Soil, Water, and Climate Change Integrated Impact Assessment on Yields:
Approach from Central Mexico

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ABSTRACT

This article describes the potential yields of maize, wheat and barley which were modeled with climate change, soil degradation and water balance scenarios in central Mexico. Two adaptation measures were also evaluated. To estimate yields the AquaCrop-FAO model was applied. Three study cases were chosen and their climate, soil, phenological and management information was compiled. Once calibrated, the authors tested the response in yields for 28 climate change scenarios: five General Circulation Models, two RCP and three-time horizons. Two adaptation actions were evaluated: changing planting date and increase of organic mulches. Results show that yield of maize in the near future (2015-2039) would fall 50% average, barley and wheat yields would decrease in 40% and 25% respectively. If soil degradation and loss is considered, the yield will reduce considerably. Adaptation measure based on changing planting date was as effective as increasing mulches. It is necessary to consider soil together with climate change scenarios in yield modeling. It is possible to suggest wrong adaptation measures if only the climate is considered and not all the variables involved.

KEYWORDS

Adaptation, Barley, Impact, Maize, Sensitivity, Vulnerability, Wheat

INTRODUCTION

Climate change has highlighted the susceptibility of the food security of Mexico (Gay Garcia & Rueda Abad, 2015). There have been many studies on this subject, most of them focused on knowing the impacts of climate change on agricultural productivity and distribution of crops (Monterroso-Rivas, Conde-Álvarez, Rosales-Dorantes, Gómez-Díaz, & Gay-García, 2011). In this sense, Cervantes et al. (2014) report a literature review of research carried out regarding the impacts of climate change in Mexico highlighting that biggest impacts are reduced yields and reduced areas suitable for crops. Under a climate change focus, Ojeda-Bustamante et al. (2011) proposed a study of future water needs and changes in the phenological cycles for maize, beans, tomatoes, potatoes, sorghum, sugar cane, alfalfa and mango; finding that crop water demand will decline 13% in the autumn-winter cycle; 6% for the spring-summer cycle and will increase by 7% for perennial crops.

Those studies highlight the importance of analyze crop yields with climate change scenarios especially because yield is a variable directly related to economic benefit of agriculture. Despite the multitude of approaches to evaluate crop yields, AquaCrop FAO model (Todorovic et al., 2009) has shown acceptable results in terms of simplicity, robustness and precision in a national and

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international context (Calderón-García, Monterroso-Rivas, & Gómez-Díaz, 2015; Flores-Gallardo, Ojeda-Bustamante, Flores-Magdaleno, Sifuentes-Ibarra, & Mejía-Saénz, 2013; Soddu et al., 2013). The number of input variables is lower compared with models like WOFOST or CropSyst, which makes AquaCrop more accessible without losing its predictive ability (Todorovic et al., 2009).

AquaCrop is a model that uses the amount of water available to simulate current and potential biomass production. It was developed by the Land and Water Division of FAO and is the result of the revision of irrigation and drainage document FAO No. 33 entitled "Yield Response to Water" (Smith & Steduto, 2012). In a study conducted in the United States validating AquaCrop for maize, it was found that the software was able to correctly simulate the progression of the accumulation of grain and fodder. Also, Garcia et al. (2015) calibrated and executed AquaCrop for maize at three sites in Colombia, finding a good fit of the modeled and observed yield. In Mexico, Flores-Gallardo et al. (2013) used AquaCrop software to validate and model maize yields in Sinaloa for the years 2003 to 2009, getting a good prediction performance.

In addition to its applications in water management of crops, it is known to have been widely used to model potential impacts of climate change on different agricultural systems. Regarding climate change focuses, Vanuytrecht, Raes and Willems (2016) modeled yields of winter wheat, maize, potatoes and sugar beets for 2050 in Belgium, finding increased variability of yield. Some increases were found due to the high amount of CO2 and the lengthening of the growing season, but decrements were associated with water stress.

Maize is a cereal of great importance to Mexico. White maize grain is mainly used for making traditional *tortillas* and *tamales*, but it can also be obtained oil for the manufacture of varnishes, paints, artificial rubbers and soaps (SIAP-SAGARPA, 2016). Barley and wheat have had an increasing economic importance from its use in the bread and brewing industry. The main use of barley in Mexico is to obtain malt grain required for brewing, and in a lesser proportion to produce fodder. According to official statistics, in our country cultivation is practiced at least in one of the two cycles of the year in 23 states in Mexico (INIFAP, 2011). In the context of crop modeling, performance evaluation is especially useful to consolidate a model which is then used with climate change scenarios (Soddu et al., 2013).

Based on the above, the objective of this work was to model the potential yield of maize, wheat and barley under climate change scenarios using software AquaCrop to propose and model adaptation actions. Also, we incorporate soil degradation in models to estimate the double impact of climate change and soil loss over crops.

METHODS

Three crops of economic importance in Mexico were chosen to model the potential yield in same study sites. The case studies are 1) maize in Chapingo, Estado de Mexico, 2) wheat in Puebla, Puebla and 3) barley in Perote, Veracruz. All located in the center of the country.

Crop yields were modeled using software AquaCrop (Smith & Steduto, 2012; Steduto, Hsiao, Raes, & Fereres, 2009; Todorovic et al., 2009; Eline Vanuytrecht et al., 2014). The input variables of the software retrieve climatic, agronomic and soil information. The outputs were calibrated by comparing observed and modeled yields. Historical records of crop yields were obtained from the Agricultural Information Service and Fisheries in Mexico (SIAP-SAGARPA, 2016). The indexes used for validation were the correlation coefficient between precipitation and yield modeling, the determination coefficient, the mean square error and the normalized mean square error. These indexes were used in accordance with the manual of AquaCrop software.

Data and Base Scenario

Since the software used requires the inclusion of specific site parameters; climatic, soil, crop and management information were referenced to weather stations. Chapingo weather station was used

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