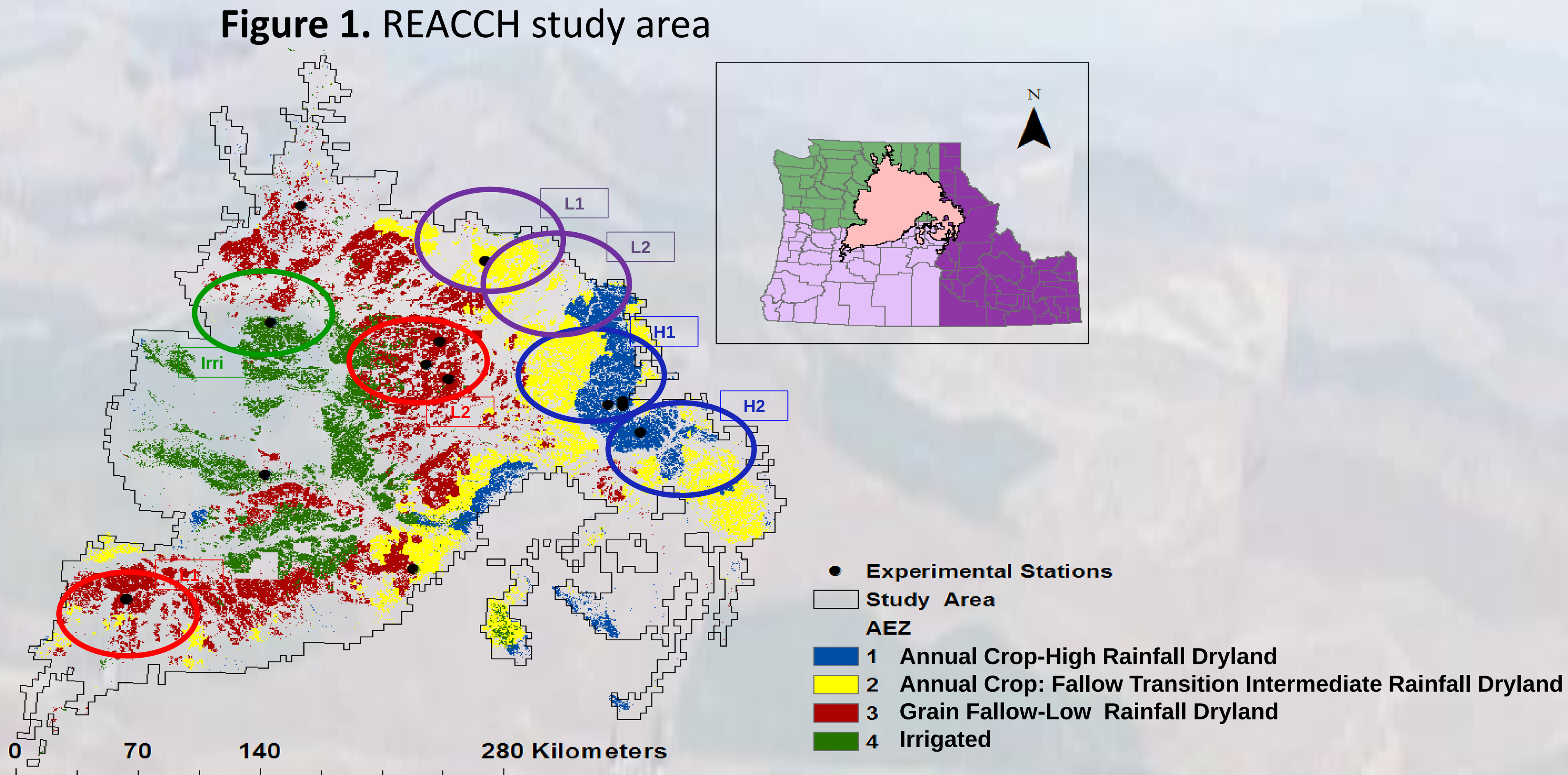
Regional simulations for wheat based cropping systems have been conducted using cropping systems models (CSM) i.e. APSIM-Wheat, CropSyst, DSSAT-CERES-Wheat, EPIC and STICS. For future weather, daily data projected by 14 general circulation models (GCM) for two representative concentration pathways (RCP) of atmospheric CO_2 (4.5 and 8.5 W m^{-2}) were used, with a total of 28 future weather scenarios at 7 different sites (Fig.1). Firstly all models were calibrated for high rainfall, medium rainfall, low rainfall and irrigated sites in the PNW using 1979–2010 as the baseline period. Response variables were related to farm management and soil properties, and included crop phenology, leaf area index (LAI), biomass and grain yield of winter wheat. All five models were run from 2000 to 2100 using the 14 GCMs and 2 RCPs to evaluate the effect of future climate (rainfall, temperature and CO_2) on winter wheat phenology, LAI, biomass, grain yield and harvest index. The REACCH region has been divided into 4 agro-ecological zones (AEZ): low, intermediate and high precipitation dryland cropping and an irrigated (Figure 1). Each AEZ has a typical conventional tillage (CT) cropping system. Drier conditions in summer and warmer temperatures specially in summer have been projected for this region.

Results

Simulated time to flowering and maturity was reduced in all models except EPIC with some level of uncertainty. All models generally predicted an increase in biomass and grain yield under elevated CO_2 but this effect was more prominent under rainfed conditions than irrigation. However, there was uncertainty in the simulation of crop phenology, biomass and grain yield under 14 GCMs during three prediction periods (2030, 2050 and 2070).

- A large variation among GCMs and CSMs projections was found, resulting in important differences in predicted future winter wheat yields (Table 1).
- Uncertainty index (UI) showed that uncertainty was more prominent among crop models compared to GCMs for three time periods (2030, 2050 and 2070) (Table 1).
- Ensemble of all GCMs and CSMs showed a consistent trend of beneficial effects of climate change on wheat yields in all sites studied (Figure 2).

Figure 1. REACCH study area



Low rainfall sites (L1 – L2)
1. Sherman County (Moro)
2. Adams County (Lind)

Intermediate rainfall sites (I1-I2)
1. Lincoln County (Wilke)
2. Whitman County (St.John)

Irrigated (Irri)
1. Grant County (Moses Lake)

High rainfall sites (H1 – H2)
1. Whitman County
2. Fremont County

Table 1. Uncertainty Index (UI) generated from ANOVA sums of squares (SS) for winter wheat yield showing uncertainty among treatments combined over RCPs and sites

SOV	2030		2050		2070	
	SS	UI	SS	UI	SS	UI
GCMs	1.896	0.011288	5.072	0.020615	14.489	0.048226
CSMs	144.101	0.857938	194.783	0.791695	213.319	0.710029
GCMs*CSMs	14.417	0.085835	25.727	0.104567	34.779	0.115761
Error	7.548	0.044939	20.452	0.083127	37.85	0.125983
Total	167.962		246.033		300.437	

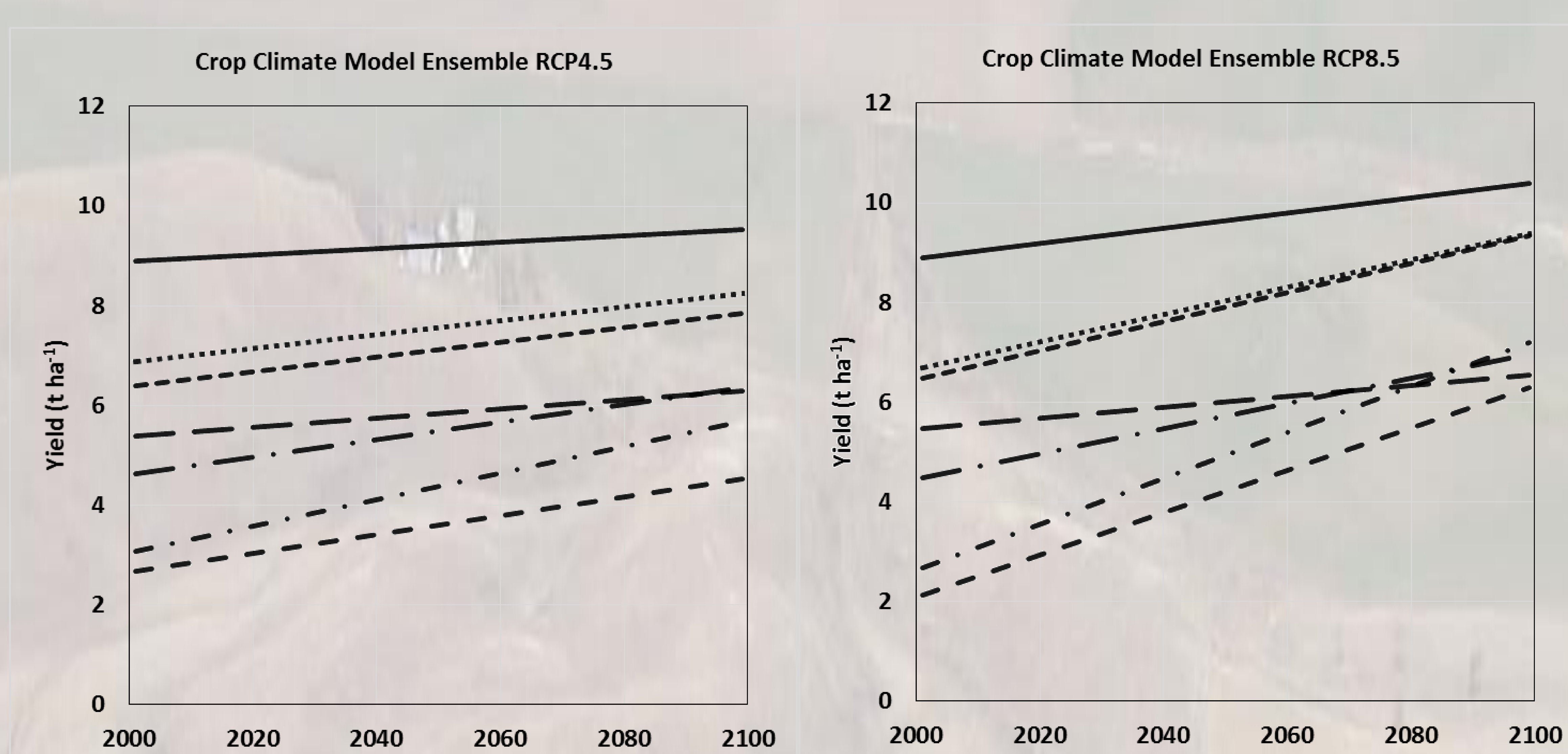


Figure 2. Winter wheat yield trend by crop climate model ensemble approach using two RCPs (RCP4.5 and 8.5) at seven diverse agro-ecological sites (Pullman ……, Kambitsch--- , Lind - - , Moro ‒ · ·, Moses Lake ——, Wilke ▬ · and St. John — ·) of the Pacific Northwest USA

Concluding Remarks

Uncertainty in climate change impact assessments due to the variability of GCMs and CSMs projections can be substantial, with the uncertainty attributed to CSMs being the largest in this study. Results from a multimodel ensemble validated previous projections in the region conducted using one crop model and a small number of GCMs.