International Journal of Biological, Life and Agricultural Sciences
ISSN: 2415-6612
Vol:7, No:7, 2013

A Comparison of Fuel Usage and Harvest Capacity in Self-Propelled Forage Harvesters

Brian H. Marsh

***Abstract*—**Self-propelled forage harvesters in the 850 horsepower range were tested over three years for fuel consumption, throughput and quality of chop for corn silage. Cut length had a significant effect on fuel consumption, throughput and some aspects of chop quality. Measure cut length was often different than theoretical length of cut. Where cut length was equivalent fuel consumption and throughput were equivalent across brands. Shortening cut length from 17 to 11mm increases fuel consumption 53 percent measured as Mg of silage harvested per gallon of fuel used and a 42 percent decrease in capacity as tons of fresh material per hour run time.

***Keywords*—**Corn silage, forage harvester, fuel use, length of cut.

I. Introduction

FORAGE harvester efficiency is one of the factors to be considered in obtaining a unit. Harvester capacity needs to be matched with capacity of vehicles needed for transporting the material. Other considerations are cost, reliability, maintenance and repair costs, dealer support and ease of operation. Chop length has a major impact on dry matter intake, total chewing activity and neutral detergent fiber left in the bunk [1]. Lengthened cut length and processing whole-plant silage improved animal performance over short cut unprocessed corn silage [2], [3] Five self-propelled forage harvesters were tested for throughput, fuel consumption and quality of processing. The initial experiment design was to have operator owned, field used machines for testing. However, to obtain the size and brands needed some new machines from dealers were used.

II. Materials and Methods

Corn (*Zea mays*) was cut for silage in a randomized complete block design with three replications for each test. In 2010, theoretical length of cut (TLC) was set at 17mm and each processor was set at 2mm. Each machine had a 7.6 meter head. Other machine specifications are listed in Table I. The machines were driven by different operators who had substantial experience operating that make and model. Harvested field length was 760 meters and harvested area was approximately 2.14 hectares.

In 2011, TLC was set at 13mm and each processor was set at 2mm. Each machine had a 7.6 meter head except for the Claas which had a 6.1 meter head. The machines made three rounds cutting 60 rows per replication for a total of 180 rows. The Claas machine cut three rounds the first replication and four rounds the other replications for a total of 176 rows. The Krone machine was operating at about 650 horsepower (hp) instead of the rated 826hp. Other machine specifications are listed in Table II. Harvested field length was 350 meters and harvested area was approximately 1.64 hectares.

In 2012 TLC was set at 16mm and each processor was set at 2mm. Each machine had a 7.6 meter head (8 rows) except for the NH 9060 which had a 6.1 meter head (6 rows). The machines made three rounds cutting 8 rows per pass for a total of 144 rows. Other machine specifications are listed in Table III. Harvested field length was 370 meters and harvested area was approximately 1.73 hectares and 1.3for the NH 9060.

Each machine was warmed up, ready to harvest and parked at a specified location where the fuel tank was topped off. Time was recorded for harvest time and for travel time to and from the field and turning on the field ends. After each plot the machine was returned to the same specified location and refueled. Fuel consumption was measured as the amount to refill the fuel tank. This methodology was the same used in other research projects [4], [5].

Approximately 50 feet on each end of the field was previously harvested to provide adequate turn around space. Sufficient trucks were available for continuous harvest. Trucks were weighed full and empty for each load. Samples for moisture analysis were collected from each load from at least 10 spots as the trucks unloaded. Two truckloads per plot were also sampled for particle size following the Penn State Particle Size Separator methodology [6]. Approximately 1 ½ liters of corn silage were placed in the upper sieve. The sieve consisted of three boxes. The upper box had 17 mm holes. The middle box had 8mm holes. The sieve was shaken back and forth five times on a flat surface, rotated 90°, shaken five times, rotated 90°, and repeated so it was shaken 40 times. Material from each box was weighed, dried and re-weighed. Twenty randomly selected segments from the middle box were measured for length before drying. Samples from each truck were composited for Corn Silage Processing Score [7]. This test was completed by Dairyland Laboratories, Inc. This test measures starch and neutral detergent fiber (NDF) before and after separation on screens sized 4.75mm and 1.18mm.

B. H. Marsh is a Farm Advisor with the University of California Cooperative Extension – Kern County, Bakersfield, CA 93307 USA (661-868-6210; fax: 661-868-6208; e-mail: bhmarsh@ucdavis.edu).

TABLE I
MACHINE SPECIFICATIONS, 2010

Make	John Deere	Claas	Krone	New Holland
Model	7950 Prodrive	Jaguar 980	Big X 800	FR 9090
Year	2010	2009	2008	2010
Rated Horsepower	800	860	826	824
Header	770	Orbis 750	Ezy Collect 7500	480 FI
Engine Hours	20	1469	890	10
Cutter Hours	3.4	1400	662	2.5
# of Knives	40	24	28	24
Processer	9.45” chrome standard	Scherer 10” chrome	10” chrome roll	10” standard
KP Differential	21%	30%	20%	22%

TABLE II
MACHINE SPECIFICATIONS, 2011

Make	John Deere	Claas	Krone	New Holland
Model	7950 Prodrive	Jaguar 980	Big X 850	FR 9090
Rated Horsepower	800	860	826	824
Header	770	Orbis 635	Ezy Collect 753	480 FI
Engine Hours	210	2181	16	19
Cutter Hours	142	411	4	5
# of Knives	40	24	20	24
Processer	9.45” chrome	9.8” standard	10” chrome roll	10” standard
KP Differential	32%	30%	30%	22%

TABLE III
MACHINE SPECIFICATIONS, 2012

Make	John Deere	Claas	Krone	New Holland	New Holland
Model	7950 Prodrive	Jaguar 980	Big X 1100	FR 9090	FR 9060
Rated Horsepower	800	860	1031	824	544
Header	770	Orbis 750	EzyCollect 753	480 FI	450 FI
Engine Hours	1401	349	16	40	78
Cutter Hours	902	309	4	20	46
# of Knives	40	24	20	24	24
Processer	9.5’ w/ Horning Spiral cut rolls	new 9.8” standard	10” chrome roll with 123 teeth/roll	heavy duty 99/126 tooth	heavy duty 99/126 tooth
KP Differential	32%	30%	30%	22%	22%

III. RESULTS AND DISCUSSION

Yield per hectare and percent moisture of the harvested corn silage were not significantly different for each machine (Table IV) in any year. Data is not shown for 2010 and 2011. Total silage harvested was different where head widths were different.

In 2010, there was a significant difference in chopping time between machines. The Claas machine moved through the plots at a higher speed and harvested more corn silage (fresh weight) per hour than the other machines (Table V). The John Deere and Krone machines were comparable and the New Holland was the slowest and harvested the least per hour. The measured cut length was significantly different. It was the shortest for the New Holland, equivalent for the John Deere and Krone machines, and the longest for the Claas machine. Cut length had a significant impact on throughput and fuel consumption.

In 2011, the Krone machine operating at less than rated horsepower harvested less per hour than the other machines (Table VI). The Claas harvested the most per hour and per unit of fuel. The John Deere and New Holland machines chopped equivalent tonnage but the John Deere used less fuel and chopped more per gallon, although not significant, and had a shorter cut length. Cut length from the New Holland and Class machines were closest to the target 13mm cut length. Average cut length from individual plots ranged from 11.2 to 13.2.

TABLE IV
MACHINE THROUGHPUT AND TIME DATA, 2012

	Forage Harvested				
	Fresh Weight	Moisture	Chopping Time	Run Time	Chopping Time
	-- Mg --	-- % --	---- minutes ----		-- % --
Claas	97.3 a	65.5	18.8 b	30.4	63.8
John Deere	98.4 a	67.6	24.3 a	37.1	69.6
Krone 1100	99.7 a	66.3	18.4 b	26.0	71.7
NH FR 9090	95.2 a	64.9	23.1 a	30.5	75.7
NH FR 9060	76.3 b	64.7	24.2 a	30.5	79.2
$LSD_{0.05}$	6.3	ns[††]	2.0	ns	ns
C.V. %	3.8	4.2	5.2	15.2	9.6

TABLE V
MACHINE THROUGHPUT AND FUEL CONSUMPTION, 2010

	Forage Harvested			Fuel		
	Fresh Weight		Cut Length	Total Used	Chop Time	Total Time
	Mg/hour	Mg/liter	mm	-- Liters --	------- Liters/hour ------	
Claas	271 a	1.86 a	16.68 a	77.5 c	152	119
John Deere	257 b	1.64 b	15.88 b	88.1 b	156	123
Krone	251 b	1.64 b	16.10 b	83.5 b	153	118
New Holland	224 c	1.46 c	14.96 c	98.7 a	154	125
$LSD_{0.05}$	10.4	0.11	0.41	5.6	ns	ns
C.V. %	2.0	3.6	8.8	3.2	3.1	9.0

TABLE VI
MACHINE THROUGHPUT AND FUEL CONSUMPTION, 2011

	Forage Harvested			Fuel		
	Fresh Weight		Cut Length	Total Used	Chop Time	Run Time
	Mg/hour	Mg/liter	mm	-- Liters --	------- Liters/hour ------	
Claas	244.7 a	1.47 a	13.0 a	45.7 b	169.7 ab	113.9 b
John Deere	199.4 b	1.29 ab	11.6 b	52.9 ab	153.8 b	116.4 b
Krone	160.9 c	1.25 b	11.8 b	53.7 ab	129.3 c	96.8 c
New Holland	206.0 b	1.15 b	12.6 a	59.0 a	178.0 a	134.6 a
$LSD_{0.05}$	12.3	0.18	0.58	9.45	16.5	11.4
C.V. %	3.0	7.2	2.4	9.0	5.2	5.0

TABLE VII
MACHINE THROUGHPUT AND FUEL CONSUMPTION, 2012

	Forage Harvested			Fuel		
	Fresh Weight		Cut Length	Total Used	Chop Time	Run Time
	Mg/hour	Mg/liter	mm	-- Liters --	------- Liters/hour ------	
Claas	310.7 a	2.07 a	17.8 a	46.9 bc	150.1 b	96.4 c
John Deere	243.8 b	1.66 c	15.2 c	60.6 a	148.6 b	102.8 bc
Krone 1100	322.2 a	1.87 b	15.1 c	53.3 ab	172.7 a	124.0 a
NH FR 9090	249.2 b	1.63 c	16.0 bc	58.8 a	153.5 b	116.0 ab
NH FR 9060	188.8 c	1.73 bc	16.9 ab	43.8 c	109.2 c	86.6 c
$LSD_{0.05}$	19.4	0.19	1.3	9.45	16.5	18.9
C.V. %	4.2	6.1	4.3	9.0	5.2	9.5

In 2012, the Claas and the higher horsepower Krone harvested equivalent amounts per hour (Table VII). The John Deere and New Holland 9090 machines harvested equivalent amounts but less that the previously mentioned machines. The smaller NH 9060 did harvest less material, as expected. Although not significantly different, there was a trend for a higher percentage of chopping time. The Class and Krone machines had significantly lower chopping times than the other machines.The Class machine chopped more per gallon of fuel. However, it also had the longest cut length, almost 2 mm longer than the TLC setting. The Krone machine with more horsepower with the same size head had a lower run time and chop time than the others. It also chopped more material per hour than the other machines with similar cut length as would be expected from a higher horsepower machine. The John Deere, although not significant, had a shorter cut length. Measured cut length from the New Holland 9090 was at the target 16mm cut length. Cut length ranged from 14.8 to 16.8mm with TLC at 17mm and 11.6 to 13.0 with TLC at 12.0mm in the 2010 and 2011 tests, respectively.

Cut length had a significant impact on throughput. A very good relationship (R^2=0.78***) was observed for Mg of fresh material harvested per hour of chop time versus cut length (Fig. 1). Shortening cut length from 17 to 11mm decreases harvest capacity 42 percent measured as Mg of silage harvested per gallon of fuel used. The following formula can be used to determine potential harvest capacity at different cut lengths:

$$Y = 16.7X - 8.42^{\dagger} \quad (1)$$

where Y = Mg of fresh silage harvested per hour of chop time, X = cut length in mm, †Krone 1100 & NH 9060 data not included in equation.

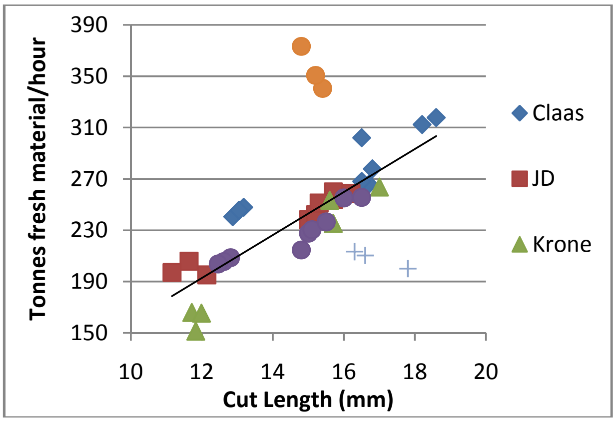

Fig. 1 Mg Fresh Weight per Hour Chop Time versus Cut Length (2010-12)

Cut length also had a significant impact on fuel consumption (R^2=0.72***) as measured by Mg of fresh material harvested per liter of fuel versus cut length (Fig. 2). Shortening cut length from 17 to 11mm increased fuel consumption measured as tons of fresh material per liter of fuel 53 percent.

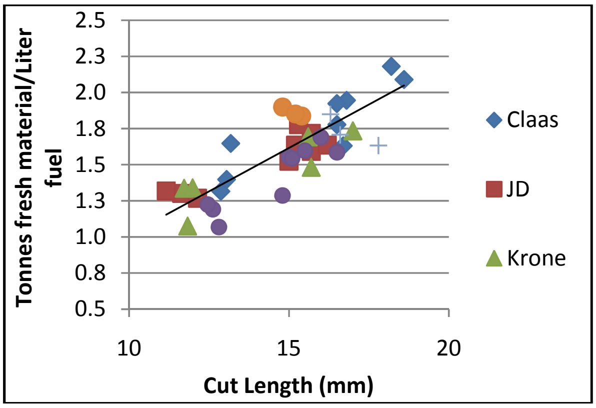

Fig. 2 Mg Fresh Weight per Liter of Fuel versus Cut Length (2010-12)

The following can be used to determine potential fuel consumption at different cut lengths:

$$Y = 0.12X - 0.19 \quad (2)$$

where Y = Mg of fresh corn silage harvested per liter of fuel, X = cut length in mm.

Quality of chop was partially determined through particle size analysis. In 2012, the Claas, and New Holland machines, with the longest cut, had the most material in the upper sieve and less in the middle sieve (Table VIII). There was no difference in the lower sieve. While these differences were statistically significant, they would have little influence on feed quality [8]. Results were similar in other years as cut length had the most impact on percentages in each shaker box (data not shown).

Quality of processing was measured using the Corn Silage Processing Score (CSPS). There was no relationship between cut length and any of the CSPS measurements in 2010 (Table IX). The John Deere and Krone machines had significantly higher amounts that did not pass through the 4.75 mm screen. The Claas and New Holland were equivalent and less than the other two. Those results are mirrored for the other size fractions. A higher percentage of material was in the medium and fine fractions for the Claas and New Holland harvesters, which were equivalent. The Krone harvester had the least amount in the medium and fine fractions. It also had more hours on its processor than the other machines. Starch in large particles (>4.75mm) is considered to have less nutritional value. The percent of total starch passing through the 4.75 mm screen is optimum above 70% and acceptable above 50%. Anything below 50% would indicate inadequate processing. Total starch percentage on unshaken samples was equivalent. The percentage of starch that passed through the 4.75mm sieve was higher for the Claas and New Holland machines, which was the same pattern as size fraction percentage.

TABLE VIII
PARTICLE SIZE ANALYSIS, 2012

	Upper > 0.75"	Middle	Lower < 0.31"	Cut Length
	--------------------	%	--------------------	mm
Claas	55.0 ab	33.0 bc	11.7	17.8 a
John Deere	40.7 c	44.0 a	15.3	15.2 c
Krone 1100	47.3 bc	39.7 ab	13.3	15.1 c
NH FR 9090	57.0 ab	29.3 c	13.7	16.0 bc
NH FR 9060	53.3 ab	35.3 bc	11.3	16.9 ab
$LSD_{0.05}$	8.05	8.9	ns	1.3
C.V. %	8.4	13.1	17.8	4.3

TABLE IX
CORN SILAGE PROCESSING SCORE, 2010

	Particle Fractions			Starch		NDF	
	Coarse	Medium	Fine	Total	CSPS	Total	†PE NDF
	-------------	-------------	-------------	%	-------------	-------------	-------------
John Deere	58.3 a	34.0 bc	7.7 b	23.6	35 b	49.2	46.4
Claas	51.3 b	39.3 ab	9.3 a	24.8	58 a	47.3	43.8
Krone	63.0 a	31.0 c	6.3 c	23.2	36 b	49.1	46.6
New Holland	51.0 b	40.3 a	8.7 ab	22.0	52 a	51.1	47.4
$LSD_{0.05}$	6.3	5.4	1.2	ns	14.6	ns	ns
C.V. %	5.6	7.5	7.5	10.0	16.2	3.9	4.5

†Physically Effective Neutral Detergent Fiber

TABLE X
CORN SILAGE PROCESSING SCORE, 2011

	Particle Fractions			Starch		NDF	
	Coarse	Medium	Fine	Total	CSPS	Total	PE NDF
	-------------	-------------	-------------	%	-------------	-------------	-------------
Krone	58.7 b	33.3 b	8.0 b	33.9	46.7	44.6	41.4
New Holland	64.7 a	28.3 c	7.0 b	32.6	42.7	45.6	44.0
John Deere	49.0 c	40.7 a	10.3 a	34.9	44.7	45.2	41.4
Claas	62.7 ab	29.3 c	7.7 b	35.3	49.3	43.2	40.4
$LSD_{0.05}$	5.16	3.5	2.0	ns	ns	ns	ns
C.V. %	4.4	5.3	12.0	7.04	15.8	6.9	6.1

TABLE XI
CORN SILAGE PROCESSING SCORE, 2012

	Particle Fractions			Starch		NDF	
	Coarse	Medium	Fine	Total	CSPS	Total	†PE NDF
	-------------	-------------	-------------	%	-------------	-------------	-------------
Claas	55.7 abc	36.3 abc	8.0	30.9	48.0 ab	47.4 bc	44.5 bc
John Deere	54.3 bc	37.3 bc	8.3	25.0	41.0 bc	51.2 a	48.2 a
Krone 1100	51.3 c	40.3 a	8.3	30.6	53.3 a	44.8 c	42.8 c
NH FR 9090	60.0 ab	33.0 bc	7.0	26.4	48.0 ab	49.8 ab	47.2 ab
NH FR 9060	61.0 a	32.0 c	6.7	26.8	35.3 c	50.4 ab	47.8 a
$LSD_{0.05}$	5.7	5.0	ns	ns	10.4	ns	3.1
C.V. %	7.1	9.6	11.2	10.5	13.2	6.9	3.8

There was significant difference was observed in 2011 between the machines for material in the upper screen (Table X). The John Deere harvester had the significantly less in the upper sieve and more in the middle and lower screens. The New Holland and Claas had the least amount in the middle screen. Percent moisture was lower than optimal which may have had an impact on processing. These differences did not have an impact of CSPS. Total starch percentage on unshaken samples, percent starch passing through the 4.75mm screen, total neutral detergent fiber (NDF) and Physically Effective NDF were equivalent.

In 2012, with each processor was set at 2mm, there were differences in size separation between machines, again influenced by the length of cut (Table XI). There was significant difference was observed between the machines for material in the upper screen (>4.75mm). Total starch percentage on unshaken samples was equivalent. There was a significant difference in CSPS. The NH 9060 had the lowest and the Krone 1100 was the highest. Starch in large particles

(> 4.75mm) is considered to have less nutritional value. The percent of total starch passing through the 4.75 mm screen is optimum when above 70% and acceptable above 50%. Anything below 50% would indicate inadequate processing. These samples were collected at harvest. Length of time in the silage pile does have an impact on CSPS which generally increases with increase time in the pile.

Acknowledgment

A special thanks to Mid Valley Harvesting, Krone N.A. Company, Garton Tractor, Inc., HB Harvesting and Lamb Chops, Inc. for furnishing equipment and labor and USCustom Harvesters, Inc. for funding the sample analysis.

References

[1] Kononoff, P., A. Heinrichs, and H. Kehman. 2003. The Effect of Corn Silage Particle Size on Eating Behavior, Chewing Activities, and Rumen Fermentation in Lactating Dairy Cows. J. Dairy Sci. 86:3343-3353.
[2] Bal, M., R. Shaver, A. Jirovec, K. Shinners, and J. Coors. 2000. Crop processing and chop length of corn silage: Effects on intake, digestion, and milk production by dairy cows. J. Dariy Sci. 83:1264-1273.
[3] Johnson, L, J. Harrison, C. Hunt, K. Shinners, C. Doggett, and D. Sapienza. 1999. Nutritive value of corn silage as affected by maturity and mechanical processing: A contemporary review. J. Dairy Sci. 82:2813-2825.
[4] Frost, J. and R. Binnie. 2004. A comparison of two systems for harvesting herbage for silage. ARINI BT26 6DR.
[5] Lancas, k., S. Upadhyaya, M. Sisme, and S. Shafii. 1996. Overinflated tractor tires waste fuel, reduce productivity. CA Agriculture. 50:28-31.
[6] Heinrichs, Jud. 1996. Evaluating particle size of forages and TMRs using the Penn State Particle Size Separator. DAS 96-20.
[7] Mertens, D. and G. Ferreira. 2001. Partitioning in vitro digestibility of corn silages of different particle sizes. Abstract #826. ADSA Meetings, Indianapolis, IN.
[8] Lammers, B., D. Buckmaster and A. Heinrichs. 1996. A Simple Method for the Analysis of Particle Sizes of Forage and Total Mixed Rations.Journal of Dairy Science 79:922-928.