Possible Effects of Corn Stover Removal on Soil Erosion in Iowa: A Panel Data Analysis

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Summary

This study uses the Iowa Soil Properties and Interpretations Database for the years 2005-07 and National Resources Inventory of Iowa for the year 1997 – the sub-county level data points (across a decade time frame) can help understand how soil erosion, soil nutrients and organic matter have changed over time with a focus on the impacts of emerging cropping patterns and changing agricultural residue cover on fields. The temporal data will be used to fit regression models using panel data analytic methods. The results can provide estimates of changes to soil erosion, nutrient or organic matter in the next 10-15 years upon removal of residues on a large scale basis for cellulosic ethanol production.

Introduction

Cellulosic materials - such as dedicated energy crops, agricultural residues, organic portion of municipal solid wastes, forestry and paper mill residues (EERE) - for ethanol production have begun to get more attention as alternative feedstocks for ethanol production. While the conventional feedstock – corn – has come under criticism for the environmental problems associated with intensive cultivation and larger use of fertilizer and pesticides, the possible environmental issues caused by cellulosic feedstocks are not fully known yet. See Table 1 for a summary of the few major issues in this regard:

Table 1. Issues associated with cellulosic feedstocks for ethanol production.

Cellulosic Feedstock	Advantages	Concerns or Issues
Dedicated energy crops	Low input production, possible high yields	Requires high yield levels (6 to 8 tons/ac/year) to become competitive, creation of new supply chains and infrastructure
Agricultural residues	Readily available, existing harvesting equipments can be modified to collect residues as well	Possible soil erosion and loss of soil nutrients due to residue removal
Forestry and paper mill residues	Sustainable supply, cheaper source of biomass	Limited in quantities

This analysis studies the extent of soil erosion possibly resulting due to residue removal for cellulosic ethanol production in the state of Iowa. The recent analyses on soil erosion have focused on modeling the field level soil movements using sophisticated models; while the micro level soil erosion is interesting and important, the removal of agricultural residues can also have a much broader geographical impact on erosion in agricultural lands – where a group of counties supplying corn stover (or wheat straw) to a cellulosic ethanol plant might face severe erosion due to continuous removal of residues over long periods of time. This shows that there are two dimensions – spatial (geographic) and temporal (over time) – for soil erosion in Iowa; both these components are to be incorporated while studying the impact of residue removal and possible soil erosion across Iowa.

Universal Soil Loss Equation (USLE)

The soil loss due to water erosion can be captured by the product of six major factors (NSERL, 2008; Stone and Hilborn, 2000):

(1) USLE = R * K * LS * C * P,

where USLE is the direct soil loss due to water erosion in metric tons per acre per year, R factor accounts for rainfall runoff erosivity (given for a field), K factor accounts for soil erodibility (given for a field), L factor stands for the slope length (usually in feet), S factor stands for the slope of the land (in percentage),[1] C factor captures the cover management activities and P factor accounts for conservation related support practices. Of these, the P factor is usually not observed directly but computed implicitly based on the amount of soil loss (USLE). The USLE equation was originally designed to study the soil erosion over large areas of land; the recent revisions RUSLE (IWR, 2002), RUSLE2 (NRCS) build upon the same above factors but with a focus on micro level field soil erosion.

The objective of this analysis is to analyze the impact of C factor on the soil loss amounts (USLE). The analysis would reveal what changes in crops, soil cover and tillage practices would result due to residue removal and how that would affect soil erosion. The relationship between C and USLE should control for the other soil erosion factors (R, K, L, S, and P) as well. Hence, the soil loss over large geographic areas (a group of counties or at state level) can be forecast by analyzing the spatial and temporal changes in these six factors.

Data and Methods

This study uses two datasets that cover almost 92 - 100 per cent of Iowa cropland for two time points – 1997 and mid-2000. See table 2. The factors C and P were not available directly for the latter time period. The C factor values for the latter year (2007) were estimated based on the crop portfolios and tillage practices; the average crop portfolios for the years 2002-07 were used, following the simplified procedure suggested in Stone and Hilborn (2000). Since P values are not usually observed directly, it was assumed to be the same during the time period of 1997-2007. This assumption may not be as limiting as it seems since the changes in conservation related support practices are slow to occur and it would take more than a decade (around 20 to 30 years) to discern significant changes. With all the six factors known for both the time periods, the USLE soil loss for the recent year 2007 can be predicted using the above said equation (1).

[1] L and S factors change with changes in cultivation such as terrace or contour cultivation.

Table 2. Summary of data sources on soil erosion factors.

Year of latest update	Source	Cropland acreage accounted for in Iowa (total cropland in million acres)	Number of data points	Soil erosion factors
1997	National Resources Inventory – 1997	28.8	23,278	USLE, R, K, L, S, C and P
Mid 2000†	ISPAID – Version 7.2	31.2	8,738	K
	NRCS – EFOTG			R, L, S

† ISPAID database is continually updated – the factors for most of the counties were updated over the period of 2002 – 07. We call the latter time period as 2007 scenario to reflect the latest changes in the data.

This dataset assembled for all cropland, pasture, hay, and conservation reserve land in Iowa over two time points provides us with a panel data which could be analyzed using standard panel data analytic techniques. The 1997 data (NRI, 2000) contained 21,302 field level observations accounting for 28.8 million acres of Iowa crop land; the latest year data (Miller et al, 2006) contained 8,738 observation covering 31.2 million acres. The field level data were aggregated in to county level data to enable matching the observations over two time periods. The average values for all the six factors and soil loss at county level were derived using the particular crop land acreages as the weighting factor. The simple forms of panel data regressions were conducted to analyze how the changes in cropping patterns and tillage (C factor) would affect soil erosion.

Table 3. Typical range of values for the various soil erosion factors.

Factor	Min	Max
R	150	175
K	0.1595	0.368
LS†	0.177	2.411
C	0.053	0.317
P	0.053	0.317

† $LS = [0.065 + 0.0456(S) + 0.006541(S)^2] \times (L \div 72.5)^{NN}$

NN values range from 0.2 to 0.5, depending on the slope value S

Preliminary Results

Table 4 presents the regression coefficients quantifying the impacts of R, K, LS, C and P factors on the soil loss (USLE). The focus is to analyze the impacts of C factor (cropping pattern and management practice) on the soil erosion; the presented results are preliminary.

Table 4. Regression coefficients for the relationship between soil loss and R, K, L, S, C and P factors.†

	Simple Regression			Panel Data Regression		
Column I	***II***	***III***	***IV***	***V***	***VI***	***VII***
			Pooled Data	Random Effects‡	Between Effects	Fixed Effects§
Time Period	1997	2007	Both time periods			
Dependent Variable	USLE97	USLE07	USLE97 and USLE07			
R	**0.049**	0.012	**0.028**	0.0002	**0.035**	**-0.14**
K	**24.296**	5.536	**10.304**	**10.084**	*11.751*	**20.244**
LS	**4.598**	**6.268**	**5.617**	**5.559**	**5.845**	**6.929**
C	**31.967**	**23.173**	**26.2289**	**16.791**	**30.609**	3.442
P	0.865	2.471	1.1854	1.659	1.581	-279661¶
Constant	**-19.914**	-9.773	**-12.555**	-6.765	-15.508	249757.2
R^2	0.8328	0.6951				
Wald Chi-Sq statistic				367.75	59.48	54.82
All Regressions were significant						

† The numbers in **bold** fonts were significant at 1% level; *italics* at 5% level

‡ Random effects estimator is a weighted average of Between Effects and Fixed Effects estimators

§ Fixed estimators are not relevant in this case since P factor was assumed to be the same in both time periods – note, C factor is insignificant in the case of fixed effects due to relatively less changes in the cropping patterns.

¶ Poorly estimated P factor coefficient

The data available for the two time periods (1997 and 2007) were used to fit two separate regressions for the two time points – these results are presented in the columns ***II*** and ***III*** of table 4; the results for pooling the data (ignoring the panel data format) of all 99 Iowa counties over the two time periods are given in column ***IV***. The panel data regression (Park, 2008) results are presented in the columns ***V***, ***VI*** and ***VII***; among the panel data regressions, the Between Effects estimators (***VI***) compute the coefficients based on inter-county variations of agricultural practices, soil erosion factors and soil losses; the Fixed Effects estimates (***VII***) compute the impacts of soil erosion within the county based on the different levels of erosion at two different time points. The Random Effects coefficient estimates (***VIII***) are a weighted average of Between and Fixed Effects estimators. It is important to note that the Fixed Effects coefficient estimates are computed by taking the difference of the factors at two different time points – As mentioned above, the P factor was assumed to be the same over the study period; this causes the coefficient estimate to be a large negative but non-significant negative number (-279661); leaving out the P factor does not change the other estimates appreciably as shown in the following table 5.

Table 5. Regression coefficients for the relationship between soil loss and R, K, L, S, and C factors.

	Column VIII	*IX*	*X*
	Random Effects	Between Effects	Fixed Effects
Dependent Variable	USLE97 and USLE07		
R	-0.0004	**0.034**	**-0.139**
K	**9.941**	*12.769*	**20.355**
LS	**5.362**	**5.447**	**6.936**
C	**16.543**	**29.594**	3.452
Constant	*-4.933*	**-13.699**	**16.017**

In all the above equations, the coefficient estimated for the C factor can capture the impacts of various types of crops grown and the tillage practices adopted, while other factors remain unchanged. For a unit change in the value of C factor, the soil erosion would change by the amount of the coefficient value. It should be noted that the C factor varied between the range of 0.053 and 0.317 – hence a unit change (change by the value of one) will not usually occur. The following table reproduced from Stone and Hilborn (2000) summarizes how the two sub-factors used in computing a simple estimate of C factor value.

Table 6. Sub factors used to compute C factor.

Crop Type	**Column A**
Grain Corn	0.4
Silage Corn, Beans & Canola	0.5
Cereals (Spring & Winter)	0.35
Seasonal Horticultural Crops	0.5
Fruit Trees	0.1
Hay and Pasture	0.02
Tillage Method Factor	**Column B**
Fall Plow	1
Spring Plow	0.9
Mulch Tillage	0.6
Ridge Tillage	0.35
Zone Tillage	0.25
No-Till	0.25
C factor = product of one value from A and one value from B	

Source: Stone and Hilborn (2000)

One particular C factor can be approximated by multiplying one value from column A and one value from column B. Hence, a silage corn crop (or soybeans) with fall plow tillage would have the highest C factor value of 0.5 (A = 0.5; B = 1; C factor = A*B = 0.5) while the pasture lands with no tillage would have the least C factor value of 0.005 (A = 0.02; B = 0.25; C factor = A*B = 0.005). Note that the computed C factor values (Table 3) for the state of Iowa are within this wide range.

In the following description, we make two assumptions: the impact of removing the residues of corn for grain crop would have the same impact on soil erosion similar to that of land under corn crop for silage. In the latter corn for silage, most of the biomass would be removed from the land. Hence the A value would be 0.4 if the farmer does not remove the residues and it will become 0.5 if he decides to remove residues (leaving less residues on the soil). This is plausible since removing residues of grain corn is equivalent to removing most of the biomass as in the case of silage corn. Hence, the C factor will increase due to an increase in the value of A. If the tillage practice (column B) changed as well, then it would affect the net value of C factor.

To illustrate, consider a piece of land that is currently under hay and pasture use (A = 0.02) under zone tillage (B = 0.25) which has a C factor value of 0.005 (A*B); if the farmer decides to grow corn and removes residues (A becomes 0.5, corresponding to corn for silage) with mulch tillage (B = 0.6), then the new C factor value would be 0.3. Hence, C factor value increased by 0.295. When the other factors (R, K, L, S and P) remain the same, for this amount of increase in C factor, the soil erosion would increase by (16.791 * 0.295) = 4.95 tons per acre per year; the value 16.791 comes from the Random Effects estimator in column ***V***. That is, the land with no erosion due to pasture management is now eroded at a level equaling the state level average erosion. Note that the average level of soil erosion in crop land was 4.9 tons per acre per year in 1997 and around 4.7 tons per acre per year in mid 2000.

Table 7 illustrates the other interesting scenarios where the soil erosion would change due to removal of agricultural residues for cellulosic ethanol production. The first two rows (i) and (ii) show that when there is no change in crops grown or tillage practices patterns, the soil erosion may increase between 0.67 and 1 ton per acre per year. This can constitute an increase in soil erosion by 10-25% in soil erosion due to residue removal with no changes in other factors. The last row (iv) shows that with proper management, even with the residue removal the soil erosion can be controlled and reduced. This shows that the soil erosion is closely tied with the kind of management and tillage practices. Hence, if the agricultural residues are removed for cellulosic feedstock purposes, the soil erosion may worsen in certain situations based on the crops grown and tillage practices. There is also evidence that the conservation measures can partly ameliorate the soil erosion. The extent of soil erosion will closely depend on the practices adopted in the individual fields. It should also be noted that the above estimates of soil erosion changes are the changes that can be seen in the fields where residues are removed compared to the state level average (not necessarily a temporal comparison – same field, different time points). Although the results hint at considerable improvements in soil erosion issues, this result should be subject to more rigorous analysis.

Table 7. Scenarios of crops and tillage practices and resultant soil erosion in Iowa.

Row	Current crop and tillage (C factor)	Future crop and proposed tillage (C factor)	Change in C factor	Change in soil erosion†
I	Grain corn with mulch tillage (0.24)	Grain corn (with residues removal) with mulch tillage (0.3)	(0.3-0.24) = +0.06	(16.791*0.06) = +1
Ii	Cereals (wheat crop) with no tillage (0.09)	Wheat crop (with residues removal) with no tillage (0.13)	(0.13 – 0.09) = +0.04	(16.791*0.04) = +0.67
Iii	Pasture land with no tillage (0.01)	Corn crop (with residues removal) and no tillage (0.13)	(0.13 – 0.01) = 0.12	(16.791 * 0.12) = +2.01
Iv	Grain corn with spring plow (0.24)	Grain corn (with residues removal) with no tillage (0.13)	(0.13-0.24) = -0.11	(16.791*(-0.11)) = -1.84

† Assuming that the Random Effects coefficients in column ***V*** (Table 4) or ***VIII*** (Table 5) are correct estimates

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