

Community Assistantship Program

Corn Stover Utilization and Soil Health

Prepared in partnership with
The Minnesota Project

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July, 2008

CAP Report 127

July 2008

CAP is a cross-college, cross-campus University of Minnesota initiative coordinated by the Center for Urban and Regional Affairs.

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Preface:

There is a broad and palpable excitement growing amongst agricultural, energy, and environmental advocates around biomass energy. The most specific excitement is around the potential for developing ethanol motor fuels from cellulose found in plants. Cellulose can be produced in greater volume and in a wider variety of plants compared to starch or simple sugars – which form the basis of the existing ethanol industry.

There are two broad directions that the collection of cellulose rich materials are being discussed. First, is through development of perennial “energy crops”. The second is through utilization of existing crop residues – particularly corn stover and wheat straw. In the Upper Midwest corn stover is the more significant potential feedstock. For many involved in advocacy or production of cellulose supplies, perennial energy crops are the end goal. Perennials crops provide more continuous ground cover, thereby improving water quality and can potentially reduce the use of synthetic chemical and energy production inputs and provide more habitat for wildlife. However, there are numerous barriers to a rapid shift toward such a cropping system.

The other option, using crop residues, is attractive in that there is already a production system that is producing this material. It is an opportunity to increase value to existing agricultural production systems. The risk for producers is relatively low. In addition, some cropping systems are facing problems with residue removal. Wheat straw is currently burned off of many fields in arid locations. Excess residue covering corn fields in can slow the drying and warming of heavy soils and reduce production. Corn stover utilization advocates promote argue that stover harvest can contribute to improved soil health by enabling more widespread adoption of minimum and no till farming practices on corn fields.

However, there has been some degree of concern emerging in various agricultural production and conservation circles regarding the wisdom of using corn stover as an energy supply. A decade or more of effort has been made promoting the importance of leaving residue on the soil to improve soil health and reduce erosion and water quality impacts.

The Minnesota Project, with support from the Center for Urban and Regional Affairs at the University of Minnesota, Minneapolis, sought to evaluate and understand the potential implications of substantial corn stover harvest. We sought to use an established US Department of Agriculture tool, the RUSLE2 model, to begin to evaluate what the actual impacts of stover harvest appear to be. While further study and analysis is needed, this paper should begin to provide some indication of the extent and conditions for which stover collection is acceptable.

Introduction

During the twentieth century, nergy consumption and CO₂ emissions have been increasing consistently worldwide. Fossil fuels (oil, coal, and natural gas) supply 85 percent of the total primary energy used in the world (Johanson,Lundqvist 1999 cited

(Lemus, Lal 2005). Long-term availability and desirability of fossil fuel use are concerns in a rapidly and expanding world economy that is expected to increase fossil fuel combustion. (Hawken 1993 cited (Lemus, Lal 2005)). The essential reasons why the United States as a nation must research, develop, and implement renewable energy resources to replace the fossil fuels are: 1) CO₂'s contribution to global warming 2) finite life of fossil fuels and 3) threats to the nation's security, economy and environment.(Nelson 2002), Greene et.al. 2004).

Agricultural biomass is a source of renewable energy that can be converted into liquid fuels (Lal 2005). Recent developments expand the use of biomass for fuel production but are contingent on the development of new organisms or enzymes to convert cellulosic (a high concentration of cellulose) biomass as opposed to grain (starchy) biomass to ethanol for use as a motor vehicle fuel (Wilhelm et al. 2004). The U.S. DOE, in concert with private enterprise, is making great strides toward developing enzymes and improving efficiency in fuel production from biomass (DiPardo, 2000; Hettenhaus et al., 2000 cited (Wilhelm et al. 2004)). The energy value of crop residue produced in the US is about barrels of diesel equivalent or 8 quadrillion btus(approximately 8% of US primary energy consumption). The corresponding values for the world are 7.5 billion barrels of diesel or 60- quadrillion Btus. (Lal 2005). The share of global biomass energy consumption varies widely, with 47% in Asia, 25% in Africa, 19% in Latin America, 5% in North America, 3% in Europe and 1% in Oceania (Lansink et al. 2002 & Goldenberg 2003 cited (Lal 2005)). . The Kyoto Protocol and its several clauses (e.g., The Clean Development Mechanism, The Joint Implementation) provide a renewed interest in using biofuel to offset fossil fuel combustion (Woods and Hall 1994 cited(Lal 2005)).

Biofuels from Crop Residues:

Biomass is defined as renewable organic material derived from plant and animal growth. It can be derived from animal products and manure, food processing and forestry by-products, urban wastes, energy crops such as switchgrass and poplar trees, and agricultural crop residues such as corn stover and wheat straw(Lal 2005, Nelson 2002). Processors produce biofuels by converting the biomass resources into such as ethanol or methane gas (Nelson 2002). Corn stover, the focus of this study, includes the stalks, leaves, and/or cobs (Nelson 2002, Sheehan et al. 2003). The crop residues can be used as fodder, fibre, industrial raw material for producing biofuel, and as soil amendment to maintain or improve soil tilth, protecting the soil surface from water and wind erosion, and helping to maintain nutrient levels(Lal 2005, Nelson 2002). Currently, IOGEN, a Canadian company, is developing a pilot plant to convert wheat straw into biofuel at Idaho, Illinois and the project is in early stages of development. Corn-stover is being targeted as a biofuel feed stock the extensive area of cultivation and the per acre production.

1.

Importance of Biofuels:

The world energy consumption is expected to increase 54 percent by 2025, with much of the energy growth occurring in rapidly expanding economies (International Energy

Outlook, 2004). Two critical disadvantages of petroleum to meet that need are: 1) the world's petroleum reserves are projected to be depleted by no later than 2050 given current rates of consumption, and 2) the energy–profit ratio (defined as the amount of energy output from an energy resource divided by the amount of energy required to find, extract, transport, refine, and distribute the resource for end-use) has been decreasing from 100:1 in the mid-1800s to around 10–5:1 today (Nelson 2002). Fossil fuel combustion is also the leading driver in global warming because of the inherent release of carbon dioxide into the atmosphere. If biofuels are developed intensely between now and 2015, by 2050, United States would be able to produce, the equivalent of more than three times, as much oil as is currently imported from the Persian Gulf. And if combined with better vehicle efficiency and smart-growth urban planning, biofuels could virtually eliminate the United States demand for gasoline by 2050. (Greene et.al 2004)

The economic and environmental benefits of producing biofuels as summarized by Greene et. al (2004) and Wilhelm (2004) are:

- Biofuels can slash global warming pollution: The use of ethanol reduces greenhouse gas (GHG) emissions (Ethanol the complete energy life cycle). On a per-gallon basis, corn ethanol reduces GHG emissions by 18% to 29%; cellulosic ethanol offers an even greater benefit, with an 80%-85% reduction in GHG. (Greene et. al. 2004, Wang 2005)
- Biofuels can be cost competitive with gasoline and diesel.
- Biofuels will provide a major new source of revenue for farmers: At \$40 per dry ton, farmers growing 200 million tons of biomass in 2025 would make a profit of \$5.1 billion per year.
- Biofuels can provide major air quality benefits: Biofuels contain no sulfur and produce low carbon monoxide, particulate and toxic emissions. Using biofuels should make it easier to reach air pollution reduction targets than using petroleum-based fuels. (Greene et. al. 2004)

Corn Stover Ethanol: Sustainable?

The corn grain has been used for ethanol production for a long time, but development of technologies to convert corn residues to ethanol fuels has started recently (Mann, Tolbert & Cushman 2002). At present, the U.S. Department of Energy and private enterprises are developing the technologies that are necessary to use crop residues for ethanol production. Corn can provide about 1.7 times more carbon than barley, oat, sorghum, soybean, sunflower and wheat residues, when the amount of residue available is compared for various crops, based on production levels, (Wilhelm et al. 2004).

Riley (2003) outlines distinctive advantages of ethanol made from corn stover compared to ethanol made from corn grain. : For each mile driven on ethanol fraction in fuel–

- could reduce fossil energy consumption by 102%

- could reduce oil consumption by 95%
- could reduce coal consumption by 12-fold

(Riley 2003)

The production of ethanol from corn stover is being actively researched upon currently, because it is available in large quantities. In some locations, continuous corn production with reduced-tillage or no-till continuous corn has resulted in accumulation of excessive residue. Such dense cover potentially contributes to planting difficulties, which in turn can lead to lower yields, and subsequently lower soil organic carbon (SOC) sequestration rates (Cannell and Hawes 1994; Swan et al. 1996 cited (Mann, Tolbert & Cushman 2002)).

Enough residue can and should be left to protect soil from wind and water erosion, and improve soil quality (Lal 2005, Sheehan et al. 2003). If residue removal is managed carelessly, it can lead to decline in soil quality with long-lasting adverse impacts on the environment (Lal 2005). Soil erosion will continue to occur in some quantity whether or not crop residues are removed from the field (Sheehan et al. 2003). To ensure environmental sustainability of the renewable fuel derived from corn residues, the removal of crop residue from the field must be balanced against soil erosion, maintaining soil organic matter levels, and preserving or enhancing productivity (Mann, Tolbert & Cushman 2002, Wilhelm et al. 2004). The objective of this study is to begin to define not only if corn stover harvest can be sustainable, but what levels of harvest might be tolerable.

What Level of Harvest is Sustainable

The amount of crop residue that can be harvested to make ethanol is not yet very clear. Several studies have given different results about the amount, which can be sustainably removed without inducing heavy soil loss. Nelson (2002 cited (Wilhelm et al. 2004)) and McAloon et al. (2000 (Wilhelm et al. 2004b)) estimated that 20% and 30% of stover can be harvested respectively, based on the need for adequate soil cover to control soil erosion. Whereas, (Sheehan et al. 2003) have estimated that 40% of the residue can be collected under continuous corn production and mulch till, and 70% under no-till. Larson et al. (1972) estimated the amount of cornstalk residue needed to prevent loss of organic C to be 6 t/ha/yr. 30% residue cover is still generally considered by the United States Department of Agriculture, National Resources Conservation Service (USDA-NRCS) as adequate to keep erosion below established *T*-values (Mann, Tolbert & Cushman 2002). Several agronomic experts were contacted directly in regards to the question of sustainable levels of harvest. It appears that consensus has not yet fully formed. Responses about the total acceptable rate of stover harvest ranged from about 25% to 75% of the residue. Although another noted that the way to look at the issues is not in terms of tons left, but rather in terms of ensuring that residue cover rate goals are met. Finally, one environmental perspective shared was that stover harvest simply adds one more level of impact to an already unsustainable production system.

All the expert interviews and most of the literature reviewed indicate that there are several effects of residue management on environment, which should be kept in mind

while estimating the amount of residue that can be removed. Residue management impacts:

- soil erosion rates,
- soil quality and future productivity,
- recycling of nutrients, and
- Soil Organic Matter (SOM).

While indiscriminate residue removal would impact these factors adversely, limited residue removal with proper crop management practices would lead to sustainable corn residue removal. Tillage is an important factor affecting soil loss and thus is important when residue removal is discussed. Soil loss is directly affected by type and number of tillage operations employed for any particular crop from the time of harvest until the next planting (Nelson 2002).

Apart from affecting the soil loss, the performance of a crop such as corn is influenced by tillage and residue management variations. For example, crop residue coverage has been observed to decrease yields because of poor weed control, excessively wet and cold soils, and poor seed placement and stand (Swan et al. 1994 cited (Wilhelm et al. 2004)). Another very important effect of tillage is on the SOC, as residue is not distributed uniformly throughout the depth of tillage (Staricka et al. 1991 cited (Wilhelm et al. 2004)); rather, the incorporated residue tends to be concentrated into relatively narrow bands (Wilhelm et al. 2004).

Allmaras et al. (2000 cited (Wilhelm et al. 2004)) concluded that the tillage tools used affect the amount of residue buried which in turn affects the SOC. They found that no-till stores more SOC than non-moldboard plow while moldboard plow stored the least SOC (Wilhelm et al. 2004a). In a study spanning 7 years (Al-Kaisi, Yin & Licht 2005) showed that no-till treatment increased SOC by 17.3, 19.5, 6.1, and 19.3% averaged over the 0–15-cm soil depth in the four studied soil associations, respectively, when compared with chisel plow treatment in a corn–soybean rotation. On the other hand Lee et al. (1993 cited (Mann, Tolbert & Cushman 2002)) found that total SOC to a depth of 1m decreased, even with no-till continuous corn, unless a winter cover crop was included. Tillage also affects soil bulk density, aeration, and other physical factors, which in turn can affect SOC storage (Angers et al., 1995; Reeves et al. 1997; Dao 1998; Needelman et al. 1999; Clapp et al. 2000 (Wilhelm et al. 2004)).

Experts consulted generally concurred that no-till would enable the greatest stover harvest, yet they also indicated that corn yields may decline incrementally- perhaps by 4-5%. The general recommendation was to combine stover harvest with a minimum tillage system, such as strip tillage. Though, one noted that well managed no-till systems might recover yield over time. These recommendations were based on maximizing corn-grain production, not necessarily based on a full cost benefit analysis of total income and total expense.

Soil erosion:

Soil erosion is a extremely important. Most, if not all, agricultural cropland in the United States experiences some degree of soil erosion each year due to rainfall (water) and/or wind forces (Nelson 2002). Careless removal of crop residues would result in heavy soil erosion.

After many years of research and wrestling with the question for decades (Sheehan et al. 2003) the Natural Resource Conservation Service (NRCS) of the USDA has established tolerable soil loss limits (T values) for all soil types in all counties throughout the United States. The tolerable soil loss values denote the maximum rate of soil erosion that can occur for a particular soil type that does not lead to prolonged soil deterioration and/or loss of productivity. Tolerable soil loss limits take into account the rate of topsoil formation, role of topsoil formation, loss of nutrients, erosion rate at which gully erosion would commence, and potential erosion-control factors that farmers would be able to implement. T values are not a function of the type of crop grown (Nelson 2002). The T value of Lester soil for the study area Freeborn county is 5 tons/acre/year.

The scientific community has questioned the T value as an adequate level of protection. As Lal (1998(Mann, Tolbert & Cushman 2002)) has stated that, there is a need for better data on rates of soil formation, parameters relating to soil quality, and offsite environmental concerns to determine soil loss tolerances that improve or minimize degradation of soil quality and yield and minimize offsite environmental effects. According to Wilhelm (2005) there is skepticism about the value of T as it does not take into account the amount of nutrient loss. In addition, T value erosion rates contribute considerable amounts of sediment and nutrients to waterways impacting water quality.

Maintaining SOC

Maintenance of SOC requires that efflux does not exceed influx. The amount of crop residue returned to soil affects the soil organic carbon, and tillage systems influence the retention of soil organic carbon. Soil productivity is maintained and improved if soil organic matter is regularly added and is subsequently decomposed. The amount of residue required per year to maintain SOC ranged from $<1 \text{ Mg ha}^{-1} \text{ yr}^{-1}$ in Montana wheat production with V-blade tillage to $<9.25 \text{ Mg ha}^{-1} \text{ yr}$ in Minnesota corn production with moldboard plowing. Returning more residue increased SOC, returning less resulted in loss of SOC (Wilhelm et al. 2004a). SOC is also influenced by the tillage, stover management and nitrogen management (Wilts et al. 2004).

Soil Compaction:

Wilhem et al (2004a) note that soil compaction is a significant factor in soil productivity and erosion. Stover removal can exacerbate soil compaction in two ways. First, removal of organic matter can impact the ability of the soil to withstand the compression of farm equipment. Second, stover harvest will likely increase wheel traffic on fields thereby adding to the compaction. In addition to decreasing yield, compaction can contribute to increased erosion. Young and Voorhees (1982 Cited in Wilhelm et al 2004a) found sediments disproportionately washing from tracked areas. Wilhelm et al (2004a) further

notes that surface compaction may require some tillage, as no-till may not adequately ameliorate surface compaction.

Mitigation Strategies:

The by-product of corn stover fermentation can be applied on land as a soil amendment. It would provide a source of C for SOM and thus reduce the environmental risk from biofuel harvest by helping to stabilize soil structure (Johnson et al. 2004, Wilhelm et al. 2004a). The composition of the by-product is 62% lignin, 13% cellulose, 3% hemicellulose, and 2% N according to the National Renewable Energy Laboratory, Golden, CO (J. McMillan, personal communication 2002 cited (Wilhelm et al. 2004)). Baled corn stover is about 20% lignin, 36% cellulose, 23% hemicellulose, and <1% N (NREL 2002 cited (Wilhelm et al. 2004a)). Laboratory experiments have shown that amendment of soil using 6.1 g by-product kg⁻¹ by-product increased CO₂ flux by 68% and increased soluble C and microbial biomass C by about 20% (Johnson et al. 2004). But since it provides little ground cover, returning the by-product to the soil would not eliminate all potential problems of removing corn stover. Although, the slow decomposition and long residence time of the by-product in the soil may allow the by-product to make a large and long-term contribution to SOM, which could be especially beneficial in severely eroded soils (Johnson et al. 2004).

There have been discussions about growing cover crops along with corn and soybean rotations. But the economic viability of these cover crops is not yet established..

Stover removal may reduce some of the problems encountered with no-till corn production by reducing diseases such as stem and stalk rots and foliar diseases, improving germination and stand establishment, particularly in cool, wet conditions. Carryover effects from persistent herbicides may be greater in colder, wetter conditions of no-till (Locke and Bryson 1997 (Mann, Tolbert & Cushman 2002)) which might be lessened with residue removal. (Mann, Tolbert & Cushman 2002).

Conclusion

On the basis of the literature studied and the interview conducted with the experts, it can be concluded that corn-stover can be a potential source of biomass energy. Although, there are limiting factors that impact the extent to which stover can be harvested. These factors are

- soil erosion rates,
- soil quality and future productivity,
- recycling of nutrients, and
- Soil Organic Matter (SOM).

Carefull attention to tillage and management is needed to limit the negative impacts of stover collection. Conservation tillage, or possibly no-till, systems should be employed. Attention to other management issues such as nutrients and compaction are also warranted.

Stover removal may also result in reduction of some problems that generally come across with no-till corn production by reducing diseases such as stem and stalk rots and foliar diseases, improving germination and stand establishment. Also, the by-product of corn stover fermentation can be applied on land as a soil amendment. These may help in mitigating some of the negative effects caused as a result of corn stover removal. But, the reduction of diseases is yet to be concretely discussed. The return of by-product to the corn field needs to be analyzed for its cost-benefit, including energy balances associated with a return haul, and the ability of the by-product to supply process energy for ethanol plants in lieu of fossil fuels.

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The literature and available expert opinions generally indicate that corn stover harvest can be accomplished sustainably, if a large portion of the residue is left behind. The literature and expert opinions also indicate that the tillage practices will have bearing on the degree to which residue harvest can be accomplished without undue negative impacts. The Minnesota Project, with support from the University of Minnesota's Center for Urban and Regional Affairs, has sought to examine soil loss under different corn stover harvest scenarios. The intent is to provide a more detailed picture about how stover harvest will impact soils and downstream water quality.

While long term field research is needed for different types of cropping systems, soils and climates, entrepreneurs, government officials, and renewable energy advocates continue to push forward with corn stover energy projects and policies. This analysis seeks to use available tools and resources to provide additional light on the practice.

The Revised Universal Soil Loss Equation, 2 (RUSLE2) is a tool developed by the US Department of Agriculture to estimate the soil loss associated with various cropping systems. RUSLE2 is a conservation planning tool, that builds upon earlier erosion prediction models (Universal Soil Loss Equation, and the Revised Universal Soil Loss Equation). In addition, RUSLE2 calculates a Soil Conditioning Index (SCI). The SCI represents a qualitative prediction of soil organic matter (SOM) trends. The SCI is based on the amount of organic matter available from crop residues, the intensity of soil disturbance and the extent of predicted erosion. The SCI is a major criteria for determining eligibility for the Conservation Security Program enacted in the 2002 Farm Bill.

The Soil Conditioning Index (SCI) provides a qualitative indication of soil organic matter trends in farm fields. The SCI is based upon the amount of organic matter returned to the soil, the extent of soil disturbance and erosion. (More detailed information on Soil Condition Index is available on line at: <http://soils.usda.gov/sqi/assessment/sci.html>).

This analysis package was chosen because, it is a widely available tool and it's use is required for determining eligibility for the Conservation Security Program (CSP). The CSP was established in the 2002 Farm Bill to reward and encourage effective conservation practices on working lands. Any lands enrolled in CSP must achieve a positive SCI.

Methods

To further understand the relative trade-offs between erosion and soil health, the 14 different management treatments were analyzed with varying intensity of tillage practices and corn stover removal. Each of the 14 options were analyzed assuming slopes ranging from 0.5% to 6%. Analysis was completed using the USDA, Natural Resources Conservation Services Revised Universal Soil Loss Equation 2 (RUSLE 2 computer software). RUSLE2 models the impacts on soil and calculates three different outputs: Soil loss per acre, Soil Conditioning Index (SCI) and soil tillage intensive rating (STIR).

RUSLE2 includes several components. The RUSLE2 analysis software solves the many mathematical sub-equations used by RUSLE2. The RUSLE2 program incorporates a large database of climate, soils, and management practices. The user selects entries from the database to describe site-specific field conditions and cropping system practices. The RUSLE2 software incorporates the mathematical equations, cropping systems research, and the scientific knowledge of climate, soil properties and location. RUSLE2 is land use independent. It is based on equations that describe how basic features like plant yield, vegetative canopy and rooting patterns, surface roughness, mechanical soil disturbance, amount of biomass on the soil surface and in the upper layer of soil, and related factors affect rill and interrill erosion. The RUSLE2 user selects information in the RUSLE2 database to describe these variables at a specific field site. The RUSLE2 user is not required to collect field data on these variables.

Erosion Estimates

RUSLE2 estimates rates of rill and interrill soil erosion caused by rainfall and its associated overland flow. Detachment (separation of soil particles from the soil mass) by surface runoff erodes small channels (rills) across the hillslope. Erosion that occurs in these channels is called rill erosion. Erosion on the areas between the rills, the interrill areas, is called interrill erosion. Detachment on interrill areas is by the impact of raindrops and waterdrops falling from vegetation. The detached particles (sediment) produced on interrill areas is transported laterally by thin flow to the rill areas where surface runoff transports the sediment downslope to concentrated flow areas (channels).

Factors Affecting Erosion

The four major factors of climate, soil, topography, and land use determine rates of rill and interrill erosion. A RUSLE2 user applies RUSLE2 to a specific site by describing field conditions at the site for these four factors. RUSLE2 uses this field description to compute erosion estimates.

Equation

RUSLE2 uses an equation structure similar to the Universal Soil Loss Equation (USLE) and RUSLE1. RUSLE2 computes average annual soil loss on each *ith* day as:

$$a_i = r_i k_i l_i S c_i p_i$$

where:

a_i = average annual soil loss,

r_i = erosivity factor,

k_i = soil erodibility factor,

l_i = soil length factor,

S = slope steepness factor,

c_i = cover-management factor,

p_i = supporting practices factor,

all on the *ith* day.

Soil Conditioning Index (SCI):

SCI combines the effect of three determinants of organic matter as follows. $SCI = OM + FO + ER$ where:

OM is the organic material or biomass factor. This component accounts for the effect of biomass returned to the soil, including material from plant or animal sources, and material either imported to the site or grown and retained on the site.

FO is the field operations factor. This component accounts for the effect of field operations that stimulate organic matter breakdown. Tillage, planting, fertilizer application, spraying, harvesting, and other operations crush and shatter plant residues and aerate or compact the soil. These effects increase the rate of residue decomposition and affect the placement of organic material in the soil profile.

ER is the erosion factor. This component accounts for the effect of removal and sorting of surface soil organic matter by sheet, rill, or wind erosion processes as predicted by water and wind erosion models. It does not account for the effects of concentrated flow erosion, such as ephemeral or classic gullies.

Other considerations. A soil texture correction factor added to the original SCI increased the accuracy of the model by requiring more biomass production to maintain the level of organic matter in the coarser textured soils. The Revised Universal Soil Loss Equation decomposition functions are used in the model to estimate relative rates of plant residue decomposition at different locations. Climate is one of the most important factors determining decomposition rates. The effect of residue quality or C:N ratio on decomposition is also considered.

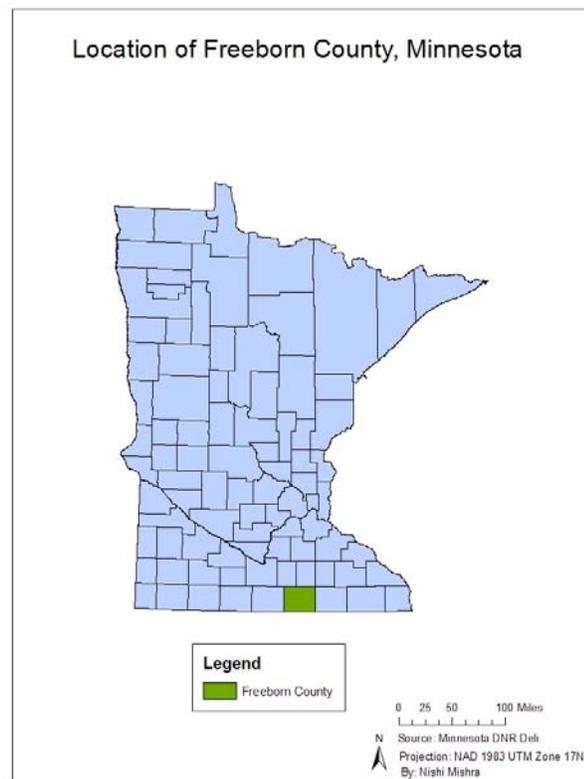
RUSLE2 takes

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Source: United States Department of Agriculture, Agricultural Research Service website online

Revised Universal Soil Loss Equation 2, User's Guide by United States Department of Agriculture, Agricultural Research Service, January 2003 at <http://www.ars.usda.gov/Research/docs.htm?docid=6010>

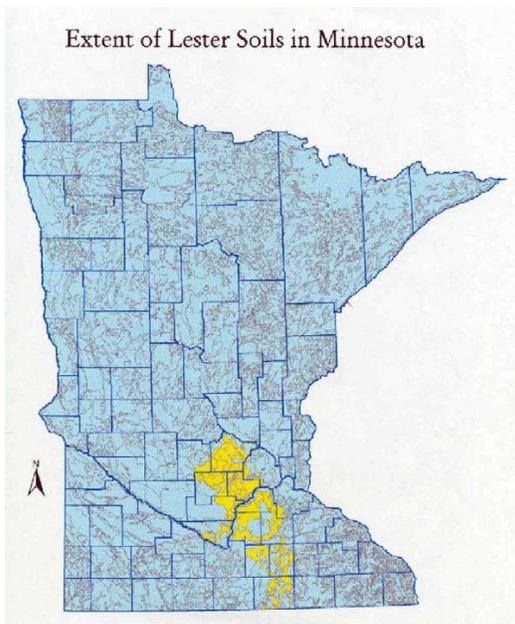
Study Area and Soil Type



Freeborn County, Minnesota is an agricultural area in South Eastern Minnesota along the – Iowa Boarder. Freeborn County’s landscape varies from gently rolling to hilly. In some places, relief is dramatic. The area was glaciated and the dominant geological features are glacial end moraines. Shallow lakes and wetlands have formed throughout the county. While scattered patches of hardwood forest remain, approximately 90% of the county’s land area is utilized for agricultural purposes. Of this 85% of the total land area in the county is cultivated. Principal crops grown are corn and soybeans(Minneosta Land Management Information Center). Soil types are typical for southern Minnesota corn-belt areas, and are dominated by clay-loams. Climate in Freeborn County is typical of the Upper Midwest: warm humid summers and cold dry winters divided by a moderate spring and fall. Normal precipitation is about 33 inches per year with approximately 20 inches coming during the growing season. Precipitation does vary substantially from year to year.

The Lester Clay-loam soil type was used for the analysis . The Lester Series consists of very deep, well drained soils that formed in loamy, calcareous glacial till, on ground moraines. Slopes range from 5 to 70 percent. These soils formed under wooded vegetation that has been removed in many areas for agricultural production. Where used for crops, corn and soybeans are the principal ones. For this analysis, yields of 160 bushels an acre for corn and 40 bushels an acre for soybeans. Lester soils are of moderate extent, occurring in 75 map units in 17 counties in south-central Minnesota. Total acres are over 600,000.

Lester series was chosen because it is a common soil that is located within the corn-belt area and at its periphery. It has significant topography and erodibility associated with it and, therefore, it may more readily demonstrate cropping system changes relative to a very flat prairie soil.



Source: Natural Resources Conservation service
http://www.mn.nrcs.usda.gov/technical/soils/st_soil.html

Treatment Scenarios:

The analysis was carried out by using 14 different cropping and residue removal managements. Each cropping system was assessed for four different slope lengths and steepness. All of the management scenarios considered were based on a corn-soybean rotation, which is the prevalent cropping system through much of the Midwestern corn belt. Base case scenario was referred to as the traditional tillage. The specific operations are listed in Table 1. Others hypothetical managements were developed to ascertain the effect of tillage and residue removal on the soil loss. The variation within a particular management was based on the tillage equipment used. The different tillage practices considered were No till, Twisted Chisel Plow, Straight Point Chisel Plow and Molboard Plow. Also, different levels of residue harvest were assessed by using the two different Baling operations included in RUSLE2. In addition, silage cutting was used as a proxy for the most aggressive residue harvest.

Table 1. Base Case Traditional Tillage

<i>Date</i>	<i>Operation</i>	<i>Vegetation</i>	<i>Surf. res. cov. after op, %</i>
10/30/0	Fert. applic. anhyd knife 30 in		84
4/25/1	Cultivator, field 6-12 in sweeps		62
5/5/1	planter, double disk opnr	Corn, grain	57
10/1/1	Harvest, killing crop 50pct standing stubble		82
10/25/1	Stalk chopper, rotary		71
11/1/1	Chisel, straight point		48
4/10/2	Cultivator, field 6-12 in sweeps		44
5/15/2	Planter, double disk opnr, 18 in rows	Soybean, mw 15 - 20 in rows	39
10/10/2	Harvest, killing crop 50pct standing stubble		86

Alternative cropping and residual removal managements

1. CSTT: Corn-Soybean rotation using Traditional Tillage with Straight point Chisel plow
2. CSTT Twisted: Corn-Soybean rotation using Traditional Tillage with Twisted point Chisel plow
3. CSTT Molboard: Corn-Soybean rotation using Traditional Tillage with Molboard plow
4. CS30: Corn-Soybean rotation, using Straight point Chisel plow and Baling corn stalk strips i.e. less residue removal
5. CS30 Twisted: Corn-Soybean rotation, using Twisted point Chisel plow and Baling corn stalk strips, less residue removal
6. CS30 Molboard: Corn-Soybean rotation, using Molboard plow and Baling corn stalk strips, less residue removal

7. CS100: Corn-Soybean rotation, using Straight point Chisel plow and Baling corn straw or residue i.e. maximum residue removal
8. CS100 Twisted: Corn-Soybean rotation, using Twisted point Chisel plow and Baling corn straw or residue i.e. maximum residue removal
9. CS100 Molboard: Corn-Soybean rotation, using Molboard plow and Baling corn straw or residue i.e. maximum residue removal
10. CSNT: Corn-Soybean rotation, No Tillage
11. CSNT Baling: Corn-Soybean rotation, No Tillage and Baling corn straw or residue i.e. maximum residue removal
12. CSSilage: Corn-Soybean rotation, using Straight point Chisel Plow and Silage harvest
13. CSSilage Twisted: Corn-Soybean rotation, using Twisted point Chisel Plow and Silage harvest
14. CSSilage Molboard: Corn-Soybean rotation, using Molboard Plow and Silage harvest

Each of these managements was used to calculate Soil Loss and soil Conditioning Index (SCI) in RUSLE II for a particular combination of slope length and slope steepness. The combination of slope length's and slope steepness used are:

Table 2: Alternate Slopes Considered

Slope	Slope Length (ft)	Slope Steepness (%)
1.	200	0.5
2.	250	2
3.	200	4
4.	150	6

Results

The results of the RUSLE II analysis are discussed in the section. Figure 1 represents the overall correlation between Soil Loss and Soil Conditioning Index (SCI).

Correlation of Soil Conditioning Index (SCI) and Soil Loss (tons/acre/year) for various cropping and residue removal managements

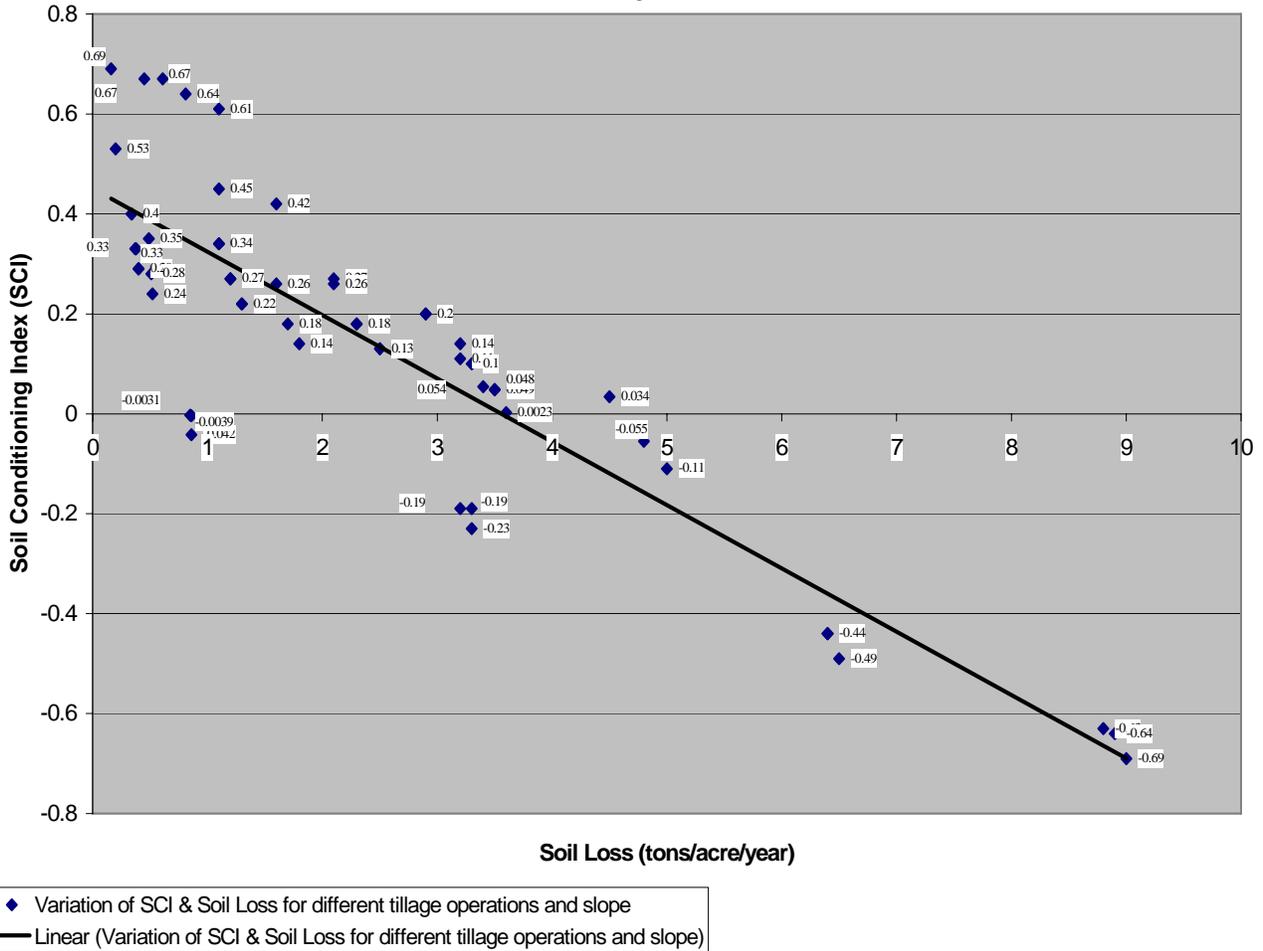


Figure 1

The Soil Conditioning Index (SCI) and Soil Loss for each management at the above mentioned combination of slope length and slope steepness is summarized in Table 1 and Table 2 respectively.

S.No	Management	SCI at 0.5% slope	SCI at 2% slope	SCI at 4% slope	SCI at 6% slope
1	CSNT	0.69	0.67	0.64	0.61
2	CSNT Baling	0.53	0.49	0.45	0.42
3	CSTT	0.40	0.34	0.27	0.20
4	CSTT Molboard	0.35	0.26	0.14	0.034
5	CSTT Twisted	0.40	0.34	0.26	0.20
6	CS30	0.33	0.27	0.18	0.11
7	CS30 Molboard	0.28	0.18	0.054	-0.055
8	CS30 Twisted	0.33	0.27	0.18	0.10

9	CS100	0.29	0.22	0.13	0.049
10	CS100 Molboard	0.24	0.14	0.0023	-0.11
11	CS100 Twisted	0.29	0.22	0.13	0.048
12	CSSilage	-0.0031	-0.19	-0.44	-0.63
13	CSSilage Molboard	-0.042	-0.23	-0.49	-0.69
14	CSSilage Twisted	-0.0039	-0.19	-0.44	-0.64

Table 1: Variation of SCI for each management at different slopes

The results in Table 1 and Figure 2 show that the SCI is affected enormously by the residue removal and tillage equipment used, even at less steeper slopes. There is a sudden decrease of SCI to negative value even at a low slope steepness of 0.5%, as the residue removal increases to maximum with Silage harvesting. The minimum value of SCI at 0.5% slope, -0.042, is observed for most aggressive tillage with Molboard plow and Silage harvesting. Similarly, at slope steepness of 2% and 4% the SCI has negative values only for Silage harvesting, and the minimum values are observed for Molboard plow along-with silage harvesting. The value of SCI decreases rapidly even with least residue removal and aggressive tillage at a high slope steepness of 6%. The SCI is negative also for CS30 with Molboard plow (least residue removal) and CS100 with Molboard plow (slightly high residue removal) apart from where silage is harvested. However, there is no marked difference in the SCI value for managements, where straight point chisel plow and twisted point chisel plow are used.

S.No	Management	Soil Loss at 0.5% slope	Soil Loss at 2% slope	Soil Loss at 4% slope	Soil Loss at 6% slope
1	CSNT	0.16	0.45	0.81	1.1
2	CSNT Baling	0.20	0.61	1.1	1.6
3	CSTT	0.34	1.1	2.1	2.9
4	CSTT Molboard	0.49	1.6	3.2	4.5
5	CSTT Twisted	0.34	1.1	2.1	2.9
6	CS30	0.37	1.2	2.3	3.2
7	CS30 Molboard	0.51	1.7	3.4	4.8
8	CS30 Twisted	0.38	1.2	2.3	3.3
9	CS100	0.40	1.3	2.5	3.5
10	CS100 Molboard	0.52	1.8	3.6	5
11	CS100 Twisted	0.40	1.3	2.5	3.5
12	CSSilage	0.85	3.2	6.4	8.8
13	CSSilage Molboard	0.86	3.3	6.5	9
14	CSSilage Twisted	0.86	3.3	6.4	8.9

Table 2: Variation of Soil loss (tons/acre/year) for each management at different slopes

The soil loss increases rapidly even for No Till (CSNT) management as the slope steepness increases from 0.5% to 6% and amounts to 0.94 tons/acre/year. The soil loss increases considerably from 0.49 tons/acre/year at 0.5% slope to 4.5 tons/acre/year at 6% slope, which is just 0.5 tons/acre/year less than the T value, in case CSTT management. The soil loss variation becomes alarmingly high 8.14 tons/acre/year for residue removal with aggressive tillage using Molboard plow from 0.5% slope to 6% slope steepness. Figure 3 shows that the soil loss defies the T value at 4% and 6% slopes whereas it well within limit at 2% slope for silage harvest. Thus, it is clear that silage harvesting leads to increase in the soil loss even with small increase in the slope steepness.

The soil loss increases merely 0.7 tons/acre/year from CSNT management to CSSilage Molboard at 0.5% slope. However, the increase in soil loss from CSNT to CSSilage Molboard at is more apparent 2%, 4% and 6% slopes. The increase amounts to 2.9 tons/acre/year, 5.6tons/acre/year, and 7.8 tons/acre/year for 2%, 4%, and 6% slopes respectively. Thus, the resulting line graph is steeper for 4% and 6% slopes compared to others.

The effect of tillage and residue removal on soil loss is also evident at higher slopes more than at lower slopes. Even with no residue removal, the use of a Molboard plow leads to high soil loss of 4.5 tons/acre/year in case of CSTT Molboard management at 6% slope. Soil loss almost reaches the T value in the CS30 Molboard plow management at 6% slope, and equal to T value for CS100 Molboard plow management. These managements show a trend of increasing soil loss even at lower slopes.

SCI and Soil Loss are correlated. While, SCI is affected relatively more by the residue removal and tillage equipment used, Soil loss is affected considerably more by the slope steepness.

Variation of Soil Loss with slope for each management

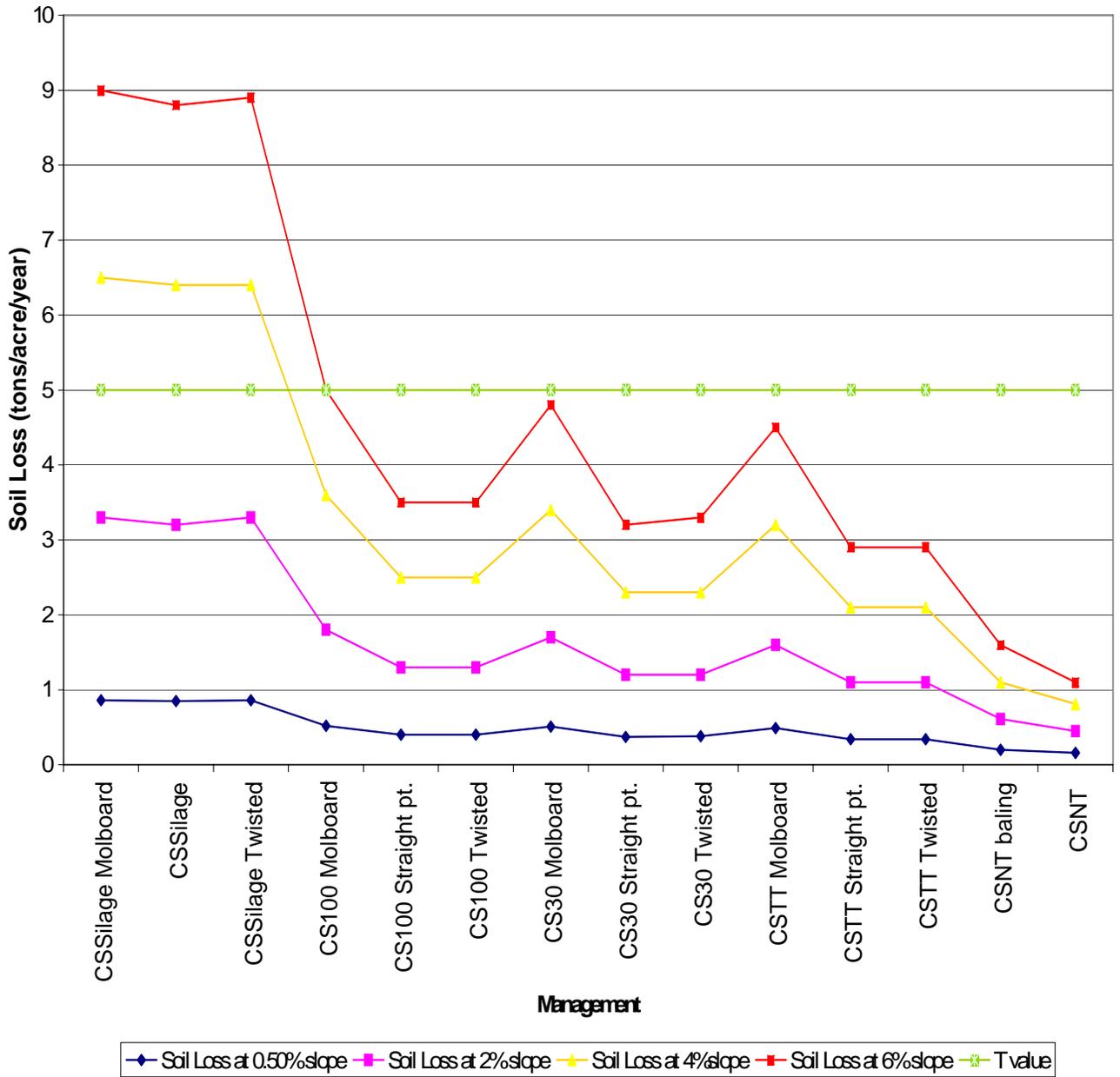


Figure 3

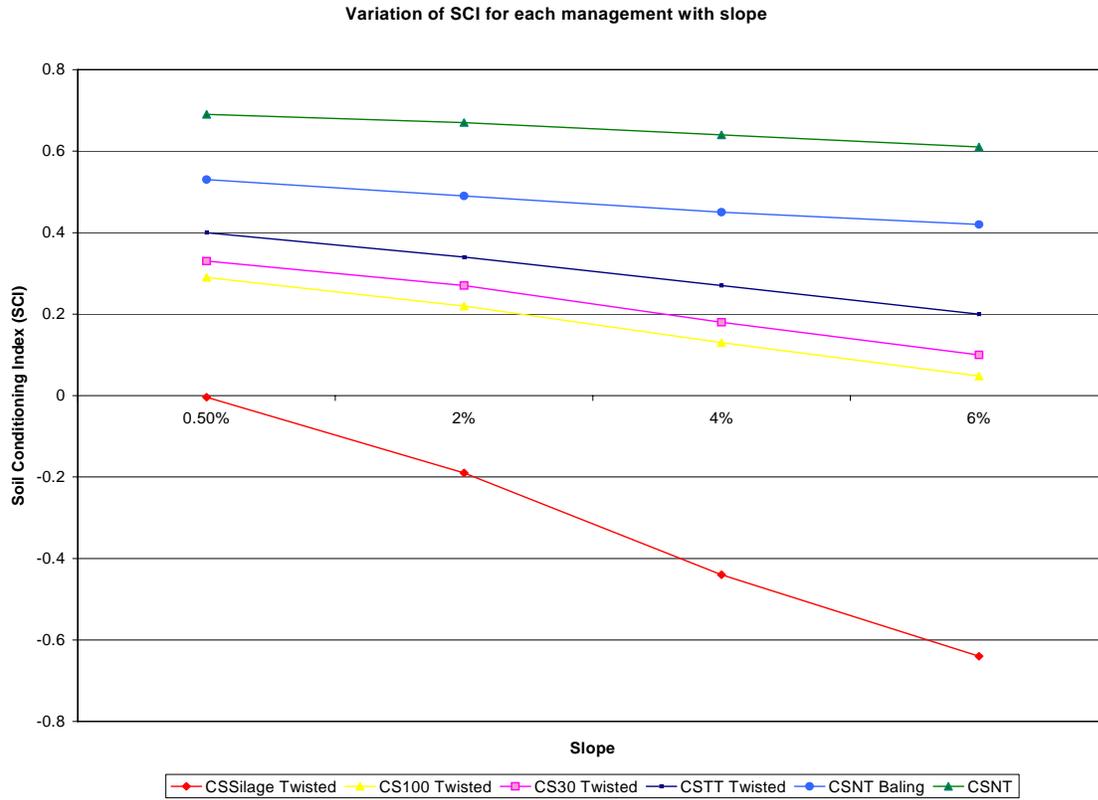


Figure 4

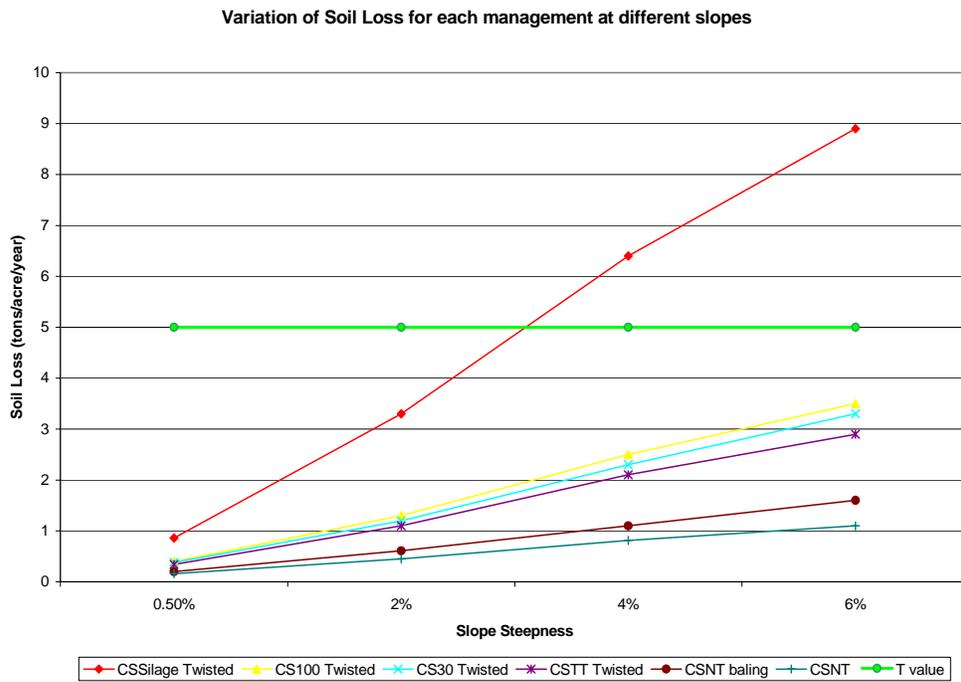


Figure 5

As shown in Figure 4 the SCI for CSSilage Twisted is negative at each slope and decreases further as the slope increases. Thus, it is obvious that Silage harvest even at less steep slopes would result in degradation of soil quality. While the The soil loss for CSSilage twisted is also much greater than no stover collection or more limited stover collection scenarios.

The moderately aggressive tillage with high amount of residue removal in case of CS100 Twisted results in positive SCI and soil loss less than T value through the range of slopes. Thus it seems sustainable on the whole. But at steep slopes like 6% it would result in high soil loss, 3.5 tons/acre/year. Thus, high amount of residue removal with moderately aggressive tillage would be sustainable only for less steeper slopes ranging from 0.5% to 4%.

Similarly, moderately aggressive tillage with less residue removal - CS30 Twisted - would be appear acceptable at less steep slopes ranging from 0.5% to 4%. Since, in this case too, the SCI is positive and soil loss is not very high for these slopes, and almost equivalent amount of soil loss would occur even if the residue is not removed while twisted chisel plow is used i.e CSTT Twisted.

However, CSNT and CSNT baling have the highest SCI and least amount of soil loss even at high steep slopes. Thus, the long term sustainable practice of residue removal among the studied managements would be CSNT baling as it allows maximum residue to be taken off from the field without affecting the SCI or soil loss in a harmful way.

References

Land Management Information Center, Minnesota Department of Administration.
Datanet: Minnesota land use and cover statistics. Online Database
<http://www.lmic.state.mn.us/datanetweb/>

Revised Universal Soil Loss Equation 2, User's Guide by United States Department of Agriculture, Agricultural Research Service, January 2003 at
<http://www.ars.usda.gov/Research/docs.htm?docid=6010>

Conclusion

The RUSLE2 software package appears to be a useful tool in assessing general impacts of corn stover harvest. Outcomes appear to be consistent with public literature and expert opinions about the impacts of such practices.

- Corn stover harvest will incrementally increase soil loss and incrementally decrease SCI for any given set of management practices. The incremental impact increases with the rate of stover removal.
- Aggressive stover harvest combined with aggressive tillage and even moderate slopes appears to cause soil degradation, as SCI is pushed near or even below 0.
- Maximum stover harvest represented by silage harvest is problematic with SCI falling into the negative range even on relatively flat soils using traditional chisel plow tillage systems.
- The negative impacts of both tillage and stover harvest are increasingly exacerbated as slope increases.
- Corn stover harvest can be accomplished in many cases and still lie within the accepted SCI range, if coupled with a reduction in tillage intensity.
- No-Till operations will dramatically decrease the impact of stover harvest on SCI and soil loss, even on a relatively steep 6% slope.
- In nearly all cases examined, soil loss was less than T

Corn stover harvest paired with reduced tillage intensity on the lester series of clay-loam soils can likely be accomplished within the existing range of SCI and soil loss of existing practices.

Corn stover

The more aggressive the stover harvest, the more concern for soil erosion and soil health.

1. Corn stover can be harvested in large amount at less steep slopes with less aggressive tillage.
2. Positive SCI can be maintained with aggressive tillage but limited residue harvest at less steep slope like 0.5% to 4% without causing a huge amount of soil loss.
3. I don't think this has been researched from the residue removal aspect – it is generally considered true with no residue removal when corn on corn. Removal of large amount of residue with No Till does not result in a high amount of soil loss to cause an unacceptable SCI?
4. Not many studies directly related to corn stover harvesting and its impact on environment or productivity are available.
5. Whatever literature is available does not portray a clear scenario about the topic of discussion.

Recommendations

Further Research

The analysis completed here was an initial attempt to use RUSLE2 software package to assess the impacts of removing corn stover for use as an energy feedstock. The analysis was limited in scope as it focused on a relatively small number of tillage practices using one soil type and in one county in Minnesota. Subsequent analysis should to include:

- A wider range of soils and soil types – loams, sandy loams, and silty loams – should be modeled to represent a range of conditions.
- A wider range of locations and climactic conditions need to be modeled to better understand how stover removal will impact soils over a wider.
- Additional management options should be modeled including:
 - A wider range of crop rotations – including continuous corn, longer rotation cycles that include forage production, and cropping systems that include small grains.
 - Cropping systems that harvest stover every other corn crop should be assessed.
 - Additional management systems should be assessed including minimum tillage practices such as strip or ridge tilling. Expert interviews suggested that such tillage practices are likely more acceptable and productive than a no-till system.
 - This analysis assumed that tillage operation would not be conducted on the contour.. Further analysis assuming contour farming and other conservation practices should be evaluated.
- This analysis raised concerns about the impact of silage removal. If corn biomass is harvested using silage cutting practices that remove nearly all of the residue, more field studies are needed to understand the implications of the biomass harvest.
- The impacts of manure utilization instead of anhydrous ammonia on SCI/SOC levels should be considered. RUSLE does allow manure application scenarios – inject, high/low disturbance, spread-incorporate, etc.
- The RUSLE2 Package primarily looks at soil loss and SOC accumulation trends. Additional tools and research are needed to better understand nutrient cycling, weed, disease and pest cycles and other agronomic considerations associated with large scale corn stover harvest.
- No till systems are generally viewed as having suppressing corn yield by a few percent. Additional field studies are needed to evaluate the potential for stover removal to over come the draw-backs of no-till corn. Such field trials should look at conventional corn-soybean rotations as well as continuous corn systems.
- Economic studies are needed to determine the marginal economic costs of a no-till corn system that includes stover removal. Does the cost of the additional tillage pass, exceed the additional revenue that might be derived from additional yield.

- Such analysis would benefit from factoring potential “energy enhancement payments” that are made under the Conservation Security Program for operations that meet a specific STIR rating standards.

Production Practices

- Corn stover harvest can be incorporated into production systems: With the following caveats:
 - Tillage practices should be reduced to the maximum extent practical if stover is being harvested. This is increasingly important as slope increases.
 - Stover harvest should be concentrated on flat crop ground, and decreasingly pursued with increased slope.
 - Other conservation practices should be considered in conjunction with stover harvest.
 - Producers should be working with their local conservation agencies and technical service providers to ensure that stover harvest is fully thought out and harvest programs are consistent with conservation goals.

Public Policy

- Public policies that support the development of corn stover as an energy feed stock are reasonable, but should also incorporate appropriate incentives to ensure adequate conservation practices.
- Public policy should not exclusively rely on corn stover and other crop residues for biomass energy feed stocks. The potential for negative outcomes on steeper slopes and with aggressive tillage will result in countervailing environmental benefits to the renewable energy development.

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