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Research paper

Implications of biofuel-induced changes in land use and crop management on sustainability of agriculture in the Texas High Plains

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ABSTRACT

Texas High Plains (THP), which is an important cotton (*Gossypium hirsutum* L.) growing region in the United States faces challenges from declining/deteriorating groundwater levels/quality, recurring droughts and severe wind erosion. Growing cover crops after harvesting cotton and/or changing land use from cotton to perennial bioenergy crops could not only address above challenges, but also assist in meeting the national biofuel target. The objective of this study is to assess the implications of changes in land use (replacing cotton with Alamo switchgrass (*Panicum virgatum* L.) and *Miscanthus* × *giganteus*) and crop management (growing winter wheat (*Triticum aestivum* L.) cover crop) on hydrology and wind erosion in the Double Mountain Fork Brazos Watershed using the Agricultural Policy/Environmental eXtender (APEX) model. Simulated average annual wind erosion, total nitrogen (TN) loss to surface water and nitrate-nitrogen (NO_3-N) leaching to groundwater reduced by more than 37%, 43% and 73%, respectively, when winter wheat was grown as a cover crop under the 457 mm (18-inch) annual groundwater pumping limit setup by the High Plains Water District. In addition, winter wheat produced about 0.20–0.26 $kg\,m^{-2}$ of biomass for biofuel purposes. Land use change from irrigated cotton to switchgrass and rainfed cotton to *Miscanthus* decreased the TN load, NO_3-N leaching and soil loss by wind erosion by > 89% relative to the baseline scenario. Under the groundwater pumping restrictions, multiple harvests of perennial grasses were found to be better in terms of biomass production (> 2 $kg\,m^{-2}$), and protection of groundwater and soil.

1. Introduction

The Texas High Plains (THP) region, which encompasses 41 counties in the northwest Texas in the United States (U.S.), is a treeless, windswept and semi-arid region within the Great Plains [1]. Cotton (*Gossypium hirsutum* L.) is one of the major crops grown in this region. The harvest area of cotton in the THP was about 37% of the entire U.S. cotton harvest acreage in 2015 [2]. In general, cotton is planted around mid-May and harvested at the end of October in the THP. Setting of cotton blooms in this region begins in late June and ends in mid-July [3]. During the early stages of cotton growth, minimal ground cover conditions that are favorable for wind erosion exist. Between setting of blooms and harvest, cotton fields have sufficient ground cover to protect the soil from wind erosion. However, after cotton is harvested, wind speeds tend to peak again during winter and spring [4]. Therefore, wind erosion is one of the major concerns for sustainable agriculture in the THP.

The discovery of the vast underground Ogallala Aquifer in the early 20th century made large quantities of groundwater available for irrigated agriculture in the THP [5]. Development of improved center pivot irrigation technology, including the Low Energy Precision Application (LEPA) and Low Elevation Spray Application (LESA) sprinkler systems, further contributed to the fast expansion of irrigated agriculture in this region. According to the local expertise, the irrigation water requirement for cotton in the THP is about 483–508 mm (19–20 inches), and the irrigation efficiency of the center pivot system is around 70–90%. Although irrigated agriculture in the THP mitigates wind erosion risk partially, groundwater levels in the Ogallala Aquifer experience a continuous decline [6] and its groundwater quality has been deteriorating over the recent times [7]. Chaudhuri and Ale [6] reported that the decadal median groundwater level in irrigation wells in the THP region has declined significantly ($p < 0.05$) from about 19 m in the 1930s to 52 m in the 2000s due to excessive pumping to meet irrigation demand for agriculture. In view of the declining groundwater levels in the Ogallala Aquifer, groundwater conservation districts in the THP have started imposing restrictions on groundwater pumping for irrigation. For example, the High Plains Underground Water Conservation District (HPUWCD) set the limit on annual

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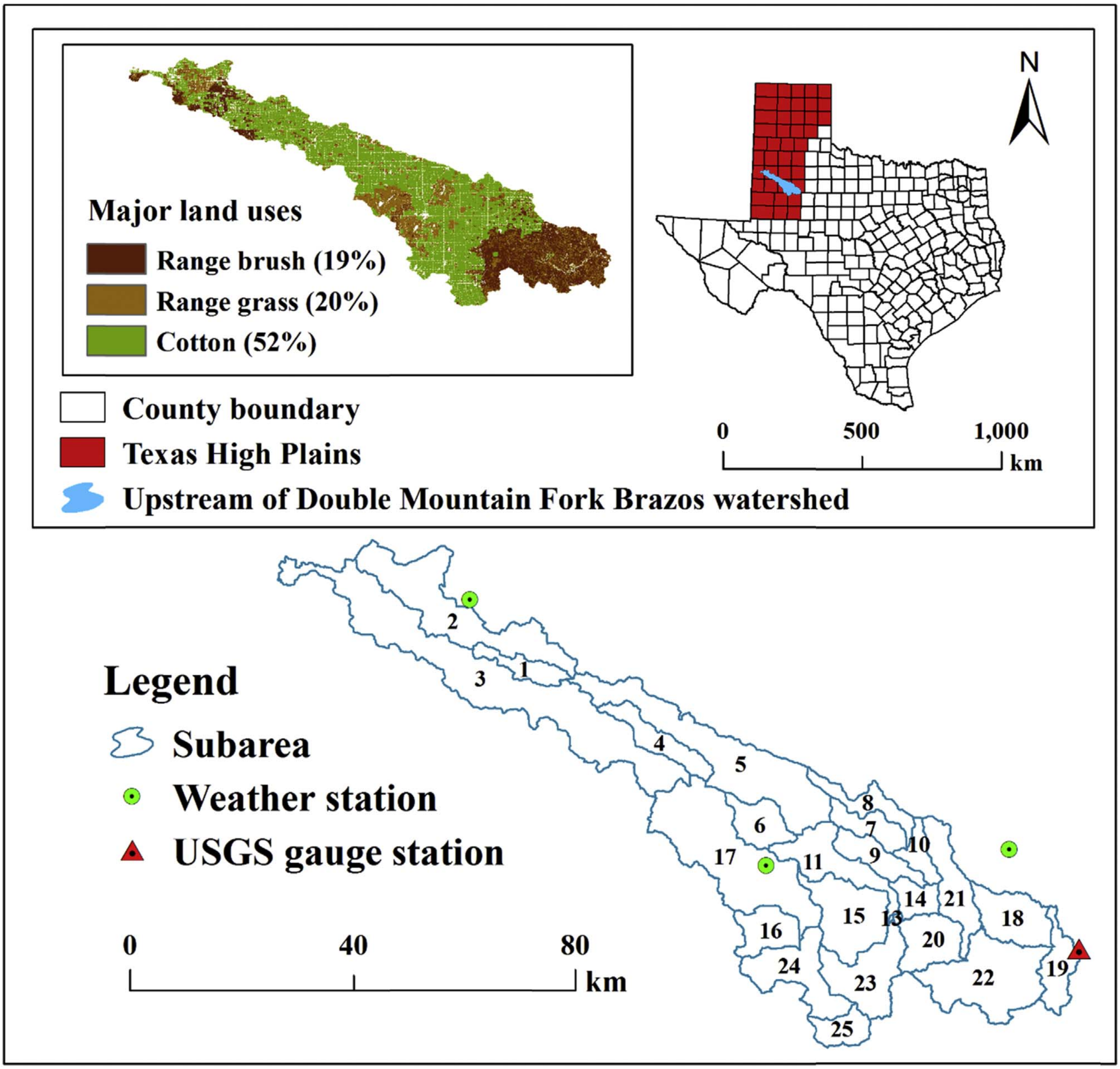

Fig. 1. Locations of the U.S. Geological Survey (USGS) gauging station and the National Climatic Data Center (NCDC) weather stations, and the major land uses in the upstream subwatershed of the Double Mountain Fork Brazos Watershed in the Texas High Plains.

allowable groundwater pumping at 457 mm (18 inches). Chaudhuri and Ale [7] also found that the percentage of groundwater quality observations from the shallow wells in the THP region that exceeded the United States Environmental Protection Agency's Maximum Contaminant Level (MCL) for nitrate (NO_3) (44 g m^{-3}) increased from 3% in the 1960s (1960–1969) to 32% in the 2000s (2000–2010).

Recently, cellulosic bioenergy crops have been promoted to fulfill the mandated 2022 U.S. biofuel target of 79 million m^3 [8] and about 11.4% of existing croplands and pastures in the Southeastern U.S., including the THP, were estimated to be required for producing biofuel according to the U.S. Department of Agriculture (USDA) [9]. Groundwater concerns, wind erosion and the biofuel target may necessitate substantial changes in land use and management in the THP such as adoption of the best management practices (BMPs) for cotton production and land use change from cotton to environment-friendly bioenergy crops. While groundwater pumping restrictions imposed by the HPUWCD address groundwater depletion concerns, growing of cover crops in the winter could not only serve as one of the BMPs for reducing wind erosion and improving groundwater quality, but also provide biomass for biofuel production. In addition, replacing cotton in the THP region with perennial grasses such as Alamo switchgrass (*Panicum virgatum* L.) and *Miscanthus* (*Miscanthus* × *giganteus*), which were identified as environment-friendly bioenergy crops in many studies [10–14] could also provide multiple benefits of protecting soil and groundwater quality, and meeting the national biofuel target. However, studies evaluating the long-term effects of growing cover crops and changes in land use from cotton to perennial grasses on hydrology and wind erosion are lacking in this region and this study focuses on this research gap.

The Agricultural Policy Environmental eXtender (APEX) model, a continuous, daily time step model with a built-in wind erosion module, was used in this study. The APEX model has demonstrated strength in simulating the impacts of BMPs and land use change on hydrology and wind erosion in many intensively farmed watersheds [15–23]. For example, using the APEX model, Wang et al. [24] found that the total sediment yield from the Shoal Creek Watershed in Texas was