Chaff Collection and Weed Impacts

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Chaff is the residual material from field crops that passes over the combine shoe and falls to the ground or is spread behind the combine. This material consists of glumes, hulls, parts of heads, short straw, leafy material, weed and crop seeds. There are two mechanization options for collecting chaff. One collects the chaff as a separate material using an auger located behind the combine shoe and a blower assembly that blows the chaff into a trailing wagon. When the wagon is full, the combine operator dumps the load off the wagon into the field or a waiting truck, or tows the wagon to a yard for dumping. The second option collects the chaff with the grain for separation in a central location.

Chaff may have significant economic value as a ruminant feed or as a biomass feedstock, and its collection and removal may be a means of reducing herbicide usage and tillage. This paper will review the results of some of the studies that have been done to estimate the impact of chaff collection on weed communities and the potential value of chaff as a ruminant feed or industrial material.

Soil Quality and Weed Population Impacts

In the first study, fifty farms located throughout the Brown, Dark Brown, and Black/Grey Wooded soil zones of Saskatchewan were surveyed to determine the costs and benefits associated with their existing chaff collection systems. Agronomic benefits in the form of cost savings due to reduced herbicide, reduced tillage, and general crop and summerfallow conditions were estimated from information provided by survey respondents. Data were collected on the type, size, age, replacement cost, and current market value of machines, time spent and distances hauled to evaluate the cost side of chaff collection.

The results of the survey for the Brown and Dark Brown soil zones showed:

1) 50% of producers noted input cost savings of at least one tillage operation per year;
2) 67% of producers indicated reduced input costs as a result of reduced herbicide use and/or saving of one tillage operation per year;
3) 69% of producers who had cattle and fed chaff were able to substitute chaff for a minimum of 50% of their on-farm hay/straw requirements. An additional 16% were able to substitute chaff to a level of 25-50% of their hay/straw requirement.

The overall system benefit to cost (b/c) ratios for producers in the Brown and Dark Brown soil zones who observe agronomic benefits alone was 1.28 : 1. For those who recognized agronomic- and feed-related benefits, the b/c ratio rose to 2.35 : 1. The b/c ratios were weighted averages taking into account each farm's b/c ratio and the number of tonnes of chaff they collect. The results show that, if a producer were able to realize potential tillage/herbicide savings alone, the benefits of chaff removal would pay for the equipment investment normally required to collect this material. If the producer had cattle, the value to the farm operation was substantially improved to a b/c of 2.35, with that improvement likely to increase with the onset of drought.

An eight year study conducted in Melfort and Swift Current examined the long term impacts of chaff removal on soil quality and weed populations in the Black and Brown soil zones. The crop treatments at Melfort were chosen to represent two rotations, continuous wheat and fallow-canola-wheat-wheat. The experimental area was managed in a reduced tillage system. Appropriate registered post-emergent chemicals were used to control the weeds present. The Swift Current experiment represented two rotations, continuous wheat and fallow-wheat. The experimental area was managed as a reduced tillage system. Chemical applications, primarily glyphosate and fall-applied 2-4-D, replaced one or more tillage operations in the fallow treatment. Herbicides were used to control the three major weed problems encountered (green foxtail, red-root pigweed, and Russian thistle).

Representative soil samples from each plot were taken at both sites in 1988, 1992, and 1996. Mineralizable nitrogen (Nmin), mineralizable carbon (Cmin), light fraction organic matter (LFOM), total carbon, and total nitrogen were the soil quality factors examined in detail. Aggregate stability was determined for the Swift Current location. Detailed weed seedbank samples were also taken from the field and grown out in a greenhouse to determine the effect of chaff collection on weed populations.

1. Crop Production

At both Swift Current and Melfort, crop yield and protein varied in response to the normal variations in yearly weather. Chaff collection from 1988 to 1995 did not significantly affect crop yield, protein or seed size. Crop yield, protein and seed size in the final year were not significantly affected by the previous 8 years of chaff collection.

2. Soil productivity

At Melfort, the 0 to 15 cm layer had higher soil nitrate levels (25 kg ha^{-1}) in the continuous wheat with chaff collected than in the four year rotation (19.5 kg ha^{-1}) or continuous wheat with chaff left on the field (18.5 kg ha^{-1}). At Swift Current chaff collection had no significant effect on soil nitrate in the 0 to 15 cm layer (7 kg ha^{-1} where chaff was collected and 8 kg ha^{-1} where chaff remained on the field). For each location, there was no significant difference in the mineralizable N between plots where chaff was collected and where chaff was left on the field. The authors concluded that chaff collection had not influenced soil quality.

3. Weed populations

As many small weed seeds end up in the chaff, chaff collection was expected to reduce both weed populations and volunteer crop problems. Weed populations were monitored at several times during this study. At Melfort, several weeds, including green foxtail, lamb's quarter, ball mustard and shepherd's purse were present in some but not all of the plots. The situation was similar at Swift Current, with green foxtail and Russian thistle the most common weeds at study initiation. The combination of patchy distribution of all weed species at the beginning of the study and effective herbicide management made it difficult to show any effect on weeds from chaff collection using traditional experimental methods based on the randomized complete block design used in this study, and no conclusions could be drawn.

In the third series of studies, the University of Manitoba evaluated two aspects of the McLeod Harvest Method ™: 1) the ability of the system to separate weed seeds from the collected graff for different field crops, and 2) the impact of weed collection on wild oat seed dispersal for canola and flax crops. The McLeod Harvest Method ™ gathers the chaff and grain into a single large bin on the field unit, and then the entire mixture, called graff, is transported to a central point for separation into grain and chaff. The net effect intended is that the weeds and grain that have not shattered prior to or during the harvest operation are collected and removed from the field.

Shirtliffe, (1999) sampled the chaff material following yard separation of an oat and a wheat crop to determine the system's ability to separate weed seeds. The results are provided in Table 1.

Table 1: Weed seed populations in graff and chaff components of harvested oat and wheat crops.

Weight of Graff in grams	Weight of Chaff in grams	Chaff as a % of Graff	No. of Weed Seeds per gram of Grain	No. of Weed Seeds per gram of Chaff	% of Weeds in Graff Captured by the Chaff
53.0 (Oat Crop)	43.6	82	Green Foxtail: 1.32 RR pigweed: 0.18	Green Foxtail: 6.62 RR Pigweed: 0.10 Oats: 0.27	Green Foxtail: 91.5 RR Pigweed: 100
80.9 (Wheat Crop)	60.6	74	Green Foxtail: 0.55 Oat: 0.01 Vol. Flax: 1.02	Green Foxtail: 2.6 Oat: 0.1 Vol. Flax: 0.08	Green Foxtail: 84.2 Oat: 40 Vol. Flax: 100

The McLeod Harvest™ system was evaluated on canola and flax crops but it appeared that the system was not as successful at separating weed seeds when compared to the results reported for wheat and oat crops.

Martens (2000) evaluated the effect of the system on weed seed harvest in a swathed canola and a straight cut flax crops. Collection pans were placed in the field, and the McLeod Harvester and a conventional combine were operated in the field over adjacent sets of pans. The material in the collection pans was then sorted and weighed, with the results provided in Table 2.

Table 2: Comparison of grain and weed seed collected for the McLeod Harvest™ system and a conventional combine.

Swathed Canola						Straight Cut Flax					
Total seeds g ¼ m^{-2}		Wild oats Count ¼ m^{-2}		Wheat Count ¼ m^{-2}		Total seeds g ¼ m^{-2}		Wild oats Count ¼ m^{-2}		Wheat Count ¼ m^{-2}	
MH	Con	MH	Con	MH	Con	MH	Con	MH	Con	MH	Con
4.3	8.3	0.3	3.3	2.5	6.8	0.9	6.8	0	1.3	0	0

MH = McLeod Harvest™ system
Con = Conventional combine harvest

Most of the seed weight collected behind both harvesters was crop seeds, but the McLeod system lost ~ 50 % as much canola and only ~ 13 % as much flax seed as the conventional combine. The wild oat results are even more impressive, with the McLeod system dramatically reducing the wild oat seed return to the field.

Chaff Value

The economic implications of the collection of weed seeds were modelled by Entz (1999). Based on the reduction of weed seeds returned to the seed bank, the author expected that producers may be better able to employ the concept of economic thresholds when making herbicide application decisions. The author anticipated a minimum of a reduction of one grassy and one broadleaf application could be skipped every three cropping years at an estimated herbicide savings of \$6.66 ac^{-1} $year^{-1}$. Combining the Shirtliffe work with the modelling of Entz, the estimate of benefits from patch containment and overall field herbicide reduction rose to:

$$(\$6.66\ ac^{-1}\ year^{-1} + \$\ 5.43\ \text{(short term) to } \$13.40\ \text{(long term) } ac^{-1}\ year^{-1})$$
$$= \$12.09\ \text{(short term) to } \$20.06\ ac^{-1}\ year^{-1}\ \text{(long term)}$$

These results substantiate the results of the producer survey conducted by the Saskatchewan Research Council and Agriculture and Agri-Food Canada. Current pricing for a chaff collection system from a Redekop Manufacturing is ~\$6500. If a producer collected chaff from 1200 acres using this system, the projected agronomic savings would amount to \$14,500 per year, easily paying for the investment in chaff collection even if the chaff is simply dumped in one location per field and destroyed.

Stumborg and Townley-Smith (1997) estimated the value of chaff to Black soil zone producers by modelling the amount of chaff expected for a given grain yield using combine yield data from the Prairie Agricultural Machinery Institute. The delivered value to an industrial plant of \$40 T^{-1} for the chaff was used, a value that compared to the value of straw at that time. Costs for transportation were estimated at \$15.00 T^{-1} over a 60 km distance and field collection and other producer costs were estimated at
\$13.50 T^{-1}. Given the agronomic benefits estimated for chaff removal, no cost for nutrient removal was charged to the chaff, leaving a value of \$11.50 T^{-1} for the chaff FOB the plant gate.

Table 3 provides a comparison of the expected improvements for producers for the three Prairie Provinces.

Table 3: Expected returns to Black soil zone producers (fallow seeded crops) from residue exports.

	Barley		Spring Wheat	
	Average	Minimum	Average	Minimum
Saskatchewan				
Grain Yield[1] in kg ha^{-1}	2530	1930	1960	1170
Total Available Chaff in kg ha^{-1}	380	328	333	199
Net Returns for Chaff in \$ ha^{-1}	$4.36	$3.77	$3.83	$2.29
Grain Cash-Only Margin[2,3] in \$ ha^{-1}	$81.47	$33.47	$81.47	($20.44)
Grain Total Margin[4] in \$ ha^{-1}	($30.10)	($78.10)	($30.10)	($132.01)
Cash Margin Improvement	5.4%	11.3%	4.7%	11.2%
Manitoba				
Grain Yield[1] in kg ha^{-1}	2850	1800	2180	1170
Total Available Chaff in kg ha^{-1}	428	306	371	199
Net Returns for Chaff in \$ ha^{-1}	$4.92	$3.52	$4.26	$2.29
Grain Cash-Only Margin[2,3] in \$ ha^{-1}	$107.07	$23.07	$109.85	($20.44)
Grain Total Margin[4] in \$ ha^{-1}	($4.50)	($88.50)	($1.72)	($132.01)
Cash Margin Improvement	4.6%	15.3%	3.9%	11.2%

1 Average yield based upon 4 highest yielding crop districts for each province.
2 Assumes \$80 MT^{-1} (\$1.75 bu^{-1}) price for barley, and \$129 MT^{-1} (\$3.50 bu^{-1}) price for wheat.
3 Based on Saskatchewan Agriculture and Food calculations adjusted for the higher Alberta and Manitoba yields.
4 Labour costs have been removed from the sum of cash and non-cash costs.

Prentice, et.al. (1999) evaluated the value of chaff derived from the McLeod Harvest™ system from two standpoints: its value as a cattle feed for over-wintering cows, and 2) its agronomic value. The feed value was estimated by Racz and Christensen (1999) at \$71 T^{-1}. At an average chaff yield in Saskatchewan of 333 kg ha^{-1} (from Table 3), the gross value of this material was \$23 ha^{-1} or \$9.30 $acre^{-1}$.

The agronomic value was estimated to include the benefit of reduced grain loss and improved weed management. The reduced grain loss was estimated to be equivalent to the shoe loss normally experienced by a conventional combine, or ~ 2% of the total grain harvested. This was equal to \$2.00 $acre^{-1}$ or \$5.00 ha^{-1}in Saskatchewan, equivalent to \$15 T^{-1} of chaff. Similarly, improved dockage was also estimated given the potential for the McLeod system to deliver a cleaner grain sample, saving storage and freight costs. For the purposes of their study, a value of \$1.30 ha^{-1} or \$0.53 $acre^{-1}$ was used, equivalent to a value of \$3.90 T^{-1} of chaff.

An average weed component value (average of the short and long term values) for chaff removal from the Shirtliffe study of \$16 acre^{-1} or \$39.50 ha^{-1} was used, a value assumed to be equivalent for Saskatchewan. The potential value of the chaff to Saskatchewan producers using the Shirtliffe data is summarized in Table 4.

Table 4: Potential field benefits of chaff collected with the McLeod Harvest™ system for Saskatchewan Black soil zone producers.

	\$ acre^{-1}	\$ hectare^{-1}
Reduced Grain Loss	\$2.00	\$5.00
Improved Dockage	\$0.53	\$1.30
Improved Weed Management	\$16.00	\$39.50
Industrial Value	\$1.68	\$4.16
Feed Value	\$9.50	\$23.00
Total Value: Agronomy	\$18.53	\$45.80
Total Value: Industrial	\$20.21	\$49.96
Total Value: Cattle	\$28.03	\$68.80

Stumborg and Townley-Smith (1997) reported the results of three separate projects examined chaff as an ethanol feedstock. The first was a series of trials conducted by the Saskatchewan Research Council (SRC) in 1989. Four different conversion processes were evaluated, including Stake Technology (steam explosion/combined acid and enzymatic hydrolysis), Iogen (enzymatic hydrolysis), Wayman process (extrusion pretreatment/combined acid and enzymatic hydrolysis), and the Bio-Hol process (acid hydrolysis). The results of this study are summarized in Table 5. Additional work by Iogen has shown that wheat chaff is an excellent feed stock for ethanol. Lower cost enzymes, more efficient pretreatment technologies, and pentose fermentation have improved the economics of conversion such that ethanol can be produced at an estimated cost of 30 ¢ L^{-1} from \$20 T^{-1} chaff with a 20% return on investment.

Table 4: Comparison of Four Ethanol Processing Technologies

	Bio-Hol Process	Stake Tech Process	Wayman Process
Ethanol Yield (L T^{-1})	259	142	367-403
Pentose Fermentation	Yes	No	Yes
Hydrolysis Type	Acid	Acid and Enzymatic	Acid and Enzymatic
Ethanol Cost[1] (¢ L^{-1})	31.6	68	N/A

Conclusions

1) Chaff can be collected from all crops and soil zones every year without negatively impacting soil quality or productivity.

2) The agronomic benefits of chaff removal, even without feed or industrial values, appear to provide positive economic returns to producers.

3) Chaff can provide a viable feed to assist in the potential expansion of the cattle sector or to mitigate feed shortages due to drought.

4) Chaff has potential as an industrial material for ethanol, providing a potential market for those producers without a feed market.

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