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Harvesting Rate, Power Requirements and Fuel Use for Single-Pass Harvesting of Corn Stover

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Abstract. A grain combine was modified to produce single-pass, whole-plant corn harvesting with two crop streams, grain and stover. Three corn heads were used: ear-snapper, whole-plant and stalk-gathering. Modifications were made to the stalk-gathering head to increase stover capture efficiency and decrease particle-size compared to its stock configuration. Particle-size was reduced by 47% but actual particle-size was three times the theoretical-length-of-cut. Stover density in the transport container was not improved despite the reduced particle-size. Aggregate stover moisture was reduced by harvesting at a higher cut height using the whole-plant and stalk gathering heads. Greater stover feedrate limited ground speed, so area capacity was 2.9, 1.4, and 1.8 ha/h, for the ear-snapper, stalk-gathering and whole-plant heads, respectively. Poor feeding of crop through the flail chopper reduced harvester capacity due to plugging concerns. Specific fuel use was 1.46, 1.83 and 1.46 L/Mg DM and 17.0, 27.4, and 33.4 L/ha, for the ear-snapper, stalk-gathering and whole-plant heads, respectively. The power required by the flail chopper and blower at the rear of the combine was approximately 69, 59 and 46% of the maximum available for the whole-plant, ear-snapper and stalk-gathering heads, respectively.

Keywords. Biomass, biomass harvest; corn stover, density, fuel-use, harvest-rate, power, particle-size

Introduction

Corn stover consists of all the above ground, non-grain fractions of the plant including the stalk, leaf, cob and husk. Corn stover has great potential as a biomass feedstock in North America, with potential annual yields of 130 Tg producing 38.4 GL of bioethanol (Kim and Dale, 2003). A major obstacle to the widespread adoption of corn stover as a biomass feedstock are the costs associated with harvesting, handling, transporting, and storing corn stover.

Corn stover is most often harvested as a dry product and packaged in large round or large square bales, typically involving the following steps after grain harvesting: shredding, field drying, raking into a windrow, baling, gathering bales, transporting to storage, unloading, and storing. Problems with this system include difficult field drying due to short day length and low ambient air temperatures, short harvesting window between grain harvest and first snow cover, frequent weather delays, soil contamination of stover during shredding and raking, and low harvesting efficiency (ratio of harvested to total available stover mass). The many field operations results in high costs per unit harvested mass.

Harvesting stover right after grain harvest by chopping with a forage harvester can eliminate the need for field drying and raking; and eliminate bale gathering, staging and loading. Harvest efficiency of a three-pass wet-stover system was 55% (Shinners et al., 2007b). Wet-stover storage in a bag silo was quite successful, with DM losses over eight months less than 4%. Concerns with either scenario would include forage harvester availability on grain farms, low harvesting efficiency, soil contamination, and cost due to the number of field operations required.

A single-pass harvesting system which produces grain and stover harvest in separate crop streams might be the most effective harvest method because costs will be reduced by further elimination of field operations. Shinners et al. (2003) estimated this was the least cost stover harvest scenario, reducing harvest cost by 26% compared to dry stover harvest in bales. The concept of harvesting two crop streams in a single-pass from a corn crop is not new. For instance, Burgin (1941) was issued a patent on a corn harvester that provided two crop streams: husked ear corn and chopped stalks. Research work was carried out in the 1960's and 1970's looking at the feasibility of harvesting corn grain and stover with the ensiled stover intended for beef animal feed. Some of this research involved single-pass-harvesting in which the grain and non-grain fractions were separated, processed and transported from the machine in separate streams (Albert and Stephens, 1969; Ayres and Buchele, 1971; Ayres and Buchele, 1976; Buchele, 1976; Hitzhusen et al., 1970; Schroeder and Buchele, 1969).

A single-pass harvester using either a ear-snapping or whole-plant corn head has been used to harvest various stover fractions (Shinners et al., 2006 and 2007c). The non-grain fractions were sized reduced and transported by a flail chopper and blower located at the discharge of the harvester. When the ear-snapper head was used, harvesting rate was not affected but yield of stover was low. When the whole-plant head was used, harvesting rate was slowed by the potential plugging at the flail chopper.

Another head, referred to as a stalk-gathering head, was modified to harvest, size-reduce and transport the leaf and stalk fraction into a container pulled alongside header. This configuration reduced the volume of non-grain material through the harvester. Although faster harvesting rates were obtained with this concept, size-reduction and transport performance were not deemed acceptable (Shinners et al., 2006).

Objectives

The objectives of this research were to modify the flail chopper to reduce tendencies for material plugging, and to modify the stalk-gathering head to increase stover capture efficiency and decrease particle-size compared to its stock configuration. Performance of the harvester with these modifications would then be quantified in field evaluations, including measurement of power to specific harvester functions and overall machine fuel consumption.

Materials and Methods

Machine Description

A John Deere[1] model 9750 combine was altered to produce single-pass, split-stream harvesting of corn grain and stover (fig. 1). A flail chopper (TLC ~ 22 mm), cylindrical blower, and spout were added to the rear discharge of the combine to size reduce and convey the non-grain fractions. Particulars of these additions are detailed in Shinners et al., 2006 and 2007c. When mass-flow of stalks was heavy, plugging often occurred at the entrance to the flail chopper. It was speculated that the rigid nature of the stalks and the restricted entrance throat to the chopper caused feeding difficulty. Two changes were made in 2006 to remedy this situation. First the throat area was increased from 7450 to 8870 cm^2. Next, a set of crop processing rolls similar to those found in forage harvesters was added at the exit of the cylinder discharge beater (fig. 5). These rolls operated at close clearance (3 – 10 mm) and with differential speed (~21%) so that they crushed and shredded the stover. The rolls were 152 mm diameter and 137 cm wide and were belt driven from the chopper main shaft.

Three different heads were used to harvest different stover fractions. First, a John Deere[1] model 693 ear-snapper corn head was used without modification and served as the harvester control. In this configuration, the stover fractions targeted for collection from the rear of the combine were the cob, husk and some leaf and upper stalk. Next, a John Deere[1] model 666R whole-plant corn head was used to harvest both the stover and grain fractions. All the standing stover fractions were targeted for harvest with this configuration. The final machine configuration involved modifying a Slavutich[1] model KMM-6 ear-snapper, stalk-gathering head (Shinners et al., 2006) (fig. 2). The stalk-gathering head was configured to not only snap the ears but to also harvest the stalk, leaf and some husk. The head had a full-width knife rotor located below and behind the snapper rolls to gather and size-reduce the crop before discharging it into an auger (fig.

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[1] Mention of trade names in this manuscript are made solely to provide specific information and do not imply endorsement of the product or service by the University of Wisconsin-Madison and the USDA–ARS.

3). The material gathered by this rotor was then augered to the left hand side of the head where it was fed into a cutterhead/blower which further size reduced (TLC~44 mm) the stover before discharging it to the spout which directed the material into a wagon pulled along side (fig. 4). The cob, husk and some leaf and upper stalk were also targeted for harvest when an additional wagon was used at the rear of the combine (fig. 4).

The performance of the stalk-gathering head was not deemed satisfactory in 2005, so modifications were made to improve its performance. Frequent plugging occurred at the auger and at the entrance to the feedroll. The actual-length-of-cut (ALC) averaged over twice the TLC, which adversely affected density in the wagon (Shinners et al., 2006). Blowing distance was often inadequate to allow safe distance between the wagon and spout. In 2006, the auger was modified to improve feeding by decreasing the inner diameter of the tube from 305 to 200 mm. More aggressive feed paddles were also added at the interface between the auger and the feedroll to improve material flow. The TLC was reduced to 25 mm by both slowing the feedroll speed from 298 to 200 rpm and increasing the cutterhead speed from 1588 to 2033 rpm. The latter modification would also aid throwing and blowing. Finally, baffles were added behind and perpendicular to the cutterhead knives to help eject chopped material from the knife at the spout entrance and not carryover behind the knife.

Instrumentation

The shaft that drove the crop processing rolls, flail chopper, and blower were instrumented with strain gauges and a slip ring assembly to measure shaft torque and speed. The clutch that operated the drive for the head and the feeder house was similarly instrumented to measure torque and speed for the header. All torque and speed signals were captured by a LabView data acquisition system at a frequency of 200 Hz. A FloScan model 8500 fuel measurement system was used to measure total machine fuel requirements. It incorporated an opto-electronic turbine flow transducer with pulsation dampening elements in both the to-engine and leak-off fuel lines. Difference between these two flows was total fuel consumed during a test. The fuel flow meter was zeroed at the beginning of each test and a digital output to the nearest 0.4 L was hand recorded after each test.

Field Evaluations

The objective of the field trails was to quantify harvester performance, particularly the power and fuel requirements of single-pass stover harvest. Replicated block field experiments were conducted at the Arlington Agricultural Research Station of the University of Wisconsin on various dates (table 1). During the first four trials, all three head configurations were considered: whole-plant, stalk-gathering and ear-snapper. The three corn heads were set to operate at about 50 cm above ground level. Maximum harvest height of all heads was limited by the lowest height of the hanging ears. Several rounds were made around the field to first remove the field edges and headlands. The field was then separated into plots of 250 m length by 4.6 m wide (6 rows). Three replicate tests were conducted per treatment and the three treatments and replicates were randomly assigned to the nine plots.

Ground speed was altered with the harvester hydrostatic transmission so that engine speed was maintained at approximately 2,260 rpm in an attempt to maintain similar harvester loading between treatments. Threshing cylinder speed was maintained at 300 rev/min and cleaning fan speed at 920 rev/min. The processing roll clearance was 5 mm during all tests. Time to harvest the plot was recorded so that ground speed, and stover and grain mass-flow-rate could be calculated. Actual cut height as determined by measuring stubble height at 15 random locations in each harvested plot. A single wagon was used at the rear of the harvester to collect the harvested stover when using the ear-snapper or whole-plant heads. When using the stalk-gathering head, one wagon adjacent to the head collected primarily the stalk and leaf fractions while the rear wagon was used to collect the cob and husk fractions. Load cells on the wagons were used to determine the mass of stover harvested by weighing the contents to the nearest 2 kg. The post harvest volume of the stover in the wagons was estimated by leveling the load by hand and recording the height of the material. Several random grab samples were collected from all loads. Three sub-samples were used to determine stover moisture by oven drying for 24 h at 103º C. An additional two sub-samples were collected for particle-size analysis using procedures described in ASAE Standard S424.1 (ASAE, 2005). The harvester grain tank was unloaded after each plot and the grain weight was determined to the nearest 2 kg through load cells on the grain cart. Several random grab samples were collected from each load to determine grain moisture by drying at 103º C for 24 h.

The fifth trial quantified the added power required by the processing rolls when the whole-plant head was used. Two treatments were considered: processed and unprocessed. The processing roll clearance was 3 and 38 mm, respectively. All other aspects of the machine were similar between the two treatments and similar to those described above. The final two tests (table 1) quantified the effect of ground speed and mass-flow on the machine performance when using the whole-plant and ear-snapper heads (trials 6 and 7 respectively). The procedures for data collection were similar to those described above in trials 1 – 4.

Differences between treatments were analyzed using analysis of variance and statistical differences were determined using a least-significant-difference test (LSD) at the 95% probability level. When appropriate, a two way analysis of variance was conducted to block the confounding effects of results collected on different days.

Figure 1. Modified grain combine with whole-plant forage harvester corn head. *Photo courtesy of Wolfgang Hoffman.*

Figure 2. Modified grain combine harvester with stalk-gathering head to gather, size-reduce and transport the stalk and leaf fractions at the head

Figure 3. Knife rotor used to gather and size-reduce the stover ejected from the snapping rolls of the stalk-gathering head.

<u>Figure 4</u>. Modified grain combine harvester with stalk-gathering head, collecting stalk and leaf in front wagon and cob and husk in rear wagon.

***Figure 5*.** Crop processing rolls at exit of cylinder discharge beater.

Table 1. Characteristics of crop used in quantifying the machine performance of the single-pass stover and grain harvester in 2006.

	Trial 1	Trial 2	Trial 3	Trial 4
Field No.	742	742	699	591
Variety	Pioneer[1] 35Y67	Pioneer[1] 35Y67	Pioneer[1] 35A30	Pioneer[1] 34A16
CRM .. day	105	105	103	108
Planting date	4/24	4/24	5/6	4/24
Harvest date	10/28	11/1	11/17	11/21
Drooped ear height .. mm	950	935	900	800
Stover moisture .. % w.b.	45.8	40.7	36.8	32.9
Grain moisture .. % w.b.	25.6	21.5	21.0	20.9

	Trial 5	Trial 6	Trial 7
Field No.	591	591	591
Variety	Pioneer[1] 34A16	Pioneer[1] 34A16	Pioneer[1] 34A16
CRM .. day	108	108	108
Planting date	4/24	4/24	4/24
Harvest date	12/1	12/8	12/15
Drooped ear height .. mm	1,050	935	900
Stover moisture .. % w.b.	38.3	31.6	30.9
Grain moisture .. % w.b.	20.1	20.1	20.0

Results

Machine Operation

Grain yield was about 10% less in 2006 than in 2005, so it can be assumed that available stover yield was also 10% less in 2006 (Shinners et al., 2007). In 2006, the whole-plant and stalk-gathering heads were operated about 30 cm higher than in 2005 to leave more material in the field for erosion protection and to preserve soil nutrients (Hess et al., 2007). Stover yield from the whole-plant head was 21% less in 2006 than in 2005, more than the difference due to lower available yield (table 2). Changes in head height did not affect year to year yields with the ear snapper head or from the rear of the combine equipped stalk-gathering head. Yield of stalk/leaf from the stalk gathering head were down only 13% from 2006 to 2005, despite operating the head considerably higher in 2006. This was attributed to improved material capture from the higher capacity auger used in 2006. It was observed that there was improved collection of cut stalks when the high-capacity auger was used.

The differences in moisture between the various fractions were similar in both years, although the range tended to narrow in 2006. Material was harvested later in 2006, and fractional moisture differences tend to narrow as the fall progresses (Shinners et al., 2007a). Also, the higher harvest height in 2006 would have left more of the high moisture bottom stalk unharvested. Grain yield was not significantly different between the head types in the both years.

The stalk-gathering head was able to harvest with greater area productivity than the whole-plant head in both years (table 3). Ground speed was limited with both configurations by plugging at the size-reduction components rather than due to power limitations. With the stalk-gathering head, material plugged the spout at high feed rates, likely because of large particles wedging in the neck of the spout (see below). With the whole-plant head, the addition of the crop processing rolls appeared to improve feeding from the cylinder beater to the flail chopper. This led to a slightly higher stover DM mass-flow-rate in 2006. However, it was observed that material re-circulation in the flail chopper continued to be a problem even with the pre-processed stalks. Higher mass-flow-rates would eventually cause so much material re-circulation that plugging occurred at the entrance to the flail chopper. Area productivity with the ear-snapper head was twice that with the whole-plant head, results similar to those found in 2004 and 2005 (Shinners et al., 2007c and 2006, respectively).

Stover particle-size and wagon density are well correlated (Shinners et al., 2007c). Processing rolls have been shown to decrease particle-size and make the stover fraction of whole-plant corn silage more compliant (Shinners, 2003). However, in 2006 there was no meaningful improvement in wagon density when the processing rolls were used with the whole-plant head. Particle-size and density were actually less in 2006 than 2005 (table 4). The crop was harvested later and was drier in 2006, so it likely had greater mechanical strength and offered greater resistance to compaction. The extra weight of the additional water also may have created greater density in 2005. Actual particle-size of the material harvested from the stalk-gathering head was considerably less in 2006 because of the changes made to reduce the TLC to 25 mm (see above). However, the particle-size was still much greater than the TLC due to poor alignment of the material as it entered the cutting cylinder. The stalk-gathering rotor did some size reduction and the transfer auger tended to mix this rough cut material so that many stalks were not aligned perpendicular to the shear bar as it entered the cutting cylinder. The smaller particle-size from the stalk-gathering head did lead to slightly improved wagon density, but still way short of the density from the other two heads.

Table 2. Stover and grain yield for the different head types based on mass of material harvested (trials 1 – 4, table 1).

Head type	Ratio of Head to Ear Height	Aggregate Stover Moisture % w.b.	Stover Yield .. Mg / ha		Grain Yield .. Mg / ha	
			WM	DM	WM	DM
2006[a]						
Ear-snapper	0.57_c	36.9_a	2.9_a	1.8_a	13.0	10.1
Whole-plant	0.50_b	38.8_b	10.0_d	6.1_d	12.8	9.9
Stalk-gathering	0.43_a	39.4_b	8.3_c	5.0_c	13.0	10.2
Front wagon		41.0_c	5.5_b	3.2_b		
Rear wagon		36.0_a	2.8_a	1.8_a		
LSD[b] (P = 0.05)	0.03	1.5	0.4	0.2	1.1	0.9
2005[c]						
Ear-snapper	0.45	39.4_a	3.5_a	2.1_a	14.7	11.1
Whole-plant	0.20	51.6_{bc}	15.8_d	7.7_d	15.2	11.2
Stalk-gathering	0.24	47.8_b	10.8_c	5.6_c	14.7	10.9
Front wagon		52.6_c	7.8_b	3.7_b		
Rear wagon		38.8_a	3.0_a	1.9_a		
LSD[b] (P = 0.05)		4.2	0.7	0.3	0.7	0.4

[a] Data from trails 1 – 4 represented in table 1.
[b] Averages with different subscripts in the same column are significantly different at 95% confidence.
[c] Data from Shinners et al., 2006

Table 3. Stover and grain mass-flow-rate for the different crop units types based on mass of material harvested (trials 1 – 4, table 1).

Head type	Ratio of Head to Ear Height	Area Productivity ha / h	Stover Mass-flow .. Mg / h		Grain Mass-flow … Mg / h	
			WM	DM	WM	DM
2006[a]						
Ear-snapper	0.57_c	2.9_c	8.4_b	5.3_b	37.6_c	29.2_c
Whole-plant	0.50_b	1.4_a	14.3_e	8.8_c	18.7_a	14.6_a
Stalk-gathering	0.43_a	1.8_b	12.8_d	8.8_c	23.2_b	18.1_b
Front wagon			9.9_c	5.7_b		
Rear wagon			4.9_a	3.1_a		
LSD[b] (P = 0.05)	0.03	0.1	0.8	0.5	3.0	2.4
2005[c]						
Whole-plant	0.24	1.1_a	15.0_c	7.4_c	15.1_a	12.1_a
Stalk-gathering	0.23	1.6_b	14.9_c	7.7_c	20.4_b	15.9_b
Front wagon			11.3_b	5.5_b		
Rear wagon			3.6_a	2.2_a		
LSD[b] (P = 0.05)		0.4	1.8	0.9	3.3	2.6

[a] Data from trails 1 – 4 represented in table 1.
[b] Averages with different subscripts in the same column are significantly different at 95% confidence.
[c] Data from Shinners et al., 2006

Table 4. Particle-size and transport density of the harvested stover fractions (trials 1 – 4, table 1).

Head type	Ratio of Head to Ear Height	Stover particle-size Mean (mm)	Stover particle-size Fraction Long (%)	Wagon Density kg/m³ WM	Wagon Density kg/m³ DM
			2006[a]		
Ear-snapper	0.57_c	12_a	23_a	147	93
Whole-plant	0.50_b	25_b	34_b	92	56
Stalk-gathering	0.43_a				
Front wagon		72_c	81_c	74	42
Rear wagon		13_a	26_a	153	98
LSD[b] (P = 0.05)	0.03	4	3		
			2005[c]		
Ear-snapper	0.45	15_a	36_a	172_b	106_c
Whole-plant	0.20	20_a	47_b	147_b	72_b
Stalk-gathering	0.24				
Front wagon		137_b	91_c	81_a	38_a
Rear wagon		14_a	31_a	159_b	97_c
LSD[b] (P = 0.05)		20	5	27	15

[a] Data from trails 1 – 4 described in table 1.
[b] Averages with different subscripts in the same column are significantly different at 95% confidence.
[c] Data from Shinners et al., 2006

Table 5. Fuel use and specific energy requirements for single-pass harvesting of corn grain and stover using three harvester heads (trials 1 – 4, table 1).

Head type	Fuel Use			Mass Flow				Specific Energy			
				Wet		Dry		Wet		Dry	
	Wet	Dry		Head[a]	Rear[b]	Head[a]	Rear[b]	Head[a]	Rear[b]	Head[a]	Rear[b]
	L / Mg[a]		L/ha	Mg WM / h		Mg DM / h		kW-h/Mg WM		kW-h/Mg DM	
Ear-snapper	1.10_a	1.46_a	17.0_a	46.0_b	8.4_b	34.5_b	5.3_b	0.8_b	7.3_b	1.1_b	11.2_b
Whole-plant	1.36_c	2.07_c	33.4_c	33.0_a	14.3_c	23.4_a	8.8_c	0.4_a	5.1_a	0.5_a	7.8_a
Stalk-gathering	1.30_b	1.83_b	27.4_b	36.0_a	4.9_a	25.7_a	3.1_a	2.0_c	9.8_c	2.7_c	15.0_c
LSD[c] (P = 0.05)	0.03	0.17	1.3	3.8	0.9	2.9	0.6	0.2	0.8	0.4	1.2

[a] – Mass of both grain and stover fractions entering the harvester at feederhouse from head.
[b] – Mass of stover harvested from rear of harvester.
[c] – Averages with different subscripts in the same column are significantly different at 95% confidence.

Table 6. Fuel use and specific energy requirements for single-pass harvesting of corn grain and stover when the processing rolls were active and inactive. Harvester was equipped with whole-plant head (trial 5, table 1).

Processing Rolls	Fuel Use Wet (L / Mg[a])	Fuel Use Dry (L / Mg[a])	Fuel Use (L/ha)	Mass-flow[b] Wet (Mg / h)	Mass-flow[b] Dry (Mg / h)	Specific Energy[c] Wet (kW-h / Mg)	Specific Energy[c] Dry (kW-h / Mg)	Stover Moisture (% w.b.)	Particle-Size (mm)
Active[d]	1.20	1.67	30.8	15.8	9.7	5.3_b	8.6_b	38.7	32_a
Inactive[d]	1.23	1.70	30.6	15.0	9.3	5.0_a	8.1_a	37.8	39_b
LSD[e] (P = 0.05)	0.06	0.07	1.2	1.0	0.4	0.1	0.3	2.6	3

[a] – Mass of both grain and stover fractions entering the harvester at feederhouse from head.
[b] – Based on mass-flow-rate of stover harvested and processed through processing rolls, flail chopper and blower.
[c] – Specific energy for processing stover at rear of harvester, i.e. through processing rolls, flail chopper and blower.
[d] – Processing roll clearance was 3 and 38mm, defined as rolls be active or inactive, respectively.
[e] – Averages with different subscripts in the same column are significantly different at 95% confidence.

Table 7. Fuel use and specific energy requirements for single-pass harvesting of corn grain and stover using two types of harvester heads at various ground speeds (trial 6 and 7, table 1).

Head Type	Fuel use			Mass flow				Specific energy			
				Wet		Dry		Wet		Dry	
				Head[a]	Rear[b]	Head[a]	Rear[b]	Head[a]	Rear[b]	Head[a]	Rear[b]
Ground speed	Wet	Dry									
km/h	L / Mg[a]		L/ha	Mg WM / h		Mg DM / h		kW-h/Mg WM		kW-h/Mg DM	
Ear Snapper											
4.5	1.17	1.50	20.4	39.2	5.6	30.7	3.8	2.1	10.3	2.7	14.9
5.8	0.93	1.18	16.2	51.5	7.4	40.4	5.1	1.7	9.0	2.2	13.0
7.2	0.86	1.10	14.9	62.8	9.1	49.2	6.3	1.5	8.3	2.0	12.0
Whole-plant											
2.4	1.47	1.93	34.3	25.7	9.6	19.5	6.7	0.7	6.2	0.9	8.8
3.5	1.13	1.50	27.0	38.2	14.6	28.8	9.9	0.5	5.5	0.6	8.1
4.6	1.03	1.38	24.7	49.8	19.2	37.4	12.9	0.4	5.2	0.6	7.7

[a] – Mass of both grain and stover fractions entering the harvester at feederhouse from head.
[b] – Mass of stover harvested from rear of harvester.

The combine processed 66% more MOG per unit time when using the whole-plant compared to the ear-snapper head (table 5). However, the grain mass-flow was more than double for the ear-snapper head. Even though total mass-flow was less for the whole-plant head, specific fuel consumption on per unit mass and per unit area basis was 42 and 96% greater than with the ear-snapper head. The difference shows the added energy required to process the stalk through the threshing mechanisms and size-reducing it with the flail chopper. The total mass-flow was slightly greater when using the stalk-gathering head, but specific fuel consumption on per unit mass and area basis was 25 and 61% greater than with the ear-snapper head. The difference in specific fuel consumption show the benefit that could be achieved by not passing the stalk fraction through the combine threshing mechanisms and by using a precision-cut cutterhead rather than flail chopper for size-reduction.

Specific energy requirements at the head were the least for the whole-plant head because the stalk was simply cut at one location and then conveyed the whole-plant to the feederhouse (table 5). The specific energy for the ear-snapper head was greater because the snapping rolls crushed the stalks along a significant fraction of their length before the ear was snapped. The stalk-gathering head had the highest specific energy because it was not only crushing the stalks, but also gathering and size-reducing the captured stover. The power required by the head and feederhouse was approximately 16, 51 and 92% of the maximum available for the whole-plant, ear-snapper and stalk-gathering heads, respectively. The power required by the flail chopper and blower at the rear of the combine was approximately 69, 59 and 46% of the maximum available for the whole-plant, ear-snapper and stalk-gathering heads, respectively.

Reducing processing roll clearance from 38 to 3 mm (defined as inactive to active) significantly reduced the average particle-size of the stover by 18% (table 6). Activating the rolls in this manner increased the specific energy requirements by 0.5 kW-h/Mg DM, an increase of 6%. At the mass-flow harvested, this represented an increase of 8.1 kW, which is small in comparison to the total machine power requirements. Therefore, the use of the processing rolls had no significant impact on the specific fuel consumption of the harvester as a whole (table 6).

Specific fuel consumption was measured over a range of ground speeds when using the whole-plant and ear-snapper heads (figs. 6 and 7.) The equilibrium fuel consumption when using the whole-plant head was 27% greater than with the ear-snapper head. At equilibrium, the dry total mass-flow ratio of grain and stover was 32% greater when using the ear-snapper head but specific fuel consumption was 40% less on a per unit area basis and 20% less on a per unit mass basis (table 7). However, at equilibrium, the specific power requirement at the head was 70% less when using the whole-plant head. These results show that the processing of the greater quantities of stover in the threshing cylinder, flail chopper and blower is much more power intensive than threshing and separating greater quantities of grain.

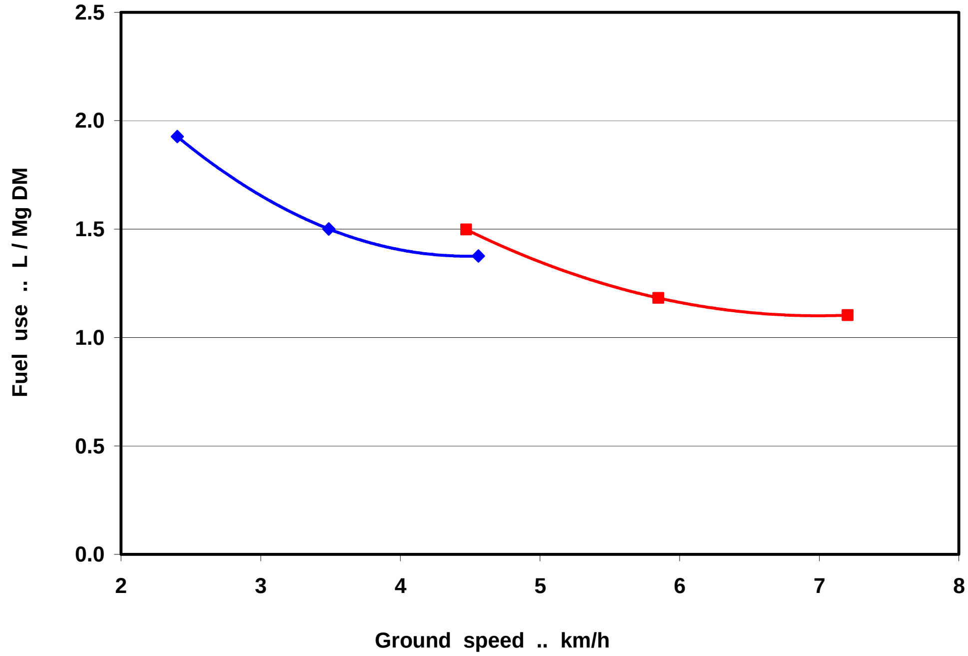

Figure 6. Fuel consumption per unit mass of crop harvested (grain and stover) as a function of ground speed for the whole-plant (♦) and ear-snapper (■) heads (trials 4 and 5, table 1).

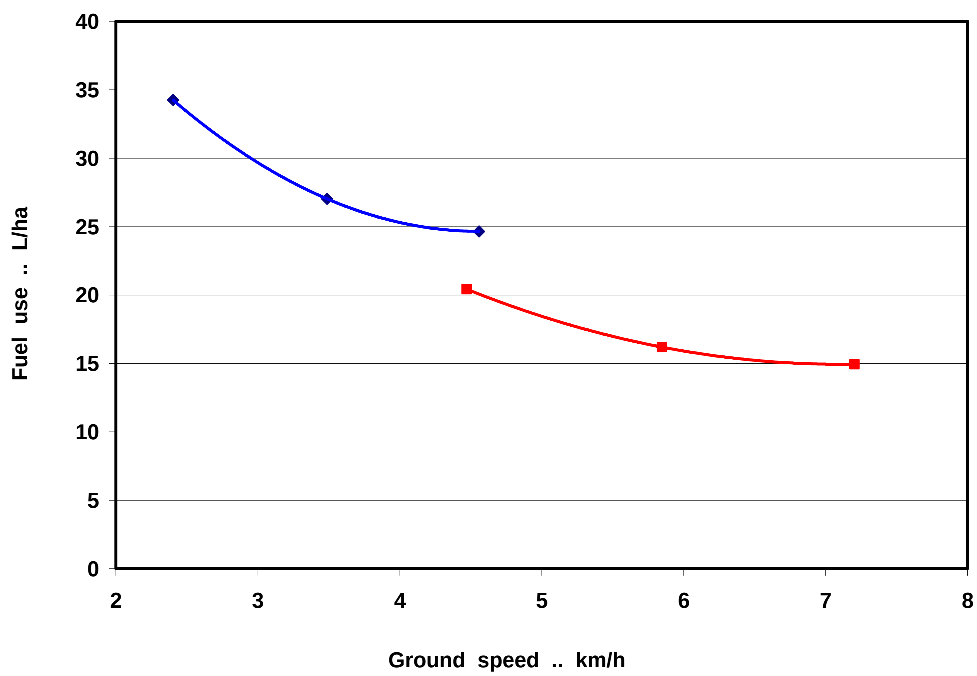

Figure 7. Fuel consumption per unit area as a function of ground speed for the whole-plant (♦) and ear-snapper (■) heads (trials 4 and 5, table 1).

Conclusions

- Improvements to the converging auger improved gathering effectiveness of the stalk-gathering head. The theoretical-length-of-cut was decreased from 45 to 25 mm, which reduced actual particle-size from 137 to 72 mm, respectively. However, this change did not improve material density in the transport wagon.

- The addition of processing rolls between the threshing rotor and the flail chopper was intended to shred the stalks, making them more compliant and thereby improve stover mass-flow-rate when using the whole-plant head. The processing rolls did reduce particle-size, but had no significant effect on the tendency for plugging at the flail chopper to limit harvesting rate.

- Stover aggregate moisture was 51.0 and 52.5% (w.b.) for the whole-plant and stalk-gathering head (front wagon only), respectively. Aggregate moisture of stover from the ear-snapper and stalk-gathering heads (rear wagon only) was 38.5% (w.b.).

- Specific fuel use was 1.46, 1.83 and 1.46 L/Mg DM and 17.0, 27.4, and 33.4 L/ha, for the ear-snapper, stalk-gathering and whole-plant heads, respectively. The power required by the flail chopper and blower at the rear of the combine was approximately 69, 59 and 46% of the maximum available for the whole-plant, ear-snapper and stalk-gathering heads, respectively.

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