2008-2011 Project Report

Project Name: **Emmetsburg Soil Study: Evaluation of corn cob and stover removal levels on crop production, soil quality and nutrient levels.**

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Summary

This project is a collaborative project between POET-DSM Advanced Biofuels, Iowa State University (ISU), and the USDA-Agricultural Research Service (ARS), initiated in 2008 to investigate emerging questions regarding the sustainability of stover residue harvest. The objective of this work to compare various corn stover harvest strategies to determine which would be the most sustainable and to evaluate 1) the effect of stover harvest and removal on subsequent crop yields, and (2) the effect of stover harvest and removal on soil quality, soil fertility, and soil organic matter.

The 4 year study, included replicated field trials (80+ total acres) with 7 different stover harvest treatments including:

1) Conventional grain harvest (zero removal),
2) Cob harvest (0.5 ton/ac removal),
3) Plant material other than grain (MOG) harvest (0.7 ton/ac removal),
4) Plant material other than grain (MOG) Direct Bale harvest (0.9 ton/ac removal),
5) High-Cut, below ear stover harvest (1.9 ton/ac removal),
6) Low-Cut, 4 inch stubble harvest (2.5 ton/ac removal),
7) Multiple-pass round bale harvest (2.0 ton/ac removal)

The average grain yields were 182, 162, 155, and 151 bu/ac in 2008, 2009, 2010 and 2011, respectively. The seasonal reductions in yield were partly due to the yield penalty related to continuous corn production, variability in soil fertility, excessive early season rainfall in 2010, and severe wind damage in August 2011.

However, grain yield was not significantly affected by stover harvest treatments (α=0.05). Over the four years, relative yearly yields for the various treatments ranged from 92% to 117% of the conventional grain harvest treatment. When all four years are pooled, the average relative yearly yields for the various treatments ranged from 93 to 107% of the average conventional grain harvest yield. Although, there were no significant differences in amongst the stover harvest treatments, the highest removal treatment (Low Cut, 2.5 ton removal rate), did show on average a 10 bu/ac (7%) increase in average yield over the conventional harvest treatment. The relative yield for the Low-cut stover harvest was 105%, 108%, 117% and 98% of the conventional harvest treatment in 2008, 2009, 2010 and 2011, respectively.

The most likely cause for the higher yields in the high removal rate plots (Low Cut, 2.5 ton removal rate) was soil temperature affects due to cold spring germination conditions, and that the removal of carbon resulted in lower use of nitrogen by microbes. These results are consistent with other studies conducted in Ames. However, it must be realized that this increase in yield may not be sustainable in the long term due to required mass balance of nutrients to maintain an equilibrium within the soil. Over time depletion of organic matter will reduce residual nitrate and other nutrient levels.

Wilhelm et al. (2007) estimated that 2.27 ton/ac of corn stover must be returned to the field to maintain soil carbon. The average yield for the low cut harvest treatment was 172 bu/ac, and assuming a HI of 0.54 the total mass of stover produced would be 4.1 ton/ac. Therefore the maximum estimated sustainable removal rate would be 1.8

ton/ac, which is less than the actual low cut removal rate (2.5 ton/ac). Based on Wilhelm and colleagues recommendations, a 2.5 ton/ac removal level would require a yield of 200 bu/ac or more.

Over the 4 years, the collected biomass yield was 2.5, 2.0, 1.9, 0.7, 0.9 and 0.5 ton/ac for the Low cut harvest, Multiple-pass round bale harvest, High cut harvest, MOG harvest, MOG direct bale harvest and Cob harvest treatments, respectively. The stover moisture contents ranged from 9.3% (Cob, MOG harvest treatments) to 35 % (Low Cut Harvest treatment).

The stover nutrient concentration was correlated to the percentage of lower stalk in the collected stover. The nitrogen concentration increased as a higher percentage of the lower portions of the plant were collected, from 0.45% for the cob only harvest to 0.52% for the low cut harvest treatment, and were significantly different (α=0.05). Similarly, P and K concentrations increased as a higher perecentage of the lower portions of the plant were collected, although these differences were not statistically significant at the 5% level. The changes in nutrient concentration are a result of translocation of nutrients from the upper portions of the plant to lower stems and roots as plant senescence occurs.

The nitrogen removal rates per ton of biomass ranged from 9 lbs-N/per ton (cob only harvest) to 12 lbs-N/per ton (low cut harvest), with an average of 10 lbs-N/per ton for all treatments. The phosphorous removal rates per ton of biomass ranged from 1.2 lbs-P/per ton (cob only harvest) to 1.6 lbs-P/per ton (low cut harvest), with an average of 1.4 lbs-P/per ton for all treatments. The potassium removal rates per ton of biomass ranged from 12 lbs-K/per ton to 13.6 lbs-K/per ton (low cut harvest), with an average of 13 lbs-K/per ton for all treatments.

Soil test analyses showed substantial field variability but no significant stover harvest treatment effects. There was a slight decrease in soil organic carbon, unrelated to the stover harvest treatments, that is attributed to the intensity of tillage and crop yields that were lower than expected.

In summary, both grain yields and soil nutrient levels were not significantly affected by stover harvest treatments. However, the spatial variability and seasonal effects for both grain yield and soil nutrient levels emphasize the important of a strong fertility testing and nutrient management program, before implementing crop residue harvesting. The spatial and temporal variation in soil nutrients and overall crop management can have a much greater effect on crop yields and sustainable production than the effect of different stover harvest removal rates. In addition, when overall soil fertility levels and nutrient management plans are marginal the removal of crop residue could serve as the tipping point to reduce yields.

The four-year results of this project have shown that with good management practices corn stover can be safely and sustainably harvested from fields similar in nature, provided stover removal rates are maintained below 2 tons/ac with an average yield of above 175 bu/ac. If management practices are improved such that grain yields are greater than 200 bu/ac there may be the possibility of increased grain yields with higher rates (2.5 ton/ac) of stover removal. However, these higher rates of stover removal are not sustainable at lower yields and will reduce soil carbon if these higher grain yields are not maintained.

Objectives

The goal of this work is the evaluation of harvest efficiency and capacity, biomass yield and the soil quality impacts of the different harvest systems, including cob only and different stover harvest scenarios. The overall research objective is to measure soil composition effects resulting from various levels of residue removal and evaluation of the practices for sustainable feedstock production.

The specific objectives of this project include:

1) Evaluation of the effect of corn cob and stover removal levels on yield, nutrient removal rates, soil composition and soil quality.
2) Development and evaluation of recommendations for sustainable feedstock production systems.

Methods and Procedures

In 2008, the field tests included six 32 row treatment plots (Low cut (90%), High cut (50%) removal, rake and bale removal, MOG removal, cobs only removal, conventional grain only harvest) in 3 replicated blocks (Figure 1). In 2009, a single pass baling system was added to the treatments. Soil samples to determine baseline soil nutrient levels and carbon status, and post-harvest soil samples for surface nutrient analysis were collected. All stover harvest treatments were imposed using the Iowa State Biomass Harvester single pass harvester, with the exception of the rake and bale treatment, and the cob only collection in 2008, and the single pass baling treatment. The data collected included measurements required for harvest capacity, material collection efficiency, yield and moisture content for all materials (grain, stover, cob, residue cover) and collection of samples for nutrient compositional analysis.

Experimental Plot Layout

The natural soil productivity levels differ between replications; therefore the plot layout was selected to minimize natural soil variability within replications.

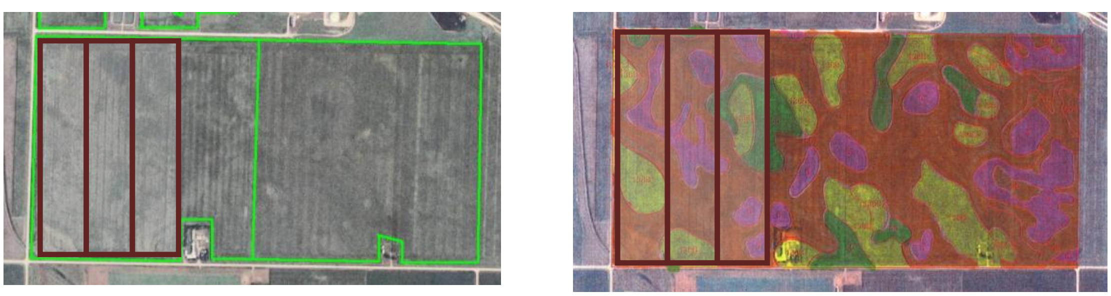

Figure 1: Layout of replicate and field boundaries (left) and yield potential (right) based on soil type (Green-High potential, Pink–Low potential).

Each replicate contained 7 treatment units consisting of four 8-row passes (32 rows) through the field, with one 8 row buffer between each replicate block (Table1). The treatment layout is shown below with Rep 1 beginning from the west side of the field. The agronomic data and field operations for the field located at Latitude 43°04'59.30" N; Longitude 94°39'13.97" W are shown in Table 2.

Table 1 Plot layout starting from west edge of the field

Rep 1 Treatment	Rows	Rep 2 Treatment	Rows	Rep 3 Treatment	Rows
Buffer Strip	16	Buffer Strip	8	Buffer Strip	8
Single Pass MOG Baler	32	MOG Removal	32	High cut (50%) Removal	32
Shred, Rake and Bale	32	Single Pass MOG Baler	32	Single Pass MOG Baler	32
MOG Removal	32	Low cut (90%)	32	Low cut (90%)	32
High cut (50%) Removal	32	Conventional	32	MOG Removal	32
Conventional	32	High cut (50%) Removal	32	Cobs Only	32
Cobs Only	32	Shred, Rake and Bale	32	Shred, Rake and Bale	32
Low cut (90%)	32	Cobs Only	32	Conventional	32
				Buffer Strip	8

Note: In 2008, Single Pass MOG Baler plots were treated as spare conventional plots

Table 2: Summary of Tillage operations, Fertilizer applications and planting dates for fields

Harvest Year, Dates	Date Planted	Hybrid (Tillage, prior to planting)	Total Fertilizer Application for plots (lbs./ac) N	P2O5	K20	S	Zn	Plot Removal Rate
2008 11/4-8	4-May	DeKalb 50-44VT3, Agrigold 6325VT3 and Northrup-King NK 3616VT3 (Fall_DR, Spr_D, Spr_FC)[a]	202	70	50	0	0	All Plots
2009	2-May	NC+ 1775 VT3	180	60	20	0	0	Low Removal Plots[b]
11/5-9		(Fall_DR, Spr_D, Spr_FC)[a]	180	60	40	0	0	High Removal Plots[c]
			2	8	0			Starter Fertilizer, All
2010	5-May	NC+ 197-84STX	200	65	30	0	0	Low Removal Plots[b]
10/6-11		(Fall_DR, Spr_D, Spr_FC)[a]	220	65	50	0	0	High Removal Plots[c]
			2	9	2			Starter Fertilizer, All
2011	-------	NC 202-32STX	200	65	65	0	0	Low Removal Plots[b]
10/6-20		(Fall_DR, Spr_D, Spr_FC)[a]	220	65	80	0	0	High Removal Plots[c]
			2	9	6			Starter Fertilizer, All
2012	-------	Pioneer P0448XR	168	80	120	20	2	All Plots
		(Fall_DR, Spr_D, Spr_FC)[a]	40					Foliar or Side-dress

Notes: [a] Fall_DR = Fall Disk-Rip, Spr_D = Spring Disk, Spr_FC = Spring Field Cultivate prior to planting
[b] Low Removal Plots = Conventional, Cobs only, MOG, MOG Direct Bale
[c] High Removal Plots = High Cut, Low Cut, Baled 2 pass Plots

Harvest Equipment and Procedures

The Low cut (90%), High cut (50%) removal, MOG removal, Cob removal and conventional grain harvest treatments were harvested utilizing the single pass, dual stream biomass harvester, based on a John Deere 9750 STS combine, with the single exception in 2008, when the Cob removal plots were harvested with the Redakop Cob Caddy. The single pass baler MOG Collection plots were harvested using a prototype machine also provided by Poet. The stover material was collected in a forage wagon with instrumented weigh cells. Stover samples were collected from each plot for moisture content and constituent analysis as described by Hoskinson et al., (2007). The mass of grain from each plot and grain moisture was determined from weigh scale tickets for each plot. The shred rake and bale operation was contracted to a local farmer. The standing stalks after combining were shredded with a rotary cutter, windrowed and baled using a large round baler. The mass of at least three sample bales per plot were measured, and samples collected for moisture content and constituent analysis.

In 2008, the total harvest window was extended over a two week period, from November 4-18, 2008. Although this was not ideal, the results yield results appear to be consistent, and removal rates were as expected. The only significant deviation was that the harvest height for the High cut (50%). Removal was lower than planned, since high winds prior to harvest resulted in moderate lodging. Therefore, the combine header was run much lower than normal, and the removal rate for the High cut (50%) treatment was higher than normal. In 2009, the total harvest window was extended over a one week period, from November 5-11, 2009. In 2009, the cob plots were harvested with the Deere STS machine. However due to mechanical issues the purity of cob samples was less than 80% by weight, as reflected in the higher collection efficiency. In 2010, the total harvest window was extended from October 6-11, 2010. In 2010, due to excessive early season rainfall in some plots isolated low areas of the field were drowned out. The total area with zero production was estimated during harvest and reported yields corrected for the non-productive areas. However, these locations significantly increased variability in the reported yields for single plots, and therefore made it less likely that significant statistical differences between treatments would be found due to the high variable between reps plots. In 2011, the total harvest window was extended from October 6-20, 2011. On, August 23, 2011 a high wind event in the area caused significant lodging in the field, this made combining very difficult.

Prior to harvest, the total biomass production was estimated by hand harvest of above ground biomass for a 2m row length for each treatment plot. The material was segregated into the following four categories, Top 50% (all material above the cob attachment location including husks), Bottom 50% (all material below cob attachment location), Cobs only, and hand-shelled grain mass. After 2009, in addition to the standing material, all stover on the ground was collected separately, and included in the total manual biomass yield.

Soil Quality Assessment

In 2008, initial soil fertility samples were collected on June 4, to determine general soil fertility levels after planting, and in subsequent years surface soil samples (0-15 cm) were collected each fall after harvest. The surface samples (0-15 cm) were collected from 10 cores utilizing a ~32mm (1¼ inch) hand probe, for each treatment plot. The deeper soil samples to 1 meter depth, to document soil C and N distribution and other soil properties needed to define soil quality, were collected in spring 2009. Deeper samples were collected using a mechanical probe with a ~50 mm probe diameter as described in Cambardella et al., (2004) in spring 2009.

The following soil profile data were analyzed as described in Karlen et al., (2006) and Cambardella and Elliott, (1993); Soil bulk density (BD), soil pH and EC, Total organic C and N, Mehlich III extractable P and K, standard soil fertility testing soil micronutrient analysis, microbial biomass C, Aggregate stability (WSA), Particulate organic matter C (POM-C) and N (POM-N), N mineralization potential (PMIN-N).

Results and Conclusions

Grain Yield

In 2008, grain yields ranged from 177-188 bu/ac (mean 182 bu/ac) and as expected there was not a significant difference in yield between treatments, since no stover removal had occurred in 2007 (Table 3). The grain moisture content ranged from 15.2 to 17.5 percent.

In 2009, the grain yields were lower and ranged from 153-171 bu/ac (mean 162 bu/ac). In 2009, plots with higher removal rates in 2008 (low cut 2.2 ton/ac, high cut 2.1 ton/ac, and 2-pass baling 2.3 ton/ac removal rates), had yields 14, 12 and 11 bu/ac higher than the conventional plots (zero removal). However, the lower removal rates (cobs only 0.5 ton/ac, and MOG removal 0.7 ton/ac) where not significantly different than the conventional plots. The grain moisture content ranged from 15.9 to 19.7 percent.

In 2010, the grain yields were lower than previous years due to significant ponding in the field and possible nutrient stress. The grain yields ranged from 140-178 bu/ac (mean 155 bu/ac). In addition, the ponding resulted in much higher than normal variability in yields between plots, within each treatment rep. Similar to 2009, in 2010 the high removal rate treatment (low cut 2.5 ton/ac removal rate) on average yielded 25 bu/ac more than the conventional plots (zero removal). However, due to the high variability between individual plot yields the 25 bu/ac difference was not statistically significantly different (α=0.05). The grain moisture content ranged from 14.0 to 16.3 percent.

In 2011, the grain yields ranged from 132-159 bu/ac (mean 151 bu/ac). On, August 23, 2011 a high wind event in the area caused significant lodging in the field. As before, the lodging resulted in much higher than normal variability in yields throughout the field, and made combining very difficult. Due to the high variability between individual plot yields the treatment difference were not statistically significantly different (α=0.05), with the exception of the single pass baling plots. However, this is most likely due to the use of a different combine for these plots which seemed to have higher harvest losses in the heavily lodged field. The grain moisture content ranged from 13.8 to 16.1 percent.

When all years are considered, the most of the treatment means ranged from 160-162 bu/ac, with the exception of the single pass direct bale treatment plots (average 150 bu/ac), and the high removal rate treatment (low cut 2.5 ton/ac removal rate) which averaged 172 bu/ac over the four years. The lower average for single pass direct bale treatment plots was a result of higher combine harvest losses in 2011 in the heavily lodged field. Therefore over the four years, the high removal rate treatment (low cut 2.5 ton/ac removal rate) on average yielded 10 bu/ac more than the conventional plots (zero removal). However, due to the high variability between individual plot yields, and seasonal variation in yields, the 10 bu/ac difference was not statistically significantly different (α=0.05) from the conventional and the lower removal rate plots.

The most likely cause for the higher yields in the high removal rate plots was soil temperature affects due to cold spring germination weather, and that the removal of carbon resulted in lower use of nitrogen by microbes. These results are consistent with other studies conducted in Ames. However, it must be realized that this increase in yield may not be sustainable in the long term due to required mass balance of nutrients to maintain equilibrium within the soil. Over time depletion of organic matter will reduce residual nitrate levels.

In summary, there were no statistical significant differences in amongst the stover harvest treatments, although the highest removal treatment (Low Cut), did show a 10 bu/ac (7%) increase in average yield over the conventional harvest treatment. However, grain yield did showed significant difference seasonal effects, but no significant seasonal and treatment interaction. The seasonal effects were most likely due to the decline in yield related to continuous corn production (2007-2011), high spatial variability in soil fertility, excessive early season rainfall in 2010, and severe wind damage in August 2011.

Table 3. Grain yields for seven harvest treatments for 2008-2011, Emmetsburg, IA.

Treatment	--------------- Grain Yield (bu/ac) ---------------				
	2008	2009	2010	2011	Average
Conventional	180.1	156.5	151.8	157.6	**161.5**
Cobs only	178.0	153.5	150.9	158.5	**160.2**
MOG	185.8	152.8	152.6	157.1	**162.1**
High cut (50%)	178.9	170.7	140.3	149.3	**159.8**
Low cut (90%)	188.4	168.3	177.5	154.0	**172.1**
2-pass baling	176.6	167.2	156.8	148.6	**162.3**
Direct bale	---	163.6	155.2	132.4	**150.4**
Average	**181.8**	**161.8**	**155.0**	**151.1**	**162.4**

All treatments were not statistically different (α=0.05)

Stover Yield

In 2008, the collected biomass yield was 2.2, 2.3, 2.1, 0.7 and 0.5 ton/ac for the Low cut, 2 pass baling, high cut, MOG and Cob only removal treatments respectively (Table 4). The moisture contents ranged from 14.3% for cobs only to 24.9% for the low cut, with an average of 19% for all treatments.

In 2009, collected biomass yield were similar to the 2008 results, with a few exceptions. In 2009, the removal rate for the High Cut (50%) was lower than in abnormally high 2008 stover yields, when it was necessary to run the high cut much lower due to lodging of the corn. In addition, the 2-pass baling operation was far less aggressive in 2009 and a more moderate stover yield was achieved. It is interesting to note that the yield for the MOG removal utilizing the Direct bale (0.9 ton/ac) is consistent with those for the single pass bulk MOG system (0.9 ton/ac), as would be expected. The moisture contents ranged from 10.3% for Direct bale to 16.2% for the cobs only, with an average of 13% for all treatments.

In 2010, collected biomass yield were consistent with the 2009 results. The moisture contents ranged from 9.3% for Direct bale to 35.6% for the Low cut, with an average of 19.6% for all treatments.

In 2011, the cobs only collection yields were much lower than expected due to losses in collection system resulting insufficient transport from combine collection system to the wagon. In addition the high cut treatment yields were higher than expected due to significant lodging required a much lower than normal cut height. The moisture contents ranged from 9.3 % for MOG removal to 35.6% for the low cut, with an average of 19.6% for all treatments

Over the 4 years, the collected biomass yield was 2.5, 2.0, 1.9, 0.7, 0.9 and 0.5 ton/ac for the Low cut, 2 pass baling, high cut, MOG, single pass direct bale and Cob only removal treatments respectively (Table 4).

Table 4. Stover yield for seven harvest treatments for 2008-2011, Emmetsburg, IA.

Treatment	--------------- Stover Yield (dry ton/ac) ---------------				
	2008	2009	2010	2011	Average
Conventional	---	---	---	---	---
Cobs only	0.5	0.7	0.5	0.2	0.5
MOG	0.7	0.9	0.6	0.8	0.7
High cut (50%)	2.1	1.8	1.7	2.2	1.9
Low cut (90%)	2.2	2.5	2.5	2.7	2.5
2-pass baling	2.3	1.5	1.4	2.9	2.0
Direct bale	---	0.9	0.8	1.1	0.9
Average	**1.3**	**1.2**	**1.1**	**1.4**	**1.2**

Stover Consituent analysis

The average stover consituent analysis for the different harvest treatments are shown in Table 5. The nitrogen concentration in the collected stover increased as a higher percentage of the lower portions of the plant were collected. The nitrogen concentration increased from 0.45% for the cob only harvest to 0.52% for the low cut harvest treatment, and these two treatment were significantly different (α=0.05). Similarly, P and K concentrations in the collected stover increased as a higher perecentage of the lower portions of the plant were collected, although these differences were not statistically significant at the 5% level. The changes in nutrient concentration as a larger percentage of the lower portions of the plant are collected are a result of translocation of nutrients from the upper portions of the plant to lower stems and roots as plant senescence occurs.

The nitrogen removal rates per ton of biomass ranged from 9 lbs-N/per ton (cob only harvest) to 12 lbs-N/per ton (low cut harvest), with an average of 10 lbs-N/per ton for all treatments. The phosphorous removal rates per ton of biomass ranged from 1.2 lbs-P/per ton (cob only harvest) to 1.6 lbs-N/per ton (low cut harvest), with an average of

1.4 lbs-P/per ton for all treatments. The potassium removal rates per ton of biomass ranged from 12 lbs-K/per ton to 13.6 lbs-K/per ton (low cut harvest), with an average of 13 lbs-K/per ton for all treatments.

Table 5. Stover constituent analysis by harvest scenario for 2008-2010, Emmetsburg, IA.

Treatment	Concentration of Nutrients in Stover Removed from Field							
	C	**N**	**P**	**K**	**Ca**	**Mg**	**S**	**Na**
	%							
Cob only	45.36 ab	0.45 b	0.06 a	0.65 a	0.14 d	0.07 c	0.053 a	0.040 a
MOG	45.05 ab	0.46 b	0.06 a	0.61 a	0.16 d	0.08 c	0.056 a	0.040 a
High cut	44.72 ab	0.53 ab	0.08 a	0.67 a	0.26 c	0.14 b	0.059 a	0.041 a
Low cut	43.88 b	0.59 a	0.08 a	0.68 a	0.34 b	0.17 a	0.058 a	0.040 a
Baled – 2	41.22 c	0.54 ab	0.08 a	0.63 a	0.41 a	0.18 a	0.061 a	0.040 a
Direct bale	44.97 ab	0.54 ab	0.06 a	0.59 a	0.15 d	0.07 c	0.032 a	0.012 a
Average	**44.15**	**0.52**	**0.07**	**0.64**	**0.25**	**0.12**	**0.054**	**0.037**

Treatment	**Al**	**B**	**Cu**	**Fe**	**Mn**	**Zn**
	ppm					
Cob only	21 b	5.9 c	2.1 c	36 b	12.3 d	19.3 a
MOG	22 b	6.4 c	2.0 c	44 b	17.5 cd	22.3 a
High cut	28 b	6.7 bc	2.9 ab	50 b	22.9 bc	93.2 a
Low cut	50 b	7.5 ab	2.8 b	82 b	30.1 b	14.5 a
Baled – 2	659 a	8.4 a	3.6 a	855 b	56.9 a	15.2 a
Direct bale	30 b	5.8 c	2.1 c	70 a	17.2 cd	21.0 a
Average	**141**	**6.8**	**2.6**	**197**	**26.7**	**31.5**

Levels not connected by same letter are significantly different (α=0.05)

Manual Yield Sample and Collection Efficiency

The grain yield and dry matter yield from the 2m hand harvested transects in 2008-2011 shown in Table 6.

In 2008, the manual grain yields ranged from 180 to 200 bu/ac with an average yield of 189 bu/ac which was slightly higher but consistent with the combine grain yields (range 177 to188 bu/ac; average yield 182 bu/ac). In 2009, the manual grain yields ranged from 137 to 152 bu/ac with an average yield of 146 bu/ac which was slightly lower than the combine grain yields (range 152 to172 bu/ac; average yield 162 bu/ac).

In 2010, the manual grain yields ranged from 153 to 191 bu/ac with an average yield of 173 bu/ac which was higher than the combine grain yields (range 140 to 178 bu/ac; average yield 155 bu/ac). However, in 2010 there was significant ponding in the lower elevation areas in the plots, which reduced overall plot yields. These low yield areas where not located where random manual plot samples were collected.

In 2011, the manual grain yields ranged from 149 to 218 bu/ac with an average yield of 194 bu/ac which was much higher than the combine grain yields (range 132 to 159 bu/ac; average yield 151 bu/ac). The much lower machine harvest grain yields were much lower than the manual grain yields due to significant lodging in the field due to a high wind event in August. Over 50% of the field was severely lodging which resulted in very high harvest losses during combining.

Table 6. Manually Harvested Grain, Cobs and Stover Yields (2008-2011) for seven harvest scenarios.

Treatment	Grain and Cob Yield		Stover Yields		
	Grain, bu/ac	Cobs, ton/ac*	Top 50%, ton/ac	Bottom 50%, ton/ac	Total Stover, ton/ac
		2008 Manual Harvest			
Low cut (90%)	197	0.66	1.22	1.56	3.44
High cut (50%)	201	0.71	1.16	1.76	3.64
Baled	180	0.70	1.08	1.45	3.23
Single Pass Sq. Bale	---	---	---	---	---
MOG Removal	185	0.67	1.12	1.52	3.31
Cobs Only	192	0.79	1.17	1.51	3.48
Conventional	180	0.74	0.94	1.60	3.27
Average (2008)	**189**	**0.71**	**1.12**	**1.57**	**3.40**
		2009 Manual Harvest			
Low cut (90%)	148	1.02	0.91	1.96	4.36
High cut (50%)	150	1.04	0.90	1.98	4.51
Baled	137	0.92	0.79	1.72	3.93
Single Pass Sq. Bale	148	0.98	0.88	1.76	4.22
MOG Removal	147	1.01	0.96	1.64	4.24
Cobs Only	139	0.85	0.79	1.79	3.89
Conventional	152	0.75	0.90	1.81	3.98
Average (2009)	**146**	**0.94**	**0.88**	**1.81**	**4.16**
		2010 Manual Harvest			
Low cut (90%)	182	0.68	1.47	1.60	3.75
High cut (50%)	161	0.60	1.30	1.53	3.43
Baled	191	0.72	1.49	1.68	3.89
Single Pass Sq. Bale	168	0.63	1.32	1.48	3.42
MOG Removal	153	0.58	1.34	1.49	3.41
Cobs Only	171	0.64	1.34	1.54	3.52
Conventional	184	0.69	1.29	1.59	3.57
Average (2010)	**173**	**0.65**	**1.36**	**1.56**	**3.57**
		2011 Manual Harvest			
Low cut (90%)	199	0.51	0.80	1.40	3.46
High cut (50%)	149	0.46	0.83	1.05	2.98
Baled	205	0.52	0.80	1.58	3.61
Single Pass Sq. Bale	204	0.51	0.78	1.27	3.18
MOG Removal	218	0.56	0.76	1.45	3.45
Cobs Only	190	0.52	0.70	1.20	3.01
Conventional	195	0.50	0.79	1.98	3.97
Average (2011)	**194**	**0.51**	**0.78**	**1.42**	**3.38**

In 2008, the hand harvested cob yields ranged from 0.66 to 0.79 ton/ac, with an average of 0.71 ton/ac, and the total stover yield ranged from 3.23 to 64 ton/ac, with an average of 3.40 ton/ac. In 2008, estimated total stover yield did not include biomass already on ground and therefore the total stover yield was underestimated and this was reflected in the slightly higher than expected HI in 2008

In 2009, the hand harvested cob yields ranged from 0.75 to 1.04 ton/ac, with an average of 0.94 ton/ac, and the total stover yield ranged from 3.89 to 5.51 ton/ac, with an average of 4.16 ton/ac. In 2010, the hand harvested cob yields ranged from 0.58 to 0.72 ton/ac, with an average of 0.65 ton/ac, and the total stover yield ranged from 3.41 to 3.81 ton/ac, with an average of 3.57 ton/ac. In 2011, the hand harvested cob yields ranged from 0.46 to 0.56 ton/ac, with an average of 0.51 ton/ac, and the total stover yield ranged from 3.01 to 3.97 ton/ac, with an average of 3.38 ton/ac.

Over the four years, the hand harvested cob yields ranged from 0.50 to 1.04 ton/ac, with an average of 0.70 ton/ac, and the total stover yield ranged from 3.27 to 3.64 ton/ac, with an average of 3.63 ton/ac. The estimated harvest index (HI) ranged from 0.48 to 0.64, with an average of 0.57. The estimated harvest index is slightly higher than expected. The cob mass was on average 14% of the total grain mass and consistent with values reported in literature, and the cob mass was 19% of the total stover biomass.

In 2008, when the combine stover harvested yields are compared to the total hand harvested stover yields, the Low cut (90%) rate collected approximately 70% of the nominal available above ground biomass and the High cut (50%) collection efficiency was about 58%. The MOG removal and Cob removal provided 20% and 13% of the nominal available biomass, respectively. When the combine cob yield (0.46 ton/ac) is compared with the hand harvest cob yield (0.71 ton/ac), the estimated collection efficiency of the cob harvest operations is approximately 65%.

In 2009, the Low cut (90%) rate collected approximately 57% of the total available above ground biomass, and the High cut (50%) collection efficiency was about 41%. The MOG removal and Cob removal provided 21% and 17% of the total available biomass, respectively. When the combine cob yield (0.66 ton/ac) is compared with the hand harvest cob yield (0.85 ton/ac), the estimated collection efficiency of the cob harvest operations is approximately 78%. In 2009, the increase in nominal cob collection efficiency increased above was partly due to lower purity cob samples. The sample purity was below 80% by weight.

In 2010, the Low cut (90%) rate collected approximately 65% of the total available above ground biomass, and the High cut (50%) collection efficiency was about 49%. The MOG removal and Cob removal provided 17% and 14% of the total available biomass, respectively. When the combine cob yield (0.50 ton/ac) is compared with the hand harvest cob yield (0.64 ton/ac), the estimated collection efficiency of the cob harvest operations is approximately 78%.

In 2011, the Low cut (90%) rate collected approximately 79% of the total available above ground biomass, and the High cut (50%) collection efficiency was about 73%. The latter was higher than normal due to the severe lodging. The MOG removal and Cob removal provided 21% and 8% of the total available biomass, respectively. When the combine cob yield (0.25 ton/ac) is compared with the hand harvest cob yield (0.70 ton/ac), the estimated collection efficiency of the cob harvest operations is only 50%. The cobs collection yield was much lower than expected due to losses in transporting the cobs from combine to the wagon.

Over, the four years, the Low cut (90%) rate collected approximately 66% of the total available above ground biomass, and the High cut (50%) collection efficiency was about 53%. The MOG removal and Cob removal provided 21% and 13% of the total available biomass, respectively. When the combine cob yield is compared with the hand harvest cob yield, the estimated average collection efficiency of the cob harvest operations is only 67%, although this is slightly inflated due to husk contamination

Soil Quality Assessment and Nutrient Removal Rates

The macro-nutrient and micronutrient analysis results for the 0-15cm soil fertility samples collected on 2008 - 2011 by year and treatment are shown in Table 7. The average soil fertility levels across all treatments are shown in Table 8.

The different stover removal treatments resulted in no significant differences (α=0.05) for all soil nutrients, soil OM, and soil pH. However, there was a significant difference between repetitions for all for soil nutrients (except Mg, Zn, S, and Na), soil OM and pH, reflecting the spatial variability in soil type and natural fertility levels across the field. In addition, when the soil nutrients (except Fe), soil OM and pH for all treatments were pooled and compared across the years, a significant difference between was found (α=0.05).

In 2008 and 2009, the residual nitrate levels in the soil after harvest were lower than those in 2010 and 2011. This is most likely due to the increased rates of nitrogen applied in the spring of 2010 and 2011, resulting increased residual nitrogen in fall. The Nitrogen fertilizer rates were increased in 2010 and 2011 as a result of N ear leaf nutrient levels testing below critical values. In addition, soil P decreased from 2008 to 2010 from 35.1 to 19.0 ppm, although average P ear leaf nutrient levels remained above critical values. In 2011, post harvest soil P levels increased back to 28.3 ppm. Soil K decreased from 2008 to 2010 from 1971 to 147 ppm, although average P ear leaf nutrient levels remained above critical values. Prior to 2011 planting, K fertilization rates were increased (Table 2), and which resulted in average post harvest soil K levels increasing to 183 ppm. In addition, over the four years of the study there was slight decrease in soil organic matter from 4.5 to 4.0 %, although this was unrelated to harvest treatment effects. These changes in organic matter are attributed to the intensity of tillage and lower than expected crop yields due to weather and other factors. Stover removal may provide an opportunity to reduce tillage intensity levels.

Both grain yields and soil nutrient levels, were not significantly affected by stover harvest treatments. However, the signifcant difference between repetitons and seasonal effects for both grain yield and soil nutrient levels, emphasize the important of a strong fertility testing and nutrient management program, before implementing crop residue harvesting. The spatial and temporal variation in soil nutrients and overall crop management can have a much greater effect on crop yields and sustainable production than the effect of different stover harvest removal rates. In addition, when overall soil fertility levels and nutrient management plans are marginal the removal of crop residue could serve as the tipping point to reduce overall production.

Table 7. Near-surface soil test values after harvest, by year and harvest treatments

Near-surface soil test values after 2008 Harvest														
Treatment	pH	OM	N03-N	P	K	Ca	Mg	Na	S	B	Cu	Fe	Mn	Zn
		%	ppm											
Conventional	6.9	4.2	5.0	30.0	191	6217	539	---	---	---	0.80	42.0	10.7	0.43
Cobs only	7.0	4.5	4.7	38.7	178	6150	518	---	---	---	0.73	39.7	9.2	0.53
MOG	6.7	4.4	4.3	37.0	207	5603	521	---	---	---	0.77	44.3	10.8	0.40
High cut	7.0	4.5	4.3	27.0	190	6784	562	---	---	---	0.73	18.3	6.5	0.40
Low cut	6.9	4.8	4.3	31.3	191	6977	550	---	---	---	0.73	39.0	8.6	0.43
Baled – 2 pass	6.8	4.2	5.7	31.7	190	5743	580	---	---	---	0.77	38.7	10.5	0.47
Direct Bale	6.5	5.8	3.0	35.0	209	7608	523	---	---	---	0.70	14.0	7.4	0.40
Mean all treatments	**6.8**	**4.5**	**4.8**	**35.1**	**197**	**6264**	**543**	---	---	---	**0.76**	**36.8**	**9.3**	**0.45**

Near-surface soil test values after 2009 Harvest														
Treatment	pH	OM	N03-N	P	K	Ca	Mg	Na	S	B	Cu	Fe	Mn	Zn
		%	ppm											
Conventional	6.9	4.7	10.7	22.7	152	5073	389	6.3	7.00	0.73	1.13	46.3	1.7	0.47
Cobs only	6.9	4.8	10.3	29.7	174	5036	396	7.0	6.33	0.73	1.07	57.0	2.1	0.43
MOG	7.1	4.4	9.0	29.7	153	4919	399	8.3	7.33	0.70	1.13	50.3	1.4	0.47
High cut	7.2	4.4	9.0	16.3	144	5061	377	7.0	7.00	0.67	1.10	33.3	1.7	0.47
Low cut	7.1	4.6	8.3	28.3	159	5401	378	7.0	6.33	0.77	1.10	45.3	2.4	0.50
Baled – 2 pass	7.0	4.7	9.3	23.7	157	4932	398	8.0	7.00	0.73	1.03	43.0	1.5	0.50
Direct Bale	7.3	4.4	8.3	21.3	150	5144	396	6.7	5.67	0.70	1.00	24.7	1.7	0.47
Mean all treatments	**7.1**	**4.6**	**9.3**	**24.5**	**156**	**5081**	**390**	**7.2**	**6.67**	**0.72**	**1.08**	**42.9**	**1.8**	**0.47**

Near-surface soil test values after 2010 Harvest														
Treatment	pH	OM	N03-N	P	K	Ca	Mg	Na	S	B	Cu	Fe	Mn	Zn
		%	ppm											
Conventional	6.8	4.4	12.3	19.3	148	4257	323	9.7	8.33	0.43	####	66.3	4.6	5.07
Cobs only	7.1	4.4	13.7	23.3	149	4451	352	10.7	9.33	0.37	####	55.7	2.9	3.23
MOG	7.3	4.3	12.3	20.3	141	4528	321	8.3	7.33	0.40	####	38.7	3.2	3.60
High cut	7.4	4.0	11.7	15.0	148	4877	329	10.7	8.00	0.43	####	25.7	3.3	3.20
Low cut	7.3	4.3	12.3	19.0	153	4732	312	9.7	8.00	0.43	####	37.0	2.8	2.30
Baled – 2 pass	7.3	4.3	14.0	18.7	139	4528	350	9.7	7.67	0.40	####	45.0	3.0	5.80
Direct Bale	7.4	4.2	12.7	17.3	154	4566	342	8.3	7.00	0.47	####	32.0	3.0	3.67
Mean all treatments	**7.2**	**4.3**	**12.7**	**19.0**	**147**	**4563**	**333**	**9.6**	**7.95**	**0.42**	**####**	**42.9**	**3.3**	**3.84**

Near-surface soil test values after 2011 Harvest														
Treatment	pH	OM	N03-N	P	K	Ca	Mg	Na	S	B	Cu	Fe	Mn	Zn
		%	ppm											
Conventional	6.9	4.1	12.3	27.7	184	5931	396	14.3	9.33	1.10	1.33	58.7	10.3	0.93
Cobs only	6.8	3.9	10.7	29.7	177	5461	386	14.0	9.33	0.90	1.23	69.3	8.6	0.73
MOG	6.7	3.9	9.7	26.7	185	5513	404	14.3	7.00	0.87	1.17	56.1	5.8	0.73
High cut	6.7	3.8	9.0	22.7	182	5370	444	13.7	7.00	0.77	1.37	47.1	5.2	0.73
Low cut	6.9	4.3	10.3	29.3	184	5958	366	14.0	8.33	1.03	1.27	55.6	7.6	0.70
Baled – 2 pass	6.7	4.0	11.3	32.0	190	5316	423	14.7	8.67	0.83	1.30	74.0	11.5	1.10
Direct Bale	6.9	3.8	10.0	30.0	183	5240	437	15.3	7.67	0.83	1.17	51.6	6.3	0.90
Mean all treatments	**6.8**	**4.0**	**10.5**	**28.3**	**183**	**5541**	**408**	**14.3**	**8.19**	**0.90**	**1.26**	**58.9**	**7.9**	**0.83**

Table 7. Near-surface soil test values Harvest, Mean for all Treatments by Year

	Near-surface soil test values Harvest, Mean for all Treatments by Year												
Treatment	pH	OM	N03-N	P	K	Ca	Mg	Na	S	B	Fe	Mn	Zn
		%	ppm										
Mean all treatments, 2008	6.8 [b]	4.5 [a]	4.8 [c]	35.1 [a]	197 [a]	6264 [a]	543 [a]	---	---	---	36.8 [a]	9.3 [a]	0.45 [b]
Mean all treatments,2009	7.1 [ab]	4.6 [a]	9.3 [b]	24.5 [bc]	156 [b]	5081 [bc]	390 [b]	7.2 [c]	6.67 [b]	0.72 [b]	42.9 [a]	1.8 [b]	0.47 [b]
Mean all treatments, 2010	7.2 [a]	4.3 [ab]	12.7 [a]	19.0 [c]	147 [b]	4563 [c]	333 [c]	9.6 [b]	7.95 [a]	0.42 [c]	42.9 [a]	3.3 [b]	3.84 [a]
Mean all treatments, 2011	6.8 [b]	4.0 [b]	10.5 [b]	28.3 [ab]	183 [a]	5541 [ab]	408 [b]	14.3 [a]	8.19 [a]	0.90 [a]	58.9 [a]	7.9 [a]	0.83 [b]

Levels not connected by same letter are signifcantly different (α=0.05)

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