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Regional food production and land redistribution as adaptation to climate change in the U.S. Northeast Seaboard

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ABSTRACT

Potential corn and winter-wheat grain, and potato crop yields in the United States Northeastern Seaboard Region (NESR) were simulated under current and future climate scenarios and two water management regimes to evaluate production shifts and land-based adaptation methods. Geospatial data consisting of historical climate, land use, soil, and crop management were coupled with a weather generator, three explanatory crop models, and spatially and temporally downscaled mid-century climate change scenarios to conduct the simulations at sub-county spatial resolution. Unadapted winter wheat yield increased 48% in response to mid-century projected climate changes, but corn grain declined 19% and potato 42% across the NESR, resulting in a net loss in caloric production. The contribution of the three crops to regional food production with respect to historical and mid-century climate conditions was evaluated on the basis of caloric content as a measure of yield capacity. The caloric content declined by 7 to 15% across the three commodities when averaged among all states in the region if no adaptation changes were implemented. Two land redistribution schemes were derived to compensate for this loss by re-allocating the existing land-base within each county to specific crops based on model predicted changes in productivity along with identifying additional increments of additional potential land. These approaches showed that less than 1.6% of the potentially available agricultural land base in the region would be needed to compensate for calorie losses due to climate change. These results qualify land redistribution as a pragmatic and direct adaptation strategy to the threat of climate change on regional food security.

1. Introduction

Agriculture production and global food security face substantial challenges. World-wide population is expected to exceed 9 billion by 2050, and an estimated 70% increase in food production over today's output will be required to prevent rising food insecurity (FAO, 2009). Annual increases in grain yields per unit land area for rice, wheat, and corn have plateaued in the U.S. and most developed nations (Cassman et al., 2010). There is increasing pressure from industrial, commercial, and public sectors regarding land and water resources necessary for agriculture to meet this need (Foley et al., 2011). Climate projections indicate that warming air temperature and changes in water availability are likely to negatively impact current/future yields of most agriculturally important crops without adaptation, despite the elevated CO_2 enrichment affect commonly observed for crops with the C3 photosynthetic biochemical pathway (IPCC, 2014; e.g. Parry et al., 2004). These factors indicate a crucial need to evaluate potential adaptation methods.

Explanatory crop models synthesize mechanistic knowledge of soil, plant, and atmospheric interactions and can be used to assess climate change impacts and derive adaptation strategies (Boote et al., 2011; Lobell, 2013). When coupled with geospatial data and used to simulate crop production under different climate change scenarios, predictions of climate change impacts have been derived for single (e.g. Behrman et al., 2012; Jones and Thornton, 2003; Moore et al., 2011; Thaler et al., 2012) and multiple (e.g. Angulo et al., 2013; Mearns et al., 1999; Osborne et al., 2013; Parry et al., 2004; Rosenzweig et al., 2014; Tao and Zhang, 2010) crops at various spatial scales. Climate change

Abbreviations: CLU, current land use areas for cultivated crop production; CR, current climate (1981 through 2010); GCM, general circulation model; NESR, North Eastern Seaboard Region; NL, irrigated, or non-limited, crop production scenario; PLU_{CC}, potential land use area based on cultivated crop production area as defined by USDA NLCD database; PLU_{TOT}, potential land use area based on cultivate crop areas and other classifications in the USDA NLCD database; RCP, representative concentration pathway; WL, water limited crop production (rainfed) scenario. Tmax, maximum daily air temperature (°C); Tmin, minimum daily air temperature (°C)

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adaptation studies utilizing crop models as a basic component have focused on crop genetics (e.g. variety selection or breeding characteristics to confer drought and heat tolerance resistance) and farm management (e.g. shifting planting dates, crop water and fertilization management) strategies. Brassard and Singh (2007), Rosenzweig et al. (2014), Daccache et al. (2011b) and Resop et al. (2016) showed that increased irrigation alone could offset substantial yield losses for several crops in many regions around the world. Hijmans (2003), Cammarano et al. (2012), Tao and Zhang (2010) and Resop et al. (2016) found simple management options such as planting date shifts effective at countering yield losses in wheat, corn, and potato. Tao and Zhang (2010) and Ramirez-Villegas et al. (2015) investigated the potential of using alternative cultivars to respond to temperature induced changes in growing season duration. Daccache et al. (2011a) used soil maps and geographic information system technology to identify potential land areas suitable for future potato production in the United Kingdom. However, as underscored by Challinor et al. (2014), we are not aware of previous studies that have evaluated the potential of land redistribution as an adaptation approach to climate change using crop models to estimate productivity changes. In the context of climate change, where crops historically adapted for specific regions may need to be supplanted by other commodities which respond more favorably to these new conditions, evaluating land re-distribution concepts for food security purposes is warranted.

This study presents a regional crop production assessment and a land redistribution adaptation approach to projected changes in climate in the thirteen state region from Maine to Virginia that make up the United States Northeastern Seaboard Region (NESR) (Fig. 1). The NESR is historically a major agricultural production region in the U.S. and still maintains significant swathes of prime agricultural land (Auch et al., 2012). Food production is driven by fertile soil, favorable temperatures, and a humid and wet climate during the growing season. The region produces a number of crops for export and local consumption, with the overall contribution of the agricultural sector to the regional economy exceeding $7.5 billion per year (http://www.nass.usda.gov/Census_of_Agriculture/index.asp). Shifts in climate normal from historical patterns, and associated impacts on the region's agricultural sector, have already begun to occur and are expected to be disruptive to the current system (Wolfe et al., 2007). Resop et al. (2012) developed a geospatial coupled crop model, Geospatial Agricultural Management and Crop Assessment Framework (GAMCAF), for use as a regional decision support system for assessing food security vulnerabilities to climate change in the NESR. GAMCAF simulated current and potential production of corn and potato (Resop et al., 2016, 2014). The simulations conducted at fine spatial resolution (30 m) and aggregated to county level enabled localized diagnostics of potato and corn yield shifts due to climate change and resource management. These studies indicated a significant land-base was still available for expanding agricultural land that, as an adaption approach, may compensate for production loss due to climate change.

Land redistribution and allocation in this study was defined as (a) the proportional allocation of more land from a region's available agricultural land-base to a crop on the basis of its potential productivity, as well as (b) the re-assignment of existing agricultural land to different commodities using the same principle. The study leverages the GAMCAF databases to simulate regional crop production and evaluate land redistribution adaptation approaches to increase crop production under current and projected climate change scenarios. Three questions were investigated and discussed: (i) what is the current potential food production capacity of NESR using corn (*Zea mays*), potato (*Solanum tuberosum*), and winter wheat (*Triticum aestivum*) as representative food commodities? (ii) what is the associated impact of climate change on NESR food production? and (iii) what is the potential of land redistribution as an adaptation strategy to increase crop production in NESR? For symmetric analysis, the contribution of the three crops to regional food production was evaluated on the basis of caloric content, rather than total yield, as a measure of yield capacity.

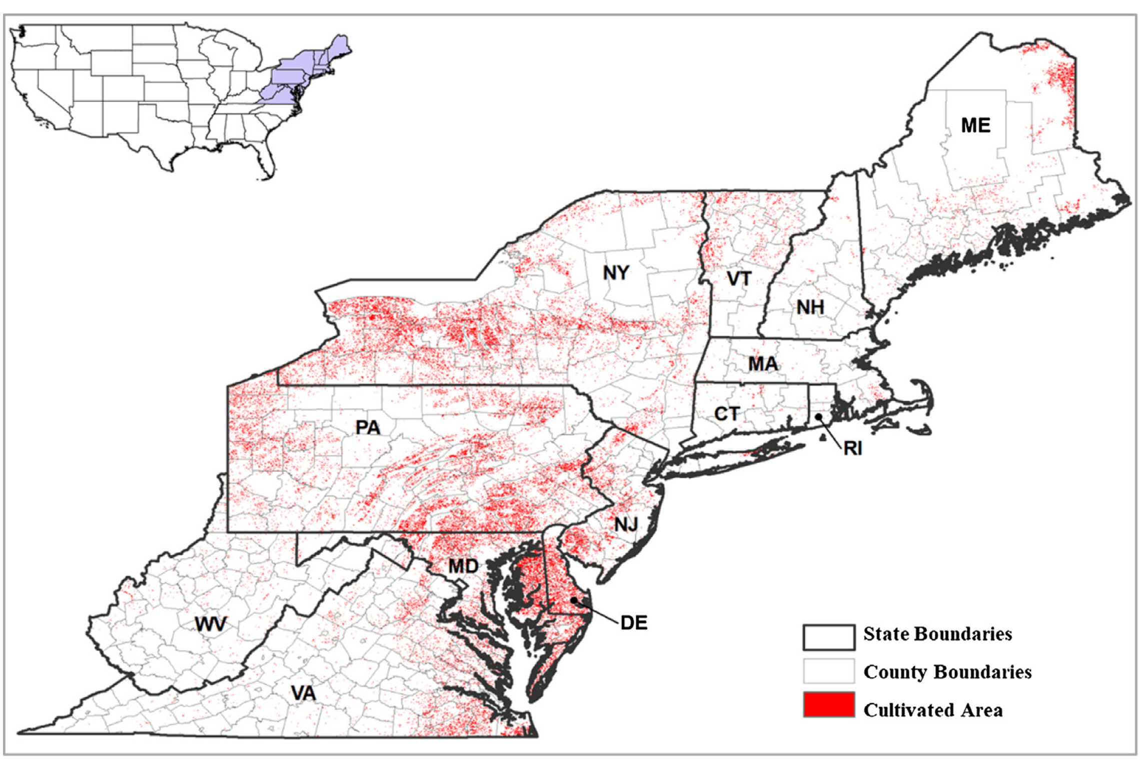

Fig. 1. Map of currently cultivated cropland area in the United States Northeastern Seaboard Region (NESR) composed of 13 states including: Maine (ME), New Hampshire (NH), Vermont (VT), New York (NY), Massachusetts (MA), Connecticut (CT), Rhode Island (RI), Pennsylvania (PA), New Jersey (NJ), Maryland (MD), Delware (DE), West Virginia (WV), and Virginia (VA). The region is comprised of 434 counties. Data source: National Land Cover Dataset (NLCD), 2011.