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Corn Belt soil carbon and macronutrient budgets with projected sustainable stover harvest

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ABSTRACT

Corn (*Zea mays* L.) stover has been identified as a prime feedstock for biofuel production in the U.S. Corn Belt because of its perceived abundance and availability, but long-term stover harvest effects on regional nutrient budgets have not been evaluated. We defined the minimum stover requirement (MSR) to maintain current soil organic carbon levels and then estimated current and future soil carbon (C), nitrogen (N), phosphorus (P), and potassium (K) budgets for various stover harvest scenarios. Analyses for 2006 through 2010 across the entire Corn Belt indicated that currently, 28 Tg or 1.6 Mg ha^{-1} of stover could be sustainably harvested from 17.95 million hectares (Mha) with N, P, and K removal of 113, 26, and 47 kg ha^{-1}, respectively, and C removal for that period was estimated to be 4.55 Mg C ha^{-1}. Assuming continued yield increases and a planted area of 26.74 Mha in 2050, 77.4 Tg stover (or 2.4 Mg ha^{-1}) could be sustainably harvested with N, P, and K removal of 177, 37, and 72 kg ha^{-1}, respectively, along with C removal of ~6.57 Mg C ha^{-1}. Although there would be significant variation across the region, harvesting only the excess over the MSR under current fertilization rates would result in a small depletion of soil N (−5 ± 27 kg ha^{-1}) and K (−20 ± 31 kg ha^{-1}) and a moderate surplus of P (36 ± 18 kg ha^{-1}). Our 2050 projections based on continuing to keep the MSR, but having higher yields indicate that soil N and K deficits would become larger, thus emphasize the importance of balancing soil nutrient supply with crop residue removal.

1. Introduction

Corn (*Zea mays* L.) stover in the Corn Belt can be a prime feedstock for biofuel production in the United States because of its abundance (Shinners and Binversie, 2007) and the well-developed transportation infrastructure from the field to storage and processing facilities (Moore et al., 2013; Karlen et al., 2014). However, excessive removal of stover could adversely impact soil fertility and productivity (Varvel and Wilhelm, 2008; Tan et al., 2012; Kenney et al., 2013). With an increasing demand for crop residue as biofuel feedstock, balancing residue harvest and nutrient budgets to achieve sustainable crop production and soil fertility is becoming increasingly important. Excessive residue removal will enhance soil erosion, degrade soil physical properties and reduce the soil organic carbon (SOC) pool (Hammerbeck et al., 2012; Khanal et al., 2014). To define how much residue is required to maintain soil fertility, Johnson et al. (2006) proposed the minimum source carbon concept and used it to estimate the minimum amount of crop residue that needed to be retained to sustain soil carbon levels for continuous corn and corn-soybean systems in the U.S. Corn Belt. Wilhelm et al. (2007) also defined the minimum amount of stover retention as a function of soil erodibility, tolerable soil loss, surface slope, tillage method, cropping system, and grain yield. They concluded that the amount of stover required to maintain SOC was even greater than that required to control erosion. By defining the minimum stover requirement (MSR) associated with the baseline SOC level, tillage practice, and crop rotation, Tan et al. (2012) estimated current and future stover production and the harvestable stover amount (HSA) for corn-growing counties across the conterminous United States. More recently, Muth and Bryden (2013) proposed an erosion control integrated model to estimate crop residue removable limits at a state level. The U.S. Department of Energy (2011) documented the potential residue supplies from corn and other grain crops in the U.S. Billion-Ton Update using the POLYSYS model (a policy simulation model of the U.S. agricultural sector) (De La Torre

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Ugarte and Ray, 2000). This model estimates crop residue production by taking the residue as a function of crop yield, moisture, and residue-to-grain ratio. POLYSYS also considers residue production costs and the amount of residue that must remain to keep erosion within tolerable soil loss levels and to maintain SOC levels.

Regardless of the modeling approach, the basic criterion for determining the HSA is still "to maintain SOC level." Explicitly, the removable rate of corn stover varies with corn grain yield, climatic conditions, and management practices at a specific site (Johnson et al., 2010; Karlen et al., 2014). Karlen et al. (2014) evaluated the effects of corn stover harvest on corn grain yield and nutrient budgets based on multi-location observations across the Midwestern U.S. corn growing states. Their results are site-specific but can be used to verify model simulations and projections of available feedstock as addressed in the revised U.S. Billion-Ton Update.

Macronutrient and SOC budgets are frequently used to evaluate long-term sustainability of farming systems. According to Oenema et al. (2003), overall soil nutrient budgets reflect inputs and outputs, recycling, losses, and changes in soil nutrient pools even though specific losses from leaching, runoff, volatilization, and denitrification are usually uncertain (Oenema and Heinen, 1999).

Many studies have been conducted to estimate nutrient removal with corn grain and stover harvest (Johnson et al., 2010; Khanal et al., 2014; Karlen et al., 2014) and to understand nutrient uptake dynamics under diverse growth conditions (Setiyono et al., 2010; Karlen et al., 2014). Soil nutrient budgets are generally determined by either calculating nutrient removal from harvested crop components and the nutrient concentrations in those components as described by Murrell (2008) and Karlen et al. (2014), or by using a mathematical modeling approach such as a spherical model (Setiyono et al., 2010). The results from both approaches have been determined to be in good agreement for N, P, and K uptake (Tan et al., 2012).

This study was designed to (1) define baseline soil C, N, P, and K pools under predefined minimum stover requirement scenarios; and (2) evaluate the impacts of minimum stover requirement-based harvestable stover amount on soil C, N, P, and K pools for projected current and future stover production at state and regional scales.

2. Materials and methods

2.1. Study area

The U.S. Corn Belt is a region in the middle of the United States where corn is the predominant crop grown on relatively level land with deep, fertile soils. Specific geographic boundaries for the Corn Belt vary, but for this study we defined the area to include Iowa, Illinois, Indiana, Nebraska, Kansas, Ohio, eastern South Dakota, southeastern North Dakota, southern Minnesota, southern Michigan, southern Wisconsin, and northern Missouri (Fig. 1). For 2006 through 2010, corn was planted on an average area of 29.035 million hectares (Mha) and total grain production was 272.60×10^{12} g (Tg) (http://www.nass.usda.gov/Statistics_by_Subject/index.php?sector=CROPS).

2.2. Datasets

The datasets used for this study were: (1) historical county-based corn grain yield statistics for 12 states within the Corn Belt, derived from the U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) (http://www.nass.usda.gov/Statistics_by_Subject/index.php?sector=CROPS); (2) minimum

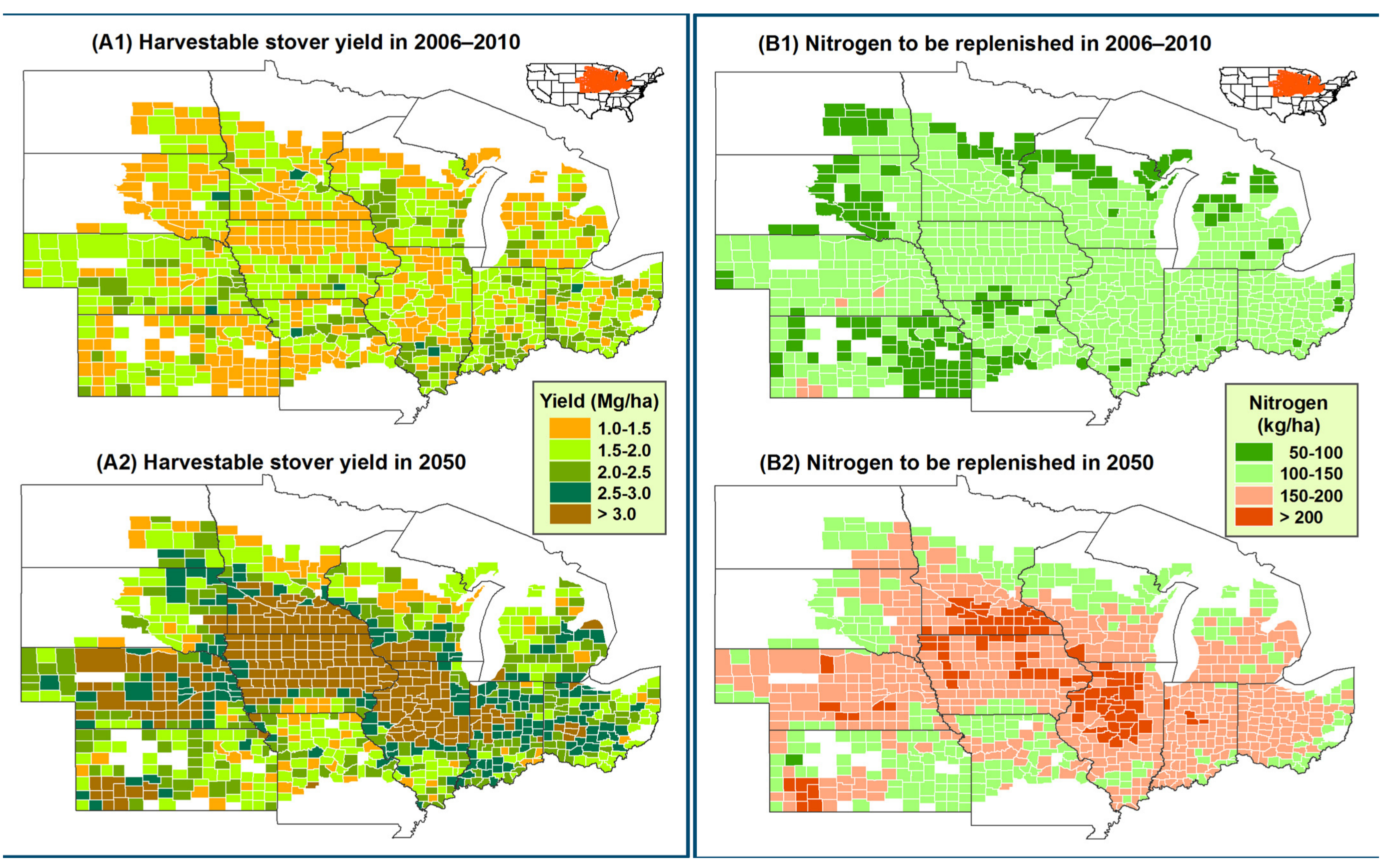

Fig. 1. Spatial distribution of projected harvestable stover yield and extra amount of nitrogen needed with the harvest option II at a county scale across the U.S. Corn Belt.