Corn Stover Nutrient Removal Estimates for Central Iowa

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One of the most frequently asked questions Project Liberty coordinators receive is "what quantity of nutrients will be removed if I harvest my corn (*Zea mays* L.) stover?" This report summarizes plant nutrient composition data collected in Boone and Palo Alto Counties of Iowa from 2008 through 2012 to help answer that question. More than 500 site-years of samples were collected by hand from approximately six linear feet of row and divided into four plant fractions: vegetative material from the ear shank upward, vegetative material from approximately four inches above the soil surface to just below the ear, cobs, and grain. Another 388 stover samples, representing the vegetative material collected directly from a single-pass combine harvesting system or from bales that had been prepared using two-pass stover harvest technologies were also collected. All samples were analyzed to determine C, N, P, K, Ca, Mg, S, Al, B, Cu, Fe, Mn, and Zn concentrations. Mean concentration and dry matter estimates for each sample were used to calculate nutrient removal per dry ton of stover. Compared to harvesting only the grain, stover harvest increased N, P, and K removal by 14, 1.4, and 16 lbs per ton, respectively. For stover harvest rates of one ton/acre, we recommend making no changes in current N and P fertilization practices, but routine soil testing and plant analysis should be used to monitor plant available K levels.

INTRODUCTION

Corn stover is the above-ground, non-grain plant material that remains following grain harvest. To support emerging cellulosic bioenergy operations such as Project Liberty near Emmetsburg, IA and DuPont Cellulosic Ethanol near Nevada, IA, stover was identified as the primary feedstock [1] because of the vast area upon which the crop is grown. For example, from 2004 through 2013, corn was planted on an average of 13.5 million acres in Iowa and produced an average of 2.2 billion bushels of grain each year [2].

Farmers have harvested corn stover for many years as animal feed and bedding, but elemental composition was rarely measured since most nutrients were cycled back to the fields through manure. Interest in quantifying stover nutrient removal began following the 1970's oil crisis when cellulosic feedstocks were first evaluated for bioenergy production [3], because those operations were destined to increase export of plant nutrients from individual fields. Furthermore, even though nutrient composition for corn silage was well known, the corn stover studies showed significant differences in nutrient concentrations because of a later harvest and eparation of grain and vegetative plant fractions [4]. Estimating stover nutrient removal was also complicated by potential translocation or leaching of soluble elements such as K from upper plant parts during the period between physiological maturity and combine harvest. Those challenges, plus the wide variation associated with stover harvest operations remain, so even though some stover nutrient composition data are available [5-8], estimates are often quite variable and may be useful for making operational decisions regarding whether or not to harvest and market a portion of this resource from specific fields.

Several authors [1, 9, 10] have suggested that harvesting stover can be a "win-win" management practice, often stating that it is an underutilized resource that could be used as a

feedstock and simultaneously reduce residue management costs that currently range from $20 to $30 ac^{-1} [11]. However, the decision to harvest corn stover for bioenergy or any other use is not that simple, because stover (plant residue) also supports many ecosystem services [12–14] and its harvest will increase annual nutrient removal [15–17] when compared to harvesting only the grain.

To support emerging U.S. cellulosic bioenergy industries, several field research studies were conducted by the USDA Agricultural Research Service (ARS) Resilient Economic Agricultural Practices (REAP) team [formerly known as the Renewable Energy Assessment Project (REAP) team] and their university partners as part of the Department of Energy (DOE) Bioenergy Technologies Office's Regional Feedstock Partnership Corn Stover Team and USDA-National Institute for Food and Agriculture (NIFA) Sun Grant Initiative. Studies at 36 sites in seven states produced 239 site-years of data [6] that were summarized to provide an overview of crop yield and nutrient removal impacts of stover harvest. This report provides more detail, using 530 site-years data for various hand-sampled plant fractions and 388 site-years of machine-collected stover samples, collected in Boone and Palo Alto Counties in Central Iowa between 2008 and 2012. Our objective is to help producers make more informed decisions when deciding whether or not to market a portion of their corn stover for bioenergy or other bio-products.

METHODS AND MATERIALS

Hand samples were collected from six linear feet within each plot during the three-week period between physiologic maturity and combine harvest to obtain an estimate of the potential above-ground stover production and the harvest index for each year Samples were fractionated into four components: (1) vegetative material from the ear shank upward, (2) vegetative material

from approximately four inches above the soil surface to just below the ear, (3) cobs, and (4) grain. Weights for the non-grain components were summed to estimate the above-ground biomass. The grain weight was divided by the sum of all five fractions to estimate the harvest index (HI). Stover samples were generally collected with a John Deere 9750 STS[1] combine [5], although a few were collected using an AgCo combine with attached baler, or through a multi-pass rake and round bale operation for which standing stalks were shredded with a rotary cutter, windrowed and baled [8]. Stover samples from baled treatments were collected by taking multiple cores from each bale. All plant samples were dried, weighed and used to estimate total above-ground biomass production. Plant samples were subsequently ground to pass a 0.5 mm screen. One sub-sample was analyzed by dry combustion to determine C and N concentrations, while another was digested with sulfuric acid and hydrogen peroxide before analyzing the material to determine P, K, Ca, Mg, Na, S, Al, B, Cu, Fe, Mn, and Zn concentrations using an inductively-coupled plasma spectrophotometer (ICP).

Nutrient concentration data for the stover, three vegetative plant fractions, and grain were analyzed using Proc Means with SAS Version 9.3 software, since the primary goal was to provide producers with nutrient composition information needed to make more informed decisions when deciding whether or not to market a portion of their corn stover for bioenergy or other bio-products.

RESULTS AND DISCUSSION

Mean and standard deviation data for ~530 site-years of plant fraction samples collected in Boone and Palo Alto Counties in Iowa (Table 1). Corn grain yield for the 530 site-

[1] Mention of a specific product or proprietary name is for reference only and does not constitute preference or endorsement by Iowa State University or the USDA-Agricultural Research Service (ARS).

years averaged 163 bu/acre which was consistent with the average 2008–2012 grain yield (165 bu/acre) for Iowa in the NASS database [2]. Above-ground biomass averaged 3044, 3765, and 1449 lb/acre for plant material from (a) the ear shank upward, (b) a stubble height of ~4 inches to just below the ear, and (c) the cobs, respectively. Dividing grain yield by above-ground dry matter at 0% water content results in an average harvest index (HI) of 0.49 which is within the typical range (0.48 to 0.53) for corn [17]. Cobs accounted for 18% of the average above-ground biomass which is also very consistent with values reported in literature [18]. Therefore, based on these indicators, we are confident the nutrient composition data (Table 1) are also very representative of current Iowa corn crops.

For those interested in carbon balance and the amount of potential soil organic matter that could be added by returning various amounts of corn residue, the three plant fractions listed above contained an average of 861, 877, and 909 lbs C per ton, respectively. We also noted that the carbon estimate for stover samples averaged 891 lbs C per ton, perhaps reflecting a higher portion of cob in those samples. In comparison to the vegetative plant fractions, corn grain from these sites contained an average of 736 lbs C per ton (Table 2).

Mean N, P, and K concentrations within the various non-grain plant fractions (Table 1), ranged from 0.58 to 0.79, 0.04 to 0.09, and 0.66 to 0.98 percent, respectively. When compared to grain N concentrations (Table 2), levels in upper plant parts, lower plant parts, or cobs were 37, 46, or 52% lower. Grain P concentrations (Table 2) showed even greater differences, being 289, 650, or 650% higher than in the various vegetative plant fractions, respectively. In contrast, grain K concentrations were only 36, 36, or 53% of that found in the various vegetative plant fractions.

Based on our measured grain nutrient concentrations, a 175 bu/acre grain crop would remove 104, 22, and 29 lbs/acre of N, P, and K, respectively. Harvesting one ton/acre of cobs

would increase N, P, and K removal by 13, 0.7, or 13 lbs/acre, respectively, while harvesting one ton/acre of upper plant parts would increase N, P, and K removal by 16, 1.9, or 19 lbs/acre, respectively. The stover data (Table 1) provides similar estimates showing N, P, and K removal levels of 12, 1.2, and 16 lbs/acre, reflecting both the mixture of cobs and upper plant parts and the slightly later sample collection time (as much as two weeks before grain harvest) which has been reported [4] to significantly influence stover nutrient concentrations. As discussed for C, lower average stover K concentrations also presumably reflected a higher percentage of upper plant parts, since K concentrations in corn cobs were quite low. Therefore, when compared to macronutrient removal with the grain, stover or its various plant fractions removed an additional 65, 29, or 283% of the N, P, or K per ton, respectively, (Table 2) when compared to harvesting only grain. This data confirms previous reports [4–8] and emphasizes that K is the most important macronutrient to be concerned about when deciding to harvest corn stover for bioenergy or other bio-products.

Secondary nutrient (Ca, Mg, and S) concentrations (Table 1) had very low standard deviations associated with mean values for each of the plant fractions analyzed. Vegetative fractions above and below the ear were very consistent as expected. Concentrations of Ca, Mg, and S in cob tissue were all much lower than in the other vegetative parts, and as discussed previously, contributed to lower values in the machine-collected stover samples. As expected, Na concentrations in all samples were very low, with essentially no detectable standard deviation within the data. Analysis of grain samples (Table 2) showed secondary nutrient concentrations that were similar to those in the cob fraction, but substantially lower than in the other vegetative fractions.

Micronutrient (Al, B, Cu, Fe, Mn, and Zn) concentrations in stover or the various plant fractions showed much greater variation, especially for Al, Fe, and Zn, presumably due to soil contamination, since no attempt was made to wash the material before grinding it for chemical analysis. Overall, the values for these nutrients were consistent with previously reported removal amounts [4]. Micronutrient removal by the grain (Table 2) was also very consistent with previously published levels [4].

The large number of samples analyzed and contributing to the mean values presented in this report, coupled with the consistency with previously reported results [4–8], provides confidence that the values can be used to estimate potential nutrient removal for various stover harvest scenarios. For example, POET-DSM's Project Liberty is promoting harvest of a small portion of the crop residue from appropriate areas (slopes ≤ 3%) using "2nd Pass Cob Bales" which are also being referred to as the "EZ Bale™" because they are "EZ to harvest, EZ to store, and EZ on your land." Our data set (Table 1) did not include any "EZ bale" data, but to assist producers who are considering this harvest strategy, we offer the following guidelines and comparisons with standard corn stover bales for estimating potential nutrient removal from their land. Based on Project Liberty (www.projectliberty.com) marketing data, EZ bales consist of 33% cob, 43% leaf/husk, and 16% stalk material plus 8% ash. The bales are made by simply turning off the residue chopper/spreader on the grain combine and dropping the crop residue passing through the machine in a windrow. After drying for a few days, the windrowed material is baled. Since the remaining corn stalks are not shredded or disturbed in any way, we assume the baled material will consist of only cobs and plant material from above the ear (Table 1). In contrast, standard stover bales are generally made by allowing the stover to dry for a few days, followed by chopping and raking a portion of the material into windrows before baling. Using

the same Project Liberty (www.projectliberty.com) marketing data, standard stover bales are assumed to consist of 9% cobs, 42% leaf/husk, and 35% stalk material plus 14% ash. Also, because of mixing associated with the chopping and raking operations, we assume that 40% of the leaf/husk and stalk material collected in standard stover bales can be attributed to material from below the ear shank. This assumption is supported by the higher ash content which generally reflects an increased amount of soil contamination as noted above when discussing Al, Fe, and Mn concentrations. Projections of N, P, and K removals (Table 3) for EZ bales™, and "standard" stover bales were calculated with the following equations:

N removal = (Cob fraction * Cob N content) + (Upper plant fraction * Upper plant N content) + (Lower plant fraction * Lower plant N content)

P removal = (Cob fraction * Cob P content) + (Upper plant fraction * Upper plant P content) + (Lower plant fraction * Lower plant P content)

K removal = (Cob fraction * Cob K content) + (Upper plant fraction * Upper plant K content) + (Lower plant fraction * Lower plant K content).

Based on our 530 site-years of data for Iowa, both harvest methods would remove an additional14, 1.4, and 16 lbs of N, P, and K per ton, respectively, when compared to harvesting only the grain. We interpret the increase in N and P removal as inconsequential at the field scale, and as such should not affect annual fertilization strategies for those nutrients. For K the increase in removal could have significant consequences if initial soil-test levels are low [7]. We also caution those using the template (Table 3) to calculate their own nutrient removal values, that due to the potential rapid change in plant nutrient composition during senescence, it is important

to know exactly when the plant samples were collected as well as the prevailing weather conditions between collection, harvesting grain, and/or making the "EZ bales" or stover bales.

SUMMARY AND CONCLUSIONS

To assist producers wanting to better understand how to estimate nutrient removal if they chose to harvest a portion of their corn stover as feedstock for bioenergy or other bio-products, we summarized more than 500 site-years of hand-collected plant samples and almost 400 site-years of machine-collected stover samples that had been analyzed to determine C, N, P, K, Ca, Mg, S, Na, Al, B, Cu, Fe, Mn, and Zn concentrations. The samples represented a typical Iowa corn crop with a harvest index of 0.49, approximately 18% cob material, and an average (2008 – 2012) grain yield of 163 bu/acre. Estimated nutrient removal per ton for the various plant fractions and stover samples was calculated. To enable producers to make their own estimates for various stover harvest strategies, equations and guidelines for their use are also provided.

Overall, we conclude that successful deployment of cellulosic bioenergy production operations such as the POET-DSM 'Project Liberty' program near Emmetsburg, Iowa can strengthen rural economies, help ensure energy security, and reduce greenhouse gas (GHG) emissions without contributing to soil degradation – another global challenge. Coordinated USDA-ARS and university soil and crop management research conducted at the Emmetsburg site and throughout the Corn Belt has shown that with appropriate, site-specific management, preferably at the sub-field scale, harvesting a portion of the crop biomass can be a valuable and sustainable practice for many farmers. Based on multiple studies, we recommend that to be sustainable, fields chosen for stover harvest should have slopes of less than 3%, consistent grain

yield histories of at least 175 bu/acre and good nutrient management plans with soil-test records for at least pH, P, and K levels. If soil and plant data collected from fields being considered for stover harvest meet those criteria, it will be safe to harvest an average of 1 ton/acre of corn stover. However, by using sub-field management, it is very likely that even more stover could be harvested in a sustainable manner from selected areas within most fields. Doing so will not only provide material for cellulosic bioenergy, but also minimize subsequent residue management problems such as nutrient immobilization, cool wet soils, or poor soil-seed contact. Also, for a one ton/acre harvest rate, current, grain-based N and P fertilizer applications will generally suffice, but due to higher K removal, routine soil-tests should be monitored to determine if enough of that nutrient is being applied. Finally, we recommend effects of cover crops, animal manures, and diverse crop rotations be incorporated into future biomass feedstock studies.

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Table 1. Nutrient concentration and calculated removal per ton of dry matter for three hand-sampled plant fractions and machine-collected corn stover.

		Ear Shank and Above			Below Ear Shank		
Nutrient	**Unit**	**Mean**	**Standard Deviation**	**Removal pounds per ton**	**Mean**	**Standard Deviation**	**Removal pounds per ton**
Carbon	Percent	43.1	0.8	861	43.8	1.0	877
Nitrogen	Percent	0.79	0.14	16	0.68	0.14	14
Phosphorus	Percent	0.09	0.05	1.9	0.07	0.04	1.4
Potassium	Percent	0.96	0.27	19	0.98	0.34	20
Calcium	Percent	0.37	0.11	7.3	0.35	0.09	7.1
Magnesium	Percent	0.23	0.12	4.6	0.21	0.07	4.2
Sulfur	Percent	0.07	0.02	1.5	0.05	0.01	1.0
Sodium	Percent	0.01	0.00	0.2	0.01	0.00	0.2
Aluminum	ppm	51	74	0.102	122	101	0.243
Boron	ppm	8.7	2.1	0.017	6.9	1.7	0.014
Copper	ppm	7.3	2.4	0.014	4.2	1.6	0.008
Iron	ppm	109	157	0.218	206	268	0.411
Manganeese	ppm	40	16	0.080	31	12	0.062
Zinc	ppm	14.9	8.4	0.030	9.4	10.4	0.019
		Cobs			Stover		
Carbon	Percent	45.5	1.0	909	44.6	1.4	891
Nitrogen	Percent	0.66	0.18	13	0.58	0.12	12
Phosphorus	Percent	0.04	0.02	0.7	0.06	0.03	1.2
Potassium	Percent	0.66	0.15	13	0.81	0.22	16
Calcium	Percent	0.06	0.03	1.3	0.22	0.09	4.3
Magnesium	Percent	0.03	0.02	0.6	0.13	0.07	2.6
Sulfur	Percent	0.03	0.01	0.6	0.05	0.02	0.9
Sodium	Percent	0.01	0.00	0.2	0.02	0.02	0.3

Aluminum	ppm	13	30	0.027	57	202	0.114
Boron	ppm	3.6	1.3	0.007	5.8	1.9	0.012
Copper	ppm	3.2	1.5	0.006	4.7	1.8	0.009
Iron	ppm	41	65	0.082	106	302	0.211
Manganeese	ppm	4	4	0.008	23	13	0.046
Zinc	ppm	11.6	8.3	0.023	13.8	39.7	0.027

Table 2. Nutrient concentration and calculated removal per ton of corn grain at 15.5% water content

Nutrient	Unit	Mean	Standard Deviation	Removal pounds per ton
Carbon	Percent	43.6	0.7	736
Nitrogen	Percent	1.26	0.15	21
Phosphorus	Percent	0.26	0.04	4.5
Potassium	Percent	0.35	0.05	6
Calcium	Percent	0.07	0.06	1.1
Magnesium	Percent	0.09	0.03	1.6
Sulfur	Percent	0.09	0.01	1.5
Sodium	Percent	0.01	0.00	0.2
Aluminum	ppm	9	12	0.015
Boron	ppm	4.1	1.7	0.007
Copper	ppm	2.2	1.6	0.004
Iron	ppm	27	131	0.045
Manganeese	ppm	3	2	0.005
Zinc	ppm	15.88	5.54	0.03

Table 3. Nitrogen, phosphorus and potassium removal estimates per ton for EZ™ and "standard" stover bales, corn grain and a template for producer estimates using site-specific bale fraction and nutrient concentration data.

Plant part		**Nitrogen**		**Phosphorus**		**Potassium**	
Constituent	**Fraction of bale**	**Content**	**Removal**	**Content**	**Removal**	**Content**	**Removal**
			---------- Pounds per ton ----------				
			EZ™ Bales				
Upper plant	0.59	16	9.4	1.9	1.1	19	11.2
Cobs	0.33	13	4.3	0.7	0.2	13	4.3
	Total		13.7		1.3		15.5
	"Standard" Stover Bales (assuming 60% upper plant parts and 40% lower plant parts in the leaf/husk & stalk fraction)						
Upper plant	0.462	16	7.4	1.9	0.88	19	8.78
Lower plant	0.308	14	4.3	1.4	0.43	20	6.16
Cobs	0,09	13	1.2	0.7	0.06	13	1.17
	Total		12.9		1.4		16.1
			Producer Template (based on Project Liberty Bale Fractions)				
Leaf/Husk	A	1	A*1	4	A*4	7	A*7
Stalk	B	2	B*2	5	B*5	8	B*8
Cobs	C	3	C*3	6	C*6	9	C*9
	Total		(A*1+B*2+C*3)		(A*4+B*5+C*6)		(A*7+B*8+C*9)
			Corn Grain				
Grain	1.00	21	21	4.5	4.5	6	6