Bio-Mass Opportunity for Imperial, NE Region

Corn Stover: What is the Value?

by

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PROJECT SUMMARY

Objective

Define the value, for the region's farmers and potential processors across the supply chain, of sustainable removal of the "excess" feedstock using innovative methods for corn and stover collection, wet storage of stover, rail transport from collection sites to a large biorefinery and validation of the stored feedstock in a biorefinery process.

Project Results

Sustainable Removal

Removing 80% of the stover on non-sandy soils with continuous no-till is sustainable. Soil Carbon is maintained with minimal erosion. Grid sampling of pivots, applying the Century Model and the Soil Conditioning Index were in good agreement and provided the same results.

One-pass Harvest

A one-pass harvester results in a more reliable and economic feedstock than present baling practice. One-pass collection of the ears and stalks doubles the removal per acre from 5 to 10 tons of plant material for 200 bushels (bu) of corn. Collecting the ears and stalks from 40% of the acres within a 10 mile radius, 80,000 acres, requires hauling 800,000 tons.

Logistics: Transport to the Collection Center

The additional truck traffic during harvest can be disruptive. In order to maintain the current harvester rates of 12 acres per hour, collecting both the ear and stalk, requires 9 to 12 trucks per harvester depending on the crop yield. Each standard 3,000 cubic foot trailer can transport approximately 11 tons of material.

Using existing grain elevators as collection and processing centers for transporting a more dense form of feedstock to the biorefinery can reduce congestion during one-pass harvest. In the Imperial, NE area many grain elevators are less than 10 miles apart. Harvesting within a 5 mile radius, the average round trip to deliver a load and return to the field is 10 miles or less. The 'grain-elevator' model provides farmers an affordable option to participate in the value chain and provides a reliable feedstock supply that better enables debt financing of biorefineries.

Wet Storage Validation.

Annual samples showed that the stover in the open storage pile exhibited a negligible glucan loss at the end of the two year period. The holocellulose yield was 94%. Circulating the water through the stover pile during construction removed the soluble material and increased the stover holocellulose fraction from 59% to 67% in storage. The fermentation yield was 95% of the theoretical yield, which further validates the Ritter Method for feedstock storage up to two years.

Water Management.

During normal harvest, stover is 50% moisture when the corn is 15% moisture, conserving water. A dry ton of stover contains more than 200 gallons of water while each bale with 15% moisture contains only 36 gallons. The water required for the biorefining process is reduced, by an equivalent amount. As the stover is removed from the pile for processing, the soluble inorganic nutrients are removed for recycling to the field.

Logistics: Transport to the Biorefinery
Rail transport on major railroads is feasible when employing unit trains consisting of 80 to 100 cars transporting 50 tons per car--beyond the expected capacity for the next 5 to 8 years. Regional rail systems offer potential for smaller shipments, especially if suitable loading and unloading systems are in place. Installing pipelines from the collection sites to the biorefinery appears most attractive. This would be best achieved by processing the solid feedstock into soluble liquids, for example carboxylic salts (Terrabon) or soluble lignin and holocellulose (Pure Vision Technology).

Delivered Cost
The one-pass harvest of corn ears and stalk billets is estimated to have a margin of $87 to $181 per acre for the farmer. This is three times greater than in the baling case, Table S1.

Table S!
Farmer's Pretax Margin Comparison

Basis: $70/dry ton Delivered to Biorefinery, 1.4M Acre	160 bu/ac	200 bu/ac	240 bu/ac
Ear and Stalk Harvest, $/acre	$ 90	$ 135	$ 180
Baling, $/acre	$ 40	$ 50	$ 80
Margin Improvement	$ 50	$ 85	$ 100

A comparison of the costs associated with baling and one-pass harvest for equivalent areas is made in Table S2 and Table S3.

Table S2
Custom Bale & Haul: Excess Stover Sale
Net to Farmer, Dollars per Acre

Basis: $70/dry ton (dt) Delivered, 1.4 M Acres, 27 mi radius Collection Site			
	160 bu/ac	200 bu/ac	240 bu/ac
Corn Stover, 1:1 ratio, dt/ac	3.8	4.8	5.7
1 dt/ac Left in Field	1.0	1.0	1.0
Net Stover Sold, 15% Moisture, dt/ac	2.8	3.8	4.7
Sale, $70/dt	$197	$263	$330
P & K Nutrient Credit, $10/dt	$(28)	$(38)	$(47)
Reduced Field Operations, $14/ac	$14	$14	$14
Less Stalk Chopping, $11/ac	$(12)	$(12)	$(12)
Less Raking, $6/ac	$(8)	$(8)	$(8)
Less Custom Bale, $23/dt	$(76)	$(102)	$(128)
Handle, Stack and Store, $5/dt	$(14)	$(15)	$(19)
Shrinkage, 10%	(20)	(26)	(33)
Hauling, 13 mile radius, $2.50/mi, $2.30/dt	$(12)	$(16)	$(19)
Net to Farmer, $/ac	$ 40	$ 50	$ 80

Table S3
One-pass Harvest and Transport: Excess Stover Sale
Net to Farmer, Dollars per Acre

Basis: $70/dry ton Delivered, 1.4M Acres, 7-10 mi radius Collection Sites			
	160 bu/ac	200 bu/ac	240 bu/ac
Corn Stover 1:1 ratio	3.8	4.8	5.7
Stover dt/ac Left in Field	1.2	1.3	1.8
Net Stover Sold, dt/ac	2.6	3.4	3.9
Sale, $70/dt	$ 183	$ 263	$330
P & K Nutrients, $10/dt	$(26)	$(34)	$(39)
Reduced Field Operations, $10/ac	$14	$14	$14
Less One-pass Harvest, $10/ac	$(10)	$(10)	$(10)
Field to Collection Site Transport, $8.26/dt	$(22)	$(28)	$(32)
Unload, Separate and Shell at, $3/dt	$(8)	$(10)	$(12)
Store, Wash, Process Stover, $10/dt	$(26)	$(34)	$(39)
Shrinkage, 3%	(6)	(8)	(10)
Transport Solubles to Biorefinery, 20 mi, $5/dt	$(13)	$(17)	$(20)
Net to Farmer, $/ac	$ 90	$ 135	$ 180

Life Cycle Analysis[1]

The single pass harvesting system combined with wet storage has been the primary focus of this project. The more detailed collection and storage process schematic is shown in the following figure. For this work it has been assumed that both the corncobs and the stored wet material are used as feedstock to the ethanol process

The energy balance for the collection and transportation is nearly four times more favourable for the single pass system due to the lower diesel fuel use and the reduced nutrient load resulting from the recycling summarized in Table S4

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[1] The Life Cycle Analysis was performed by Don O'Connor using the input-output analysis by J. Hettenhaus. The full life cycle assessment report is submitted separately

Table S4
Post Harvest Stover Baling and One Pass Corn Harvest Energy Balance

Fuel	Corn Stover	Corn Stover
Feedstock	Corn (Post harvest)	Corn (Single Pass)
	Joules consumed/Joule Delivered	
Fuel dispensing	0.0000	0.0000
Fuel distribution, storage	0.0000	0.0000
Fuel production	0.0000	0.0000
Feedstock transmission	0.0017	0.0039
Feedstock recovery	0.0681	0.1760
Ag. chemical manufacture	0.0459	0.1117
Co-product credits	0.0000	-0.2602
Total	**0.1156**	**0.0313**
Net Energy Ratio (J delivered/J consumed)	**8.6499**	**31.9568**

The single pass collection system produces significantly lower GHG emissions than the post harvest system. This is a function of not only the lower emissions associated with the stover collection, as shown earlier, but also the higher yield in the ethanol plant. Note that the feedstock transmission emissions are higher in the single pass system and that is a function of the higher moisture of the material that is moved from the collection center to the ethanol plant, resulting from the wet storage, Table S5.

Table S5
Lifecycle GHG Emissions Comparison

Fuel	Gasoline	Ethanol	
Feedstock	Crude Oil	Post Harvest Stover	Single Pass Stover
	g CO_2eq/GJ (HHV)		
Fuel dispensing	414	645	645
Fuel distribution and storage	1,216	1,656	1,656
Fuel production	12,189	38,274	31,135
Feedstock transmission	2,177	4,256	7,399
Feedstock recovery	7,231	24,574	49,582
Land-use changes, cultivation	75	0	38,585
Fertilizer manufacture	0	8,581	17,008
Gas leaks and flares	2,359	0	0
CO2, H_2S removed from NG	0	0	0
Emissions displaced	-39	-21,518	-119,487
Total	25,622	56,468	26,522
Combustion	64,861	2,097	2,097
Grand Total	90,483	58,565	28,619
% Reduction	-	35.3	68.4

PROJECT REPORT

Introduction

By the year 2022 the Energy Independence and Security Act has set a goal for biorefineries to produce 16 billion gallons of transportation fuels from cellulosic biomass, which primarily consists of crop residues like straw and corn stover.

The *Energy Independence and Security Act of 2007* establishes new Renewable Fuel Standard (RFS) goals to move the United States ethanol industry beyond cereal grain, mainly by using corn as a feedstock. Beginning in 2008, minimum goals were mandated for advanced biofuels, which include cellulosic biofuel and biodiesel. Table 1 summarizes this mandate.

Table 1
Renewable Fuel Standard Goals

	Billions of Gallons				
Year	Conventional Biofuel	Advanced Biofuel	Cellulosic Biofuel	Biomass-based Diesel	Total RFS
2012	13.2	2.000	0.500	1.000	15.200
2014	14.4	3.750	1.750	*	18.150
2016	15	7.250	4.250	*	22.250
2018	15	11.000	7.000	*	26.000
2020	15	15.000	10.500	*	30.000
2022	15	21.000	16.000	*	36.000
* At least 1.000 (specific amount to be determined by the Administrator)					

Conventional biofuel is ethanol produced from corn starch. Advanced biofuel[2] is the total production of biomass-based diesel and biogas produced through the conversion of organic matter from renewable cellulosic feedstock.

While great strides have been made in improving the biomass conversion process to fuels, questions remain on feedstock supply. Recent studies document the nation's capacity to meet this need on a macro level. In order to meet this goal 200 Million Dry Tons per Year (MDTY) of feedstock are required; there are 300 MDTY of corn stover grown. On a 'micro' level, a large amount of uncertainty in sourcing the regional and local feedstock supply remains. The cost, reliability and environmental impact of feedstock removal vary from field to field, and even across each field. Demonstrating benefits from changing cropping practices to the farmer and assuring potential processors that the infrastructure is as secure as the pipeline supplying the petroleum refineries naphtha cracker, with stable pricing and a suitable Life Cycle Analysis is required to meet this goal.

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[2] Advanced biofuel is derived from cellulose or lignin from renewable biomass and has a life-cycle greenhouse gas emission that achieves a 50% or more reduction over base life-cycle greenhouse gas emissions. Included are sugar or starch (other than corn starch), crop residues, vegetative waste material, animal waste, food waste and yard waste.

This project addresses these issues for corn stover centered on Imperial, NE. The project objective:

> Define the region's value, to farmers and potential processors across the supply chain, for sustainable feedstock removal using innovative methods for corn and stover collection, wet storage of stover, rail transport from collection sites to supply a large biorefinery near Imperial, NE and validation of the processability of the material in a biorefinery process.

The findings can be quickly implemented in the short term and are readily adapted to straw and energy crops as markets for feedstock develop.

Imperial, Nebraska Opportunity

To economically operate a biorefinery, about 1 MDTY cellulosic feedstock is required based on currently available process technology. The cropland surrounding Imperial, NE provides a large, reliable and economic feedstock supply that can be sustainable. Below are listed some supporting points that illustrate the above statement.

- Large Area: 2.3 million acres of cropland with stover and straw available
- Sustainable: Significant adoption of no-till corn practice
- Reliable: 1 million acres irrigated and usually dry harvest weather
- Economic: High yielding (irrigated) cropland
- Favorable truck and rail transport

A preliminary study estimated counties within a 50-mile radius of Imperial, NE have 3.6 M dry tons per year of excess stover and straw with no-till. This is the amount above the surface cover requirements necessary for complying with USDA erosion control guidelines. In addition, using grain elevators as collection centers improves logistics, lowers transport costs and economically expands the area supply to 6 M dry tons per year at $70 per dry ton delivered to the biorefinery. The net margin to the farmer is estimated to be $81 per acre or more, using one-pass harvest, wet storage, preprocessing and liquid transport from collection centers. This feedstock is equivalent to 500 M gallons of ethanol annually.

Additional investment and learning new management methods is required to provide sustainable feedstock in adequate quantities. The farmers, as stewards of the land, require improved information to better enable them and other stakeholders in the area to establish a sound basis for decisions to be taken in meeting the biorefinery supply needs. In 2005, the USDA NRCS awarded the Imperial Young Farmers and Ranchers $2 million to help answer these questions for corn stover in the Imperial, NE area. Other collaborators committed another $1.2 million. Information findings reported from this project include the following:

- Sustainable Removal
- Wet Storage
- Delivered Cost

? One-pass Harvest
? Logistics
? Life Cycle Modeling

Project Results

A. Sustainable Removal[3]

Objective: Sustainable Removal

The project accomplished the objective of *validating and improving soil related models applied for the sustainable removal of stover.* The Century Model and Soil Conditioning Index (2006) were applied at the field level and used to estimate the regional supply. The simulation with the Century Model correlated well with the actual soil carbon sample analysis and determined Soil Organic Carbon (SOC) can be maintained when 80% of the residue is removed from the no-till fields (non-sandy soils) in the study. Regional analysis showed SOC is maintained when 50% to 80% of the stover is removed with no-till. When connected to land use data from the Carbon Sequestration Rural Appraisal (CSRA) program, Comet-VR offers an improved tool for the farmer and others and calculates in real time the annual carbon flux using a dynamic Century Model simulation.

Economic collection is doubtful if the crop practice is not no-till, because 50% or more of the residue material must remain in the field to maintain SOC. The Century Model does not consider erosion. The Soil Conditioning Index (SCI), which is based on soil erosion models for wind and water, shows similar results. It shows a positive SCI is achieved with the removal of 80% of the residue from no-till fields in the study.

Project Soil Investigation

The project studies were performed with the guidance of soil-scientists who worked with farmers on 1,200 acres of irrigated pivots. There was one pivot per plot and each used commercial scale equipment for various crop management practices. The results provide field-scale measurements of soil carbon and soil quality, which are indicators for different harvesting strategies and tillage. These affect the sustainability as well as offer a comprehensive regional assessment that can be used for planning and implementation of production facilities. The results show a good fit when compared with existing models: RUSLE2, WEPP and CENTURY.

Two criterion were applied:

1. Century Modeling led by Keith Paustian with Amy Swan, Karolein Denaf et al at the Natural Resource Ecology Center, Colorado State University
2. Soil Conditioning Index by John Kimble, Innovative Soil Solutions

The field-scale measurements and the monitoring of residue removal impacts on the soil and a regional assessment of the sustainability of biomass removal are summarized below for three farms.

- K. Messke: 3 pivots and native grassland
- R. Johnson: 4 pivots

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[3] Prepared by James Hettenhaus, cea Inc from summaries by collaborators Amy Swan and Keith Paustian, Colorado State University; John Kimble, Innovative Soil Solutions;

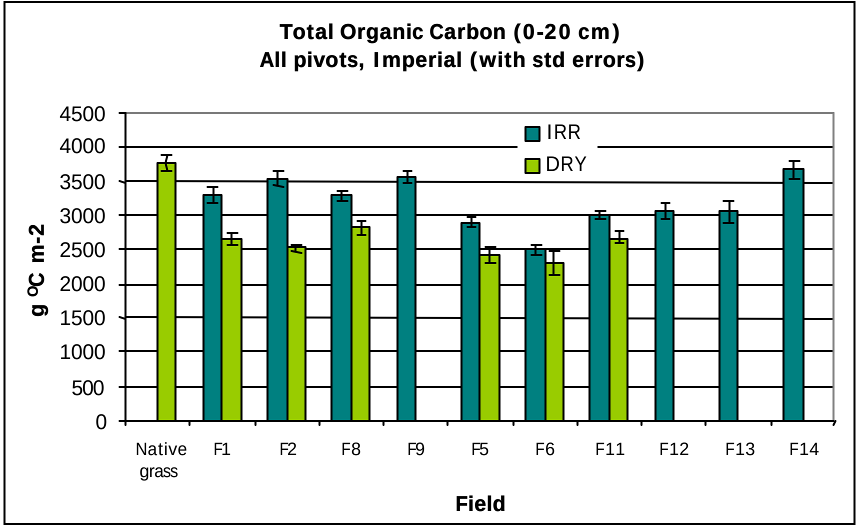
- T. Terryberry: 3 pivots

These fields include 12 irrigated pivot samples and 6 dry-land corner samples for the following conditions:

- Cultivation
  - Native grassland (one field)
  - Cultivated farmland (pivots and corners) (9 fields)
- Irrigation management
  - Irrigated pivots (9 fields)
  - Dry-land corners (6 fields)
- Crop rotation
  - Pivots: Corn-Soybean-Wheat (C-S-W)
  - (C-S-W) (3 fields)
  - Corn-Soybean (C-S) (3 fields)
  - Continuous Corn (C) (3 fields)
  - Corners: Corn-Wheat (C-W) (6 fields)

The sampling depth was 1 meter where possible with a depth separation of 0-5, 5-20, 20-50, 50-75, 75-100 centimeters. Each analysis included: bulk density, soil texture, total soil Carbon and Nitrogen, inorganic Carbon, soil aggregate size distribution, aggregate-associated Carbon and free particulate organic matter. The total Carbon to a 20 centimeter depth for each field is given in Figure 1.

Figure 1
Total Organic Carbon for All Pivots in Imperial Region



Century Model: The model results for the Johnson and Meske Farms show good agreement with the soil samples, Figure 2 and 3.

Figure 2
The Johnson Farm

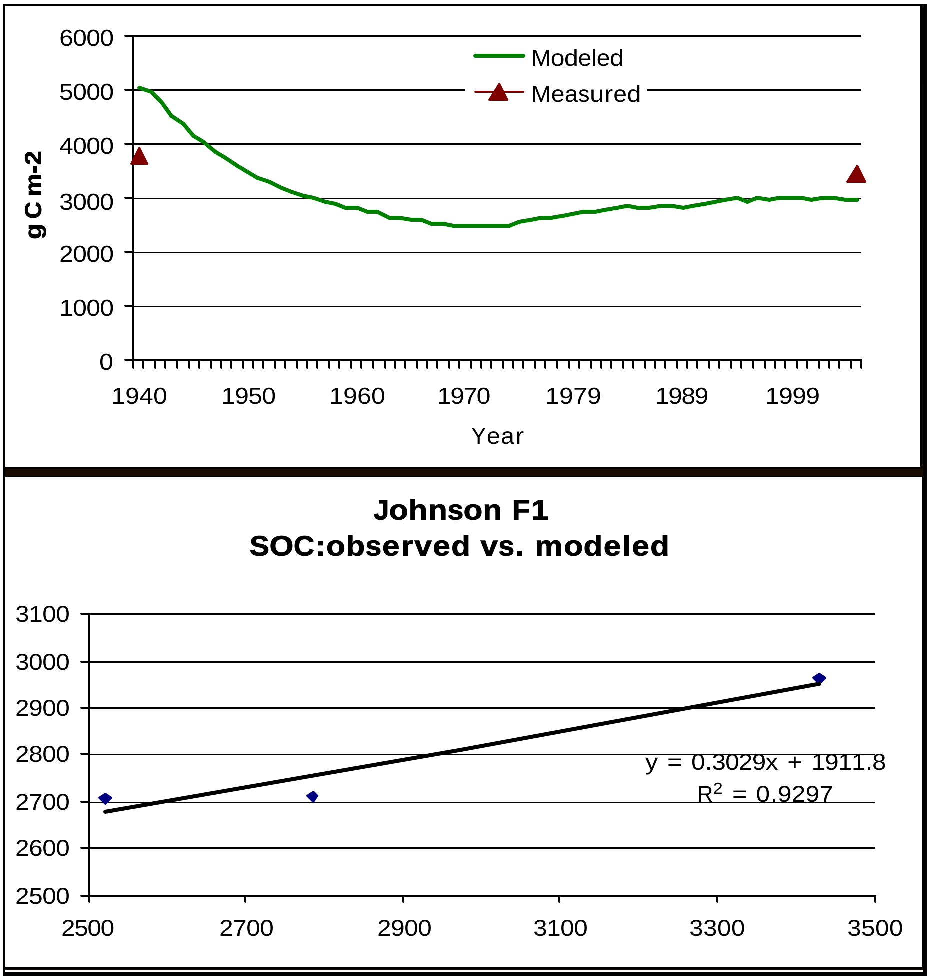
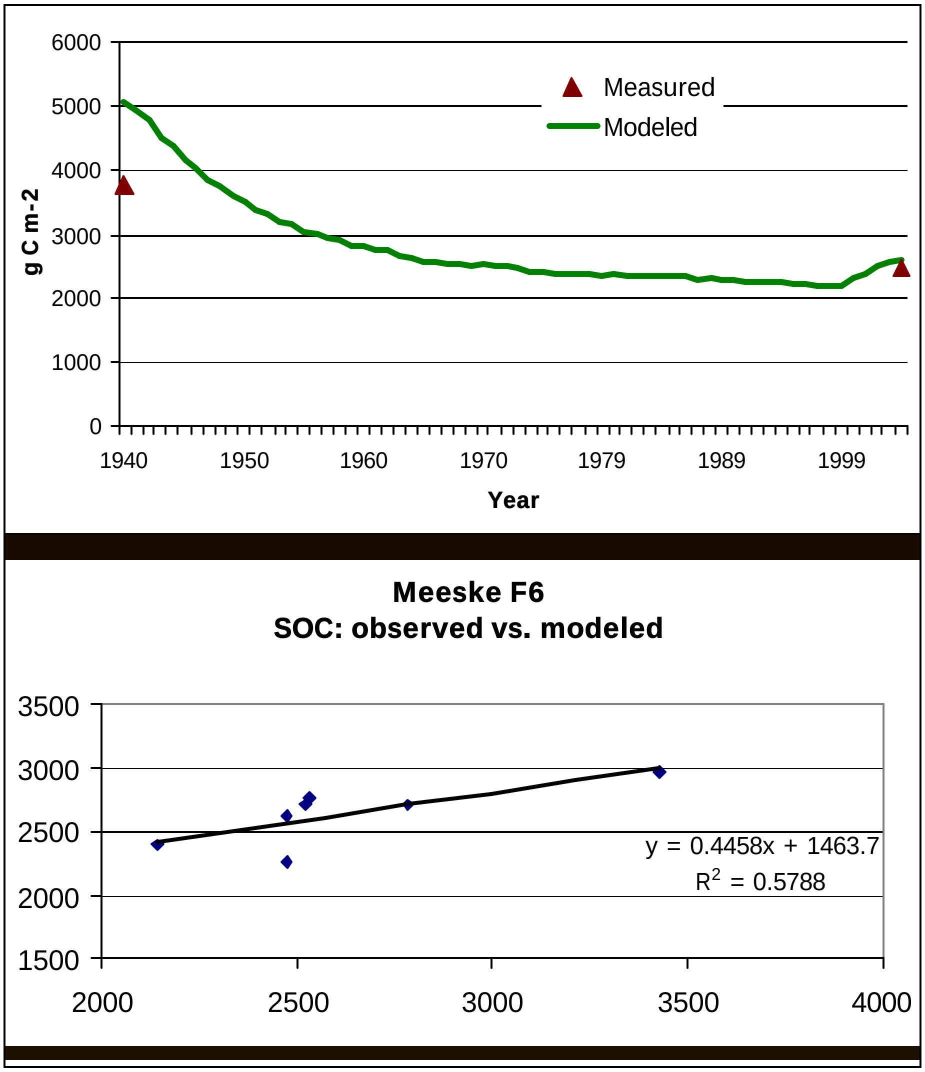
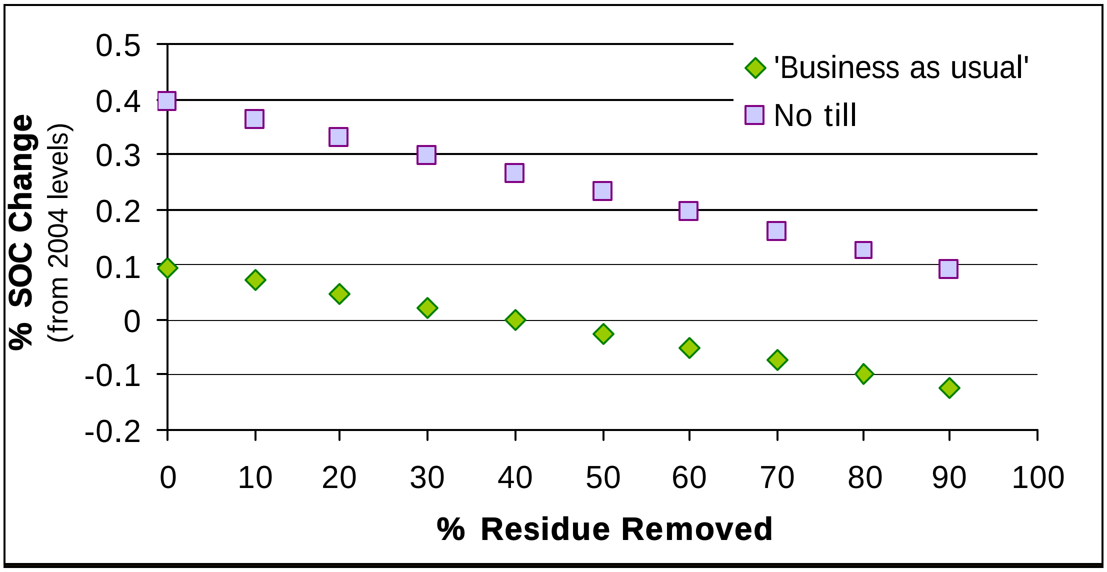


Figure 3
The Meeske Farm



The Century Model simulated the impact for relative amounts of stover residue removal under no-till practice compared to the present tilling practice for each of the farms. Figure 4 shows an example of the results for the Johnson Farm. Continuing with the present tilling practice limits the stover removal to less than 30%. This is hardly an economic practice when the tillage cost and the higher collection cost per unit of residue removed are considered.

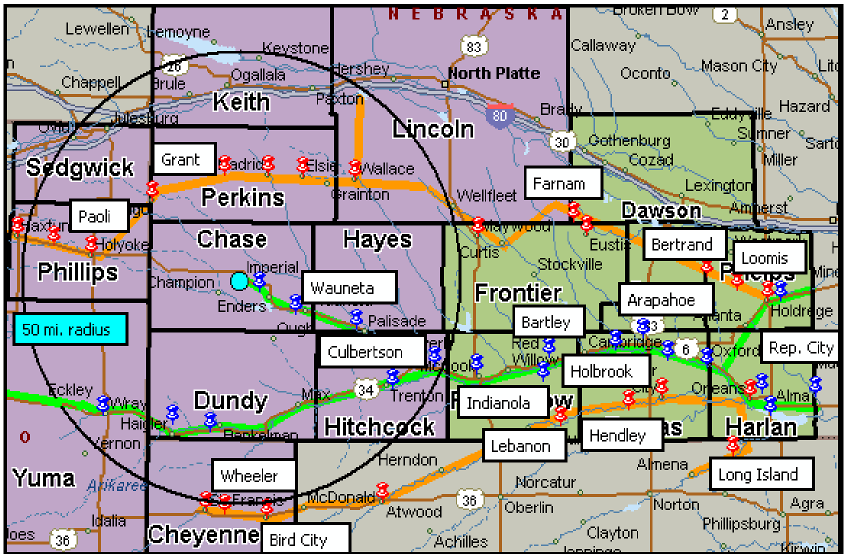
Figure 4
The Johnson Farm



In contrast, moving to a no-till practice can increase residue removal to the practical collection limit of about 80%. In addition it will show an increase in soil carbon which is equal to no residue removal with the "business as usual" tillage case. Overall, there is a 0.1% SOC change.

A regional assessment, depicting where the rail lines and grain elevators are located, was made for Chase County and the surrounding counties shown in purple in Figure 5.

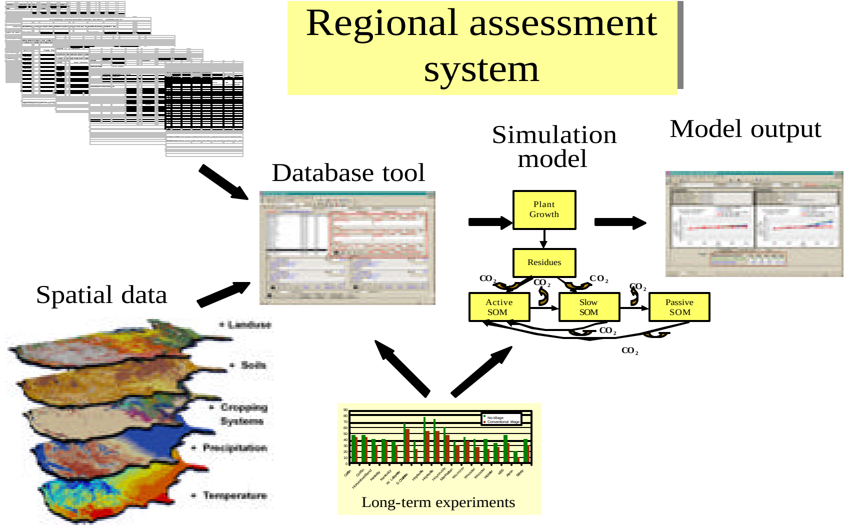
Figure 5
Collection Region with Rail and Elevator Sites



Circle: Imperial 50 mile radius
Orange: NKCR rail
Red Pins: NKCR elevator locations
Green: BNSF rail
Blue Pins: BNSF elevator locations

The regional analysis, shown in Figure 6, was performed by compiling climate, soil, land use and crop management practices and survey data (e.g., CSRA, NRI, NASS, CTIC), and then simulating current Carbon stocks and Carbon stock trajectories to evaluate the effect of varying rates of stover removal.

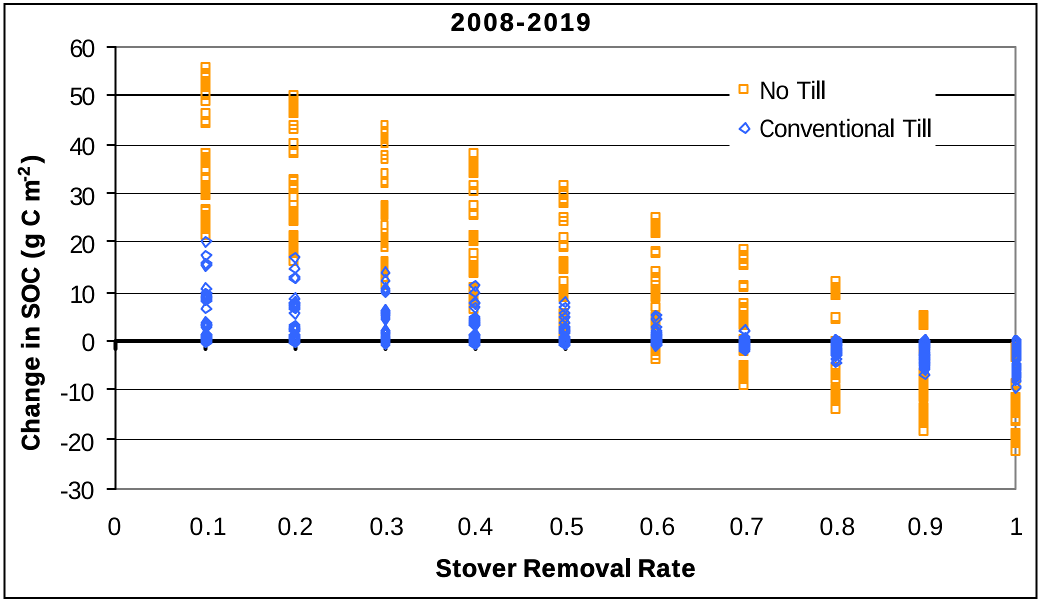
Figure 6



The results are tabulated in Figure 7, showing the change in SOC vs. the Stover removal rates for both no-till and conventional till practices from 2008-2019.

Figure 7

Change in SOC vs. Rate of Stover Removal



The simulation results show that 50% stover removal improves SOC in the region and up to 80% is possible in some counties. For a conventional till practice, the residue needs to remain in the field to maintain SOC.

The quantity of stover available by county in this region is tabulated in Table 1. Based on this initial analysis, 1.9 million dry tons is available in this region with 50% stover removal. Economics, policies and markets along with changing crop practices, like adding cover crops, are certain to shift these values in the future.

Table 2

Counties	Stover Yield, Thousands of Dry Tons									
	Total Stover	90%	80%	70%	60%	50%	40%	30%	20%	10%
Chase	521	469	417	365	313	261	208	156	104	52
Cheyenne, KS	117	105	94	82	70	59	47	35	23	12
Deuel	50	45	40	35	30	25	20	15	10	5
Dundy	268	241	214	188	161	134	107	80	54	27
Hayes	144	130	115	101	86	72	58	43	29	14
Hitchcock	116	104	93	81	70	58	46	35	23	12
Keith	238	214	190	167	143	119	95	71	48	24
Lincoln	629	566	503	440	377	315	252	189	126	63
Perkins	473	426	378	331	284	237	189	142	95	47
Phillips, CO	299	269	239	209	179	150	120	90	60	30
Sedgwick, CO	159	143	127	111	95	80	64	48	32	16
Yuma, CO	808	727	646	566	485	404	323	242	162	81
Total	3,822	3,441	3,058	2,676	2,294	1,912	1,529	1,147	765	382

Additional analysis with the Century Model could consider alternative cropping practices like the incorporation of cover crops.

Soil Conditioning Index (SCI): In addition to the Century Model the Soil Conditioning Index was used to guide sustainable stover removal. The model is built into the RUSLE2 Worksheet Erosion Calculation Record: http://soils.usda.gov/sqi/management/files/sq_atn_16.pdf

The information is available to the farmer as a spread sheet: http://soils.usda.gov/sqi/concepts/soil_organic_matter/som_sci.html

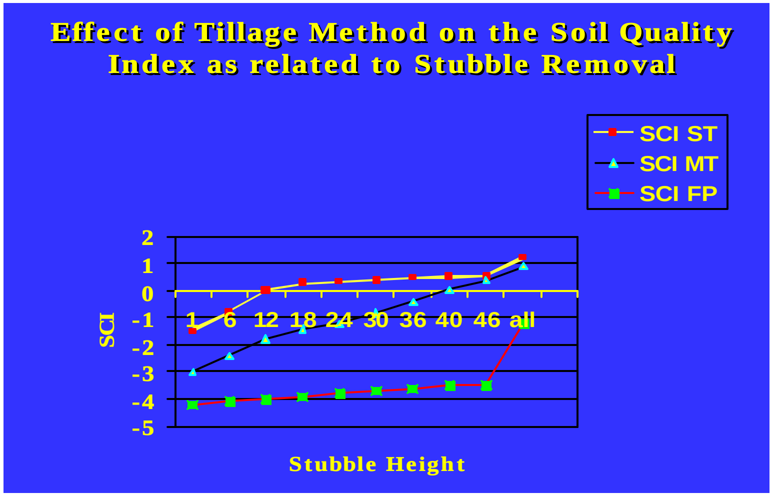
The model requires manual inputs including:

- Types and dates of tillage operations
- Planting dates
- Harvested grain and stover
- Crop(s)
- Amount of water applied and timing
- Soils (Type, T-value, slope length and steepness)

The SCI does provide an indication of soil quality as an index for various situations. Several examples follow for conditions that fit the Imperial Region.

Figure 8 shows the effect of the tillage method on the SCI related to the remaining stubble height measured in inches. The three tillage cases are strip tillage, mulch tillage and fall tillage, which leaves the soil uncovered all winter. Strip tillage, which is tilling only a small row about 6 inches wide, is the only method with a positive SCI. This method of tillage leaves 12 inches of standing stubble in the field.

Figure 8
Effect of Tillage Method on SQI



The effect of tillage type and stubble height on wind erosion is shown in Figure 9 for the same three tillage practices. Again, strip tillage minimizes wind erosion with 12 inches of standing stubble. The equivalent of removing 85% of the material is shown in Figure 10.

Figure 9
Effect of Tillage Method on Wind Erosion

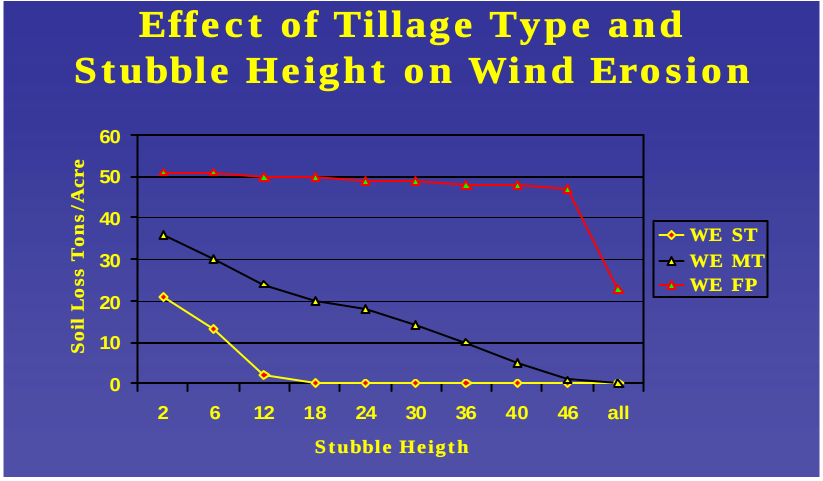
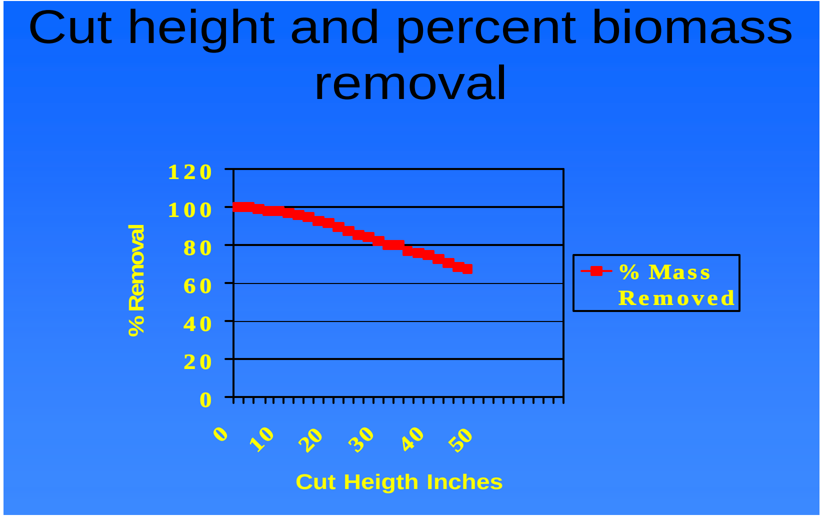


Figure 10

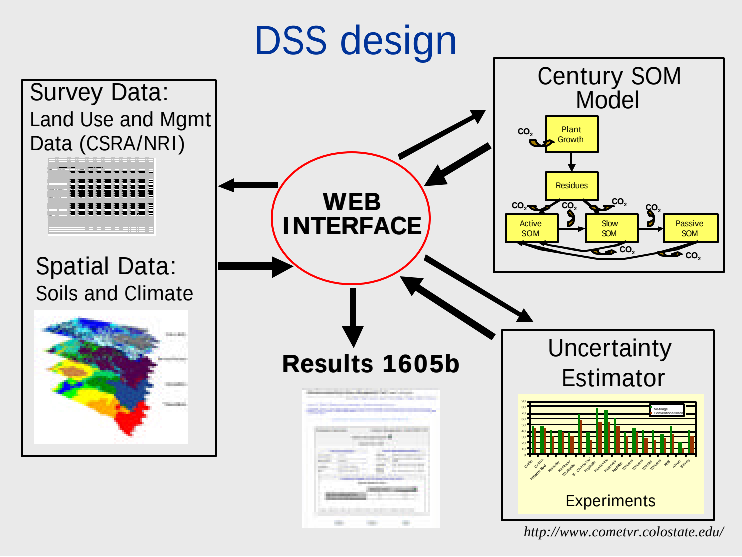


Decision Support System: An improved decision support system is desired for the farmer to consider the environmental and economic impact on changes in the cropping system. Figure 11 shows one DSS design. The **V**oluntary **R**eporting of Greenhouse Gases-**C**arb**O**n **M**anagement **E**valuation **T**ool (COMET-VR) is a decision support tool for agricultural producers, land managers, soil scientists and other agricultural interests.

COMET-VR (http://www.cometvr.colostate.edu/) provides an interface to a database containing land use data from the Carbon Sequestration Rural Appraisal (CSRA) and calculates in real time the annual carbon flux using a dynamic Century Model simulation.

Users of COMET-VR specify a history of agricultural management practices on one or more parcels of land. The results are presented as ten year averages of soil carbon sequestration or emissions with associated statistical uncertainty values. The results meet the requirements for voluntarily reporting Greenhouse Gas (GHG) emissions according to Section 1605(b) of the Energy Policy Act of 1992, often referred to as the 1605(b) program. Also the estimates can be used to construct a soil carbon inventory for the 1605(b) program. The Chicago Climate Exchange makes payments to the landowner based on the COMET-VR carbon sequestration results for Agricultural land and Rangeland.

Figure 11
Decision Support System Design



http://www.cometvr.colostate.edu/

Additional enhancements suggested including the following:

- Inclusion of an agroforestry component
- Improved feedback and user response
- Improved uncertainty estimation
- Continue soil carbon reporting in the Conservation Security Program (CSP)
- Tool evaluations and questionnaires

The enhanced version would provide the following information:

- Estimate field-level impacts of biomass utilization of soil carbon, erosion, nitrogen gas emissions (including nitrous oxide (N_2O)), and nitrogen leaching
- Estimate biomass production
- Economic analysis of net returns for alternative practices
- Allow 'gaming' of alternative management systems by the user

The attributes of the Decision Support System (DSS) would provide default model inputs including:

- – Soil maps (e.g. SSURGO digital soil surveys)
- – Elevation and slope
- – Weather variables

The DSS would utilize farm-specific information (by field):

- – Yield history and yield targets
- – Management information by field
    - Crop sequence
    - Fertilizer and manure applications by crop
    - Irrigation
    - Tillage
    - Pesticide use

B. One-Pass Corn Harvest

While baling can fit other residues and energy crops, the collection choice for stover appears to favor one-pass harvest.

Reliable Feedstock Supply: A wet harvest season can preclude stover baling due to high moisture. The grain is harvested when the grain is mature, usually after drying below 20%. However, in a wet harvest season the grain is harvested when field conditions permit after it matures, regardless of the moisture. Higher moisture grain is dried in specially designed dryers before storage to maintain quality. One-pass harvests the wet stover material with the grain. The stover is stored wet, adding water as required to be at 60% or more moisture. For stable bale storage, the moisture should be 18% or lower. Wet weather keeps residue moisture too high for baling. In regards to baling, the bulky material is flammable, expensive and a fire risk to transport.

Equipment Utilization: With one-pass harvesters replacing the existing combines for corn harvest, a number of possibilities are introduced including the following:

- Wet or Dry harvesting
- Bales or Bulk storage
- One, two or three streams from the harvester
- Collect ears only
- Collect both the ears and stalks

For reliable harvest, a provision for wet stover collection is required, which eliminates dry bales. One truck in the field simplifies field logistics and is least likely to slow down the harvest. No special hauling equipment is required and standard, 3,000 cubic foot, open-top trailers are readily available. Their light load, 11 tons with ears and stalks, results in less soil compaction than fully loaded grain trucks. The bulk density of ears and ears and stalks are the same, 9 pounds per cubic foot. Less field horsepower (HP) is required and the GHG emissions footprint is less. Ear and stalk separation and shelling are done with stationary, electrically powered conventional corn heads at the collection site.

Collection Resources: During the seasonal harvest, operations are planned well in advance, supplementing the regular workforce with all able-bodied folks including spouses, retirees, students after school and contract labor. There is little to no slack, as 12 or more hours per day are the norm. Any additional work, including harvesting, transporting and storing residues, requires additional people. One of the issues associated with harvesting for one million dry tons is maintaining 12 acres per hour with a one-pass harvester requires more trucks. For 200 bushels per acre, a grain truck is loaded in 20 minutes, 22 tons. Each acre harvested of ears and stalks fills a standard trailer, one 11 ton load, every 5 minutes. Depending on yield and distance, present corn harvesters operate with 3 to 4 trucks per combine. Therefore, for similar distances, 9 to 10 trucks are required per one-pass harvester.

One-pass Investment: Several one-pass prototypes are being investigated, but most slow down the grain harvest or require multiple trucks in the field. The base case shown above assumes the stalk and ear are removed together in one truck from the field using an ear-corn harvester that has been modified to collect the stalk under the corn head. Grain is separated at the collection center. Collection centers are located at the existing grain elevators, the ’grain elevator model’, and make use of existing infrastructure to store the corn. These assets are often underutilized since much of the local corn is sold to nearby ethanol plants. Land may need to be acquired at some locations to accommodate the additional cellulosic storage.

To collect 1 million dry tons of stover in the example above 30 one-pass harvesters would be required based on the following:

- 14 acres per hour average harvest
- 200 bushels per hour average
- Stover (1:1 ratio), 4.8 dry tons per acre
- 20 hours per day operating
- 2 spare harvesters

The number of one-pass harvesters drops as the harvest days are lengthened beyond thirty. Table 6, which includes no spare harvesters in its values, summarizes the above point. To maintain the harvest rate of 14 acres per hour a 12 head combine is needed in a 200 bushels per acre field. This combine harvests 40 bushels per minute, filling a trailer to its legal weight of 20 tons in 15 minutes. A one-pass harvester will fill this same truck in 5 minutes. The number of trucks required per harvester triple, and the trucks are volume limited (3000 cubic feet, 8 pounds per cubic foot, 12 tons as is). Depending on yield and distance, present corn harvesters operate with a minimum of 3 to 4 trucks per combine. Therefore, for similar distances, 10 to 12 trucks are required per one-pass harvester. The Logistics section discusses this issue further.

Table 3
One-Pass Harvester Requirements
Example: 200 Bushels per Acre

Stover Collected Million dt	Harvest Days		
	30	40	50
	Harvesters Required		
1	28	21	17
2	56	42	34
3	84	63	51
4	112	84	67
5	141	105	84

The list price of a 12 row, 375 HP Rotary Combine is approximately $300,000. Assuming trucks can be contracted with no additional investment and the same harvest cost can be achieved when the additional handling is done off site, the investment in new one-pass harvest equipment is $9 million (30 times $300,000) per 1 million dry tons of stover collected. Replacing the existing combines with one-pass harvesters is a trade-off for operators. Currently, support crews are deployed for combines and a similar crew would support one-pass harvest.

Baling

The basis for the required baling units is the same as for the one-pass harvest example. Additional assumptions include the following:

- Cover Left, 1.0 dry ton per acre
- Stover Baled, 3.8 dry tons per acre
- Area Baled, 265,000 acres

Baling unit requirements are shown in Table 3. The stalk chopper is widely used now to help the microbial attack of the stover residue. For baling, the stalks are chopped immediately after the harvest to accelerate drying.

The chopped material is raked to form a windrow after it dries to less than 18% moisture. Since raking adds stalks knocked to the ground during the grain harvest, it inevitably introduces dirt into the bale. The windrow reduces the number of passes the baler makes across the field, improving the baling rate. Windrows once wet due to rain or even a heavy dew, are difficult to dry back down so raking is scheduled just prior to baling.

Tractors are multi-purpose. A 60 HP tractor can rake and pull the round baler. The 130 HP Mechanical Front Wheel Drive tractor can handle all the assignments, but is only required for the stalk chopper and the square baler.

Table 3
Baling Equipment Requirements

		Harvest Days		
		30	40	50
Harvest Hours,	10 hr days	300	400	500
Collection Rate Required	*ac/hr*	*1,212*	*909*	*727*
Equipment Employed	Equipment Rate ac/hr	*Units Required*		
Stalk Chopper with 130 HP MFWD Tractor	7.8	112		
			84	68
Rake, 14 ft with 100 HP Tractor	6.8	128		
All Square Balers with Sq Baler Tractor, 200 HP MFWD	16	54	96	78
All Round Balers, 12 ft with Round Baler Tractor, 170 HP			42	32
	4.0	393		
			227	182
Bale Mover, Edge of field. 130 HP MFWD	10	432		

Baling 1 million dry tons produces 2 million bales and nearly 200 additional positions are needed to operate the equipment. Table 4 shows the baling equipment staffing needs for a spring harvest that utilizes a no-till practice where 30% are round bales and 70% are square bales.

Table 4
Baling Equipment Staffing Needs

Operation	**Positions**
Stalk Choppers	56
Rakes	64
Rotary Balers, 30 % of Balers	33
Square Balers, 70% of Balers	20
Baling Support Crew, 15%	27
Total Operators, Bales Left in Field	**200**

The number of operators required for baling 1 million dry tons of stover depends on the harvest days, the operating hours per day and the type of balers. Table 5 shows that the estimated staffing level for a square bale operation is about 260 to 430 people based on 30 to 50 days, baling 10 hour per day. The use of round balers would add an additional 3 operators per square baler replaced.

Table 5
Square Baling Staffing Level

	Harvest Days (10 hr days)		
	30	40	50
Operation	Positions		
Rake	178	134	107
Round Balers, 100 % of Balers	*303*	*227*	*182*
Square Balers, 100% of Balers	76	57	45
Move Sq Bales to/from Edge, Stack	121	91	73
Sq Baling Support Crew, 15%	56	42	34
Total Operators, Sq Bales at Field Edge	432	324	259

Since the work week is 24 hours a day and seven days a week, 400 people are required to staff the baling operation.

There are three operations for bale harvest: chopping, raking and baling. Stalk chopping, if not shredded by the combine head, is done immediately after the grain is harvested to accelerate field drying. When the residue reaches the required moisture, a baling crew is deployed. The baling crews work only when the stover dries below 20% or more in the fields and with dry weather this is usually 4 or 5 days after the corn grain harvest. The raking and baling operations are done together and the windrow is collected immediately to prevent it from getting wet. Advance scheduling is difficult because weather is unpredictable. After the stover field dries, heavy dew will delay the morning start until the moisture on the stover is gone and if it begins to rain or if water condenses on the stover surface as the evening cools, baling must stop.

The net wrapping protects round bales from weather so that they can be left in the field for collection until the next field operation. Square bales are not protected, and must be moved, stacked and covered to protect them from the weather in most areas. This labor is additional, and is not included in the above operations.

When wet weather curtails the collection, there are limited other assignments for the baling crews, and their fixed costs continue to accumulate. One such assignment could be to cover the square bales.

Soil Quality and Compaction: When making a choice to remove stover, the impact on soil quality is a serious factor. Field traffic can cause excessive soil compaction and can damage the soil structure. Compacted soil inhibits root growth, increases water runoff and reduces the flow of nutrients to the plant. All of these factors reduce crop yields. In both harvest cases, more traffic will occur on the field.

Compaction can be avoided in several ways. First, wide tires that better distribute the weight of the truck can be used. Second, limiting the truck traffic to tracks between the crop rows can localize the soil compaction to specified areas. Finally, one can till the compacted area after harvest. Tilling is the least attractive solution, because it adds cost and it releases soil organic matter. One-pass harvest, collecting the ear or the ear with wet stalks, reduces the amount of compaction from the multiple passes that are required for baling.

Capital Investment Requirements

Capital Equipment Utilization:

- One-pass harvesters replace the existing combines for corn harvest. The grain and stover are collected in one pass, which uses more trucks, and stalk chopping in one-pass harvested fields is eliminated.

- Conventional combines continue to be used when baling residue. The baling equipment is additional investment and its utilization is weather dependent.

Harvest Choices: While baling can fit other residues and energy crops, for stover, the collection choice appears to favor one-pass harvest. Reasons include the following:

- Wet harvest season: The grain is harvested when the grain is mature, usually after drying below 20%. However, in a wet season the grain is harvested when field conditions permit and dried in specially designed dryers.

- One-pass harvests the wet stover material with the grain. The stover is stored wet and water is added as required to be at 60% or more moisture.

- Baling requires material be at 18% moisture. Wet weather keeps residue moisture too high for baling and feedstock remains in the field.

The requirement for making all square bales or all round bales is included in Table 7. The square baler, which cost $100,000 each, is more productive than the round baler and is the choice for the larger, mostly flat fields found in the western Corn Belt. Round balers are 33% of the cost of square balers and are more maneuverable for smaller, irregular fields found in the central and eastern Corn Belt. Square balers are four times as efficient, but the bales must be stacked and covered to prevent wet weather damage. Round bales are net wrapped and can shed water without being covered. Improved corn heads that chop the stalk as it is discharged from the combine can eliminate the need for a stalk chopper. The rake is used to form a windrow, improving baler efficiency.

One-pass Investment: The list price of a 12 row, 375 HP Rotary Combine is approximately $300,000. Assuming trucks can be contracted with no additional investment and the same harvest cost can be achieved when the additional handling is done off site, the investment in new one-pass harvest equipment is $9 million (30 times $300,000) per one million dry tons of stover collected. Replacing the existing combines with one-pass harvesters is a trade-off for operators. This investment seems to be reasonable because larger operators lease their combines. If the economics worked then this opportunity would warrant serious consideration.

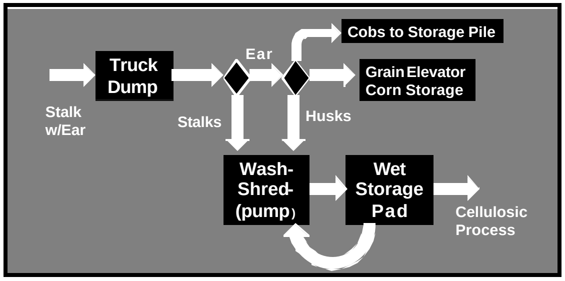
Baling Investment: The equipment investment for baling 1 million dry tons of stover in 30 days is $15 million. The capital is the same for round or square bales and can be seen in Table 6 Table 6 does not include the cost of the equipment needed to move the bales from the field, to store them or to transport them.

Table 6
Capital Equipment Investment for Baling

CAPITAL EQUIPMENT	Unit Cost $(000)	Harvest Days 30	40	50
		Capital Employed, $ Million		
Stalk Chopper	20	1.1	0.8	0.7
Rake	27	1.7	1.3	1.0
Square Baler	75	2.1	1.5	1.2
Round Baler	21	2.3	1.7	1.4
Tractor, 60 HP with Rake	26	1.5	1.1	0.9
Tractor, 60 HP with Rnd Baler	26	2.9	2.1	1.7
Tractor, 130 HP MFWD, Chop	106	5.0	4.5	3.6
Tractor, 130 HP MFWD, Sq baler	106	2.9	2.2	1.7
Chop, Rake, Sq Baler Only		15.3	11.4	9.1
Chop, Rake, Rnd Baler Only		15.4	11.6	9.3

One-Pass Ear and Stalk Handling System: The ear and stalk are transported to a collection center, which is discussed in the logistics section. The standard trailer load is weighed, sampled and dumped onto a conveyor. The ears are fed to stationary corn heads after they are separated from the stalks. A simplified flow is shown in Figure 12 below.

Figure 12
Ear and Stalk Handling for Ritter Storage System



C. Wet Storage

Validate Wet Storage (Ritter Method): Wet non-wood fibers like bagasse have been successfully stored at 75% to 80% moisture to supply pulp mills for more than 50 years, Figure 13.

Figure 13
Bagasse Wet Storage

This method offers significant advantages over bales: the piles will not burn, they require 10% of the storage area and wet storage fits one-pass corn harvest. The Ritter Method for storage is an improvement over silage piles for pulping applications. Studies of the commercial pulping of bagasse showed that building piles by circulating 3% solids slurry resulted in the following advantages when pulped over other methods:

- Low, 3%, loss of holocellulose
- Nutrient recycled to fields
- More consistent feedstock
- Increased throughput

? Removed 70% to 80% of solubles
? Reduced process ash
? Higher feedstock quality
? Reduced treatment cost

While stover is similar to bagasse, this method needs to be validated on a credible scale to measure yield, solubles extracted and processing quality of the feedstock.

The wet storage yield and fermentation results validate wet corn stover storage for three crop years. A corn stover pile was constructed in 2005 to investigate wet stover storage using the Ritter Method. The Ritter Method circulates water through the pile during construction. Dirt and solubles are removed from the stover. The circulation compacts the pile, excluding air and ensiling the material at a pH of 4.5 as the sucrose in the stover ferments to organic acids.

The 700 dry ton pile was 30 feet high with an initial angle of repose of 45 degrees. The height was chosen based on experience with bagasse storage. It is the minimum acceptable height for stable conditions. After seven months of storage, the pile further compacted, measuring 19 feet high. This pile along with the collaborators is shown in Figure 14.

Figure 14
Corn Stover Wet Storage Pile, May 2006

The storage samples evaluated by the Laboratory of Renewable Resources Engineering (LORRE) at Purdue University showed that the stover in the open storage pile exhibited negligible glucan loss at the end of two years. The composition analysis for the wet storage is shown in Table 7.

Table 7
Wet Storage Composition Analysis

Crop Year	2004-2005	2005-2006	2006-2007	2007-2008
	Incoming Stover	Annual Storage Samples % Dry Matter		
Glucan	31%	42%	42%	37%
Holocellulose	59%	68%	66%	57%
Acid Insoluble Residue	12%	17%	20%	22%
Acid Soluble Lignin	3.8%	1.5%	1.8%	2.1%
Ash	6.0%	6.7%	6.9%	6.9%
Solubles	15%	4.8%	5.5%	8.1%
Structural mass	84%	94%	95.2%	86%
Dry Matter Balance	99%	98%	101%	94%

The holocellulose yield was 94%. Removing the solubles by circulating water through the stover pile during construction increased the stover holocellulose fraction from 59% to 67% during the first two years of storage. In the third year, the pile height diminished to 15 feet which exposed more surface area and incurred more holocellulose loss.

The fermentation yield was 95% of theoretical yield, which further validates the Ritter Method for feedstock storage up to two years. Based on bagasse experience, a higher, larger pile is expected to reduce the glucan loss to 3% as less surface area would be exposed.

Stover hydrolysis was done with two different loadings. One was at 4% weight per volume (w/v) of solids and the other was at 15% w/v solids. Both loadings had 15 filter paper units (FPU) of cellulose per gram of glucan. The hydrolyzate was fermented using xylose which caused the co-fermention of yeast. After 48 hours, the final ethanol concentration was 34 grams per liter (3.4% w/v).

Water management becomes important for the Ritter Method. During harvest, stover contains 40% to 50% moisture. The additional water collected is nearly 4 times greater than the water contained in bales, 43 gallons per dry ton versus 160 to 240 gallons per dry ton. Table 8 displays the water differential between baled stover and one-pass stover.

Table 8
Water Contained in Collected Feedstock

	% M	Gal/dt
Bales	15%	43
One-pass Stover	40% to 50%	160 to 240

Circulating water removes the soluble material during construction and further compresses the pile. During storage, the exposed pile increased to 85% moisture over time. Soluble nutrients are recovered and recycled to the soil during the removal process. The stover taken from the pile passes through two countercurrent dewatering presses. The liquor from the first press, which is high in soluble nutrients, is returned to the field. The second press uses the water normally added to the incoming biorefinery feedstock. In contrast to dry bales, this feedstock is clean of dirt and already has more than 90% of the soluble material removed. The material balance is included in the life cycle section.

D. Logistics

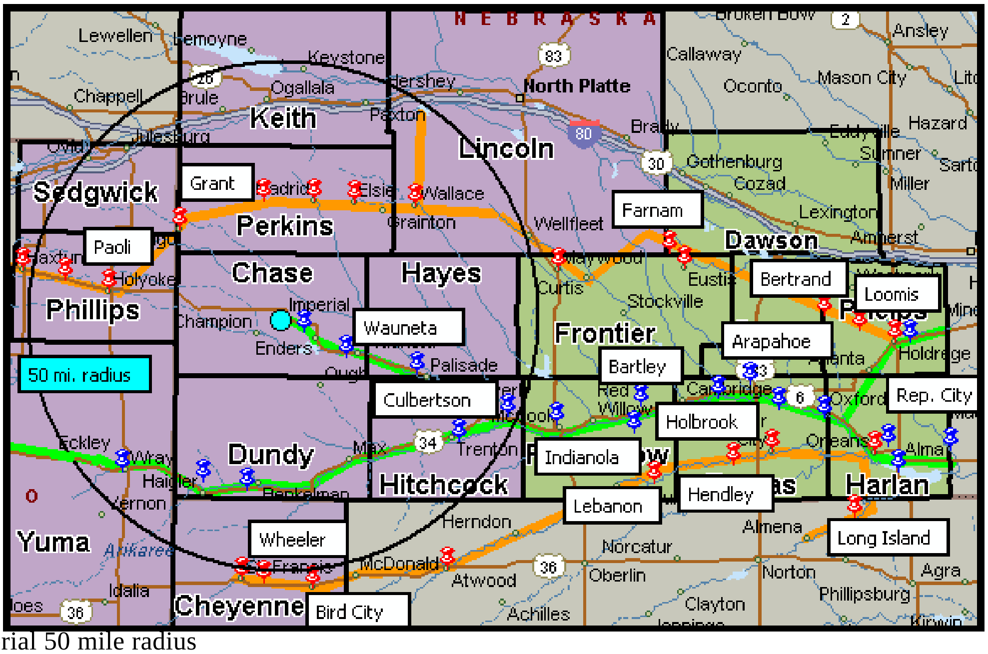
Transporting the bulky material from the field to the collection center during the short harvest window and storing the material for delivery throughout the years is accomplished in three steps:

- Field to the collection site
- Collection site unloading facilities
- Collection site to biorefinery

<u>Field to Collection Site</u>

The field to the collection site has historically been the distance between the field and the grain elevator. The map of grain elevators along the rail lines in the Imperial, NE region, Figure 15, shows a distance of 5 to 15 miles between their locations.

Figure 15
Rail & Elevator Locations



Circle: Imperial 50 mile radius
Orange: NKCR rail
Red Pins: NKCR elevator locations
Green: BNSF rail
Blue Pins: BNSF elevator locations

The truck requirements to maintain a harvest rate of 12 acres per hour for corn grain and for ears and stalks are summarized below in Table 9. Three corn yields are considered: 160, 200 and 240 bushel per acre.

Table 9
Trucks per Hour Harvested
12 Acres per Hour

Corn Yield, bu/ac		160	200	240
1. Corn Grain Trucks				
Fill Time, min		25	20	16
lbs/ft3	40			
Load, tons	22			
Trailer Volume, ft3	1100			
2. Ear & Stalk Trucks				
Fill Time, min		7	5.3	4.4
lbs/ft3	8			
Load, tons	11			
Trailer Volume, ft3	3000			

The table illustrates the significant increase in truck requirements to maintain the harvest rate. Collecting the ear and 85% of the stalk doubles the weight collected from the field. More significant, the volume removed is 20% of the corn grain density, requiring 4 times the number of trucks, all with full size trailers. This adds to the difficulty of one-pass harvesting.

Harvesting 12 acres per hour fills a corn grain truck in 16 to 25 minutes. The time to fill a standard 3,000 cubic foot trailer is 4 to 7 minutes, weighing half of the legal load of the corn grain truck's weight. The bulk density for ears and stalks, 8 pounds per cubic foot, reduces the load to 11 tons, constrained by the standard truck dimensions. Grain trucks are fully loaded, 22 tons, and can be hauled in smaller trucks, requiring just 1,100 cubic feet.

Collection Site Distance and Unloading Facilities

The number of trucks depends on the distance hauled and the unloading rate at the collection center. A more distant collection radius requires more trucks and more truck unloading facilities, but the larger area permits more feedstock storage to offset fixed costs for the added infrastructure. The optimum site for collection centers depends on the local situation.

The acres within a 5 to 50 mile radius are tabulated in Table 10 below. The average round trip is based on a 1.2 road factor. Assume 30% of the acres are collected.

Table 10
Acres (000) within Various Collection Radii
30% Acres Collected

Collection Radius mi	Avg Round Trip, mi	Total Acres (000)	30% Acres Collected (000)
5.0	4.3	50	15
7.5	13	113	34
10	17	201	60
15	25	452	136
20	34	804	241
50	42	5,000	1,500

Collecting the ear and 85% of the stalk from 30% of the acres was determined in Table 11. Yields vary between 160 and 240 bushels per acre.

Table 11
Total Stover, 30% Acres Collected

Radius, mi	160 bu/ac	200 bu/ac	240 bu/ac
	Stover, 000 tons ds		
5.0	40	52	59
7.5	89	116	133
10	158	206	237
15	356	464	533
20	632	825	948

Balancing distance and volume collected, select collection within a 10 mile radius. The average round trip distance for this area is 17 miles. A number of other assumptions are needed in order to determine the number of trucks required for collecting both the ear and the stalk. These assumptions, which are listed below, allow a comparison to be made between collecting grain and collecting the ear and stalk.

- Maintain 12 acres per hour harvest (200 bushels per acre)
- Average road speed: 30 miles per hour
- Trailer fill time: 5 minutes for ear and stalk
  20 minutes for grain
- Truck dump time: 8 minutes
- Total cycle: 40 minutes for ear and stalk (no queue)
  65 minutes for grain (no queue)
- Queue time: 5 minutes desired

The resulting truck requirements for this situation are summarized in Table 12.

Table 12
Truck Requirements: Field to Collection Center

Grain Trucks (22 ton loads)	3	4		
Queue Time, minutes	none	20		
Ear & Stalk Trucks (11 ton loads)	9	10	11	12
Queue Time, minutes	none	3	8	13

For grain harvest, three trucks are sufficient but provide no queue time. Adding a fourth truck results in a 20 minute queue to accommodate delays. For one-pass harvest, collecting the ear and stalks requires 9 to 10 trucks. Each truck adds 5 minutes, which is the same as the filling time for the truck.

The transport details are shown below for grain and the ear and stalk trucks. The first grain truck starts filling (*SF*), and is full (*F*) in 20 minutes from the start. The second truck enters the queue (*SQ*) in 15 minutes, starts to fill in 20 minutes and is full in 40 minutes. The third truck is full in 60 minutes. The first truck has dumped (*D*) the load and arrives back at the field in 60 minutes; just in time . . . but a fourth truck is used and fills in 80 minutes, providing 20 minutes slack time in the event of delays. Table 13 shows this grain truck schedule.

Table 13
Grain Truck Schedule

Trucks/minute	5	20	25	40	45	60	65	70	75	80	85	100
1	*SF*	*F*	*2.5*	*SD*	*D*	*7.5*	*SQ*	*SQ*	*SQ*	*SQ*	*SF*	F
2	*2.5*	*SQ*	*SF*	*F*	2.5	*SD*	*D*	2.5	5.0	7.5	*SQ*	*SQ*
3	5	*D*	*2.5*	*SQ*	*SF*	*F*	2.5	5.0	7.5	*SD*	*D*	7.5
4						*SQ*	*SF*	*SF*	*SF*	*F*		

The details for the trucks hauling ears and stalks are below in Table 14. The first truck is full in 5 minutes, completes dumping in 30 minutes and returns for another load in 45 minutes. At this same time, truck nine has completed loading. In order to keep some slack in the transport, three additional trucks are used which provide 13 minutes for delays in the operation without slowing the harvest.

Table 14
One-Pass Harvest: Ears & Stalks Truck Schedule

Trucks	1	5	10	15	20	25	30	35	40	45	48	49	50	51	52	53	54	55	56	57	58	59	60
1	SF	F		5		D	D		5		Q	Q	Q	Q	Q	Q	Q	Q	SF	SF	SF	SF	F
2			F		5		D	D		5						Q	Q	Q	Q	Q	Q	Q	Q
3				F		5		D	D		4		5		6		7		8		Q	Q	Q
4					F		5		D	D		2		3		4		5		6		7	
5						F		5		D	D	D	D		1		2		3		4		5
6							F		5		D	D	D	D	D	D	D	D		1		2	
7								F		5		7		8		D	D	D	D	D	D	D	D
8									F		4		5		6		7		8		D	D	D
9										F		2		3		4		5		6		7	
10											SF	SF	F		1		2		3		4		5
11														SF	SF	SF	SF	F		1		2	
12																			SF	SF	SF	SF	F

Collection Center Receiving: The timely turnaround of the incoming trucks presents a serious logistics challenge. Assuming each acre produces one trailer load of ears and corn, the daily and total unloading capability for a collection center is estimated for the following assumptions.

- Unloading time: 8 minutes, same as before
- Unloading hours: 16 per day
- Truck unloading stations: 5 or 10, depending on collection center size
- Truck unloading capacity per day: 600 or 1,200 acre-loads
  (16*60/8*5 or 10 = 600 or 1,200/day)

The Louisiana Sugar Cane refineries have demonstrated the capability of unloading 1,000 to 1,200 trucks per day during harvest. The collection center is physically able to match this performance. However, the increased traffic can overwhelm the local roads and be vigorously resisted by some, especially those not reaping any economic benefit. A short line rail system that avoids main line rail is a more likely solution. The results include the dry tons of stover collected (200 bushel per acre) and are given it Table 15.

Table 15
Collection Center Unloading Capacity

Collection Radius mi	30% Acres Collected (000)	Unloading Days Required (Loads/day)		Stover Dry Tons (000)
		1,200/day	600/day	200 bu/ac
5.0	15	13	26	60
7.5	34	28	56	133
10	60	50	100	240
15	136	113	N/A	533

The results for a 5 mile collection radius are most reasonable, except just 60,000 dry tons stover are collected. A 10 mile collection radius accumulates 240,000 dry tons, but it requires nearly two months to collect this quantity.

Rail delivery may be more acceptable to move additional ears and stalks, adopting a system similar to sugar beets. Harvested beets are staged adjacent to a rail siding in cold weather and transferred to a hopper car for shipment to the mill. Shipping the ears and stalks to a biorefinery for the processing of the corn and lignocellulosic feedstock would alleviate the additional congestion. The rail service depends on the local situation. For the Imperial, NE area, the region served by the existing rail service did not provide adequate feedstock quantities to consider.

Collection Site to Biorefinery: Two options were examined for transferring the feedstock from the wet pile to the biorefinery:

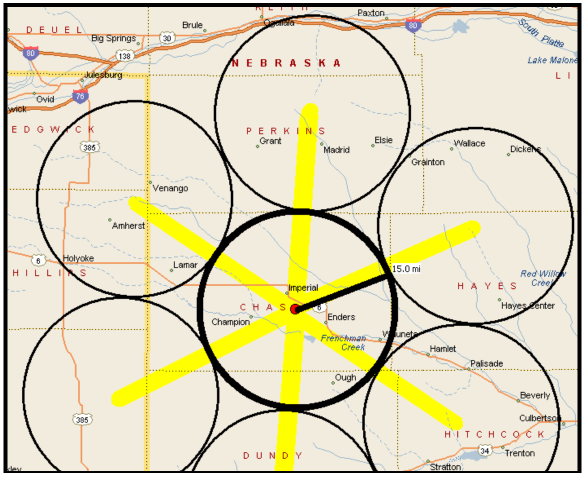
- Rail transport of wet material directly from storage
- Processing the solids to soluble solutions for truck or pipeline transport

<u>The rail transport</u> of the wet material was determined to be neither practical nor economical in the Imperial Region. BNSF divested a short line that passed through an arid region of the county. Using mainline, Class I, railroads like BNSF, Union Pacific and Norfolk Southern becomes feasible only when unit trains are employed. These unit trains need to be made up of 80 to 100 cars with a transport capacity of 50 tons per car. Coal is the largest commodity hauled in this manner.

In some local regional railroads, Class II and III, short-lines, which are owned by independent railroad companies, may offer economical transit. They typically have 150 to 350 miles of track and can significantly expand the collection area. The installation of car loading and unloading systems is required for the wet material. However, investigation showed that the installation for relatively small volumes compared to unit trains was too costly in this case.

<u>Processing the solids into soluble solutions</u> offers the most economical case for transporting feedstock to the biorefinery. Figure 16 shows six collection centers with a 10 mile radius surrounding Imperial, NE. Each collection center contains 200,000 acres of land with 1.4 M acres total. Using the same assumptions as before, a yield of 200 bushels per acre and collecting the ear and 72% of the stalk from 30% of the area, gives a total 1.4 M dry tons of stover, 240,000 dry tons of stover per collection site. Constructing a pipeline connecting each center with a central biorefinery enables simple transfer of the liquids. The composite pipeline costs approximately $350,000 per mile and the transport cost adds $0.60 to $0.80 per gallon of liquids. Using a fractionation system to produce liquid intermediates, the lignin solution is piped in one line for precipitation and filtration at the biorefinery. Another pipeline conveys a 30% solution of holocellulose for fermentation. If the Terrabon process were being used then the second pipeline would transfer carboxylic acids for additional refining.

Figure 16
Pipeline Field Collection to Biorefinery



Trucking the 30% solution eliminates the bale handling at the biorefinery, but it is more costly to transport, since the equivalent of 9 bales is contained in a 22 ton tanker.

E. Delivered Cost

The removal cost has two components. The first component is the cost per acre and the second component is the cost per dry ton of the collected ears and stalks. The more material that is collected per acre the lower the cost is per ton. The amount of material removed is constrained by both the residue required for erosion control and by maintaining the soil carbon.

Baling dry material with existing equipment requires multiple passes through the field to chop, rake, bale and remove the bales from the field. The baling cost is about $50 per dry ton for round and square bales at the roadside. Ag Equipment manufacturers, who have a wide interest in cellulosic feedstock, are pursuing innovations to lower this cost by 30% or more. One-pass harvest innovations are also being investigated. Most of the current focus is to collect the corn cobs in a caddy that is hauled behind the combine.

For delivered cost comparison of dry baling to collecting the ear and stalk in one pass, the farmer's margin is estimated using the same collection area and costs for common components.

The estimated baling costs are summarized in Table 16. This example assumes a delivered price of $70 per dry ton of material. The stover collection is within a 23 mile radius encompassing 1.4 M acres. Equipment costs are based on the average value from the 2008 Nebraska Custom Rates, Minnesota Extension Machinery Cost Estimates and the Iowa Farm Custom Rate Survey.

16
Custom Bale & Haul: Excess Stover Sale
Net to Farmer, Dollars per Acre

Basis: $70/dry ton Delivered, 1.4 M Acres, 27 mi radius Collection Site,			
	160 bu/ac	200 bu/ac	240 bu/ac
Corn Stover, 1:1 ratio, dt/ac	3.8	4.8	5.7
1 dt/ac Left in Field	1.0	1.0	1.0
Net Stover Sold, 15% Moisture, dt/ac	3	4	5
Sale, $70/dt	$197	$263	$330
P & K Nutrient Credit, $10/dt	$(28)	$(38)	$(47)
Reduced Field Operations, $14/ac	$14	$14	$14
Less Stalk Chopping, $11/ac	$(12)	$(12)	$(12)
Less Raking, $6/ac	$(8)	$(8)	$(8)
Less Custom Bale, $23/dt	$(76)	$(102)	$(128)
Handle, Stack and Store, $5/dt	$(14)	$(15)	$(19)
Shrinkage, 10%	(20)	(26)	(33)
Hauling, 13 mile radius, $2.50/mi, $2.30/dt	$(12)	$(16)	$(19)
Net to Farmer, $/ac	$ 40	$ 50	$ 78

To achieve $50 per acre pretax income, the yield needs to be greater than 200 bushels per acre when leaving one dry ton in the field for this example. To lower this cost, recovering the nutrients from the biorefinery, improving the baling efficiency and lowering the transport cost are currently being evaluated. The risk of wet weather curtailing collection remains.

The nutrients removed are the same for baling and one-pass harvest. The major nutrient components in the residues are phosphorus, potassium and nitrogen. The phosphorous and potassium content (P&K Nutrients) in straw and stover are typically 0.1% and 1%. The composition varies depending on the soil and local conditions. Rain quickly washes out these soluble nutrients. With the present price volatility for phosphate and potash, farmers are especially concerned about replacement cost for next season.

Some processors propose returning the ash from the biorefinery. With wet storage, the solubles are removed in the circulating liquor. Returning the solubles in the same season from regional collection centers is another possibility. The P and K nutrient value is shown in Table 17 for phosphate, \$700 per ton and potash, \$400 per ton.

Table 17
P & K Value Removed
Dollars per dry ton Stover

P& K Value in dry ton Stover Removed	\$ 6.42/dt
% Phosphorus, P	0.1%
% Potassium, K	1%
P in Phosphate	44%
Phosphate, P_2O_5 \$/lb	\$ 0.35
P Value in Stover	\$ 1.60/dt
K in Potash	83%
Potash, K_2O \$/lb	\$ 0.20
K Value in Stover	\$ 4.82/dt

The nitrogen fertilizer value is more complex and depends on local conditions. The nitrogen content in the stover is 0.5% to 2.0% depending on the length of time in the field after the plant has matured. However, there is conflicting information regarding its value. If the residue is plowed under the surface, microbes desire a 10:1 ratio of C:N for breaking down the residue. Since the C:N ratio of straw and stover is 40:1 to 70:1, adding 20 pounds of nitrogen fertilizer per ton of residue is recommended to avoid denitrification of the next crop. If left on the surface, there is some evidence that shows the same N deficiency occurs, but the results are not conclusive.

Reduced field operations result with the move to no-till, eliminating one pass through the field that was previously needed to manage the residue.

Stalk chopping accelerates the field drying of the stover. If it is not collected, the additional exposed surface area accelerates decomposition of the stalk by microorganism attack. Without chopping, the stalks require a week or more to dry and decomposition can carry over to the next season, hindering planting.

Raking is required to build a windrow to improve baling efficiency. Fewer passes are required for the baler to move through the field. For example, a 30 foot rake forms a windrow for a 5 foot or 6 foot wide baler, enabling the baler to move through just 17% to 20% of the field.

Custom baling is $8 to $15 per large round or square bale. The average is $11.70 per bale that varies in weight from 1000 pounds to 1500 pounds as is.

Handling, stacking and storing adds an average $3, $1.30 to $5, for round bales and the same is used for square bales. Plastic net wrapped round bales shed water well. For wet weather protection square bales must be covered to prevent major loss. Storage loss of 10% is expected to occur over a season when the bales are covered or wrapped and are stored on a well-drained surface. Unprotected, the bale loss can be high. Storage under a roof is best, but is the most costly. For outside storage, covered bales set on a well-drained surface to permit good drainage works well with the least investment. Hay bale losses over an 8 month period for different methods range from 2% to 61%, Table 18.

Table 18
Effect of Method on Bale Storage Loss

Bale Storage Method 8 Months Storage	Bale Loss (% ds)
Under Roof	2 - 10
Plastic Wrap, on Ground	4 - 7
Bale Sleeve, on Ground	4 - 8
Covered, Rock Pad or Elevated	2 - 17
Uncovered, Rock Pad or Elevated	3 - 46
Uncovered, on Ground, Net Wrap	6 - 25
Covered, on Ground	4 - 46
Uncovered, on Ground	5 - 61

The estimated cost of one-pass harvest of ears and stalks, wet storage at regional collection centers using pipelines for transporting the soluble feedstock to a central biorefinery is shown in Table 19. No land rent or insurance is included in the cost.

Table 19
One-Pass Harvest and Transport: Excess Stover Sale
Net to Farmer, Dollars per Acre

Basis: $70/dry ton Delivered, 1.4M Acres, 7-10 mi radius Collection Sites			
	160 bu/ac	200 bu/ac	240 bu/ac
Corn Stover 1:1 ratio	3.8	4.8	5.7
Stover dt/ac Left in Field	1.2	1.3	1.8
Net Stover Sold, dt/ac	2.6	3.4	3.9
Sale, $70/dt	$ 183	$ 263	$330
P & K Nutrients, $10/dt	$(26)	$(34)	$(39)
Reduced Field Operations, $10/ac	$14	$14	$14
Less One-pass Harvest, $10/ac	$(10)	$(10)	$(10)
Field to Collection Site Transport, $8.26/dt	$(22)	$(28)	$(32)
Unload, Separate and Shell, $3/dt	$(8)	$(10)	$(12)
Store, Wash, Process Stover, $10/dt	$(26)	$(34)	$(39)
Shrinkage, 3%	(6)	(8)	(10)
Transport Solubles to Biorefinery, 20 mi, $5/dt	$(13)	$(17)	$(20)
Net to Farmer, $/ac	$ 90	$ 135	$ 180

One-pass harvest of corn ears and stalk billets is estimated to have margins of $90 per acre to $180 per acre for the farmer, which is three times greater than the baling case, Table 20.

Table 20
Farmer's Pretax Margin Comparison

Basis: $70/dry ton Delivered to Biorefinery, 1.4M ac	160 bu/ac	200 bu/ac	240 bu/ac
Ear and Stalk Harvest, 7-10 mi radius, $/ac	$ 90	$ 135	$ 180
Baling, 23 mi radius. $/ac	$ 40	$ 50	$ 80
Margin Improvement	$ 50	$ 85	$ 100

More stover is left in the field with this scenario, collecting the ear and 85% of the stalk. In practice, the corn head would be adjusted to leave at least one foot of stalk above the crown to protect against wind erosion.

Nutrient removal and reduced field operations are unchanged. One-pass harvest cost is proportioned equally between the grain and the stover weight "as is". Ten dollars per dry ton is charged to the stover.

Field transport cost of stover to the collection center is $8.26 per dry ton. The cost is determined by taking the total round trip cost for the ears and stalk, $42.50, and deducting the corn grain cost, $0.06 per bushel, $2.13 per ton of grain as if only the grain was transported.

At the collection center, the load is weighed, sampled, dumped and turned around in less than 10 minutes for another load. Conventional corn heads, which are electrically driven, separate and shell the corn. The separation cost is prorated based on weight using the same method as above. The cost, $3 per dry ton, is part of the $4.5 M annual operating cost of the collection center, Table 25. The cost is based on processing 250,000 dry tons annually. The facility is designed for an easy expansion to 400,000 dry tons to accommodate other cellulosic feedstocks..

Table 21
Collection Center Operation Cost
$(000) per Year

Unload, Separate Stalks, Shell Ears, $3/dt	$ 750
Store, Wash, Process Stover, $10/dt	$ 2,500
Transport Solubles to Biorefinery, 20 mi, $5/dt	$ 1,250
Collection Center Annual Operating Cost, $(000)/yr	$ 4,500

The other operations store the stover following the harvest, and process a nominal 250 tons annually.

F. Life Cycle Analysis[4]

The single pass harvesting system combined with wet storage has been the primary focus of this project. The more detailed collection and storage process schematic is shown in the following figure. For this work it has been assumed that both the corncobs and the stored wet material are used as feedstock to the ethanol process.

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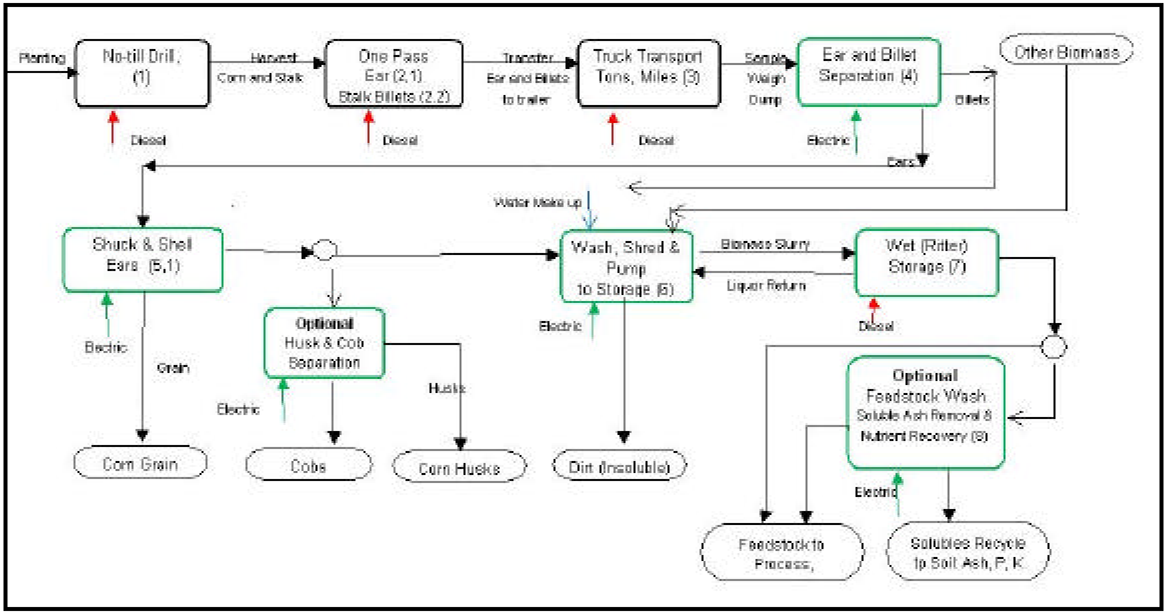
[4] The Life Cycle Analysis was performed by Don O'Connor using the input-output analysis by J. Hettenhaus. The full life cycle assessment report is submitted separately

Figure 22
One Pass Harvest System



energy balance for the collection and transportation is nearly four times more favourable for the single pass system due to the lower diesel fuel use and the reduced nutrient load resulting from the recycling summarized in Table 23

Table 23
Post Harvest Stover Baling and One Pass Corn Harvest Energy Balance

Fuel	Corn Stover	Corn Stover
Feedstock	Corn (Post harvest)	Corn (Single Pass)
	Joules consumed/Joule Delivered	
Fuel dispensing	0.0000	0.0000
Fuel distribution, storage	0.0000	0.0000
Fuel production	0.0000	0.0000
Feedstock transmission	0.0017	0.0039
Feedstock recovery	0.0681	0.1760
Ag. chemical manufacture	0.0459	0.1117
Co-product credits	0.0000	-0.2602
Total	**0.1156**	**0.0313**
Net Energy Ratio (J delivered/J consumed)	**8.6499**	**31.9568**

.The GHG emissions for the corn stover collection are summarized in Table 24. The emissions are relatively low and arise from three components, diesel fuel used for field operations, the energy required to produce the fertilizer required to replace the nutrients removed and the transport to the plant.

Table 24
Post Harvest Stover Baling and One Pass Corn Harvest GHG Emissions

Fuel	Corn Stover	Corn Stover
Feedstock	Corn	Corn
	Post Harvest Collection	Single Pass System
		g CO_2 eq/GJ (HHV)
Fuel dispensing, distribution and storage	0	0
Fuel production	0	0
Feedstock transmission	1,435	310
Feedstock recovery	8,286	19,656
Land-use changes, cultivation	0	15,296
Fertilizer manufacture	2,893	6,742
Gas leaks and flares	0	0
CO_2, H_2S removed from NG	0	0
Emissions displaced (grain corn)	0	-38,871
Total	12,614	3,134

For the full lifecycle modelling the ethanol plant is assumed to be located 150 km from the elevator. In the case of the single pass harvest system the corn cobs and the wet stover are combined for transport. The average moisture content of this material is 42%. In the base case the mode of transport is assumed to be by truck. Other modes of transportation are investigated in the full report.

Table 25 shows the energy balance results for the complete lifecycle through to the dispensing of the fuel into a vehicle. This includes the ethanol conversion process where there are expected to be differences in yield between the two feedstocks.

Table 25
Lifecycle Total Energy Balance Results

Fuel	Gasoline	Ethanol	
Feedstock	Crude Oil	Corn Stover (Post harvest)	Corn Stover (Single Pass)
	Joules consumed/Joule Delivered		
Fuel dispensing	0.0034	0.0053	0.0053
Fuel distribution, storage	0.0126	0.0201	0.0201
Fuel production	0.1375	2.4084	1.9224
Feedstock transmission	0.0218	0.0529	0.0822
Feedstock recovery	0.1054	0.2019	0.4439
Ag. chemical manufacture	0.0000	0.1360	0.2817
Co-product credits	-0.0003	-0.1759	-0.8317
Total	**0.2805**	**2.6487**	**1.9238**
Net Energy Ratio (J delivered/J consumed)	**3.5656**	**0.3775**	**0.5198**

The total energy balance is significantly better for the single pass system compared baling. This does assume that both feedstocks require the same quantity of energy in the ethanol plant and produce the same amount of excess electric power. If the ethanol process was modeled for the two separate system contains more sugar and has a higher yield of ethanol. This is expected to lower plant energy requirements.

The single pass collection system produces significantly lower GHG emissions than the post harvest system. This is a function of not only the lower emissions associated with the stover collection, as shown earlier, but also the higher yield in the ethanol plant. Note that the feedstock transmission emissions are higher in the single pass system and that is a function of the higher moisture of the material that is moved from the collection center to the ethanol plant, resulting from the wet storage, Table 26.

Table 26
Lifecycle GHG Emissions Comparison

Fuel	Gasoline	Ethanol	
Feedstock	Crude Oil	Post Harvest Stover	Single Pass Stover
	g CO_2eq/GJ (HHV)		
Fuel dispensing	414	645	645
Fuel distribution and storage	1,216	1,656	1,656
Fuel production	12,189	38,274	31,135
Feedstock transmission	2,177	4,256	7,399
Feedstock recovery	7,231	24,574	49,582
Land-use changes, cultivation	75	0	38,585
Fertilizer manufacture	0	8,581	17,008
Gas leaks and flares	2,359	0	0
CO2, H_2S removed from NG	0	0	0
Emissions displaced	-39	-21,518	-119,487
Total	25,622	56,468	26,522
Combustion	64,861	2,097	2,097
Grand Total	90,483	58,565	28,619
% Reduction	-	35.3	68.4

Conclusions

For cellulosic biomass commercialization a Reliable, Economic and Sustainable Feedstock supply is required.

Corn stover offers the largest opportunity for meeting the RFS goals by 2022.

- It is available now.
- 200 M dry tons required to meet 2022 RFS, 300 M dry tons produced last year and the seed pipeline increases residue 50% over next decade
- Stover surrounds more than 100 corn grain to ethanol plants with many farmer-investors. Modular expansion of existing infrastructure can scale cellulosic fuels rapidly

A Reliable supply of stover can be achieved with a combination of one-pass harvest and baling, dry bale storage by the edge of fields and storage at collection centers.

- Weather risk threatens reliable collection of dry stover. One-pass corn harvest potentially reduces some wet weather risk.
- Wet storage can best serve wet processes and dry storage may best serve dry processes. Both are proven for corn stover.
- Regional Biomass Processing Centers can improve supply reliability
    - Improve utilization of grain elevators
    - Modular processing units
    - Farmer affordable
    - Facilitate debt financing of biorefineries
    - Process stover to liquids or more dense solid for transport
    - Pipeline transport of liquid sugars, soluble lignin and other valued added components

An economic supply of stover can be achieved by improving present crop systems to sequester more soil carbon, reduce collection, storage, transport and processing costs and placing a value on offsetting fossil fuel emissions.

- The farmer, the processor and others in the supply chain require adequate margins
- Valuing collected and stored stover as liquid asset similar to grain in the bin would enable access to additional working capital
- Continued *BCAP* assistance will help build feedstock delivery infrastructure
- Removing residue on large scale faces logistics obstacles
    - Managing nutrients to replace what is removed
    - More robust tools to insure sustainable removal
    - New crop systems
    - New removal methods beyond baling

A sustainable supply of stover is required.

- Using Comet-VR to determine soil carbon change for different cropping practices can be a useful tool to insure sustainable removal, periodically validating the results
- Removing the stover is better than plowing the stover under the surface
- Adopting continuous no-till for non-sandy soils in flat fields maintains soil carbon and complies with 80% of the stover to be removed, with stalks cut about one foot above the crown.
- Planting cover crops with continuous no-till permits >70% removal from a wider variety of fields and soil types

RECOMMENDATIONS

Raise Farmer Interest

- Meet and improve farmer information for sustainable removal
  - Simple, transparent test for Soil Carbon
  - Soil quality spreadsheet tool, like COMET-VR, that permits ‘what if” planting scenarios impact on soil quality
  - Use soil carbon testing results in farmers fields to further validate soil carbon model (Century Model)
- Validate Crop Nutrient value, especially for N
- Incentives
  - Offer Farmer favorable equipment financing
    - No-till equipment
    - Corn grain and Stover Harvesting equipment
  - Loan guarantee for feedstock storage to enable farmer to borrow funds for equity investment in Regional Biomass Processing Centers
  - Provide option for farmer to participate in value chain
  - Establish Carbon Tax or Cap and trade to monetize;
    - Soil carbon sequestration
    - Fossil fuel offset for conversion to fuels

Harvest-Transport-Storage

- Develop Harvesting equipment that includes following
  - Maintains or exceeds current harvest rates
  - Provides data for managing nutrient replacement based on nutrients removed and soil requirements
- Continue BPAC
- Establish loans for collected feedstock in storage

Processing

- *Support the establishment of Regional Biomass Processing Centers*
  - Modular processing units
  - Farmer affordable
  - Process to liquids or more dense solid for transport
  - Pipeline transport of liquid sugars, soluble lignin and other valued added components
- Continue with Biorefinery Loan Guarantees
- Monetize GHG offset credits/Carbon tax

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APPENDIX 1
Update on Imperial Soil Analyses (09-02-2005)

The preliminary data on the soil organic carbon content is shown below in Figure 1. Separate graphs are shown for the 0-5 cm, 5-20 cm, 0-20 cm and 0-75 cm of the native grassland and 6 pivot-fields with adjacent dryland corners. Each plot was sampled in Spring 2004, Fall 2004 and Spring 2005. For each pivot field, averages and standard deviations of organic carbon were taken across 12 sites per pivot, which is 3 per quad, and 6 sites for dryland, which is 3 on each of the two corners. Organic carbon contents in the grassland were greater than under the cropland in the 0-5 cm depth. However, in the 0-20 cm depth, the irrigated pivot fields F1, F2, and F8 (Rod Johnson's farm) reached similar organic carbon stocks as seen in the native grassland. Soil organic carbon tended to be higher under irrigated conditions when compared to the dryland corners, but this was less expressed in pivot fields F5, F6 and F11 (Karl Meeske's Farm) when compared to pivot fields F1, F2 and F8 (Rod Johnson's Farm). Over the entire sampling depth, 0-75 cm, irrigation only significantly increased organic carbon contents when compared to dryland in pivot field F2 (Rod Johnson's farm).

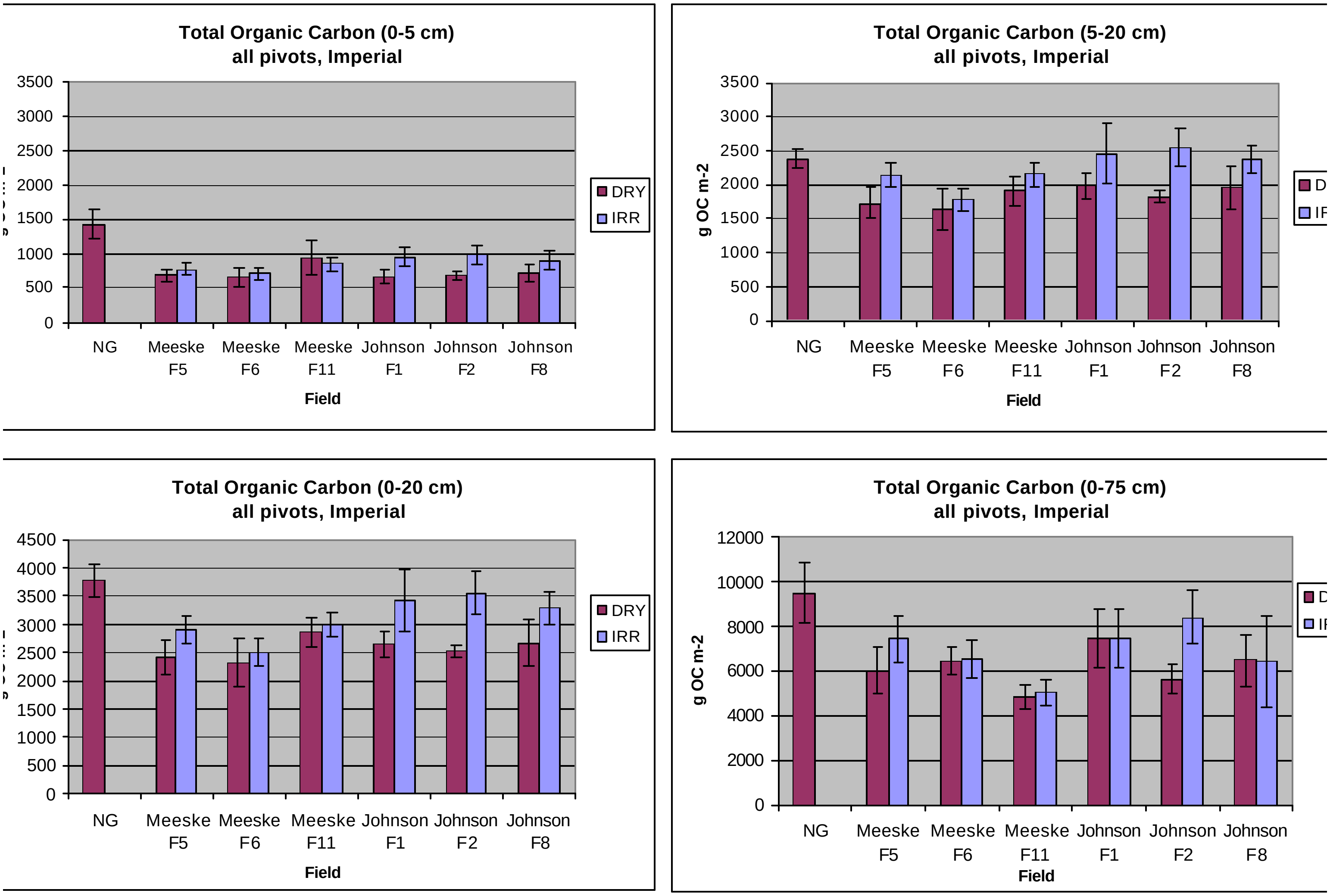


Figure 1: Total organic carbon content (g ^{o}C m-2)
for all individual pivot fields sampled in Imperial, NE.

The inorganic carbon data, across the soil profile, for all pivot fields per farm is shown below in Figure 2.

This figure represents the averages of 12 sites per pivot field for the irrigated treatment (IRR), 6 sites per grouped 2 corners for the dryland treatment (DRY), and 6 sites for the native grassland (NG). Large variability was observed across the different pivot fields of each farm area. Nevertheless, a trend of lower inorganic carbon contents across the soil profile was observed in the fields of Meeske's farm when compared to Johnson's farm. Information provided through preliminary surveys of the farmers could explain more of these differences. Pivot fields F5 and F6 had been managed under flood irrigation until 1998-1999 prior to center-pivot irrigation management. This could have leached out some carbonates down deeper in the soil profile.

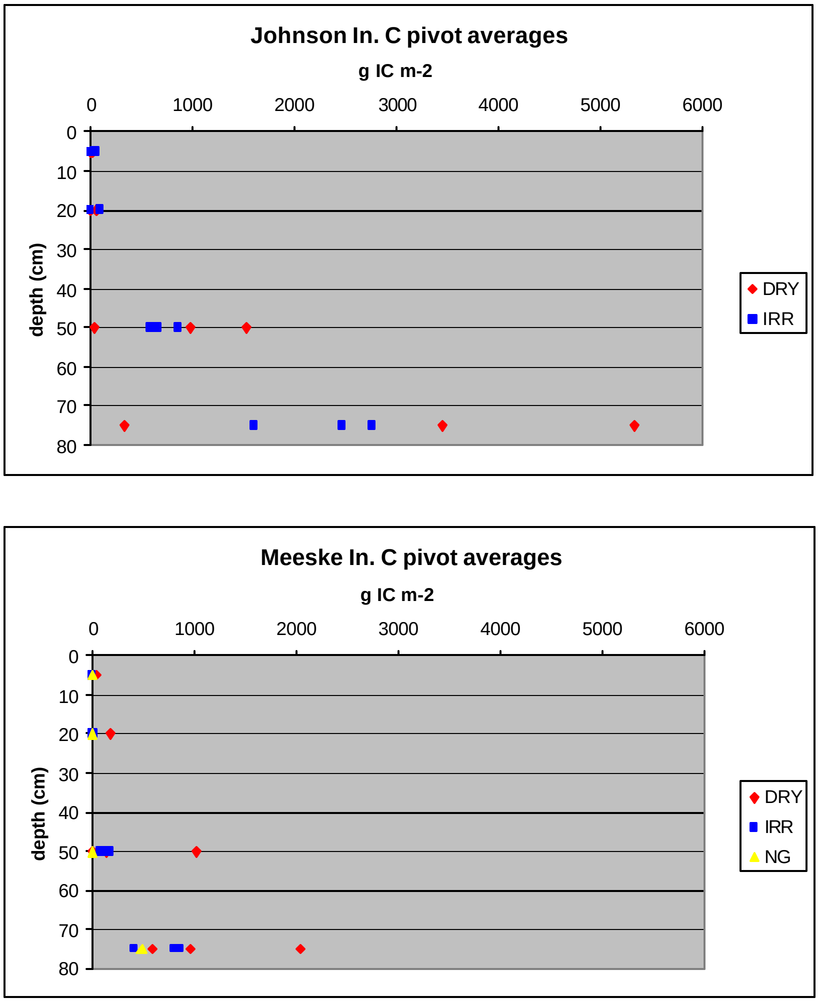


Figure 2: Total inorganic carbon contents (g IC m-2) for all individual pivot fields sampled in Imperial, NE.

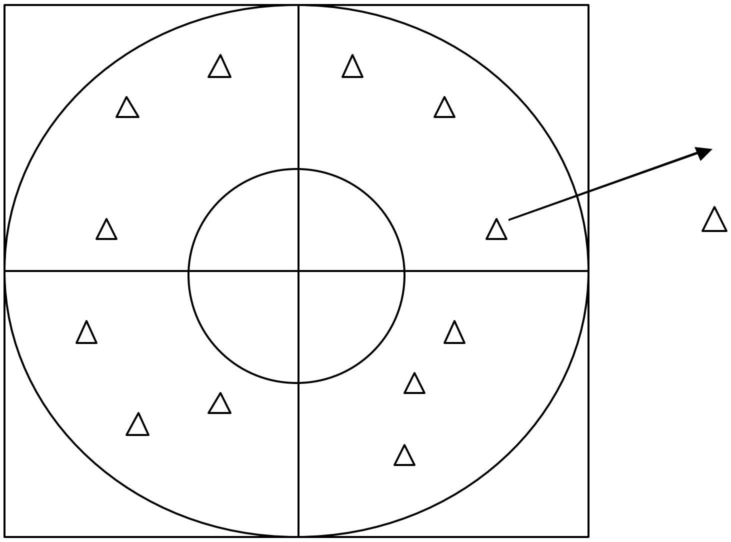
APPENDIX 2
Soil Sampling Design for Biomass-Removal Farms (Imperial, NE)

Farm and Farm Management:

1. Rod Johnson (silt-loam soils)
   - → corn-soybean rotation
   - → half pivot: residue-removal + no-tillage; other half pivot: non-removal + conventional tillage
2. Karl Meeske (silt-loam soils)
   - → continuous corn
   - → half pivot: residue-removal; other half pivot: non-removal
   - → no-tillage on all pivots
3. Tom Terryberry (high pH soils)
   - → continuous corn
   - → half pivot: residue-removal; other half pivot: non-removal
   - → strip tillage on all pivots

Sampling design:

3 pivots per farm [each pivot is 160 ac, approximately 145 ac irrigated]
3 random sites per quadrant in outer half of one pivot
At each random site: 3 soil sampling points, 1 m away from each other (1 m triangle)
At each sampling point: 1 soil core taken up to 100 cm depth
Each soil core is cut into 5 different depths (0-5, 5-20, 20-50, 50-75, 75-100 cm)



One random site in a quadrant

△ 1 m triangles of 3 sampling points

Permanent markers (for future sampling):

- GPS points at all random sites in all pivots
- Marker balls dropped in soil (2-3 ft. depth) at 1 random site per quadrant