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Crop Residue Harvest Economics: An Iowa and North Dakota Case Study

David W. Archer · Douglas L. Karlen · Mark A. Liebig

Abstract Rigorous economic analyses are crucial for the successful launch of lignocellulosic bioenergy facilities in 2014 and beyond. Our objectives are to (1) introduce readers to a query tool developed to use data downloaded from the Agricultural Research Service (ARS) REAPnet for constructing enterprise budgets and (2) demonstrate the use of the query tool with REAPnet data from two field research sites (Ames, IA, and Mandan, ND) for evaluating short-term economic performance of various biofuel feedstock production strategies. Our results for both sites showed that short-term (<3 years) impacts on grain profitability were lower at lower average annual crop residue removal rates. However, it will be important to monitor longer term changes to see if grain profitability declines over time and if biomass harvest degrades soil resources. Analyses for Iowa showed short-term breakeven field-edge biomass prices of \$26–\$42 Mg^{-1} among the most efficient strategies, while results for North Dakota showed breakeven prices of \$54–\$73 Mg^{-1}. We suggest that development of the data query tool is important because it helps illustrate several different soil and crop management strategies that could be used to provide sustainable feedstock supplies.

Keywords Enterprise budgets · Feedstock costs · REAPnet analysis

Introduction

Several economic analyses have been conducted to predict farmer interest in harvesting crop residues for bioenergy production, but the analyses have typically been based on simulation modeling or on limited field observations, with assumed grain yield impacts and nutrient replacement costs. Generally, it has been assumed that residue harvest will have no effect on grain yields [1–5], although some analyses have utilized simulation modeling [6] or single-site field research data to predict grain yield impacts associated with crop residue harvest [7]. Furthermore, most assessments have also assumed that fertilizer applications will be increased to replace the additional nutrients removed with residue [1–6]. The assumptions made for each economic analysis can substantially affect price estimates at which feedstocks can be profitably produced. In addition, these so-called breakeven prices also provide an indication of the cost that will be incurred to convince producers to harvest crop residues and are thus a primary direct cost component for biorefineries. Previous economic analyses have also typically included limited or no cropping system adjustments that producers might adopt to help mitigate crop residue harvest effects on soil resources and/or crop productivity. Other studies have included changes in crop rotation, reductions in tillage, or use of other conservation practices as alternatives that could allow for higher sustainable residue harvest rates [1, 4, 8], but with the exception of two simulation analyses [6, 9] and one analysis using crop rotation field data [7]; costs associated with management changes and grain

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yield impacts have generally not been included. In part, this may have been due to limited availability of field research data to quantify these impacts.

With the impending launch of three lignocellulosic bioenergy facilities in 2014 in the US Midwest, several field studies have been or are being conducted to quantify many aspects of bioenergy feedstock production. Unfortunately, farm and field-level economic analyses are often limited or are not being conducted [10–12]. In those cases where economic analyses were conducted, it was generally for only one or two sites [3, 7], thus limiting the potential to identify common patterns across locations and requiring substantial analyst time to assemble the same basic economic information needed for analysis at each location.

As part of the Renewable Energy Assessment Project (REAP) and Sun Grant Regional Partnership collaboration, a coordinated effort was undertaken to not only conduct field experiments at multiple sites across the USA but also to assemble the data collected at those sites into a common database, known as REAPnet, for use in evaluating biofuel feedstock production alternatives [13]. The initial release of REAPnet is a publically accessible database (http://nrrc.ars.usda.gov/reappb#/Home) that contains research results from 15 research sites [14]. The REAPnet database includes information on experimental treatments, weather, management operations and inputs, and soil and plant measurements. Measurement data include soil physical, chemical, and microbiological information; greenhouse gas flux data; biomass production; and grain yield. Additional data will be added to REAPnet semiannually through a batching process where data are first uploaded to a prerelease spreadsheet for quality control and collaboration among project team members. Updates are uploaded to the public database upon approval of the data contributor. With public availability of the database, there are opportunities to develop tools to access and utilize the data for additional specialized analysis. Some examples include development of tools to retrieve data needed for simulation model analysis and validation or data visualization tools needed to facilitate analysis and multi-site comparisons. Our objectives for this contribution to the special issue were to (1) develop a tool to query data downloaded from the REAP database in order to construct enterprise budgets for treatments that had been evaluated at various locations and (2) demonstrate the use of the query tool with REAPnet data from two field research sites to evaluate short-term economic performance for various biofuel feedstock production strategies.

Methods and Materials

The REAP database query tool was developed as a standalone Microsoft Access database. Management, treatment, and biomass harvest tables downloaded from the REAP prerelease database were imported into the Microsoft Access database. Lookup tables were constructed for machinery, pesticide, fertilizer, and seed costs, as well as crop prices. The general data structure and linkages are shown in Fig. 1. Queries were developed to link machinery and input names used in the REAP database to appropriate cost inputs and to verify that all REAPnet inputs were linked to a database cost element. Enterprise budgets were constructed for each treatment by compiling queries regarding costs for tillage, planting, fertilizer and amendment applications, pesticide applications, and harvest operations. While the query tool was designed to automate enterprise budget construction, running the query tool requires several steps: (1) downloading and importing the REAP net records, (2) updating cost and crop price tables, (3) running verification queries to ensure that cost data are included for all REAPnet input records, and (4) running the enterprise budget queries. In this initial version of the query tool, the user completes these steps manually, downloading data from REAPnet, executing a macro in the query tool to import data from the REAPnet file, then manually updating cost and crop price tables. Initial data are provided in these tables as described below. The user then executes each of the verification queries and checks that no data are missing. If any data are missing, the user must manually update the cost or price tables to fill in missing items. Finally, the user executes a query to construct and compile costs for all field operations. Additional queries are available to summarize enterprise budget results.

Enterprise budgets constructed using the query tool provide unique annual cost estimates for each crop within each experimental treatment. The budgets included machinery ownership and operating costs, including machinery operator labor and all purchased inputs. Land costs, any overall farm overhead costs, and management costs were not included, as these were assumed to be constant across treatments. Also, no crop insurance costs or benefits were included for this analysis.

Machinery costs were obtained from the University of Minnesota Extension [15] and associated “Machdata” spreadsheet. For machines not included in the Minnesota database, cost information was obtained from Costs of Owning and Operating Farm Machinery in the Pacific Northwest [16] and entered in the Machdata spreadsheet to calculate costs consistent with University of Minnesota calculations. Machinery costs included overhead costs such as interest, insurance, housing, as well as use-related costs including depreciation, repairs, and fuel and lubrication costs. Machinery cost details are in Online Resource 1. Crop prices, pesticide, and fertilizer costs were obtained from USDA National Agricultural Statistics Service (NASS) [17]. Seed prices for all major crops were also obtained from NASS records using 2012 costs of production [17], while minor crop and cover crop seed prices were based on information from local dealers for spring 2013.

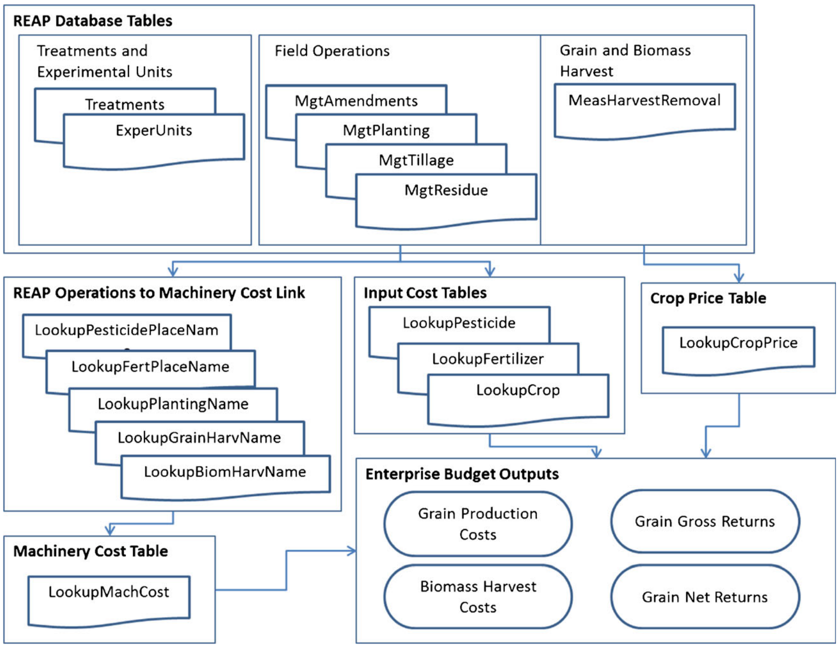

Fig. 1 Data linkages within the biomass economics query tool. Data table names shown are the actual names used in the REAPnet database and the economic query tool

Fertilizer, pesticide, and seed prices are in Online Resource 2. Pesticide and fertilizer costs were based on 2012 data. Crop price was based on 2007–2011 state-level market year averages for what producers actually received.

Queries of publically available REAPnet information showed that nearly complete management records were available for two sites: the “70/71” site near Ames, IA for 2008–2011, and the Bioenergy Cropping Systems (BCS) study site near Mandan, ND for 2009–2012. Consequently, these sites were selected for economic analysis. Data from the first year at each site were excluded from the analysis as the establishment year for each study. Gross returns for grain production were calculated from observed yields and 2007–2011 average crop prices for each state. Corn price was \$184.30 and \$171.70 Mg^{-1} for the 70/71 and BCS sites, respectively. Wheat price was \$253.50 Mg^{-1} and dry pea price was \$261.10 Mg^{-1}. Net returns from grain production were calculated for each treatment, excluding costs and income for biomass harvest. Costs for biomass harvest and transport to the field edge were calculated based on the removal treatments described in the database.

Stover harvest treatments at the 70/71 site consisted of either a “high cut” (~35 % removal leaving a 40- to 50-cm stubble height), “low cut” (~90 % removal leaving a 10-cm stubble height), or no removal. The treatments were imposed by varying the cutting height of a header attached to a single-pass, dual stream biomass harvester developed at Iowa State University using a John Deere 9750 STS combine. However, because the biomass harvester is an experimental machine, there are no data to estimate operational and other costs. Therefore, as a proxy, we used costs of chopping, raking, and baling the stalks after harvest for the high-removal treatments, while medium removal treatments included just raking and baling costs. For the BCS site, residue harvest cost was based on direct baling of windrowed material deposited by the combine when operated with the straw chopper and spreader turned off. Similar to other published analyses [1, 6], straw chopping and raking costs were estimated as being constant at \$32.43 and \$14.91 ha^{-1}, respectively, per unit area harvested, while baling and bale wrap costs were calculated as a constant at \$7.16 and \$5.07 Mg^{-1}, respectively, per unit of harvested biomass. In all cases, bale transport to the field edge was included as a constant cost per unit of biomass of \$4.54 Mg^{-1}.

Statistical analysis of economic returns for each site was conducted using SAS JMP software [18] mixed model analysis with year and replicate as random effects and treatment as a fixed effect. Multiple comparison tests for differences among treatment means were identified using the Tukey–Kramer adjustment and a significance level of 5 %.

Breakeven biomass field-edge prices for each treatment were calculated relative to the no-harvest treatment using the highest average net returns for grain at each site. This approach provides the biomass price needed to produce a net return equivalent to grain-only production, accounting for short-term effects of biomass harvest on grain production for each treatment. Breakeven biomass price was calculated as:

$$P_{\mathrm{i}} = \frac{(\mathrm{NR_e} - \mathrm{NR_i} + C_{\mathrm{i}})}{B_{\mathrm{i}}}$$

where P_{i} is the breakeven biomass price for treatment i, $\mathrm{NR_e}$ is average grain net returns for the no-harvest treatment having highest average net returns at the site, $\mathrm{NR_i}$ is average grain net returns for treatment i, C_i is biomass harvest costs for treatment i, and B_i is average harvested biomass for treatment i. Nutrient replacement costs were not included explicitly as a separate item in calculating breakeven prices. However, if nutrient applications were different for different residue harvest treatments, these differences were included in net return calculations and, therefore, in the breakeven price calculations.

Potential tradeoffs between producing grain and biomass were identified by plotting net returns for grain-only production against the average quantity of biomass harvested. Pareto-efficient treatments were identified as treatments where no other treatment had both higher grain net returns and higher biomass harvested.

Field Studies

The 70/71 research site is near Ames, IA (Lat 42.018° N, Long −93.764° W) on a Clarion–Nicollet–Webster association soil (fine-loamy, mixed, superactive, mesic Typic and Aquic Hapludolls and Typic Endoaquolls). The core experiment consisted of continuous corn (*Zea mays* L.) grown from 2008 to 2012 using either conservation tillage (chisel plowing) or no tillage practices. As stated previously, there were three stover harvest treatments—no removal, high cut (moderate removal), and low cut (high removal). During the same time period, three other soil and crop management strategies for producing corn grain and sustainable biomass supplies were also evaluated (Table 1). They consisted of (1) an intensive management system with an increased plant population using a twin-row planting configuration for both conservation and no tillage practices, increased fertilizer rates to support the higher plant population, and the three stover harvest treatments; (2) a comparison of two rates of biochar (charcoal) applied in the autumn of 2007 prior to initiating the study with all three stover harvest treatments, but only with conservation tillage; and (3) a no-tillage evaluation of the moderate and high rates of stover harvest after establishing a rye (*Secale cereale*) cover crop that was subsequently killed with glyphosate in spring before establishing the next corn crop. For additional details regarding annual management practices used for the field 70/71 study, readers are referred to the REAPnet database (http://nrrc.ars.usda.gov/reappb/#/home).

The BCS study (Table 2) was initiated in 2009 at the Northern Great Plains Research Laboratory near Mandan, ND (Lat 46.773° N, Long −100.904° W). The study site is on a Temvik–Wilton silt–loam soil (fine-silty, mixed, superactive, frigid Typic and Pachic Haplustolls). Average annual precipitation (1981–2010) is 456 mm, and monthly average temperatures range from −10.7 °C in January to 21.4 °C in July[19]. The study includes three crop rotation treatments: spring wheat (*Triticum aestivum*)–dry pea (*Pisum sativum*), spring wheat–dry pea/cover crop, and spring wheat–corn–dry pea. In the spring wheat–dry pea/cover crop treatment, a seven-species mix of cover crops is seeded after dry pea grain harvest. The cover crop mix includes soybean [*Glycine max* (L.) Merr.], sunflower (*Helianthus annuus*), vine pea, spring triticale (*X Triticosecale* Wittmack), purple top turnip (*Brassica rapa* var. *rapa*), winter canola (*Brassica napus*), and proso millet (*Panicum miliaceum*). Each phase of each rotation is included each year. These phases are identified as separate treatments in the REAP database. Each rotation includes four residue removal treatments: no residue removal, harvest and remove wheat straw only, harvest and remove residue from all crops in rotation, and graze residue from all crops in rotation. The grazing treatments were omitted from this analysis to focus on biomass harvest alternatives for bioenergy production. In the residue harvest treatments, residue is dropped in a windrow by the combine harvester, and the windrow is baled and removed. All treatments are in a no-till system. Fertilizer is applied based on annual soil tests and following North Dakota State University Extension recommendations.

Results and Discussion

Query Tool

Once data entry for all input costs and cost information for each of the field implements included in the REAPnet data was complete, the query tool rapidly generated the annual enterprise budgets for each treatment at each site (123 unique budgets). While initial entry of cost data was somewhat time-consuming for this first use of the query tool, updating costs should be less time consuming for future analyses. The verification queries included in the tool provided a quick way to ensure that cost data were populated for all management records and inputs. However, this still did not eliminate the need to closely examine enterprise budget results. While initial queries indicated that management records were largely complete for these two sites, detailed examination of the enterprise budgets indicated a few inconsistencies among treatments that were traced back to missing management data.

70/71 Site

Average cost and return results for the 70/71 site (Table 1, additional cost details in Online Resource 3) show higher gross returns for the 50 % residue removal treatment relative to no removal under both standard management (treatment 3 was higher than treatment 1) and intensive management (treatment 9 was higher than treatment 7). Highest gross returns were observed for standard management with rye cover crop and high-residue harvest and for standard management with charcoal and high-residue harvest (treatments 20, 17, and 18).

Table 1 Description of cropping system treatments at the 70/71 site near Ames, IA, and average (2009–2011) annual cost and returns results and field-edge breakeven biomass prices for each treatment. All treatments are continuous corn

ID	Management	Tillage	Amendment	Biomass harvest	Cover crop	Grain gross returns ($\$\mathrm{ha}^{-1}$)	Machinery cost ($\$\mathrm{ha}^{-1}$)	Materials cost ($\$\mathrm{ha}^{-1}$)	Grain net returns ($\$\mathrm{ha}^{-1}$)	Biomass harvested ($\mathrm{kg\ ha}^{-1}$)	Biomass harvest cost ($\$\mathrm{ha}^{-1}$)	Breakeven biomass price ($\$\mathrm{Mg}^{-1}$)
1	Standard	CT	None	None	None	1,973 d	223 b	864 e	887 abc	0 c	0 i	
2	Standard	NT	None	None	None	1,994 cd	183 c	867 e	944 ab	0 c	0 i	
3	Standard	CT	None	Medium	None	2,228 abc	229 b	1,054 cd	945 ab	4,120 b	44 h	31
4	Standard	NT	None	Medium	None	2,129 abcd	189 c	1,058 c	882 abc	4,330 b	46 fgh	45
5	Standard	CT	None	High	None	2,192 abcd	229 b	1,142 b	821 abcd	7,378 a	100 ab	46
6	Standard	NT	None	High	None	2,179 abcd	189 c	1,146 b	845 abcd	7,422 a	100 a	42
7	Intensive	CT	None	None	None	1,955 d	223 b	991 d	741 bcd	0 c	0 i	
8	Intensive	NT	None	None	None	1,989 cd	183 c	995 cd	812 abcd	0 c	0 i	
9	Intensive	CT	None	Medium	None	2,217 abc	229 b	1,182 b	806 abcd	4,145 b	45 gh	64
10	Intensive	NT	None	Medium	None	2,178 abcd	189 c	1,185 b	804 abcd	5,070 b	51 e	56
11	Intensive	CT	None	High	None	2,133 abcd	229 b	1,252 a	652 d	6,888 a	97 bcd	72
12	Intensive	NT	None	High	None	2,129 abcd	189 c	1,255 a	685 cd	6,605 a	95 cd	70
13	Standard	CT	Charcoal 1	None	None	2,007 bcd	223 b	864 e	920 ab	0 c	0 i	
14	Standard	CT	Charcoal 2	None	None	2,074 abcd	223 b	864 e	988 a	0 c	0 i	
15	Standard	CT	Charcoal 1	Medium	None	2,243 ab	229 b	1,054 cd	959 a	4,654 b	48 ef	26
16	Standard	CT	Charcoal 2	Medium	None	2,160 abcd	229 b	1,054 cd	876 abc	4,623 b	48 efg	44
17	Standard	CT	Charcoal 1	High	None	2,256 a	229 b	1,142 b	885 abc	6,497 a	94 cd	40
18	Standard	CT	Charcoal 2	High	None	2,254 a	229 b	1,142 b	883 abc	6,922 a	97 bc	39
19	Standard	NT	None	Medium	Rye	2,183 abcd	243 a	1,050 cd	891 ab	3,931 b	43 h	45
20	Standard	NT	None	High	Rye	2,264 a	243 a	1,137 b	884 abc	6,413 a	93 d	40

Different letters in the same column denote significant differences ($P<0.05$)

Tillage: *CT* conservation till (chisel plow), *NT* no till

Machinery costs were highest for the cover crop treatments (treatments 19 and 20), followed by the conservation tillage treatments (treatments 1, 3, 5, 7, 9, 11, and 13–18), and lowest for the remaining no-till treatments (treatments 2, 4, 6, 8, 10, and 12). Materials costs were highest for the intensive management treatments with high-residue harvest (treatments 11 and 12) and lowest for the standard management and standard management with charcoal treatments and no residue harvest (treatments 1, 2, 13, and 14). There were no significant differences in materials costs for no till versus conservation tillage within management systems. Grain net returns were highest for standard management with charcoal under conservation tillage with no residue harvest and medium residue harvest (treatments 14 and 15), with net returns significantly higher than intensive management under conservation tillage with no residue harvest and under either conservation tillage or no till with high-residue harvest (treatments 7, 11, and 12). It should be noted that the costs of charcoal and charcoal application were not included in this analysis since the charcoal was applied once before the start of this study and was not included in the REAP database.

Average biomass harvest amounts ranged from 3,931 to 5,070 kg ha^{-1} within the medium removal treatments and from 6,413 to 7,422 kg ha^{-1} within the high-removal treatments (Table 1). Looking at tradeoffs between grain net returns and biomass production, highest grain net returns were observed with no biomass harvest under standard management with charcoal (treatment 14). Average grain net returns and biomass harvested relative to this treatment are shown in Fig. 2. The most efficient treatments in producing grain income and harvested biomass were treatments 15, 18, and 6. These treatments produced the greatest amount of biomass with the lowest decrease in grain net returns. Looking at the most efficient treatments, increasing biomass harvest resulted in greater reductions in grain net returns. Harvest of 4.7 and 6.9 Mg ha^{-1} biomass reduced grain net returns by \$29 and \$105 ha^{-1}, respectively, or \$6 and \$15 Mg^{-1} biomass harvested. Highest biomass harvest of 7.4 Mg ha^{-1} reduced grain net returns by \$143 ha^{-1} or \$19 Mg^{-1} of biomass harvested. This represents the impact of biomass harvest on grain profitability through short-term effects on grain productivity and production costs. For comparison, costs of fertilizer needed to replace N, P, and K removed with corn stover harvest have been estimated at \$17.59–\$18.11 Mg^{-1} for above-ear and below-ear harvest fractions [20]. So, at high-removal rates, short-term impacts on grain profitability appear to be comparable to

Table 2 Description of cropping system treatments at the BCS site and average (2010–2012) annual cost and returns results and field-edge breakeven biomass prices for each treatment. All treatments are no till

	Rotation	Biomass harvest	Initial crop	Cover crop	Grain gross returns $(\$\,\mathrm{ha}^{-1})$	Machinery cost $(\$\,\mathrm{ha}^{-1})$	Materials cost $(\$\,\mathrm{ha}^{-1})$	Grain net returns $(\$\,\mathrm{ha}^{-1})$	Biomass harvested $(\mathrm{kg\ ha}^{-1})$	Biomass harvest cost $(\$\,\mathrm{ha}^{-1})$	Breakeven biomass price $(\$\,\mathrm{Mg}^{-1})$
1[a]	W-P	None	W	None	614 a	114 b	222 c	278 ab	0 d	0 b	
2	W-P	WS	W	None	619 a	114 b	222 c	283 ab	333 d	2 b	328
3	W-P	AC	W	None	598 a	114 b	222 c	262 ab	1,442 a	10 a	103
5	W-P	None	P	None	749 a	118 b	299 abc	333 ab	0 d	0 b	
6	W-P	WS	P	None	729 a	118 b	299 abc	313 ab	1,197 ab	9 a	78
7	W-P	AC	P	None	707 a	118 b	299 abc	290 ab	1,536 a	11 a	79
9	W-P/CC	None	W	Mix[b]	625 a	125 ab	240 bc	260 ab	0 d	0 b	
10	W-P/CC	WS	W	Mix	609 a	125 ab	240 bc	244 ab	400 cd	3 b	372
11	W-P/CC	AC	W	Mix	590 a	125 ab	240 bc	225 ab	1,531 a	11 a	122
13	W-P/CC	None	P	Mix	696 a	138 a	328 ab	223 ab	0 d	0 b	
14	W-P/CC	WS	P	Mix	683 a	138 a	328 ab	216 ab	1,175 abc	8 a	162
15	W-P/CC	AC	P	Mix	700 a	138 a	328 ab	234 ab	1,601 a	11 a	112
17	W-P-C	None	W	None	819 a	122 ab	337 a	360 ab	0 d	0 b	
18	W-P-C	WS	W	None	821 a	122 ab	337 a	362 ab	430 bcd	3 b	73
19	W-P-C	AC	W	None	774 a	122 ab	337 a	316 ab	1,596 a	11 a	61
21	W-P-C	None	P	None	802 a	123 ab	292 abc	386 a	0 d	0 b	
22	W-P-C	WS	P	None	734 a	123 ab	292 abc	318 ab	261 d	2 b	278
23	W-P-C	AC	P	None	738 a	123 ab	292 abc	323 ab	1,694 a	12 a	54
25	W-P-C	None	C	None	733 a	128 ab	345 a	260 ab	0 d	0 b	
26	W-P-C	WS	C	None	655 a	128 ab	345 a	182 b	393 d	3 b	537
27	W-P-C	AC	C	None	670 a	128 ab	345 a	198 ab	1,413 a	10 a	150

Different letters in the same column denote significant differences ($P<0.05$)

Crop: *W* spring wheat, *P* dry pea, *C* corn, *CC* cover crop mix; biomass harvest: *WS* wheat straw, *AC* residues from all crops

[a] Omitted treatments were grazing treatments which were excluded from this analysis to focus on biomass harvest for bioenergy use

[b] Cover crop mix: soybean, sunflower, vine pea, spring triticale, purple top turnip, winter canola, and proso millet

nutrient replacement costs. Short-term impacts on grain profitability were lower at lower removal rates. However, it will be important to monitor longer term changes to see if grain profitability declines over time with biomass harvest if the soil resource is degraded. These costs do not include the direct costs of biomass harvest and handling. Field-edge breakeven biomass prices include both these direct costs and effects on grain profitability. Breakeven biomass prices ranged from \$26 to \$72 Mg^{-1} for the treatments included at the 70/71 site (Table 1). Among Pareto-efficient treatments, field-edge breakeven biomass prices ranged from \$26 to \$42 Mg^{-1}, with lower breakeven costs at lower removal rates. These results indicate that biomass may be produced at a lower cost with lower harvest rates when the impact of biomass harvest on grain profitability is included. These results are lower than estimates from Nebraska of \$56–\$59 Mg^{-1} [5], but comparable with estimates from Indiana of \$31–\$38 Mg^{-1} [4], and higher than a recent estimate of \$3 Mg^{-1} where nutrient replacement costs were excluded and residue harvest had a positive effect on crop yield [7].

BCS Site

No significant differences were detected in average gross returns at the BCS site (Table 2, additional cost details in Online Resource 4) due to the high-annual variability in crop yields and variation in gross returns between crops since different phases of each crop rotation were included as separate treatments in this analysis. Machinery costs associated with additional field operations were significantly higher for the cover crop treatments, where cover crops were planted in 2 of the 3 years analyzed (treatments 13–15). Lowest machinery costs were incurred with the spring–wheat pea rotation (treatments 1–7). Materials costs were highest for the wheat–pea–corn rotation where wheat or corn was the initial rotation phase (treatments 17–19 and 25–27). Lowest machinery costs were incurred with the wheat–pea rotation where wheat was the initial rotation phase (treatments 1–3). Grain net returns were highest for the wheat–pea–corn rotation with no biomass removal where the initial rotation phase was pea (treatment 21). Grain net returns for this treatment were significantly

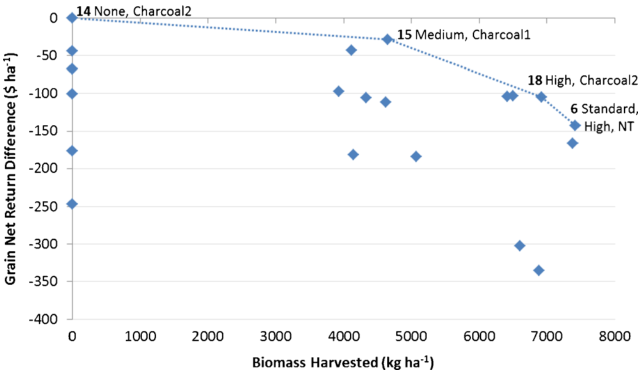

Fig. 2 Average annual grain net returns and harvested biomass for each treatment at the 70/71 site near Ames, IA relative to the no biomass harvest treatment with highest grain net returns (treatment 14). The most efficient treatments producing grain net returns and harvest biomass are connected by dashed lines and labeled with the treatment number and abbreviated treatment description

higher than returns for the wheat–pea–corn rotation with wheat straw harvested and where corn was the initial rotation phase (treatment 26). Grain net returns were relatively low in this treatment in part due to corn grain yield reductions observed in 2012 relative to treatments with no biomass harvest.

Average biomass harvested amounts ranged from 261 to 1,694 kg ha^{-1} for treatments that included biomass harvest (Table 2), with highest amounts harvested from treatments where biomass was harvested each year (treatments 3, 7, 11, 15, 19, 23, and 27). For treatments that did not include biomass harvest, highest grain net returns were observed in the wheat–pea–corn rotation where the initial rotation phase was pea (treatment 21). Relative to this treatment, harvesting wheat straw decreased grain net returns for \$24 ha^{-1} while producing 0.4 Mg ha^{-1} harvested biomass (treatment 18), a reduction of \$56 Mg^{-1} of biomass harvested (Fig. 3). The other efficient treatment in producing grain net returns and harvested biomass was treatment 23, producing 1.7 Mg^{-1} ha^{-1}, while reducing grain net returns by \$63 ha^{-1} or \$37 Mg^{-1} of biomass harvested. All of the efficient treatments were from the wheat–pea–corn rotation, indicating that the wheat–pea and wheat–pea/cover crop rotations were not as efficient in generating grain income and harvested biomass. Breakeven field-edge biomass prices ranged from \$54 to \$537 Mg^{-1} (Table 2), showing a wide range in potential for profitable biomass production among the treatments included at the BCS site. Among efficient treatments, field-edge breakeven biomass prices ranged from \$54 to \$73 Mg^{-1}.

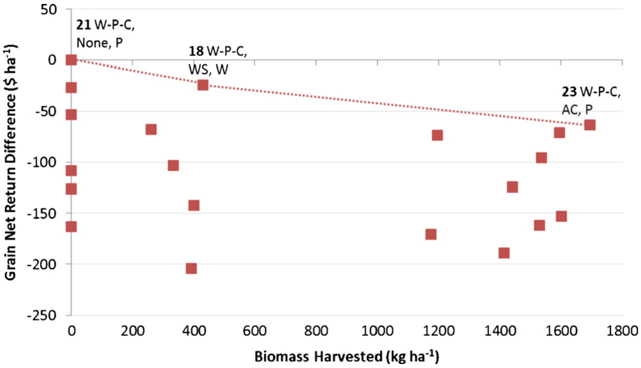

Fig. 3 Average annual grain net returns and harvested biomass for each treatment at the BCS site near Mandan, ND relative to the no biomass harvest treatment with highest grain net returns (treatment 21). The most efficient treatments producing grain net returns and harvest biomass are connected by *dashed lines* and labeled with the treatment number and abbreviated treatment description

These results show that biomass could generally be harvested at a lower breakeven price for some treatments in Iowa than in North Dakota. Also, the wider range in breakeven prices for the BCS site compared to the 70/71 site is likely due to greater differences in grain and biomass production among the treatments evaluated and comparisons across multiple crops. Although higher than breakeven prices from Indiana [7] of \$3 Mg^{-1}, this result shows the possibility for biomass to be profitably produced at a lower price if biomass removal does not have a negative impact on grain net returns either through reduced yields or increased input costs. Again, these results include only short-term effects of biomass harvest on grain net returns; any long-term effects on grain yields or input costs could change the results. It is important to note that the biomass harvest rates from the BCS site are much lower than from the 70/71 site, so it would take a much larger harvested area to produce the same biomass supply in North Dakota than in Iowa. Therefore, transportation costs would likely be higher in North Dakota, further increasing biomass supply costs for North Dakota relative to Iowa. Full transportation and logistics assessments are beyond the scope of this analysis.

Conclusions

Our results showed that grain production net returns tended to decline with higher biomass harvest rates. Results also showed that breakeven biomass prices were typically lower at lower harvest rates in Iowa, but breakeven biomass prices were higher at higher harvest rates in North Dakota. However, since the REAPnet database is not fully populated, these results must be viewed as preliminary and subject to change.

With regard to the query tool developed for this analysis, it allowed full enterprise budgets to be quickly constructed, but this did not eliminate the need to carefully examine the resulting budgets. For example, even though the database management records were largely complete for the two study sites, a detailed examination of the budget results identified a few cases where critical data were missing for some treatments. However, as work continues on the query tool, we are confident that it will help users identify and correct other currently unknown inconsistencies in the REAPnet data.

Finally, the query tool provided a method to quickly generate enterprise budget information for a wide range of biomass production strategies from field studies being conducted in Iowa and North Dakota. This facilitated economic analysis of the biomass production alternatives, allowing comparison among many more cropping system treatments than have typically been included in previous economic analyses. This is important because it helps illustrate several different soil and crop management strategies that could be used to provide sustainable feedstock supplies to the bioenergy and bioproduct industries that are developing in the USA and around the globe.

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