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Agricultural Biomass Removal Rate Estimation for Real-time Optimization of Single Pass Crop Grain and Biomass Harvesting System

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Abstract

As the demand for biomass feedstocks grows, agricultural residue may be removed in a way that compromises soil sustainability due to increased soil erosion, depletion of organic matter and deterioration of soil physical characteristics. Since soil erosion from agricultural fields depends on several factors including soil type, field terrain and cropping practice, the amount of biomass that can be removed while maintaining soil tilth varies substantially over space and time. The RUSLE soil erosion model, which takes into account these spatio-temporal variations, was used to estimate sustainable agricultural biomass removal rates for single pass crop grain and biomass harvesting system. Soil type, field topography, climate data, management practices and conservation practices were stored in individual databases on a state and/or county basis. Geographic position of the field was used as a spatial key to access the databases to select site specific information such as soil, topography and management related parameters. These parameters along with the actual grain yield were provided as the inputs to the RUSLE model to calculate the yearly soil loss per unit area of the field. An iterative technique was then used to determine the site-specific biomass removal rate that keeps the soil loss below the soil loss threshold (T) of the field. The sustainable removal rate varied substantially with field terrain, crop management practices and soil type. At a location in a field in Winnebago county, Iowa with ~1% slope steepness and conventional tillage practice, up to 98% of 11 Mg/ha total corn stover was available for collection with negligible soil loss. The study, however, has considered only the soil erosion tolerance level and has neglected the potential effects in organic matter content and other biophysical properties of the soil due to excessive biomass removal. There was no biomass available to remove with conventional tillage practice in steep slopes such as a location in Crawford County, Iowa field with a 12.6% slope. If no-till crop practices were adopted, up to 70% of available biomass could be collected at the same location with 12.6% slope. In case of soybean-corn rotation with no-till practices, about 98% biomass was available for removal at the locations in Winnebago field with low slope steepness, whereas 77% biomass was available at a location in the Crawford field with 7.5% slope steepness. Sustainable removal rates varied substantial over an agricultural field, which showed the importance of site specific removal rate estimation. These sustainable removal rates will be provided as recommended rates for the producers to use during a single pass crop grain and biomass harvesting operation. This type of site-specific biomass removal rate estimation is necessary to achieve field level sustainability in agricultural biomass production and collection systems.

Keywords

corn stover, biomass feedstocks, biomass harvesting, variable rate removal, sustainable agricultural production, rainfall erosion, soil loss

Disciplines

Bioresource and Agricultural Engineering

Comments

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Abstract. As the demand for biomass feedstocks grows, agricultural residue may be removed in a way that compromises soil sustainability due to increased soil erosion, depletion of organic matter and deterioration of soil physical characteristics. Since soil erosion from agricultural fields depends on several factors including soil type, field terrain and cropping practice, the amount of biomass that can be removed while maintaining soil tilth varies substantially over space and time. The RUSLE soil erosion model, which takes into account these spatio-temporal variations, was used to estimate sustainable agricultural biomass removal rates for single pass crop grain and biomass harvesting system. Soil type, field topography, climate data, management practices and conservation practices were stored in individual databases on a state and/or county basis. Geographic position of the field was used as a spatial key to access the databases to select site specific information such as soil, topography and management related parameters. These parameters along with the actual grain yield were provided as the inputs to the RUSLE model to calculate the yearly soil loss per unit area of the field. An iterative technique was then used to determine the site-specific biomass removal rate that keeps the soil loss below the soil loss threshold (T) of the field. The sustainable removal rate varied substantially with field terrain, crop management practices and soil type. At a location in a field in Winnebago county, Iowa with ~1% slope steepness and conventional tillage practice, up to 98% of 11 Mg/ha total corn stover was available for collection with negligible soil loss. The study, however, has considered only the soil erosion tolerance level and has neglected the potential effects in organic matter content and other biophysical properties of the soil due to excessive biomass removal. There was no biomass available to remove with conventional tillage practice in steep slopes such as a location in Crawford County, Iowa field with a 12.6% slope. If no-till crop practices were adopted, up to 70% of available biomass could be collected at the same location with 12.6% slope. In case of soybean-corn rotation with no-till practices, about 98% biomass was available for removal at the locations in Winnebago field with low slope steepness, whereas 77% biomass was available at a location in the Crawford field with 7.5% slope steepness. Sustainable removal rates varied substantial over an agricultural field, which showed the importance of site specific removal rate estimation. These sustainable removal rates will be provided as recommended rates for the producers to use during a single pass crop grain and biomass harvesting operation. This type of site-specific biomass removal rate estimation is necessary to achieve field level sustainability in agricultural biomass production and collection systems.

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Introduction

One of the most critical challenges the world is facing today is the increasing demand for energy. To minimize the adverse effects on environment and the dependence on non-renewable fossil fuels, renewable energy sources must be explored and expanded in every possible dimension (Glassner et al., 1999). Because the use of grain to produce ethanol will likely increases the food prices, there is a rapidly increasing interest in using biomass for bio-fuel generation. Studies have shown the potential and importance of using cellulosic biomass for bio-fuel and other bioenergy generation. University researchers and private companies are developing and improving technologies and infrastructure for the fuel production from cellulosic biomass (Hettenhaus et al. 2000). The US Department of Energy (USDOE, 2007) has set a 30*30 goal which aims to replace 30% of fossil fuel with bio-fuel by the year 2030. One billion dry ton of biomass feedstock is necessary to meet this goal, which will not be possible without extensive use of various types of cellulosic biomass (Perlac et al., 2005). In recent years, the use of energy crops, forest biomass and agricultural residue have been widely studied as viable sources of cellulosic biomass (Wilhelm et al., 2004; Andrews, 2006). Among these sources, agricultural residues, particularly corn stover, has been the primary focus because of its instant availability in huge quantities and relatively low cost (DePardo, 2000; Allmaras et al., 2000; Wilhelm, 2004; Blanco-Canqui, 2010). Consequently, agricultural biomass such as corn stover has been and will be collected at a steadily increasing rate to meet the increasing demand of biomass feedstocks in short to medium term.

Although agricultural biomass is a renewable energy source with great potential, it also presents sustainability challenges due to its interdependence with the soil and environment. Various studies have shown that excessive removal of agricultural biomass from the fields will have adverse effects on soil quality and environment. Soil structure, soil organic matter (SOM) content, soil organic carbon (SOC) sequestration, nutrient cycling, soil biodiversity and crop production can be affected if crop biomass is removed without considering the sustainability issues (Karlen et al., 1994; Andrews, 2006; Blanco-Canqui, 2010). Lindstrom (1986) found that increased corn stover removal at both reduced tillage and no tillage planting system will increase the water runoff and soil erosion, which may cause the nutrient removal to exceed the nutrients available from the standard fertilization practices. Studies such as Wilhelm et al. (2007) and Blanco-Conqui et al. (2009) have shown that SOM will decrease with increased corn stover removal. Karlen et al. (1994) found that a continuous removal of crop residue over a decade will cause reduced soil carbon, microbial and fungal activities and earthworm populations, which will lead to poor agricultural soil function. According to Hargrove (1991), surface biomass residue provides positive impacts on soil quality, which will lead to increased yields. However, other studies showed an improved crop yield when residue was removed (Swan et al., 1987). These conflicting results suggest that the effect of biomass removal on yield may not be substantial in short term. However, the yield is very likely to decrease in the long run with continuous biomass removal due to increased erosion, reduced SOM and nutrients and lowered biodiversity (Andrews, 2006). Therefore, it is necessary to be careful in removing agricultural residue so that degradation of soil and environment is prevented and agricultural production can be sustained.

To ensure the sustainability of agricultural production systems, only a certain proportion of biomass can be removed from agricultural fields. The actual removable amount depends on various parameters related to the agricultural field, cropping systems and environment. The effect of residue removal from agricultural fields will be more adverse in conventional tillage systems, which suggest a strong interaction between the tillage and the amount of biomass that can be removed safely (Benoit and Lindstorm, 1987; Linden et al., 2000; Wilson et al., 2004).

Sustainable biomass removal rate also depends on soil type and condition (Benoit and Lindstorm, 1987) and crop type and crop rotation (Reicosky, 1995; Dick, 1998). Climate is another factor influencing the available biomass for sustainable removal (Wilhelm, 2004). Potter et al. (1998) compared the effects on soil quality due to biomass removal in various climatic conditions and found that climatic conditions interact strongly with the biomass removal rate. Field topography will be another important factor as the level of soil erosion depends heavily on the slope and slope length. Andrews (2006) recommended the use of tools such as revised universal soil loss equation (RUSLE), wind erosion equation (WEQ), or the soil conditioning index to estimate sustainable crop residue removal rate, which take into account the factors such as soil type, terrain, management practices and yield in determining the sustainable removal rate.

Some researchers have estimated the sustainable agricultural biomass removal rates for different types of crops in various US states. Nelson (2002) used tolerable soil loss due to water/rain and wind erosion to calculate the recommended corn stover and wheat straw removal rates for 37 US states. Nelson et al. (2004) performed similar studies for corn and wheat straw in 10 largest corn producing states in mid-western USA. RUSLE was used as the water erosion model. In these studies, county level average removal rates were determined and a 20% general biomass removal rate was recommended. McAloon et al., (2000) suggested an average corn stover removal rate of 30% and Hettenhaus et al. (2000) suggested an average rate of 50% - 60% for the sustainable agricultural production in the corn-belt. Sheehan et al. (2004) applied the methodology of Nelson (2002) in 99 counties of the state of Iowa and suggested that about 40% of the residue can be collected from Iowa corn fields under reduced/mulch tillage while keeping the soil erosion at or below tolerable level. The sustainable removal rate increased to 70% for no-till condition. However, the study was making an assumption that all farmers will implement continuous corn rotation, which is not common in Iowa. Johnson et al. (2006) estimated that 50-60% of biomass can be removed from corn fields assuming that reduced tillage is used.

These studies suggest that there exists a substantial proportion of agricultural biomass such as corn stover and wheat straw that can be removed while keeping soil erosion and soil organic matter loss within tolerable limits. General guidelines for agricultural biomass removal practices can be formulated based on these studies. However, none of these studies incorporated the in-field variability into recommended biomass removal rates. The removable amount varies from 0% to 100% over the space and time within a field depending on various parameters such as soil type, crop management practices, topography, climate and yield (Nelson et al., 2004; Newman, 2010) and county level average removal rates estimated by this literature may not be useful for within field optimization of biomass collection rates. It is necessary to develop site-specific harvest guidelines that can adapt to the changing parameters within a field during harvesting operation so that a sustainable use of agricultural biomass can be ensured (Wilhelm, 2004; Andrews, 2006). The objective of this study was to develop a decision method to vary the percentage of stover material collected in a field by a single pass harvesting system based on site-specific parameters such as management practice, field topography, soil type, conservation practice, crop yield and climate.

Methods

Water/rain- and wind-induced soil erosion can deteriorate the soil tilth and hamper sustainable agricultural production. The extent of both types of soil erosion depends on various factors including soil type and condition, field operations, crop management practices, field topography, climate and extent of field cover by agricultural residue (Nelson, 2002). For a given location with all other variables being fixed, the extent of soil loss can be guided primarily by the amount of agricultural biomass left on the field. Based on the rate and role of top soil formation, USDA-NRCS has recommended a tolerable soil loss threshold (T) across the United States. This threshold can be viewed as the tolerable soil loss for the sustainable agricultural production (Nelson, 2002). If a field experiences soil erosion above this threshold, overall soil quality will decline over the years and agricultural production will not be sustainable. A methodology developed to estimate the site specific sustainable biomass removal rate will be described in this section. This methodology considered only the soil erosion andnot the other factors such as SOM and soil bio-physical characteristics in assessing sustainable biomass removal rate. Soil erosion due to wind was also neglected in this study. The RUSLE erosion model was used to estimate the biomass removal rate so that the soil erosion from agricultural fields does not exceed the soil loss threshold. Biomass removal rates estimated based on the water/rain erosion tolerance will be reasonable in the fields of Iowa where wind erosion is not substantial. However, the removal rates have to be treated carefully in relatively flat fields where SOM loss due to biomass removal may be a concern even though the soil loss is negligible.

RUSLE 2 Water/Rain-induced Soil Erosion Model

Water/rain-induced erosion moves the soil particles along the down slope of the field and deposits the mass on another portion of the field, deposits it entirely on another field or transfers it to waterways like streams and rivers. RUSLE (Revised Universal Soil Loss Equation) is a semi-emperical water/rain-induced soil loss prediction model developed based on universal soil loss equation (USLE). RUSLE is a widely used soil loss model in conservation practices. USDA Natural Resource Conservation Service (NRCS) uses RUSLE to review conservation compliance of various agricultural and conservation programs (USDA-NRCS, 2010). NRCS also suggests the use of RUSLE to estimate the sustainable biomass removal rate from agricultural fields.

The basic RUSLE and USLE model is represented by

$$A = r*k*l*S*c*p \qquad (1)$$

where, A = average annual soil loss, r = erosivity factor, k = soil erodibility factor, l = soil slope length factor, S = slope steepness factor, c = cover-management factor, and p = supporting practices factor.

RUSLE differs from USLE in the way different model parameters (factors) are calculated. Based on the RUSLE model, the USDA-Agricultural Research Service (ARS), in collaboration with the University of Tennessee, has developed and maintained a water/rain-induced soil erosion prediction software called RUSLE 2. The RUSLE2 software, which was an improved version of RUSLE software, provides a friendly graphical user interface for providing inputs and getting outputs from the model (Table 1). To simplify the usage of the model, the software takes parameters such as soil type and climatic zone and performs calculations internally to get model parameters such as erosivity and cover-management factors. The model software requires surface cover data every 15 days to calculate cover-management factor. RUSLE 2 team has also developed and distributed a collection of dynamically linked RUSLE2 libraries called RomeDLL. RomeDLL was incorporated into an application in this study to estimate the site-specific sustainable biomass removal rates.

Parameter Estimation

Input parameters required to run the erosion model were acquired using public domain data. Management practices were based on common practices of Iowa farmers and implemented with RUSLE2 using operations defined in the crop management database. Conventional and no-till crop management practices were used (Table 2). Field operations for these management practices were defined based on the recommendations of Nelson (2002), Nelson et al. (2004), Newman et al. (2010), and RUSLE2 crop management templates (RUSLE2, 2005). Two types of crop rotations were used, single year corn and two year soybean-corn rotations. Because the majority of farmers in the US corn-belt use soybean-corn rotation and apply conventional aggressive tillage (Brenner et al., 2002; Sheehan et al., 2002, Sheehan et al., 2004), it was important to study the combination of these tillage and rotation practices. It was also important to analyze continuous corn rotation with no-till as that is a likely future practice to meet the demand of cellulosic biomass.

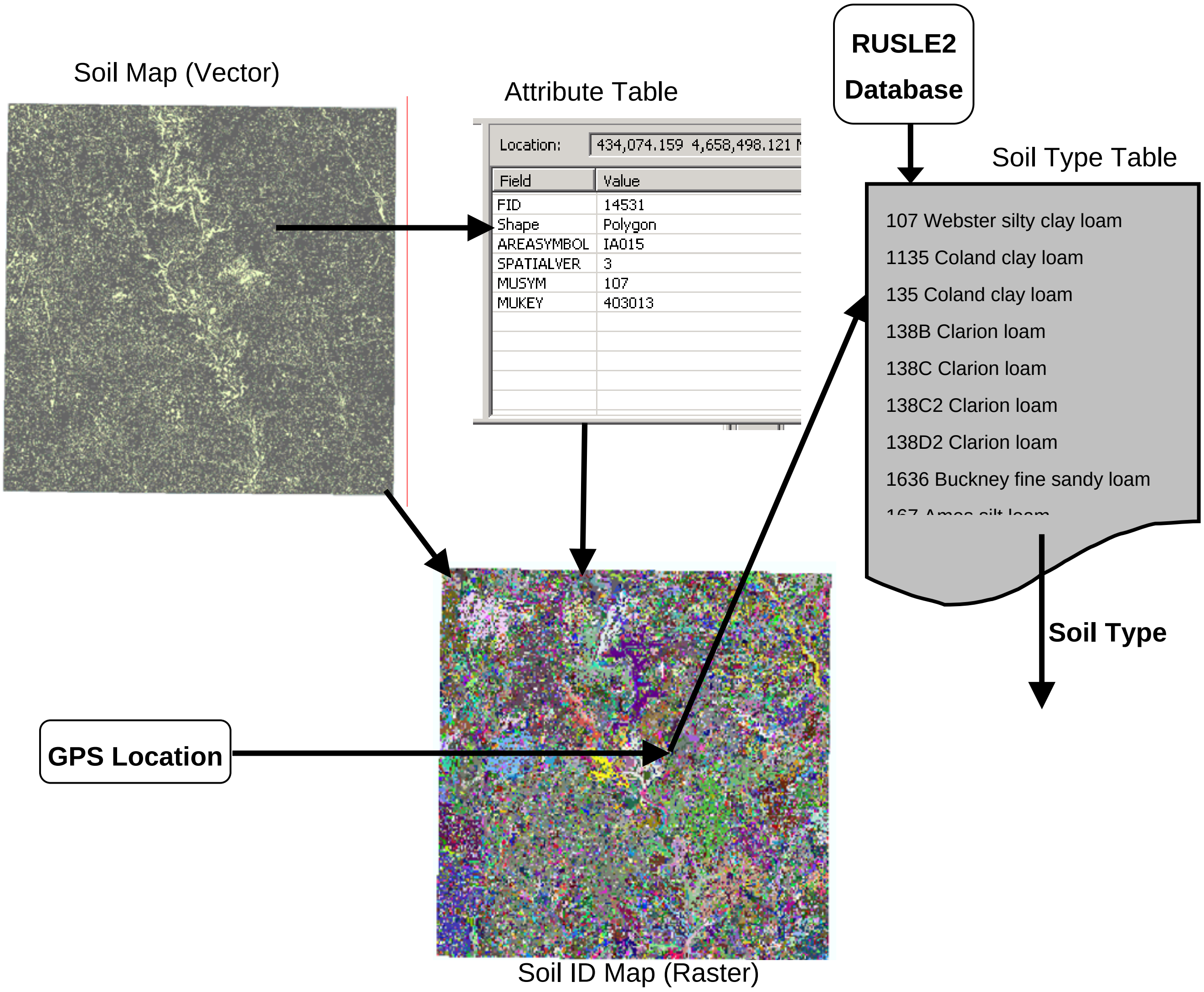
Table 1. Important inputs and outputs of the RUSLE2 software.

Inputs	Outputs
Management Practices	Soil Loss
Soil Data	Soil Loss Threshold
Slope Steepness and Slope Length	Surface Residue Cover
Climate Data	Sediment Delivery
Crop Grain Yield	
Supporting Practices	

Table 2: Field operations for conventional- and no-till management practices. These operations were used in RomeDLL to estimate the soil loss for various combinations of crop rotations and field operations at two different fields in Iowa.

	Corn		Soybean	
	Date (mm/dd)	Operation	Date (mm/dd)	Operation
Conventional Till	04/25	Plow, moldboard	05/11	Plow, moldboard
	05/10	Cultivator, field 6-12 in sweeps	05/26	Disk, tandem secondary operation
	05/15	Disk, tandem secondary operation	05/31	Disk, tandem light finishing
	05/17	Disk, tandem secondary operation	06/03	Cultivator, field 6-12 in sweeps
	05/20	Planter, double disk opener w/ fluted coulter	06/05	Planter, double disk opener w/ fluted coulter
	10/25	Harvest	10/30	Harvest
No Till	05/20	Planter, double disk opener w/ fluted coulter	06/05	Drill or air seeder single disk openers 7-10 in spacing
	10/25	Harvest	10/30	Harvest

County level soil databases were distributed with the RUSLE2. RomeDLL used the soil type name to access the database for the required soil type and its attributes. Spatial soil type maps were downloaded in ArcView shapefile format (ESRI Inc, Redlands, CA) from the United States Geological Survey (USGS) and were used to determine the soil type at particular locations (Fig. 1). The vector soil maps were converted into 10 m resolution raster maps to represent soil type identifiers (Soil ID) in gridded form. The soil type ID corresponding to a location of interest was then accessed in the raster map. This soil type ID was used to search the corresponding soil type name in the RUSLE2 database. The soil type name was then used as an input to the model. Slope steepness and slope length at a location were calculated using a 10 m resolution digital elevation model (DEM) of the field. DEMs for whole United States were acquired through USGS. Slope steepness was calculated as the resultant of the slope in east-west direction and the slope in north-south direction. A program implemented by GRASS GIS software, which was publicly available for download, was modified and used in this study to calculate the slope length parameter.



Location: 434,074.159 4,658,498.121

Field	Value
FID	14531
Shape	Polygon
AREASYMBOL	IA015
SPATIALVER	3
MUSYM	107
MUKEY	403013

107 Webster silty clay loam
1135 Coland clay loam
135 Coland clay loam
138B Clarion loam
138C Clarion loam
138C2 Clarion loam
138D2 Clarion loam
1636 Buckney fine sandy loam
167 Ames silt loam

Fig. 1: Determining soil type name at a location using vector soil map, attribute table and soil type name list available in RUSLE2 soil database.

Climatic data specific to a county was also retrieved from the databases distributed with the RUSLE2 software and RomeDLL. Crop yield data was also available in the crop management templates available in the RUSLE2 database. To be more realistic, however, county level average yield provided by USDA National Agricultural Statistics Services (USDA-NASS, 2010) was used in this study. The yield value will eventually be acquired using yield monitor when the system is used in single pass grain and biomass harvesting operation. It was assumed the crop rows were parallel to the contour lines in the field. It was also assumed that there were no supporting practices such as strips, barriers, diversion, terrace, sediment basin and subsurface drainage implemented in the field.

Calculating Sustainable Biomass Removal Rate

The RUSLE 2 model was used to calculate soil losses in a field with site-specific inputs and specific amount of agricultural residue left in the field (Fig. 2). Because the RUSLE2 database did not include single pass grain and biomass harvesting operations, a combination of harvest types, shredding operations and baling operations were used to vary the amount of biomass removed from the field, thus varying the level of surface cover due to residue. The RUSLE model calculated the soil loss iteratively with different amounts of surface cover in each iteration. The total amount of biomass available in the field was also calculated by RUSLE based on the crop yield data, and the difference between two biomass amounts was calculated as the removal rate. When two removal rates were found, which caused soil losses above and below the soil loss threshold (T), linear interpolation was applied to estimate the biomass removal rate that caused a soil loss equal to the soil loss threshold. Because the removal rate and soil erosion are not related linearly, the linear interpolation may cause some error in estimating biomass removal rates (Nelson, 2002). The iterations were repeated with small increments in biomass removal so that the two bounding points were close to each other, which helped to reduce the error due to the nonlinear relationship. A RomeDLL-based application was developed in Visual C++ (Microsoft Corporation, Redmond, WA) to perform this iterative process of estimating sustainable biomass removal rates.

This method of estimating sustainable biomass removal rate was applied to two agricultural fields in the state of Iowa (one in each of Winnebago and Crawford Counties) (Table 3, Fig. 3). Two locations were selected in the Winnebago field and four locations were selected in Crawford field with varying slope and soil type. Slope steepness values were 0.1% and 1.1% at the two locations of the Winnebago field and that at the four locations in the Crawford field ranged from 2% to 13%. At each location, combinations of two field operation practices (conventional- and no-till) and two crop rotations (single crop corn and two crop corn-soybean) were considered, which gave a total of 24 different scenarios for biomass removal rate estimation. To estimate the biomass availability in the soybean-corn rotation, it was assumed that no biomass as collected during the soybean harvesting season. The methodology was also used to develop a regularly gridded removal rate map for the western part of the Crawford county field.

Table 3: Field boundaries for the two agricultural fields (Winnebago and Crawford Counties, IA) used in the study.

Field	County	Corner	Latitude	Longitude
1	Winnebago	South-West	43.260503 N	93.881886 W
		North-East	43.262456	93.872101 W
2	Crawford	South-West	41.957432 N	95.562966 W
		North -East	41.964771 N	95.547173 W

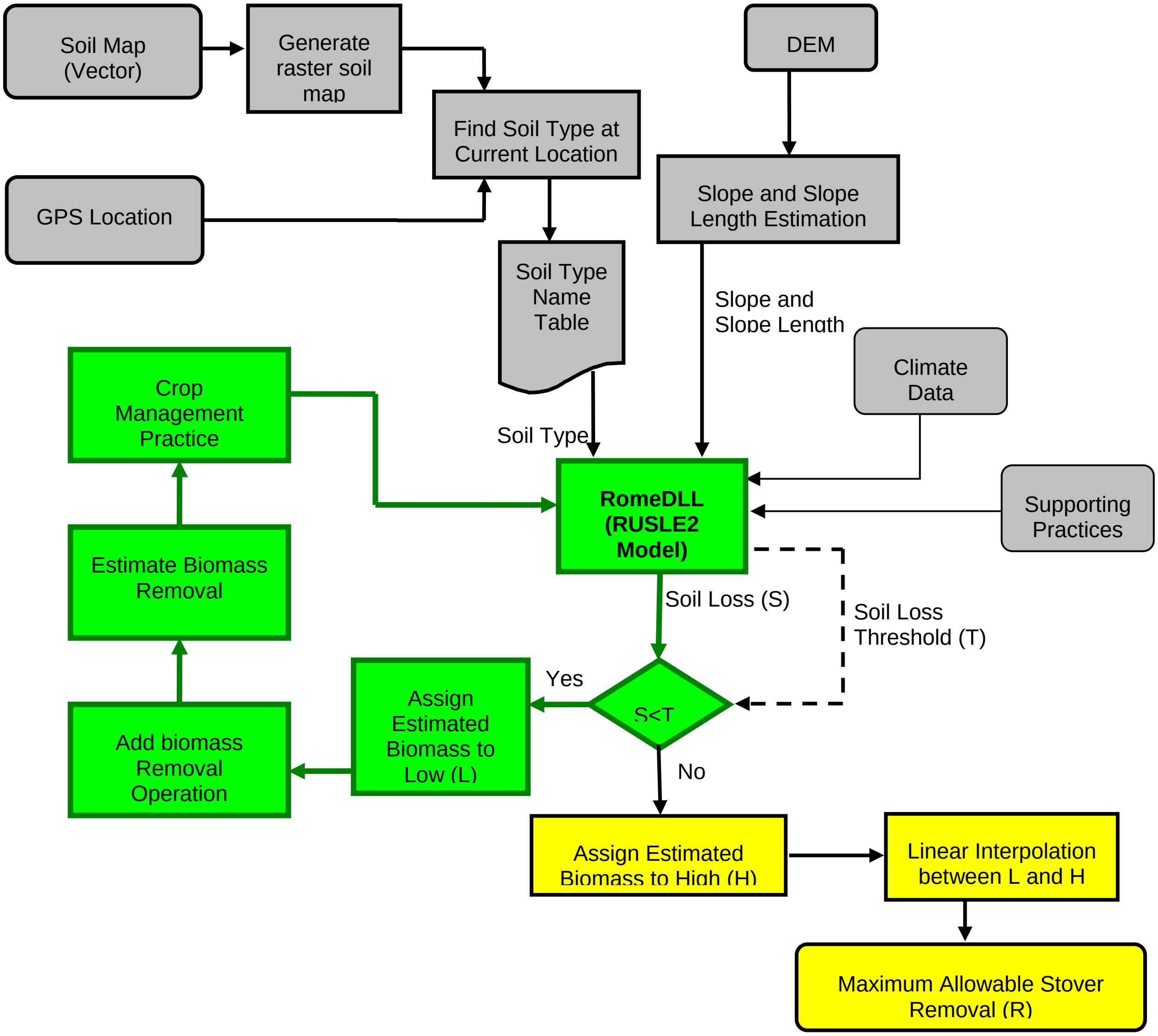


Fig. 2: Process and data flow chart for optimal biomass removal rate calculation.

Fig. 3: Soil survey maps of Winnebago (left) and Crawford (right) agricultural fields downloaded from USDA Web Soil Survey portal (websoilsurvey.nrcs.usda.gov)

Results and Discussion

Sustainable agricultural biomass removal rates varied widely over the two agricultural fields in Iowa depending on the crop management practices (tillage and rotation), field topography and soil type (Table 4, Fig. 4). At the two locations in a relatively flat field in Winnebago County, 98% of the 11 Mg/ha (9900 lb/ac) total biomass could be removed with negligible soil loss for both continuous corn and soybean-corn rotations. No changes in biomass removal rates were observed with the changes in tillage practice and soil types between the two locations in this field because the soil loss in the field was always negligible and almost all available biomass was removable. At these locations, the soil type were Nicollet Loam and Canisteo Clay respectively, 2009 county level average corn yield was 11.3 Mg/ha and soybean yield was 3.4 Mg/ha. In estimating this removal rate, however, only the soil erosion tolerance level was considered as a constraint and potential effects in organic matter content and other biophysical properties of the soil due to excessive biomass removal were neglected. These results are in agreement with the results of Newman (2010) in similar field terrains, soil types and management practices. Other studies (e.g. Nelson, 2002; Johnson et al., 2006) have reported removal rates varying from 20% to 70%. However, these studies were based on the county wise average slope steepness values which generally were higher than the slope steepness of this field.

At four locations in the rugged Crawford field, the biomass availability decreased substantially as the slope steepness increased from 2.6% to 7.5% and then to 12.6% with the same soil type, tillage practice and crop rotation. At these locations, soil types were Monana Silt Loam (first three locations) and Ida silt loam (last location), 2009 average corn yield was 12.4 Mg/ha and soybean yield was 3.6 Mg/ha. At a location with 2.6% slope, 98% biomass was available for removal in both conventional- and no-till practices when farmers were practicing continuous corn rotation. However, no biomass was available for removal at locations with 7.5% and higher slopes when the farmers were using conventional tillage practice. If no-till practices were adapted, the removal rate went as high as 88% for the continuous corn rotation and 77% for the soybean-corn rotation at the location with 7.5% slope steepness. The interaction between tillage practices and biomass removal rates became more apparent with increasing slopes. As the intensity of tillage was reduced from conventional to no-till, the amount of removable biomass increased, which is in agreement with the results from previous studies including Nelson et al. (2004) and Wilson et al. (2004). At two locations with similar slope steepness values, the biomass removal rate differed from one soil type to the other. For a no-till continuous corn management practice, the removable rate was 70% at a location with Monona silt loam and 12.6% slope steepness whereas the same was 74% at another location with Ida silt loam and similar slope steepness.

A lower level of sustainable biomass availability for the conventional tillage practices was expected as the soil erosion will be more prevalent in the tilled soil and additional surface cover is required to keep the soil loss below the tolerance level. No-till cropping practices with increased area of continuous corn production will be essential to increase the availability of removable biomass. Lower levels of sustainable removal rates in steep slopes were also expected. In sloped terrain, higher level of agricultural residue is required to minimize the soil erosion, which will leave very little to remove from the field. Generally, the actual yield in the sloped area will be lower than the county level average yield used in this study. This discrepancy may lead to even less availability of removable biomass during actual field operations. On the other hand, the single pass biomass removal operation was mimicked using conventional multi-pass operations as the single-pass harvesting operation was not included in the RUSLE2 database. This mimicking may cause underestimation of the biomass removal rates as additional field operations considered in the soil loss calculation will not be there in the actual single-pass harvesting operation. The discrepancy will favor the sustainability and soil tilth, though it may not be substantial. In this work, it was assumed that no supporting practices were used in the field. If the farmers built supporting structures such as barriers and diversions, the water/rain-induced soil erosion will decrease and the availability of removable biomass will likely increase.

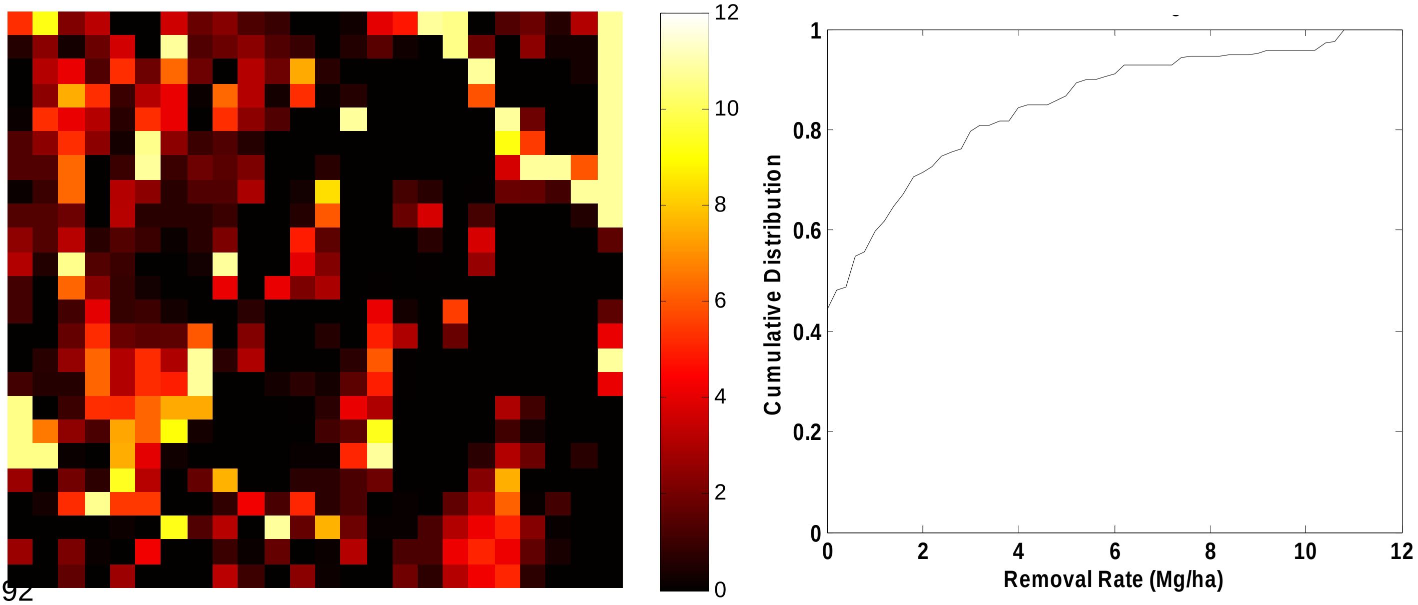
Table 4: Sustainable biomass removal rates at six different locations in two agricultural fields (Winnebago and Crawford Counties) in the state of Iowa.

Field	County	Loc.	Lat/ Lon	Soil Type	Slope (%)	Crop Rotation	Yield* (Mg/ha)	Tillage	Biomass (Mg/ha)	
									Available	Removable (%)[#]
1	Winnebago	1	3.261706 / -93.873024	55 - Nicollet Loam	00.1	Corn	11.3	Conv.	11.1	10.9 (98%)
								No-till	11.1	10.9 (98%)
						Soybean /Corn	3.4/ 11.3	Conv.	11.1	10.9 (98%)
								No-till	11.1	10.9 (98%)
		2	43.262206/ -93.872509	507- Canisteo Clay	01.1	Corn	11.3	Conv.	11.1	10.9 (98%)
								No-till	11.1	10.9 (98%)
						Soybean /Corn	3.4/ 11.3	Conv.	11.1	10.9 (98%)
								No-till	11.1	10.9 (98%)
2	Crawford	1	41.961772/ -95.562108	10B2- Monona Silt Loam	02.6	Corn	12.4	Conv.	12.3	12.1(98%)
								No-till	12.3	12.1 (98%)
						Soybean /Corn	3.6/ 12.4	Conv.	12.3	12.1 (98%)
								No-till	12.3	12.1 (98%)
		2	41.964085/ -5.560799	10C2- Monona Silt Loam	07.5	Corn	12.4	Conv.	12.3	0
								No-till	12.3	10.8(88%)
						Soybean /Corn	3.6/ 12.4	Conv.	12.3	0
								No-till	12.3	9.6 (77%)
		3	41.958852/ -95.560777	10E3 – Monona Silt Loam	12.6	Corn	12.4	Conv.	12.3	0
								No-till	12.3	8.6 (70%)
						Soybean /Corn	3.6/ 12.4	Conv.	12.3	0
								No-till	12.3	7.0 (56%)
		4	41.960320/ -95.552065	1E3-Ida Silt Loam	12.8	Corn	12.4	Conv.	12.3	0
								No-till	12.3	9.2 (74%)
						Soybean /Corn	3.6/ 12.4	Conv.	12.3	0
								No-till	12.3	8.4 (68%)

**Yield data was acquired from the USDA online resource (USDA-NASS 2010).*

[#] *Only water/soil induced erosion was considered in the removable rate estimation*

Site specific sustainable removal rates (Mg/ha) were also calculated in regular grids to create a removal rate map for part of the Crawford county field (Fig. 4a). The map was developed for the continuous corn conventional-till management practice with 35m spatial resolution. The sustainable removal rate varied from 0 to 12 Mg/ha over the field. This variation in the removable rates was cause by the changing field terrain in conjunction with the changing soil type. The field slope varied from 0 to approximately 25% and the average slope length used was 45 m. The removal rate was relatively higher in the north-west region where the field was relatively planer and the soil was less erodible. No or very small amount of biomass was available in the east-central and south-east areas of the field. This result was expected as the area was characterized by very high slope and highly erodible Monona/Ida Silt Loam soil type. The linear pattern of the pixels in the north-east area with higher removal rates was formed over the ridge line of the field terrain with very small slope steepness. The histogram showed that about 45% field area had no or negligible quantity of removable biomass and about 3% area had 11 Mg/ha to 12 Mg/ha biomass removal rate.



(a) (b)

Fig. 4: a) Sustainable biomass removal rate map (Mg/ha) for the west part of the Crawford county field (Fig. 3) and b) cumulative histogram of the removal rate map. The map was developed for continuous corn conventional tillage management practice. The spatial resolution of the map was 35m.

These results indicated that there was a substantial variability in biomass removal rates within an agricultural field and a site-specific variable rate biomass collection system is essential to develop sustainable biomass feedstock supply system. In the variable rate single-pass crop grain and biomass harvesting system, these site-specific sustainable removal rates will be estimated during the field operations and provided as a recommended rate to the operators. Depending on the willingness of the farmers, capacity of the harvesting and collection equipments, and market and weather conditions, only a certain percentage of the recommended rate may be collected.

Conclusions

A methodology was developed for the site-specific estimation of the sustainable agricultural biomass removal rates for single pass crop grain and biomass harvesting system. The methodology was used to estimate biomass removal rates in two different agricultural fields in the state of Iowa. It can be concluded from this study that the sustainable removal rates vary substantially over different locations in a field depending on the field terrain, crop management practices and soil types. At a location in a field in Winnepego county, Iowa with ~1% slope steepness and conventional tillage practice, up to 98% of 11 Mg/ha total corn stover was available for collection with negligible soil loss. The study, however, has considered only the soil erosion tolerance level and has neglected the potential effects in organic matter content and other biophysical properties of the soil due to excessive biomass removal. In contrast, there was no stover available for collection at a location in Crawford County, Iowa field with a 12.6% slope steepness and conventional tillage practice. If no-till crop practice was adapted, up to 70% biomass could be collected from the same location. In case of soybean-corn rotation with no-till practices, about 98% biomass was available for removal at the locations with small slope steepness values in Winnebago field, whereas about 56% biomass was available at a location in Crawford field with 12.6% slope steepness. The removal rate map developed in this study also showed a substantial variation in sustainable biomass removal rates over an agricultural field, which showed the importance of the site specific removal rate estimation. The sustainable removal rates estimated in this work will be provided as a recommended value for the farmers to set a biomass removal level during the single pass crop grain and biomass harvesting operation. This type of site-specific biomass removal rate estimation is necessary to achieve field level sustainability in agricultural biomass production and collection system.

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