# Environmental Impacts of Stover Removal in the Corn Belt

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***Selected Paper prepared for presentation at the Agricultural & Applied Economics Association's 2012 AAEA Annual Meeting, Seattle, Washington, August 12-14, 2012***

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## Abstract:

When considering the market for biomass from corn stover resources erosion and soil quality issues are important to consider. Removal of stover can be beneficial in some areas, especially when coordinated with other conservation practices, such as vegetative barrier strips and cover crops. However, benefits are highly dependent on several factors, namely if farmers see costs and benefits associated with erosion and the tradeoffs with the removal of biomass. This paper uses results from an integrated RUSLE2/WEPS model to incorporate six different regime choices, covering management, harvest and conservation, into a simple profit maximization model to show these tradeoffs.

**Keywords:** Production, Environment, Biomass, Erosion

## Introduction

Environmental conservation in the United States typically focuses on soil erosion and the protection of wildlife populations. Several methods and programs have been developed to decrease and limit the amount of soil lost to wind, rill, and water erosion. From establishing set-aside acreage to changing tillage, practices have decreased erosion in several areas of the country. However, as policies consider changing land management strategies to remove biomass for bioenergy production, there are tradeoffs with environmental services and their effect on long-term yields that need to be considered for the removal of stover to be sustainable. Under the assumption that biomass feedstock production will be constrained by land availability, feedstocks alternatively will be produced from waste products or as part of a value-added supply system. Corn stover, as part of a value-added system has the potential to supply the biofeedstock market an estimated 170 to 256 million dry tons annually, depending on yield and tillage assumptions (U.S. Department of Energy, 2011). Other studies link the importance of soil moisture, erosion and nutrient replacement to determine sustainable rates of removal, estimating that 58.3 million Mg of stover could be sustainably harvested (Graham, et al., 2007).

However, harvesting stover has the potential to change land management strategies and has several environmental and production tradeoffs for the farmer and society that need to be evaluated regionally and at the field level. Stover provides certain ecosystem services when left on the field, which include protection from erosion, increased soil organic matter, nutrients, improved soil structure and water holding capacity, though these benefits vary with quantity, climate and management practices (Andrews, 2006). Wilhelm et al. (2007) and Muth and Bryden (forthcoming) identified soil organic carbon, wind and water erosion, plant nutrient balances, soil water and temperature dynamics, soil compaction and off-site environmental impacts as limiting factors to sustainable residue removal. As such, a continuous, reliable and sustainable biomass supply of stover is dependent on several spatially explicit variables that affect the economic and environmental sustainability aspects of stover removal throughout the Corn Belt. Assuming that a market for stover is viable, farmers need to be able to decide whether or not they should harvest corn stover, given these tradeoffs, and policy has the opportunity to guide these decisions in order to minimize on and off-site externalities. The objective of this study is to evaluate the economic and environmental tradeoffs through optimizing profit from the production of harvesting corn, soybean and stover with the effects of nutrient applications, erosion and conservation being included in the analysis. This paper aims to quantify these economic tradeoffs with an integrated water and soil erosion model based on location specific properties, soil characteristics and management decisions commonly found throughout Indiana.

## Literature Review

Harvesting stover sustainably has several environmental, management and policy constraints to consider. Additional limitations to sustainably harvesting stover are current field management practices, which include tillage and nutrient management. The U.S. Department of Energy publication, "U.S. Billion-ton Update, Biomass Supply for a Bioenergy and Bioproducts Industry" (BTSU) assumes that stover residues will be removed from reduced or no-till land and assumes that none will be removed from land in conventional tillage[2] (U.S. Department of Energy, 2011). Conservation tillage practices vary throughout the country based on soil type and crop. Of the 83 million acres in corn production in 2008, 21% was in no-till, 1.4% ridge-till, 17.8% in mulch-till, and 24.3% in reduced tillage (Conservation Technology Information Center, 2008). Adoption of tillage practices vary based on several producer and farm characteristics, in

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[2] Conventional tillage is where producers use a disc or plow to incorporate residues into the soil post-harvest, leaves less than 15% residue. Conservation tillage includes, no-till, ridge-till and mulch-till, which leaves greater than 30% residue and reduced tillage 15-30% cover.

addition to local, state and national agency requirements (Bultena and Hoiberg, 1983). Farmers may not adopt conservation practices due to a lack of onsite economic costs incentivizing different farming practices. The economic decision of the farmer weighs the direct costs of undertaking conservation measures and replacement costs through increased inputs and increased equipment costs with the opportunity costs of forgone future productivity through soil losses (Barbier, 1996, Javurek, et al., 2007, Larson, et al., 2001). The marginal private benefits and costs may not induce conservation tillage adoption, therefore, the USDA National Resource Conservation Service suggests 30 percent of the field to be covered in the spring to prevent soil erosion with the additional tolerance level (T-Factor) that soil erosion is estimated to be no more than 3 to 5 tons of soil/acre/year[3] (Gallagher, et al., 2003). The productivity losses of erosion, except in the extreme cases, can take several decades to see through decreased yields. Additionally, due to improved seed varieties, irrigation and weather, yields can remain constant or improve even with soil losses. It is estimated that erosion between 5 and 12 tons/hectare/year or 0.4-1 mm/year can balance soil production and losses, in low sloping areas (Montgomery, 2007). Erosion rates over 100 tons/hectare/year[4] is considered extreme, 17 tons/hectare/year is average for croplands in the United States and for undisturbed forests erosion rates average about 0.05 tons/hectare/year (Pimentel, et al., 1995).

Some of the effects of erosion may be mitigated through alternative management strategies like using cover crops, green manure and precision agriculture (Tyndall, et al., 2011). However, these strategies and technologies may not be widely adopted throughout the Corn Belt. This translates into greater uncertainty in the marketplace about the long-term and local effects of removal, best management strategies and potential conflicts with current conservation policies which likely results in a farmer being conservative in harvesting or potentially unwilling to participate in the market. Adding the potential profits from stover collection may change the marginal price to induce more adoption of conservation

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[3] In order to maintain lands with soil erosion under the tolerable limits, producers are eligible for certain government programs and assistance under EQUIP, CRP, WEP. Soils that are classified as highly erodible have different stricter requirements in regards to conservation practices and acceptable erosion rates.

[4] This translates into less than an acre-inch.

management strategies like no-till and cover crops or incentivize removal with nutrient replacement as long as erosion rates remain under tolerable levels.

Several additional factors affect the amount of stover available for removal. Rainfall and temperature during different phases of the growth cycle and harvest, along with fertilizer application, are the main driving factors in corn yields, as well as the resulting quantities of biomass (Cantero-Martinez, et al., 2006, Mann, et al., 2002). Stover residues have increased in volume as a result of higher plant populations, the usage of fungicides and hybrid seeds and decreases in residue breakdown from tillage practices (Jeschke, 2011). In addition, the economic and ecosystem value attributed to stover in the field depends on soil temperature, erosion rates, increases in organic matter, increased carbon sequestration, reduced fuel consumption, lower maintenance and labor costs (Deen and Kataki, 2003, Lal, et al., 1999, Lankoski, et al., 2004, Toliver, 2010). Harvesting stover impacts nutrient removal and cycling, beyond nitrogen, phosphorous and potassium to micronutrients like calcium, magnesium and sulfur, while leaving it in the field can affect the absorption rates of nutrient application, both can impact long-term yields (Sawyer and Mallarino, 2007). The amount and the effect of residue left on the field depends on several factors (e.g. slope, soil characteristics, tillage, drainage, soil organic matter and carbon (SOM/SOC)) which need to be considered, although the interactions between these components are quite complex (Coulter and Nafziger, 2008).

Several studies have looked at the linkage between soil characteristics and the dynamics of stover removal on erosion (Johnson, et al., 2006, Mann, et al., 2002, Reicosky, et al., 1995). Although there are many factors that affect the soil characteristics in a field or region, the presence of SOC in agricultural soils has been shown to be an important but, imperfect signal on soil health and yields through direct and indirect feedback effects (Reeves, 1997). Of the soil organic matter from residues that is returned to the soil, roughly 58% of it is converted into SOC. Accumulation of SOC depends on the rate at which biomass is added to the soil minus the rate at which erosion and biological oxidation are decreasing the SOC stocks. In general, soil cultivation decreases the amount of soil organic carbon available, by increasing the rates of oxidation and erosion. Although a majority of the SOM comes from plant roots, the effects of stover removal without offsetting practices can degrade soils over time, through wind and water erosion. In addition to surface crop residue, rotation and cover crops along with conservation covers, increase the amount of biomass available for this biological process (Follett, 2001). Though a greater percentage of stover may be required to limit SOC losses, given that carbon turnover in the soil may be a slower process than the effects of SOC on erosion (Johnson, et al., 2006, Johnson, et al., 2006, Wilhelm, et al., 2007).

Nutrient replacement is a significant concern in regards to stover harvest activities. Previous studies by Fernandez (2007) and Sawyer (2007), have found that the NPK content of harvested stover also varies throughout the Corn Belt. The effectiveness of nutrient replacement depends on mobilization, concentrations, application rates and erosion. Brechbill, Tyner and Heleji (2008) calculate that nutrient replacement costs for NPK content of the stover is approximately $17.23 per metric ton of stover removed, but do not consider the costs of replacing other micronutrients that stover returns to the soil. Thompson and Tyner (Forthcoming) estimate that the cost of replacing micronutrients is estimated to be \$2.00 Mg$^{-1}$ and that total nutrient replacement costs are approximately 24.17 Mg-1, which accounted for over half the harvest costs. Estimates vary based on fertilizer costs, which change spatially and temporally, and crop rotation (U.S. Department of Energy, 2011).

The environmental and management limitations of stover harvest are weighed with the economic decisions. Private costs to the farmer may include increased nutrient and management costs and public costs to society may be incurred through increase nutrient runoff, erosion, decreases in soil organic carbon, and micronutrient losses that affect the long-term productivity of the land. These concerns were identified as potential information barriers to market participation for farmers choosing to harvest and market corn stover (Sawyer and Mallarino, 2007, Tyndall, et al., 2011). The environmental and economic factors vary throughout the Corn Belt, suggesting different marginal costs of stover and regional limitations to harvesting. These heterogeneous and temporal costs affect supply density, which in turn determines plant locations, profitability, and environmental implications of removal. When considering the removal of corn stover from agricultural fields in the Midwest, the benefits and costs associated with changes in management are considered. The biofuels market opportunities for stover harvesting and marketing weigh the additional profits of stover with the increased nutrient management costs, environmental opportunity costs and the potential changes to yields. On farm, the main objectives of the farmer are to maximize the production, minimize input costs and to keep soil erosion within tolerable limits. The effects of tillage on yields varies throughout the Corn Belt and the benefits of conservation may not be immediately seen by the farmer as a proportion of the benefits can be attributed to future soil health and production and decreases to off-site costs (Barbier, 1996, Toliver, 2010).

Recognizing the linkage between environmental factors and incentivizing stover harvest, may create unintended consequences in conservation planning of natural resources. Considering for a moment, that farmers have numerous tradeoffs that occur in the corn grain and stover harvesting decision. In order to maintain short-term productivity of the land, a farmer will manage soil health and the amount of erosion through management techniques described previously[5]. Although there are several other tradeoffs that the farmer makes, these two non-market goods are influenced by the relative prices of conservation practices and nutrient management. As a farmer undertakes practices to decrease erosion and improve soil health, the farmer can move along the production possibilities curve. It is useful to illustrate that a farmer when facing other economic constraints, will not likely be at either corner solution, as these represent such extremes as soil mining (where soil health =0) and complete conservation practices (erosion =0). An optimal internal solution would mean that a farmer is producing some erosion and some level of soil health. When taking a longer-term view of the tradeoff, farmers closer to the corner solutions productivity/yields will not likely remain constant. These tradeoffs are important to consider when defining sustainability and prescribing policies to limit soil erosion when harvesting stover.

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[5] The curvature of the production possibility curve assumes that the level of productivity and the effectiveness of the management strategy are inherent to the soil and climactic characteristics. Each location may skew these characteristics or the effectiveness of management practices.

As farmers will need to choose the optimal amount of stover harvested while minimizing the effects of removal on soil erosion and the health of the soil, the problem can be formulated into an optimization problem, to identify key tradeoffs between these decisions. McConnel (1983) used optimal control theory to identify the key tradeoffs in conservation management in soil conservation, concluding that farmers will erode the soil up until the point at which the marginal costs of erosion is equal to the marginal revenue adopting conservation practices. Though, one major assumption in this work was that the private and social objectives were identical. Barbier (1988) updates the McConnell model by adding in the temporal effects of erosion, noting that as the discount factor increases it creates incentive for erosion, as the effects of erosion may take longer to realize. Two major conclusions that this work emphasizes is that a change in output and input prices are contradictory in terms of soil conservation. As price increases maybe variable over time, short-term gains and intensification in production are reflected in potentially long-term soil losses. However, as profitability increases over time, there may be additional incentives to conserve soil. These issues can be highlighted in the corn stover problem as the additional revenues contributed to farmer profits may disproportionately effect future soil conservation as some of the effects of removal can be offset by additional applications of nutrients.

## Methods

### Integrated Environmental Model and Scenarios

The economics that interact with the biological system come in the form of the trade-offs between stover removal and changes to the soil health and yields. Through management practices of the farm, a farmer can choose strategies that benefit both the environment and their profit margins through the removal of stover. Accounting for the spatial heterogeneity of soil dynamics and erosion is accomplished through the use of an integrated model which combines the Revised Universal Soil Loss Equation (RUSLE2) and the Wind Erosion Equation (WEPS). These models are coupled with databases that contain relevant climate, soils, management weights, yields and location specific properties.

The integrated RUSLE2 and WEPS model was developed as an assessment tool for residue availability throughout the United States. Most recently the model was used to assess the sustainability of stover removal in Iowa (Muth and Bryden, 2011). The RUSLE2 model simulates field conditions at the farm level based on soil, climate, field management, cropping, and residue effects to estimate the effects of daily weather patterns on water based erosion. RUSLE2 is mainly used in conservation planning and controlling for the effects of rill and interrill types of erosion on land usage from crop, pasture, range and forest lands (Foster, 2005). The WEPS model, uses several of the same field level conditions to simulate the effects of weather on soil erosion by direction and magnitude. WEPS is comprised of several submodels (weather, hydrological, residue, soils). These models simulate the likely erosion response to a variety of environmental and management factors, as such these models enumerate the potential outcomes of farm-level decisions. David Muth and his colleagues at Idaho National Lab built the integrated model and provided the data and simulations for this paper. The scenarios that were calculated for this economic analysis can be found in Table 1.

Table 1: Regimes for the Integrated RUSLE2/WEPS Model

| | | |
|---|---|---|
| Crop Rotation | CG | Corn grain |
| | SB | Soybeans |
| Cover Crop Regime | NCC | No cover crop |
| | 100rye | 100% Rye winter cover |
| | 40rye, 60clover | 40% Rye winter cover, 60% Clover winter cover |
| | 60rye, 40radish | 60% Rye winter cover, 40% Oilseed Radish winter cover |
| Tillage Regime | RT | Reduced Tillage: Chisel Plow, Disk tandem light finishing |
| | NT | No Tillage: Minimum possible disturbance |
| Residue Removal Regime | NRH | No Residue Harvest |
| | MRH | Moderate Residue Harvest: Approximately 35% |
| | MHH | Moderately High Residue Harvest: Approximately 50% |
| | HRH | High Residue Harvest: Approximately 80% |
| Barrier Regime | NVB | No vegetative barrier |
| | SVB | Strip vegetative barrier: modeled as cool season grass 3m wide in middle of slope |

Note: For each crop management zone and soil type for Indiana, each permutation of the above regime was used in the model.

These scenarios represent the most likely cropping and management decisions for Indiana. Given the diversity in landscape of the state, the results from the integrated model were then related back to geographic locations based on SURGO soil type, slope, 2008-2010 cropping rotations, and tillage practice[6]. The scenarios were undertaken based on soil type, under the assumption that farmers will choose management practices to the dominant soil conditions of their farm for a three-year period. These choices are limited by their respective effects on the t-factor, or overall erosion.

Table 2: Example of the Regime combination for the Integrated Model

| Name | Date of operation | Description of operation | Crop |
|---|---|---|---|
| **CMZ01-CG,SB-NT-NRH-NCC-NVB** | 5/10/1 | Planter, double disk opnr w/fluted coulter | Corn, grain |
| **CMZ01-CG,SB-NT-NRH-NCC-NVB** | 9/17/1 | Harvest, killing crop 50pct standing stubble | |
| **CMZ01-CG,SB-NT-NRH-NCC-NVB** | 5/25/2 | Drill or airseeder, double disk, w/ fluted coulters | Soybean, group 0 and I, 7in rows |
| **CMZ01-CG,SB-NT-NRH-NCC-NVB** | 9/12/2 | Harvest, killing crop 20pct standing stubble | |

Note: The naming convention for this example is crop management zone 1 (CMZ01), corn-soybean rotation(CG,SB), no-till (NT), no stover harvested (NRH), no cover crop (NCC), no vegetative barrier(NVB).

The integrated modeling framework outputs four variables critical in the economic optimization framework. The first is the Soil Conditioning Index (*SCI*). The SCI is used to predict whether the management practices result in maintained or increased levels of soil organic matter. The SCI combines the effects of organic matter returned to the soil (*SCI_OM*); field operations (*SCI_FO*) such as tillage, fertilizer application, harvesting etc.; and the erosion factor (*SCI_ER*). The values of the SCI signal the trend in organic matter given these factors. It does not predict the amount or the rate of change of organic matter. It should be interpreted within the context of the soil class, as such, poor soils with a SCI near zero are maintained as poor soils (Soil Quality Institute, 2003). The second and third important variables are those relating to wind (*windEros*) and water erosion (*waterEros*). These variables dictate both on-site and off-site costs to the production decisions. On-site costs can be offset through the use of cover crops,

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[6] The data for these layers can be found the NRCS Soil data mart (SURGO, http://soildatamart.nrcs.usda.gov/), Geospatial gateway(Elevation and Cropland Data Layer, http://datagateway.nrcs.usda.gov/) and the Indiana Department of Agriculture (tillage practices, http://www.in.gov/isda/files/2011_Poster.pdf).

increased nutrient replacement and potentially decreases in yields over time. Off-site costs have to do with sediment delivery into watersheds or the transfer of this resource to other farms. The fourth variable is the total biomass (*totBioRem(yr)*) removed under the different regimes. Ultimately, the quantity of stover harvested will drive a producer's decision to participate in the biomass market.

## Economic framework

Based on these scenarios, the farmer's decision making can then be viewed through a dynamic optimization framework, in which the farmer will choose to maximize profits from the production of corn, soybeans and stover subject to the production of these crops and their relative variable and environmental costs. The basis of comparing scenarios is that farmers can choose not to harvest any stover, practice conservation buffers or cover crops and remain in reduced tillage. The general formulation of this objective is,

$$\max \mathrm{E}\pi = \int_0^T e^{-rt}[p_i y_i(s, x, z) - c_i z_i]dt \quad \textbf{(1)}$$

Subject to an equation of motion,

$$\dot{y} = h(z) \qquad \textbf{(2)}$$

$$z_{t+1} = Rate * y_t + Rate * y_{t,stover} + Rate * x_t \quad (3)$$

where *r* is the farmer (i) discount rate, *p* is the price of the output, *y* is a function of output for each cropping rotation i, (continuous corn, corn-soybean, corn-corn-bean), based on *s(t)* soil loss, *x(t)* soil quality, and *z(t)* a vector of inputs (e.g. replacement costs for fertilizer). The value of **z** in any period depends on activities in the previous period with regards to crop, stover removal and erosion. This model has been widely used for looking at the effects of soil losses on productivity from an economic standpoint (Barbier, 1988, Barbier, 1996, McConnell, 1983) and is useful for looking at the effects of current decisions on future outcomes. Although the model has been used for decades to incorporate erosion into economic and conservation decision making, constraints have been included to limit off-site damages related to sediment delivery (Shortle and Miranowski, 1987), limiting non-point pollution sources and abatement strategies over time and space (Xabadia, et al., 2006) and when looking at the spatial-temporal dynamic processes of resource systems (Smith, et al., 2009).

The heterogeneous nature of farms in the agricultural landscape for Indiana has been used to incorporate the differences in cropping patterns, soil characteristics and yields from an economic and environmental standpoint. Our model estimates the optimization problem as,

$$\max\{\pi_{CG}, \pi_{CG,SB}, \pi_{CG,CG,SB}\} \tag{4}$$

$$\pi_{CG} = p_{CG} * y_{CG} + p_{Stover} * y_{Stover} - r * \mathbf{z} - r_{Stover} * \mathbf{z}_{Stover} \tag{5}$$

$$\pi_{CG,SB} = \frac{1}{2}\{ p_{CG} * y_{CG} + p_{Stover} * y_{Stover} - r * \mathbf{z_1} - r_{Stover} * \mathbf{z}_{Stover}\} + \frac{1}{2}\frac{p_{SB} * y_{SB} - r * \mathbf{z_2}}{1+\delta} \tag{6}$$

$$\pi_{CG,CG,SB} = \frac{1}{3}\{ p_{CG} * y_{CG} - r * \mathbf{z_1} + p_{Stover} * y_{Stover} - r_{Stover} * \mathbf{z}_{Stover}\} + \frac{1}{3}\frac{\{ p_{CG} * y_{CG} - r * \mathbf{z_2} + p_{Stover} * y_{Stover} - r_{Stover} * \mathbf{z}_{2,Stover}\}}{1+\delta} + \frac{1}{3}\frac{p_{SB} * y_{SB} - r * \mathbf{z_3}}{(1+\delta)^2} \tag{7}$$

where

$\pi_i$ is measured as (\$/acre).

$\delta$ is the discount factor

**i** is the crop choice [corn, soybeans, stover]

**p**$_i$ is a vector of output prices (\$) based on 2012 Purdue Crop Budgets and stover prices are based on Thompson and Tyner (Forthcoming)

**r** is a vector of input prices (\$) based 2012 Purdue Crop Budgets

**z** are replacement nutrients [fertilizer(N,P,K)] and variable and fixed costs related to the production and harvest, nutrient replacement equations explicitly are in Equations 16-18

The optimization of profit includes discounting future aspects of the rotation to the present time. The profit decision examines the main economic drivers influencing crop choices, based on location specific parameters. Imbedded in the profit function and the equations of motions contain several of the farmer's choice variables. We surmise that the farmer can choose the crop rotation, cover crop regime, tillage regime, residual removal regime, yield regime and vegetative barrier regime (Table 1). The combinations of these six decisions enumerate 576 different options for the farmers of soil type in each county, resulting in over 1.6 million different options from the integrated erosion models. Inputs for the production of corn in regards to nutrients are the same that go into the production of stover. As time passes, the inputs in future time periods will also need to include replacement of nutrients removed when harvesting stover. Corresponding prices and costs can be found in Table 3.

As the effects of erosion can be difficult to quantify in terms of yield reductions, except in extreme events, these losses can take years to be apparent[7]. Pimentel (1995), estimates that the effects of 17 tons/hectare/year, assuming a soil depth of 15 cm, a 5% slope on loamy soil containing 4% organic matter, in conventional tillage, in the United States, would result in 8% lower corn yields in the next year, without offsetting the losses in nutrients, water and other inputs. Bishop and Allen (1989), estimate that the relationship between yields and erosion is

$$y_{t+1} = y_t e^{-\beta \Delta x_t} \qquad (8)$$

$$\mathrm{x}_{t+1} = f(y_t, z_t, CC_t, till_t, HR_t, VBR_t) \qquad (9)$$

where $\mathrm{x}_t$ is the incremental loss of soil and $\beta$ is a constant that varies by crop and slope[8]. Using the estimates from Pimentel (1995), $\beta$ would equal 0.0049. For yields to remain near constant, the rate of erosion would need to be closer to 2 tons/acre/year for a 5% slope, holding all other variables constant. In our model, $\mathrm{x}_t$ is a result of the integrated RUSLE/WEPS model and is the net wind and water erosion determined by slope, rotation, crop, cover crop (*CC*), tillage (*till*), residue removal (*HR*), and vegetative barrier (*VBR*) choices. Losses in productivity resulting from erosion are twofold; losses can be in quantity, through the physical loss of topsoil, and in quality, through the degradation and depletion of nutrients. Accounting for these decreases can be offset to varying degrees through other inputs and technologies that will affect yield.

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[7] It is important to note that here are several additional factors that go into assessing the effects of erosion on productivity, and several models (EPIC, APEX) have been built to asses these additional site-specific characteristics.

[8] Though since Bishop and Allen (Bishop, J., J. Allen, and W.B.E. Dept. 1989. *The on-site costs of soil erosion in Mali*: World Bank, Policy Planning and Research Staff, Environment Department.), was published the magnitude of erosion losses is also considered to be affected by soil type, climate, land preparation, management etc. (Enters, T. 1998. *Methods for the economic assessment of the on-and off-site impacts of soil erosion*: IBSRAM. )

Table 3: Cost Estimates For the Model

| Item | | unit | Value |
|---|---|---|---|
| **Corn** [9] | | $/ Bushel | $ 7.00 |
| **Soybeans** | | $/ Bushel | $ 12.00 |
| **Stover**[10] | | $/ ton | $ 80.00 |
| **Cover crops** | | | |
| | 100% Rye | $/acre | $ 31.69 |
| | 40/60 Rye-Clover mix | $/acre | $ 36.61 |
| | 60/40 Rye-Radish | $/acre | $ 30.41 |
| **Nutrients** [8] | | | |
| | Nitrogen | $/ lb | $ 0.54 |
| | Phosphorus | $/ lb | $ 0.74 |
| | Potassium | $/ lb | $ 0.57 |
| **Vegetative barrier**[11] | | $/acre | $ 100.00 |
| **Stover Harvest (includes net wrap, Fuel and labor)** | | $/ton | $ 34.03 |
| **Machinery Costs by Rotation and tillage**[12] | | | |
| **No-till** | | | |
| | Continuous corn (CG) | $/acre | $ 78.80 |
| | Corn in Rotation | $/acre | $ 65.06 |
| | Soybeans in Rotation | $/acre | $ 65.35 |
| **Reduced Tillage** | | | |
| | Continuous corn (CG) | $/acre | $ 78.80 |
| | Corn in Rotation | $/acre | $ 68.41 |
| | Soybeans in Rotation | $/acre | $ 74.67 |
| **Misc. Costs (seed, pesticides, hauling, drying, etc.)** | | | |
| | Continuous Corn yields less than 122 Bu/ac | $/acre | $ 256.00 |
| | Continuous Corn yields greater than 184 Bu/ac | $/acre | $ 294.00 |
| | Continuous Corn yields between 122 and 184 bu/ac | $/acre | $ 289.00 |
| | Corn in Rotation, yields less than 130 Bu/ac | $/acre | $ 252.00 |
| | Corn in Rotation, yields greater than 193 Bu/ac | $/acre | $ 285.00 |
| | Corn in Rotation, yields between 130 and 193 Bu/ac | $/acre | $ 282.00 |
| | Soybeans in Rotation | $/acre | $ 150.00 |

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[9] These costs are based on the Purdue 2012 Purdue Crop Cost & Return Guide Purdue Extension (2012) 2012 Purdue Crop Cost & Return Guide.

[10] Thompson, J.L., and W.E. Tyner. Forthcoming. "Corn Stover for Bioenergy Production: Cost Estimates and Farmer Supply Response."

[11] NRCS, N.R.C.S. *Controlling Soil Erosion.*

[12] These costs are based on the machinery used within the integrated model and on cost estimates from 2011 machinery costs from Iowa State ExtensionIowa State University Extension (2011) Estimated Costs of Crop Production in Iowa -2011 and Michigan State Extension Lazarus, W.F. (2012) Machinery Cost Estimates.

Since we want to isolate the contribution of controlling for erosion in the current period, the equation of motion needs to assume that the yield trend is zero. This allows for a simplification in the amount, type, and returns to inputs needed to maintain yields. In order for the equation of motion to be in a steady-state, the following constraint must also be true,

$$ln\, y_t = ln\, y_0 - \beta \Delta x_t \quad (10)$$

$$ln\, (y_t / y_0) = -\beta \Delta x_t \quad (11)$$

$$0 = \beta \Delta x_t \qquad (12)$$

Where β or $x_t$ must be zero. Offsetting erosion $x_t$ is captured through the changes in nutrient, management choices.

The application of nutrients has been found to have diminishing marginal benefits in areas of the Corn Belt, but can replace some of the losses due to erosion, although other micronutrients may become limiting factors in productivity (Paulson and Babcock, 2010). In order to simplify the effect of erosion and to maintain yield levels, nutrient replacement values were based on the average annual quantities lost per ton of erosion found in Pimentel (1995). For inputs needed to maintain yields in period t, the following constraint was added for fertilizer usage. The equation is based on the Tri-state Fertilizer Recommendations For Corn, Soybeans, Wheat and Alfalfa (Vitosh, et al., 1995) for nitrogen, phosphorus and potassium and with recommendations for stover nutrient replacement from (Brechbill and Tyner, 2008) and erosion losses (Pimentel, et al., 1995). The units for z, are pounds per acre.

$$z_{t+1}(Nfert) = 110 + \{1.36 * y_{ti} - 100\} - Ncredit + 17.52 * y_{Stover} + 16.01 * \mathrm{X}_{\mathrm{i,t}}$$
(13)

$$z_{t+1}(Pfert) = y_i * CR_i + 6.503 * y_{Stover} + 0.6406 * \mathrm{X}_{\mathrm{i,t}} \qquad (14)$$

$$z_{t+1}(Kfert) = y_i * CR_i + 33.06 * y_{Stover} + 131.329 * \mathrm{X}_{\mathrm{i,t}}; \qquad (15)$$

NCredit is the nitrogen credit given by the previous crop, soybean credit is 30 lbs/acre. CR is the portion of nutrients removed per pound and by bushel (For corn, 0.37 of P and 0.27 of K, for Soybeans 0.8 of P and 1.4 of K). These are averages; individual farms and soils will have specific recommendations based on levels already present in the soil. The other inputs within the vector z, (tillage, vegetative buffer strip and cover crop), decrease the overall amount of erosion, $x_t$. The effect of these practices on erosion are calculated within the integrated model, though it is important to include the costs of adopting these practices within our optimization model. Therefore, therefore z(other) will equal 1 if the practice is in place.

The analysis for this paper has been limited to Jasper County, IN, to illustrate the optimal decision making process under various scenarios and sensitivities, given the variability throughout the county. Jasper County has 79 different soil types. Given that each soil type has 576 different regime choices, there are 46,080 observations in total. Future work will include all counties in Indiana and the Midwestern region. The description of the scenarios can be found in Table 4.

Table 4: Sensitivity Scenarios

| **Scenarios** | **Description** |
|---|---|
| **Optimal** | High crop prices ($7/bu corn, $12/bu soybeans, $80/ton stover); Erosion Nutrient replacement rates of (16.01- 0.064-131.329), (NPK lbs/acre) |
| **NoCoverNoErosionRR** | High crop prices; No Cover Crops; No Erosion Nutrient Replacement |
| **HighStoverP** | $7/bu corn, $12/bu soybeans, $90.97/ton stover; Erosion Nutrient replacement rates of (16.01- 0.064-131.329), (NPK lbs/acre) |
| **LowStoverP** | $7/bu corn, $12/bu soybeans, $34.03/ton stover; Erosion Nutrient replacement rates of (16.01- 0.064-131.329), (NPK lbs/acre) |
| **HighCoverCP** | High crop prices; Erosion Nutrient replacement rates of (16.01- 0.064-131.329), (NPK lbs/acre); Cover Crop Prices increase by a factor of 3.35 |
| **NoConservation _LowErosionCost** | High crop prices; Erosion Nutrient Replacement rates of (2.32-1-0) (NPK lbs/acre); Forced Reduced Tillage, No Cover Crop and No Vegetative Barrier |
| **NoConservation _HighErosionCost** | High crop prices ($7/bu corn, $12/bu soybeans, $80/ton stover); Erosion Nutrient replacement rates of (16.01- 0.064-131.329), (NPK lbs/acre); Forced Reduced Tillage, No Cover Crop and No Vegetative Barrier |

## Results and Discussion

The economic framework laid out in the previous section was tested under a variety of scenarios, in order to look further into the tradeoffs in environmental services and the biomass market. For each scenario, different assumptions were tested and the average profit, erosion, biomass harvested and NPK nutrients can be found in Table 5. These averages smooth much of the variability throughout the landscape. Therefore, samples of each of the calculations for one specific soil type were enumerated in Tables 6 and Table 7. One important caveat when looking at the profit calculated in the model, is that it does not include labor or rental costs that the farmer would have to additionally account for when making on farm decisions.

Table 5: Selected Estimates From Model Scenarios

| | Average | | | | | |
|---|---|---|---|---|---|---|
| | **Profit** | **Erosion** | **Biomass** | **N** | **P** | **K** |
| **Scenario** | $/acre | tons/acre/year | tons/acre | lbs/acre | lbs/acre | lbs/acre |
| **Optimal** | 803.879 | 0.206 | 2.826 | 307.342 | 93.080 | 174.977 |
| **NoCoverNoErosionRR** | 746.774 | 0.447 | 2.579 | 275.769 | 84.946 | 135.024 |
| **HighStoverP** | 931.053 | 0.206 | 2.848 | 307.445 | 93.145 | 175.701 |
| **LowStoverP** | 685.388 | 0.031 | 0.140 | 236.005 | 69.760 | 58.902 |
| **HighCoverCP** | 712.009 | 0.350 | 2.409 | 277.608 | 83.650 | 175.185 |
| **NoConservation _LowErosionCost** | 679.40 | 11.872 | 3.786 | 310.653 | 100.910 | 172.173 |
| **NoConservation _HighErosionCost** | 483.58 | 1.755 | 0.039 | 239.798 | 63.218 | 277.596 |

The scenario **optimal**, captures the effects of high prices for corn, soybeans and $80/ton stover prices, but penalizes farmers highly for erosion in terms of nutrients. Stover prices were chosen through other studies that estimate that farmers will be incentivized to add additional acres to corn production to boost stover production (Thompson and Tyner, Forthcoming). This assumes a uniform price for biomass, regardless of distance to end demand markets and regional concentrations of supplies. The optimal choice for all soil types for management under this scenario was continuous corn, no-tillage, medium harvest, 100% rye cover crop, with no vegetative barrier for all soil types. Under this scenario, average profit per acre was $803,

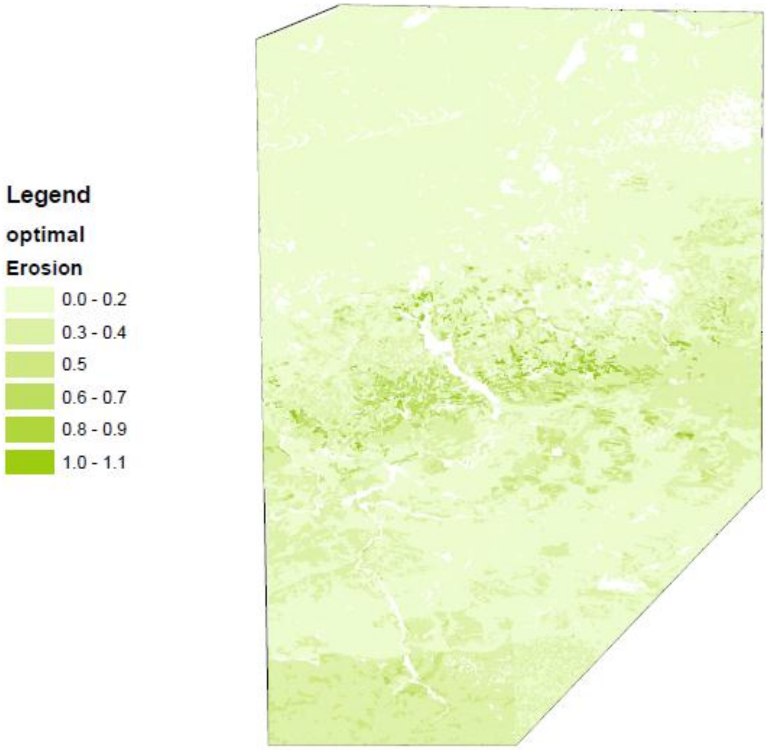

Figure 1: Erosion under the Optimal Scenario for Jasper County

Table 6: Selected Estimates From Model Scenario Optimal

| | | | | | |
|---|---|---|---|---|---|
| **Scenario** | Optimal | | | | |
| **FIPS** | 18073 | | | | |
| **MUKEY** | 161381 | | | | |
| **Regime** | CG.100rye.NT.MHH.NVB.2010YLD | | | | |
| **Profit** | | | | | $ 807.72 |
| **Revenue** | | | **units** | **Price** | **Profit** |
| | | Corn | 1400 | $ 7.00 | $ 199.99 |
| **Revenue** | | stover | 129 | $ 45.97 | $ 2.80 |
| **Revenue** | | | | | $ 1,528.66 |
| **Cost** | | | **units** | **Price** | **Net** |
| | | Nitrogen | 163 | $ 0.54 | $ 301.45 |
| | | Phosphorus | 68 | $ 0.74 | $ 92.21 |
| | | Potassium | 85 | $ 0.57 | $ 149.89 |
| | Cover Crop | | | | $ 31.69 |
| | Misc Variable Costs | | | | $ 294.00 |
| | Machinery Costs | | | | $ 78.80 |
| **Cost** | | | | | $ 720.94 |

averaging 2.8 tons/acre of biomass, and average erosion was 0.21 tons/acre/year. The significant result of this case is the overall low level of erosion from the adoption of cover crops for most areas of the county (Figure 1).

The second case has no erosion replacement cost and no cover crops or vegetation barrier strips, the **NoCoverNoErosionRR** scenario. Under this scenario, the average amount of erosion increased to 0.44 tons/acre/year. Variability through the landscape is important to consider in this scenario as the increase in erosion comes from additional biomass removed from the highly erosive soils in the northeastern corner of the county. No constraint was added to keep erosion under USDA recommendations in order to see where the market would incentivize removal regardless of erosion rates. This is an important consideration when considering the potential market for stover biomass and recommendations for cover crops.

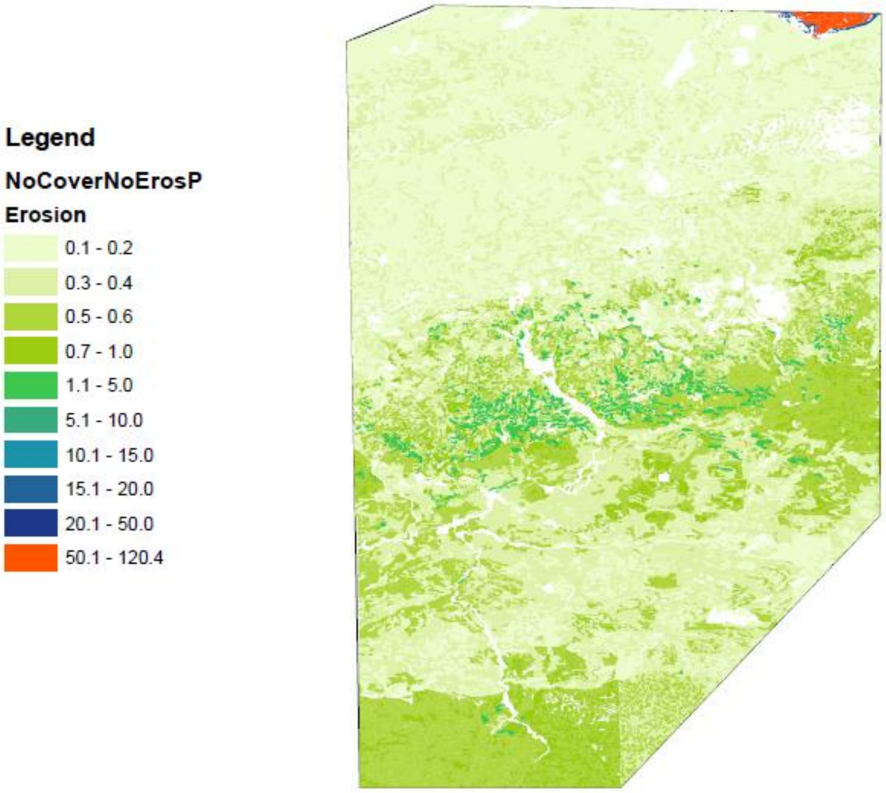

Figure 2: Erosion under the No Cover crop, No Replacement Cost for Erosion Scenario for Jasper County

As the potential for decreasing erosion is widespread, adoption of conservation practices may not be, as the benefits are not uniform over space. If farmers choose to participate in a biomass market and if they internalize erosion costs, then by the results of this model, most likely the farmer will choose to use cover crops. Cover crops provide not only the benefits of decreasing erosion, but allow for higher quantities of biomass available for removal. If farmers do not see the usefulness or the economic incentive in alternative conservation strategies and cover crops, then the potential is there to increase erosion.

Responsiveness of the farmer to price signals for stover and cover crops were also considered as important pieces of the tradeoff between erosion levels and conservation practices. Under the high price scenario (**HighStoverP**), the price was set to $125/ton less the 34.03 costs for a farmgate price of $90.97. This was the lowest high price that induced a farmer to increase the rate of harvest regime to the High Rate of Removal (HRH). Farmers under the lower stover price scenario (**LowStoverP**), where the marginal cost of stover removed is equal to the stover price (marginal benefit) tended not to harvest biomass except in one soil type in the county. Under both cases the replacement of nutrients were (16.01- 0.064-131.329), (NPK lbs/acre). Farmers did choose to undertake cover crops, though these scenarios again assume that farmers see the potential costs of erosion and choose to undertake cover crops in their conservation strategy. If farmers do not see this to be the case, the incentive for adopting cover crops is no longer motivated by an economic or an environmental incentive. One of the extensions to this work in the future is to examine the amount of erosion, which would spur the adoption of cover crops.

In terms of the economic incentive, in response to erosion in the case where farmers choose to harvest biomass, the price of cover crops must increase by 3.35 to 4.84 times in order to discourage farmers from choosing the 100% rye cover crop (**HighCoverCP**). The range in cover crop increases varies throughout the county as the marginal benefits change with erosion potential.

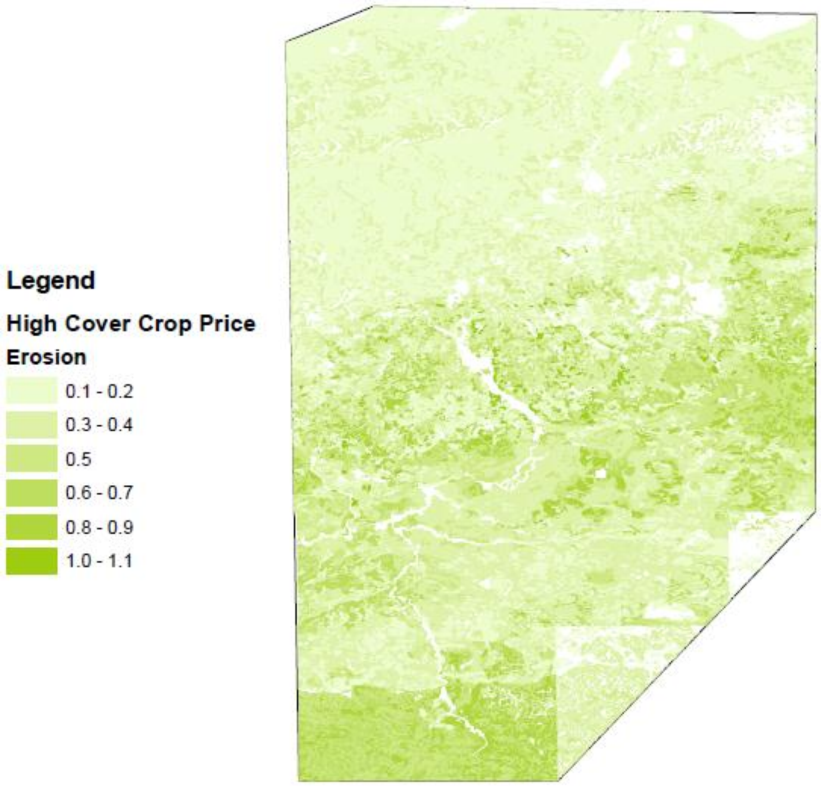

Figure 3: Erosion under the High Cover Crop Price for Jasper County

Table 7: Selected Estimates From Model Scenario HighCoverP

| | | | | | | |
|---|---|---|---|---|---|---|
| **Scenario** | HighCoverP | | | | | |
| **FIPS** | 18073 | | | | | |
| **MUKEY** | 161381 | | | | | |
| **Regime** | CG.100rye.NT.MHH.NVB.2010YLD | | | | | |
| **Profit** | | | | | | $ 733.25 |
| **Revenue** | | | **units** | **Price** | **Profit** | |
| | | Corn | 200 | $ 7.00 | $ 1,399.95 | |
| | | stover | 3 | $ 45.97 | $ 128.71 | |
| **Revenue** | | | | | | $ 1,528.66 |
| **Cost** | | | **unit** | **Price** | **Net** | |
| | Nutrients | Nitrogen | 301 | $ 0.54 | $ 162.78 | |
| | | Phosphorus | 92 | $ 0.74 | $ 68.23 | |
| | | Potassium | 150 | $ 0.57 | $ 85.44 | |
| | Cover Crop | | | | $ 106.16 | |
| | Misc Variable Costs | | | | $ 294.00 | |
| | Machinery Costs | | | | $ 78.80 | |
| **Cost** | | | | | | $ 795.41 |

With cover crop prices ranging from $147 to $177 per acre, none of the representative farmers adopted cover crops. Erosion under this scenario for the county can be seen in Figure 3. In the optimal scenario, erosion varies from 0.02 to 0.88 tons/acre/year, and in the high cover crop price scenario, the range is between 0.05 to 1.01 tons/acre/year. However, these slight differences in erosion may not be visible to farmers.

Nutrient replacement from erosion is difficult to generalize, as many farmers use soil testing in order to determine which nutrients are lacking in the soil. Losses due to erosion are specific to soil type, location and type of erosion and may not be considered separately. Therefore, the estimates from Pimentel (1995) may be much larger than what is actually needed. The erosion-nutrient replacement scenario illustrates the difference in possible behaviors if farmers have much lower nutrient replacement figures. The USDA uses erosion nutrient replacement rates of (2.32-1-0) in NPK lbs/acre in their benefit-cost analysis for the program EQUIP (NRCS, 2010). These rates are significantly lower than those in Pimentel (1995) and as such, the additional costs brought on by nutrient behavior, coupled with the low rates of erosion after the adoption of cover crops, do not spur any major regime changes. However, when testing against the adoption of conservation management strategies (no-till, cover crops, vegetation barriers), the price of erosion can determine how much biomass is removed and what the resulting level of erosion will be. Under the **NoConservation_LowErosionCost** scenario, forcing no conservation practices, erosion increases to over 11/ton/acre/year on average across the county. Removal of biomass is also significant to the increases in erosion as 91% of the soil types adopt a high harvest removal rate. Alternatively, with erosion replacement costs being high (**NoConservation_HighErosionCost**), erosion averages 1.75 tons/acre/year but biomass removal decreases to the no harvest removal rate except for in one soil type, where erosion is about half a ton under a medium high harvest rate. This implies that depending on the internal or externalized costs of erosion, farmers may not be willing to participate in the biomass market.

One of the main messages of these results is that farmer behavior will depend on perceived costs of erosion and perceived costs of erosion prevention measures. For the cases in which farmers must pay the erosion costs via nutrient replacement, they always adoped no-till or cover crops to prevent erosion. For the cases in which we forced no erosion reduction practices, erosion increased substantially. These cases are a proxy for the farmer either not perceiving erosion costs as real or perceiving the costs of erosion prevention as being high or some combination of the two.

Although the contribution of cover crops to decrease erosion can be economically and socially motivated, adoption of these crops may not be widespread for several reasons. If farmers do not see the economic or social costs of erosion on-site, or they perceive the costs of cover crops to be high, then farmers are not likely to adopt cover crops. Additionally, the benefits of erosion control vary depending on the location, soil type and other numerous factors that change through the landscape. These benefits may also diminish as the farmer reaches certain thresholds of erosion control, and then the question becomes, does the additional ton of soil loss saved through adopting a practice really make a difference for farmer decision making. These issues need to be considered further as more research is undertaken on both the environmental and economic trade-offs with cover crops as the biomass market develops.

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