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AN UPWARD CUTTING CUT-AND-THROW FORAGE HARVESTER TO REDUCE MACHINE ENERGY REQUIREMENTS

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ABSTRACT

An alternative forage harvester was developed to reduce machine energy requirements by utilizing an upward cutting cut-and-throw configuration. The cutterhead was inverted from its conventional orientation so that the knives entered the mat of uncut material from below. This upward cutting concept allowed the chopped material to be thrown directly out of the cutterhead without the subsequent friction loss of sliding the chopped material one-half revolution around the cutterhead housing as typical with conventional cut-and-throw configurations. This upward cutting configuration reduced specific energy requirements by 30 and 34% compared to conventional cut-and-throw and cut-and-blow configurations, respectively. The machine's throwing and blowing capabilities were considered adequate to convey chopped forage to a trailing wagon, although throwing distance was only about 60% as great as a cut-and-blow harvester.

KEYWORDS. Harvesters, Forage, Energy requirements.

INTRODUCTION

With a forage harvester and its complementary equipment, the silage production system is highly mechanized. Because of this, the forage harvester has become indispensable on many cattle and dairy farms. The forage harvester, however, has a rather high power requirement that often dictates the size power unit that must be available on the forage producing farm (Koegel et al., 1985). This has implications not only for harvesting rates and fuel costs, but also affects the overall capital cost of the farm equipment.

The energy requirements of unit operations within the forage harvester have been separated roughly as follows: 40% for pneumatic conveying, 40% for the cutterhead, and 20% for material pick-up and drive train losses (Blevins and Hansen, 1956; O'Dogherty, 1982; Persson, 1987). The energy requirement of the pneumatic conveying device (blower) can be divided into energy used for acceleration, impact and friction (Totten and Millier, 1966). The energy expenditures for the cutterhead include that required to compress and shear the incoming mat of forage, to accelerate the chopped forage to the speed of the knives and to overcome friction (Okokon and Finner, 1983; Persson, 1987).

Because the blower power requirement is a large percentage of the machine total, it has been the subject of much research. Chancellor (1960) estimated that in most cases more than 50% of the kinetic energy of the forage material is lost in a 90° elbow. Therefore, blowers on forage harvesters operate at high speeds in order to impart enough energy to the material to ensure that it will travel to the rear of the trailed wagon after it has been subjected to the elbow loss. In practice the blower/impeller is usually about 25 to 50% efficient (Totten and Millier, 1966).

It is possible to reduce the forage harvester energy requirement by utilizing the kinetic energy imparted to the forage particles at the cutterhead for conveying. Kinetic energy is imparted to the chopped particles when they are accelerated to the peripheral speed of the cutterhead knives. Currently, most forage harvesters are not designed to utilize this energy. With the cut-and-blow forage harvester, the particles are accelerated downward against the cutterhead housing. The kinetic energy imparted to the chopped particles is wasted and friction loss is created as the chopped particles are dragged around the cutterhead housing.

One way to overcome the first disadvantage is to configure the forage harvester so that the cutterhead is used to direct the particles to the trailed wagon without the addition of an auxiliary blower. This type of forage harvester is known as a cut-and-throw configuration. This type of machine has been marketed for many years, but its use has waned.

With the cut-and-throw forage harvester, considerable care is required by the operator to adjust the clearance between the cutterhead housing and the knives. After each knife sharpening, this clearance must be readjusted and operators have found this to be a nuisance. If this clearance is not properly adjusted, poor throwing action and greater friction loss occurs. Also, experience has shown that the cut-and-throw forage harvester works well when harvesting corn, but the throwing action in legumes and grasses is poor. This is attributed to the differences in coefficient of friction between these crops (ASAE Standard D251.1, 1991; Richter, 1954).

One way to overcome some of the inherent problems with the cut-and-throw cutterhead design is to reverse its

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rotational direction. Frictional losses could be eliminated by directing the chopped material upward, toward the trailing wagon without dragging it along a housing (fig. 1). The Swedish National Machinery Testing Institute (SNMTI) reported a machine with such a configuration required 30% less power than a flywheel type and 41% less power than a cylinder type forage harvester (SNMTI Report No. 3032, 1985).

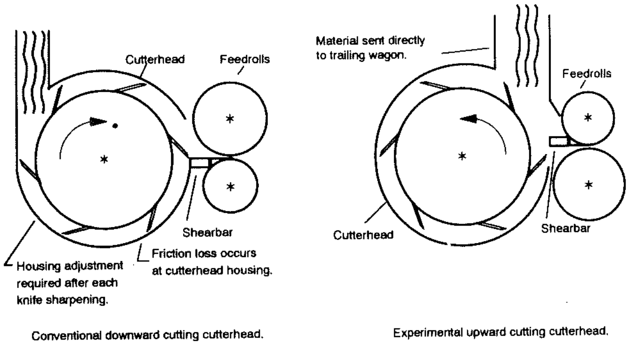
To summarize the possible benefits of reversing the rotational direction of the cutterhead to provide upward cutting:

- The kinetic energy imparted to the chopped particles is utilized for conveying the material to the trailed wagon, thereby eliminating the need for an auxiliary blower. This may allow a less expensive and more reliable machine by eliminating several components.
- By throwing the chopped material directly out of the cutterhead, friction losses at the cutterhead should be almost eliminated, reducing the power requirements of the forage harvester.
- Because the material is no longer carried along the cutterhead housing by the knives, this design eliminates the need for adjusting the housing to knife clearance after each knife sharpening.

MACHINE DESCRIPTION

Modifications were made to a New Holland Model 717 cut-and-throw forage harvester (fig. 2). The feed roll and cutterhead section of the machine were cut from the frame, inverted and re-attached to the machine frame. This allowed the geometric relationship between the feed rolls, shear bar and cutterhead cylinder to remain as they were in the original machine. By driving the feed rolls and cutterhead in the opposite rotational direction, the knives entered the mat of uncut material from below and threw the material upward out of the machine.

The entire feed roll and cutterhead assembly was mounted so that it could be pivoted about the main frame in order to provide trajectory adjustment for the chopped material. No modifications were made to the cutterhead knives. After initial tests, it was felt that there was insufficient air movement through the cutterhead housing. Axial paddles sold by the manufacturer were placed directly behind the knives to improve the air pumping action of the cutterhead. The open area on the cutterhead side walls was increased from 200 to 720 cm^2 to increase the air flow.



Conventional downward cutting cutterhead.

Experimental upward cutting cutterhead.

Figure 1–Schematic of different cutting configurations for cut and throw forage harvesters.

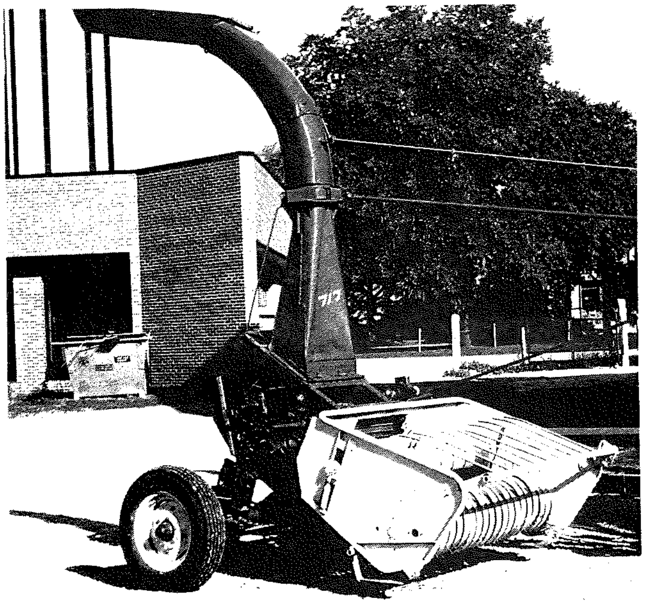


Figure 2–Experimental upward cutting cut-and-throw forage harvester.

PROCEDURE

For all experimental conditions, the performance of experimental and control forage harvesters were quantified by pto torque, pto speed, and material feed rate. The first two parameters were measured and recorded with a torque transducer and datalogger. Torque and speed were recorded at a frequency of 10 Hz. The torque transducer was placed between the tractor and the harvester so that total machine power could be calculated. The machine feed rate was determined by weighing the quantity of forage chopped during a test run and dividing by the test run time. Test run time was recorded by the datalogger. Machine specific energy was calculated by dividing the required power by the feed rate.

In order to decrease data scatter due to differences in crop moisture between tests, the machine specific energy and feed rate were adjusted using moisture compensation equations as outlined in Engineering Practice EP502 (ASAE, 1991). These equations adjust all feed rate and specific energy measurements to a common moisture level of 65% wet basis (w.b.). This procedure was found to reduce data scatter as a function of crop moisture when compared to data on a wet or dry basis (Linde and Bowen, 1988).

All tests were conducted using either first, second or third crop alfalfa at the UW West Madison Agricultural Research Station. The crop was cut with a mower-conditioner, placed immediately into a windrow and allowed to partially field dry. Each test run was approximately 75 m in length such that approximately 300 kg of material would be processed per test. The material was conveyed into a small trailer and the material weight was determined by weighing the trailer and its contents and subtracting the tare weight of the trailer. Several samples of the chopped material were gathered to determine moisture content using the oven dry method (ASAE Standard S358.1, ASAE, 1991). Another set of samples was periodically gathered to determine the material particle size using the procedure in ASAE Standard S424

(ASAE, 1991). The theoretical length of cut of all machines tested was set to about 10 mm.

An initial experiment was conducted to compare the performance of the upward cutting harvester with that of a conventional cut-and-blow harvester. The cut-and-blow forage harvester used was a John Deere Model 3950. Blower paddle clearance with the band was set to approximately 3 mm. All tests were conducted with the forage harvester blower operating at 1000 rpm. A subsequent experiment was conducted to compare the performance of the upward cutting, cut-and-blow and conventional cut-and-throw harvesters. The latter machine was a New Holland Model Super 717 with the knife to housing clearance set to about 3 mm.

The first experiment was conducted over five days, harvesting either first or second crop alfalfa. The second experiment was conducted over three days, harvesting either second or third crop alfalfa. In both experiments, six replicates were conducted per machine per day. Crop maturity ranged from one-half to full bloom. Statistical analyses of feed rate and specific energy data was conducted using two way analysis of variance, where the day effects were removed by blocking. The least significant difference (LSD) presented in the tables indicates a 5% probability of no significant difference.

The throwing performance of each machine was determined by operating the machines in a stationary manner and hand feeding about 19 kg of alfalfa onto the machine's pick-up in 4 s. The chopped forage was blown onto a 15-m long plastic tarp, placed on the ground, which was marked off in 3-m increments. The tarp started below the tip of the deflector cap. Material was collected from each section, weighed and a particle size analysis was done to determine the distribution of the material particle length versus distance. Three replicates were conducted for each machine.

The blowing performance was measured by operating the machines at rated speed and placing a pitot tube, attached to a manometer, within the directional spout. The largest pressure measured was related directly to the air velocity.

RESULTS

Initial trials with the upward cutting cut-and-throw machine indicated that feeding and cutting were satisfactory. The material was thrown from the machine, but it appeared that there was insufficient air movement with the material which caused the stream of material from the elbow to be displaced by cross-winds. The axial paddles and side plate open area modifications outlined in the procedure were subsequently made. Measurements at the exit of the elbow indicated that air velocity was increased from 10 to 19 m/s. Blowing and throwing action were considered adequate with these modifications.

The upward cutting cut-and-throw was initially compared to only the cut-and-blow machine (Table 1). The tests were conducted on first and second cutting of alfalfa. The modified cut-and-throw produced a 31% reduction in specific energy requirement.

The upward cutting cut-and-throw machine was then compared to the cut-and-blow machine and a conventional cut-and-throw machine (Table 2). The tests were conducted on second and third cutting of alfalfa. The upward cutting cut-and-throw reduced the energy requirements by 31 and 37% compared to the conventional cut-and-throw and cut-and-blow machines, respectively.

TABLE 1. Energy requirements of upward cutting cut-and-throw and conventional cut-and-blow harvesters

Machine Configuration	Moisture Content (% w.b.)	Moisture Adjusted Feed Rate (t/h)	Moisture Adjusted Specific Energy (kWh/t)	Mean Length of Cut (mm)	Observations
Cut-and-blow	61.1	14.5	2.12	9.4	30
Upward cutting cut-and-throw	61.4	12.9	1.46	8.2	30
LSD	4.7	2.2	0.16	1.9	
Significance	ND	ND	SD	ND	

* Tests conducted harvesting first or second crop alfalfa. Feed rate and specific energy are reported on a wet basis, adjusted to a common crop moisture level of 65% using ASAE Engineering Practice EP502.

The upward cutting cut-and-throw reduced overall machine energy requirements compared to the cut-and-blow machine presumably because the blower was eliminated and friction loss in the cutterhead housing was virtually eliminated. The conventional cut-and-throw and the cut-and-blow had statistically similar energy requirements. This indicates that the benefits of eliminating the blower is offset by the large friction loss at the cutterhead housing.

Two final experiments quantified the throwing and blowing capabilities of various configurations. The distribution of material versus distance from the tip of the deflector cap is presented in figure 3. The cut-and-blow machine had the greatest throwing distance. Approximately 85% of the total material was thrown a distance greater than 6 m. The conventional cut-and-throw machine threw 85% of the total between 6 and 9 m. The throwing distance of the upward cutting cut-and-throw was the shortest. This configuration threw about 80% of the total material between 3 and 6 m. No knife modifications were performed on the upward cutting cutterhead. Improved throwing action by different knife designs is the subject of on-going research.

Figure 4 displays the distribution of particle length versus the distance in which the particles were thrown. In

TABLE 2. Energy requirements of upward cutting cut-and-throw, conventional cut-and-throw, and conventional cut-and-blow harvesters

Machine Configuration	Moisture Content (% w.b.)	Moisture Adjusted Feed Rate (t/h)	Moisture Adjusted Specific Energy (kWh/t)	Mean Length of Cut (mm)	Observations
Cut-and-blow	63.4	13.5	1.98	10.9	18
Conventional cut-and-throw	64.0	13.8	1.80	11.4	18
Upward cutting cut-and-throw	64.0	13.2	1.25	12.0	18
LSD	4.7	4.4	0.35	0.6	
Significance	ND	ND	SD	SD	

* Tests conducted harvesting second or third crop alfalfa. Feed rate and specific energy are reported on a wet basis, adjusted to a common crop moisture level of 65% using ASAE Engineering Practice EP502.

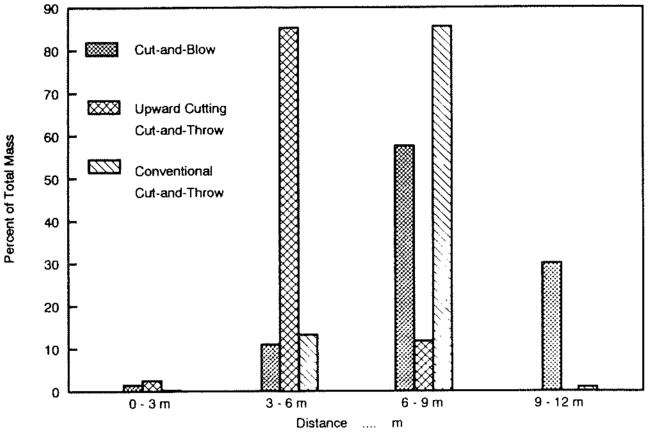


Figure 3–Throwing effectiveness as measured by percent of total mass vs. throwing distance.

the 3- to 9-m sections, the particle lengths for all of the machines were similar to each other and close to the theoretical length of cut (TLC) of 10 mm. In the 0- to 3-m section, the particle length was less than the TLC. In the 9- to 12-m section, the material left by the cut-and-blow machine was somewhat longer than the TLC and several times longer than material left by the other machines.

The maximum air velocity in the directional spout of each harvester configuration is presented in Table 3. The cut-and-blow machine had 18% greater air velocity than the upward cutting cut-and-throw machine, which at least partially accounts for its superior conveying ability.

CONCLUSIONS

The direction of rotation of a cut-and-throw cutterhead was reversed so that the cutterhead knives entered the mat of material from below. This upward cutting configuration allowed the chopped material to be thrown directly from the cutterhead without the subsequent friction loss at the cutterhead housing as typically experienced with conventional cut-and-throw configurations.

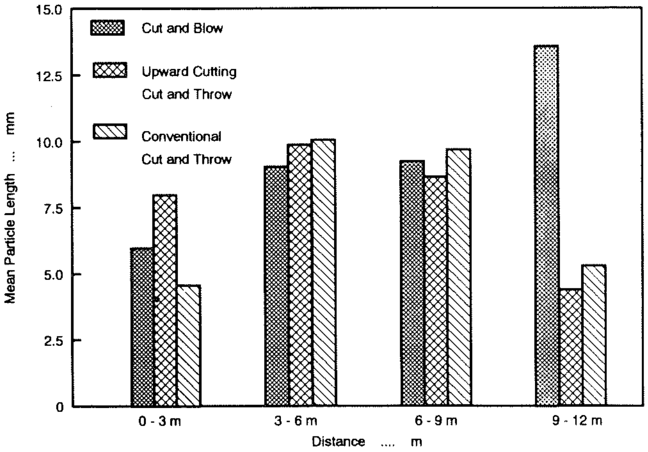


Figure 4–Mean particle length vs. throwing distance.

TABLE 3. Maximum air velocity within directional spout

Machine Configuration	Maximum Air Velocity (m / s)
Upward cutting cut-and-throw	19.3
Conventional cut-and-throw	18.2
Cut-and-blow	22.7

The upward cutting cut-and-throw reduced the energy requirements by 31 and 34% compared to the conventional cut-and-throw and cut-and-blow machines, respectively. The upward cutting cut-and-throw reduced overall machine energy requirements compared to the other configurations because the blower was eliminated and friction loss at cutterhead housing was virtually eliminated.

Throwing distance from the upward cutting cut-and-throw machine was the shortest of the configurations tested. Eighty percent of the chopped material was placed 3 to 6 m from the tip of the deflector cap. However, this distance is sufficient to fill most commercially available forage wagons.

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