HARVESTER MODIFICATIONS TO ALTER COMPOSITION AND DRY MATTER OF CORN-SILAGE

B. J. Nigon, K. J. Shinners, D. E. Cook

ABSTRACT. *Two common variants to conventional whole-plant corn silage (WP) are high-cut silage (HC) and snaplage (SNPL) which are harvested to alter DM content, fiber, and starch contents compared to WP silage. A conventional ear-snapper (ES) header is used to harvest SNPL which creates a low-fiber, starch-rich feed. However, the plant fractions in SNPL can dry quickly, creating issues with digestibility, palatability, fermentation, and aerobic stability. Stalk cut-off knives were added to the ES header to harvest more leaves and upper stalk to increase SNPL fiber content, yield and moisture. The DM content, yield and nutrient composition of the resulting material, referred to here as "toplage" (TPL), was between that of HC and SNPL. TPL yield averaged 72% to 77% of WP yield. Compared to HC or WP silages, TPL starch concentration was greater but the concentrations of fiber and lignin were less. To offset the loss in yield with harvesting only TPL, the biomass remaining after TPL was then harvested as a high-fiber roughage feed, referred to here as "stalklage" (STKL). STKL was either direct harvested or windrowed and then wilted to greater DM content before final harvest. The combination of TPL followed by STKL resulted in total yield 3% to 8% less than achieved with conventional WP silage. Windrowing increased STKL yield by collecting more leaves that had been dropped during TPL harvest compared to direct cutting, resulting in STKL with greater protein and lower fiber content. STKL had similar or better nutrient composition than reported values for corn stover harvested after grain harvest. Both TPL and STKL fermented well in mini-silos across a wide range of DM contents. The stalk cut-off knives are simple to adapt to the ES header, and by altering the number of knives, producers can easily change corn silage yield, DM content, and nutrient composition, offering an alternative to conventional SNPL or WP silages.*

Keywords. *Corn, Ensiling, Forage, Header, Silage.*

Whole-plant corn silage (WP) is widely used in dairy and beef rations because of its rapid harvest; ease of ensiling; and high energy content, digestibility, and yield. The nutritive value of corn silage improves with a greater grain to stover ratio (Coors et al., 1997) but genetic advances to increase grain yield have resulted in corresponding increases in stover content, resulting in greater yield of low-digestibility stalk. Higher cutting height at harvest can be used to manage the grain to stover ratio and subsequent corn silage nutritive composition. Additionally, high-cut corn silage (HC) can be used to manage harvest dry matter (DM) content, and thus harvest timing.

Increasing cut height has improved corn silage nutritive value by decreasing concentrations of high-fiber fractions, resulting in improved digestibility of the harvested fiber (Caetano et al., 2011). Increasing cut height from 12 to 46 cm decreased DM yield by 5% to 7%, but the milk yield per unit area decreased only 1% to 2% because of the greater digestibility of the fiber fraction of HC (Neylon and Kung, Jr., 2003; Lewis et al., 2004). Wu and Roth (2005) compiled nutritive and yield results from 11 peer-reviewed corn silage cutting height studies, concluding that increasing cutting height from 16 to 48 cm resulted in silages with lower fiber and greater starch concentrations. Although average DM yield decreased by 7%, average milk yield per unit area only decreased by 2% because of greater fiber digestion.

Corn grain fed to dairy cattle is typically harvested with a combine; and stored and fed as either dry ground shelled corn or ensiled high-moisture shelled corn that is processed in a roller mill at the silo (Mader and Erickson, 2006). An alternative to shelled corn is referred to as "earlage" or "snaplage" (Mahanna, 2008; Lardy and Anderson, 2010). Earlage is typically harvested with a combine and consists mainly of grain, cob, and some husk. Snaplage (SNPL) is typically harvested with a forage harvester equipped with an ear-snapper (ES) header and a kernel processor. The harvested material consists of finely-chopped and processed grain, cob, husk, and some of the upper plant material and is typically harvested at 60% to 65% DM. SNPL starch and fiber concentrations are typically between HC and high-moisture shelled corn (Akins and Shaver, 2014). A high-fiber roughage feed is sometimes harvested from the biomass residue remaining after SNPL harvest,

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partially offsetting the yield reduction associated with harvesting SNPL compared to WP.

The plant fractions that make up SNPL can dry quickly, creating issues with digestibility, palatability, fermentation, and aerobic stability (Mahanna, 2008). SNPL has greater digestibility and lower physically effective fiber than WP, which could result in rumen acidosis (Plaizier et al., 2008). Changing harvesting practices so that more of the upper stalk and leaves are collected with SNPL would increase yield and effective fiber content while providing added moisture to improve fermentation and aerobic stability.

In this research, ES header modifications were designed and deployed to produce corn silage yield and nutritive composition between HC and SNPL. Stalk cut-off knives (described below) were added to a conventional ES header to increase the yield of the top portion of the plant when using equipment normally used to harvest SNPL. Yield and composition of the harvested material referred to here as "toplage" (TPL) could be altered by number of rows with stalk cut-off knives; fore-and-aft position of the knives with respect to the snapper rolls; and header height. Additionally, the harvester wheel spacing was configured to leave stalks standing after the first operation and the remaining biomass harvested as high-fiber roughage, now referred to as "stalklage" (STKL) in a subsequent operation. With this approach, producers have the opportunity to fine-tune the yield, DM content and nutritive composition of both TPL and STKL corn silage.

The objectives of this research were: (a) to modify a conventional ES header with stalk cut-off knives to increase the yield of the top of the plant when harvesting SNPL; (b) to evaluate the modified header performance by quantifying yield, DM content, composition, and fermentation characteristics of the TPL and STKL fractions; and (c) to investigate various scenarios to harvest STKL.

Machine Description

Conventional ES headers use a pair of counter-rotating intermeshing rolls to aggressively pull the stalk downward, snapping the ear against a set of deck plates (fig. 1) while ejecting the stalk and leaves onto the ground. This configuration is intended to collect only the ear and very little other material. To cut the stalk and capture a greater fraction of the leaves and upper stalk, a rotating stalk cut-off knife was placed above the snapper rolls (fig. 1). The knives were 17 cm diameter; had 16 sharpened serrations; and were powered by the right-side gathering chain. The knives cut the stalk against stationary anvils located just below the knife. It was hypothesized that stalk and leaf yield would be increased by greater forward position of the knife relative to the rear of the snapper rolls. Therefore,

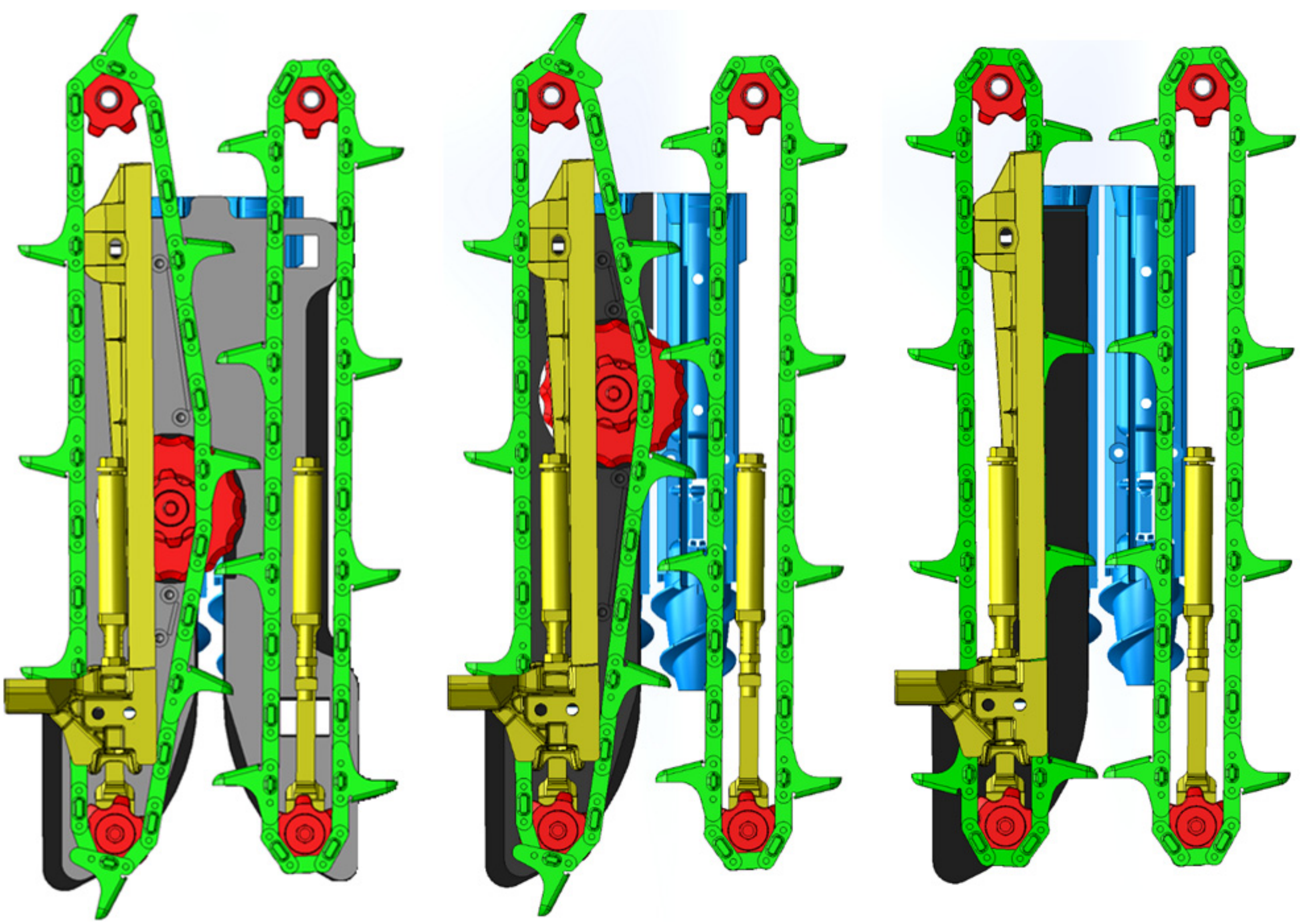

Figure 1. Ear-snapper row-unit with stalk-cutting knives (left – forward knife, center – rearward knife) and conventional row-unit (right). The right-side deck plate is removed on center and right views to show position of stalk-cutting knives relative to rear of snapper rolls. Rearward and forward knife centers were located 16 and 32 cm from the rearmost part of the snapper rolls, respectively.

assemblies were fabricated with the knife center located 16 and 32 cm from the rearmost part of the snapper rolls. The knife assembly was located on a modified deck plate with the assembly designed to be easily removed and replaced with the conventional deck plates. The design intent was to allow producers to easily and quickly alter the number of rows with cut-off knives to better manage TPL yield, and DM and nutrient contents.

The modifications were applied to a 6-row John Deere model 693 ES header (John Deere, Moline, Ill.), which was used on a John Deere model 6950 self-propelled forage harvester (SPFH). Also used in this study was a conventional row-crop (RC) header (John Deere model 666R, Moline, Ill.). The SPFH header lift system was modified by moving the lift cylinder connections so that the maximum height of the stalk cut-off knives on the 666R header was 125 cm. This modification allowed both headers to be operated just below the ear of the plant. The wheel spacing of the harvester was modified so that the front and rear tires were located between rows (76 cm row-spacing) that allowed the unharvested stalks to be left standing when first-pass TPL or SNPL was harvested.

Harvesting Scenarios

Two potential strategies to harvest TPL and STKL were considered. In the first, STKL was direct-cut with a SPFH and RC header. Harvesting STKL immediately after TPL could create ensiling challenges from effluent and clostridial fermentation because of high stalk moisture; plus harvesting logistics could be complicated with two crop streams leaving the field simultaneously. These issues are mitigated if STKL harvest is delayed for a few days to allow for some wilting, but standing stalks might be run over by transporter traffic and result in excessive STKL losses. An alternative scenario was used where a windrower was used to cut and windrow the remaining biomass immediately after TPL harvest, which reduced issues with standing stalks being run over by transporter traffic. After field wilting to reduce STKL moisture, windrows were harvested with a SPFH equipped with a windrow pick-up (WPU) header. However, this scenario required two additional operations to harvest the low-value STKL and increased chances of soil or rock contamination by harvesting windrows from the ground.

Materials and Methods

In 2013, experiments were conducted on two fields (table 1) on the University of Wisconsin Arlington Agricultural Research Station (AARS) located at 43.326868 N, 89.363082 W. Prior to harvest, corn yield and DM content were tracked from 16 September to 8 October 2013. Depending upon the weather, approximately every three to five days, five randomly located plants per field were harvested by hand cutting at the first node above the ground. The five plants were pooled together each day to form a representative sample of each field. The plants were transported to a laboratory and hand separated into five fractions: grain, cob, husk, leaf, and stalk. The stalk was further subdivided into thirds by nodes and identified as bottom (1^{st}-5^{th} nodes), middle (5^{th}-9^{th} nodes), and top (>9^{th} node) fractions. All sub-fractions, except the grain, were size-reduced by chopping with a laboratory scale cutterhead set to a theoretical length-of-cut (TLOC) of 12 mm. The mass of each sub-fraction was determined before and after oven drying at 103°C for 24 h (ASABE Standard S358.2, 2013). The estimated yield of each fraction was determined by multiplying the fractional mass by the plant population. The potential DM content of TPL was calculated from the mass of the ear, top stalk and half the leaves; SNPL DM calculated from the ear only; and STKL DM from the bottom and middle stalk and half the leaves.

Three harvest dates were used to investigate yield and composition of TPL and STKL harvested with different headers, header configurations and number of operations (table 1). All experiments included a WP control treatment harvested in a conventional manner using the RC header.

The harvest experiments were conducted using a randomized block design with four replicated blocks on each harvest date. The harvester TLOC was set at 6 mm. Treatment plots were randomly assigned within blocks and each plot was six rows wide (6 × 0.76 m) and 30 m long. Material harvested from each plot was collected in an H & S model 7+4 forage wagon (Marshfield, Wisc.) equipped with load cells to weigh harvested material to the nearest 5 kg. Harvested stalk height was manually measured to the nearest 5 cm on two plants per row across all harvested rows. After harvest, two subsamples per plot were collected from the wagon for DM determination by oven drying at 103°C for 24 h (ASABE Standard S358.2, 2013). An additional two subsamples were collected for nutrient composition analysis and were oven dried at 60°C for 72 h (ASABE Standard S358.2, 2013).

After harvest of each replicate plot, approximately 5 kg of chopped material was collected and placed in a plastic bag. This material was then placed into 19 l plastic containers, compacted using a hydraulic cylinder to a target density of 225 kg DM·m^{-3}, sealed, and then weighed to the nearest 0.01 kg. A locking lid with a neoprene gasket was used to tightly seal the container. The containers were filled to the top so the locking lid maintained achieved density. Gas was manually released one week after filling by partially opening the lid. The containers then remained sealed during the remainder of the storage period. The silos were stored indoors in an unheated room for 147 to 165 days before the containers were opened. Upon removal, the mass of each pilot-scale silo and its contents were first weighed to the nearest 0.01 kg, then the contents were removed and homogenized prior to sub-sampling. Four sub-samples were collected from each silo – two each to determine DM and nutrient composition – and oven dried at 60°C for 72 h (ASABE Standard S358.2, 2013). An additional sub-sample of about 200g DM was collected and frozen for later determination of fermentation characteristics.

In 2014, a single experiment was conducted at University of Wisconsin AARS (table 1) again focusing on yield and composition of TPL and STKL harvested with different

Table 1. Harvest description, header type, machine configurations, and number of operations for evaluation tests conducted in 2013 and 2014.

Harvest Description[a]	First Harvest Operation: Header Type[b]	Target Cut Height (cm)	Cut-Off Knife Configuration[c]: Forward	Rearward	None	Stalklage Harvest: Header Type[b]	No. of Oper.[d]
Trials Conducted on 23 Sept.; 29 Sept.; and 7 Oct. 2013 [e]							
TPL	ES	100	2	2	2	RC	1
TPL	ES	100	2	2	2	WPU	2
SNPL	ES	100	0	0	6	WPU	2
HC	RC	100	–	–	–	RC	1
WP	RC	20	–	–	–	–	–
Trial Conducted on 24 Sept. 2014[f]							
TPL	ES	100	4	0	2	RC	1
TPL	ES	100	4	0	2	WPU	2
TPL	ES	100	0	4	2	RC	1
TPL	ES	100	0	4	2	WPU	2
SNPL	ES	100	0	0	6	RC	1
SNPL	ES	100	0	0	6	WPU	2
HC	RC	65	–	–	–	–	–
WP	RC	25	–	–	–	–	–

[a] TPL - toplage; SNPL - snaplage; HC - high-cut silage; WP - whole-plant corn silage

[b] ES - ear snapper header with or without stalk cut-off knives; RC - row-crop header; WPU - windrow pick-up header.

[c] Number of stalk cut-off knives on ear snapper header. Forward and rearward indicate center of stalk cut-off disk knife was located 32 and 16 cm from the rear of the snapper rolls, respectively.

[d] One operation - harvest standing stalks with RC header.
Two operations - windrow standing stalks with windrower and then harvest the windrow with WPU on forage harvester.

[e] Corn harvested in September was Pioneer PO453AM (104 day CRM) planted on 21 May.
Corn harvested in October was Pioneer 35F37 (105 day CRM) planted on 3 June.

[f] Corn harvested was Renk Seeds RK744 VT3P (107 CRM) planted on 21 May.

headers, header configurations and number of operations (table 1). Harvest methods were the same as described above except that plots were 40 m long; TLOC was 16 mm for all treatments; and crop processing rolls were used with clearance of 3 mm. After TPL or SNPL harvest, standing and windrowed stalk moisture was quantified on 24-26; and 29 September. Samples from the windrow or standing stalks were collected at mid-day and oven dried at 103°C for 24 h. Methods to ensile material in the mini-silos were the same except that two silos were made per plot, one with bacterial inoculant (Pioneer 11C33 with *L. buchneri*, and *L. plantarum* at 1.10 $\times 10^{11}$ colony forming units/g product) and one without. The inoculant was applied at a rate of 1 g diluted inoculant per 100 g fresh crop weight and the dilution rate was 0.11 g inoculant/L of distilled water. Silos were stored indoors in a heated room (nominal temperature 20°C) for 177 days. Removal and sampling methods were the same as described above.

All nutrient composition samples removed from the mini-silos were ground through a 1 mm screen using a Wiley No. 4 mill (Thomas Scientific, Swedesboro, N.J.). Constituent analysis was performed by Rock River Labs (Watertown, Wisc.) using NIR techniques to determine neutral detergent fiber (NDF); crude protein (CP); lignin; starch; ash and digestible NDF (NDFD). Corn silage (WP, TPL), snaplage (SNPL), or corn stover (STKL) calibrations were used for analysis. Rock River Labs also quantified pH and fermentation products using high performance liquid chromatography.

To assess degree of kernel processing, samples of approximately 400 g DM of TPL, SNPL, HC, and WP harvested in 2014 were separated after ensiling into grain and non-grain fractions using a hydrodynamic separation technique (Savoie et al., 2004). The grain fraction was oven dried (24 h; 103°C) and then placed in a Tyler Ro-Tap shaker (W.S. Tyler Industrial Group, Mentor, Ohio). The shaker was operated for 1 min. using a cascade of sieves with 6.3, 4.8, 2.8, 2.0, and 1.0 mm openings. The contents of each screen were weighed to the nearest 0.1 g and grain particle-size was then determined using ASABE Standard S319.4 (*ASABE Standards*, 2008).

STATISTICAL ANALYSIS

Data were analyzed using the Fit Model platform in JMP Pro Version 11 (SAS Institute Inc., Cary, N.C.). Significant differences between treatments in 2013 were determined using two-way (harvest method × date) analysis of variance (ANOVA) to block the confounding effect of analyzing data across the three harvest dates. The 2014 TPL, HC, and WP field performance and composition data were analyzed using one-way ANOVA; and the fermentation data analyzed as a factorial design (5 harvest methods × 2 inoculation methods). The 2014 STKL field performance and compositional data were analyzed as a factorial design (3 first operations × 2 harvest methods). Fermentation data from 2014 were analyzed as a factorial design (3 first operations × 2 harvest methods × 2 inoculation methods). Any interaction effects with $P > 0.25$ found in the full factorial analysis were removed from the model and the analysis repeated. Differences among means were tested using the Tukey's test with significance declared at $P < 0.05$.

RESULTS

Harvest of WP corn silage typically occurs when DM content is 300 to 400 $g \cdot kg^{-1}$, a range which occurred from

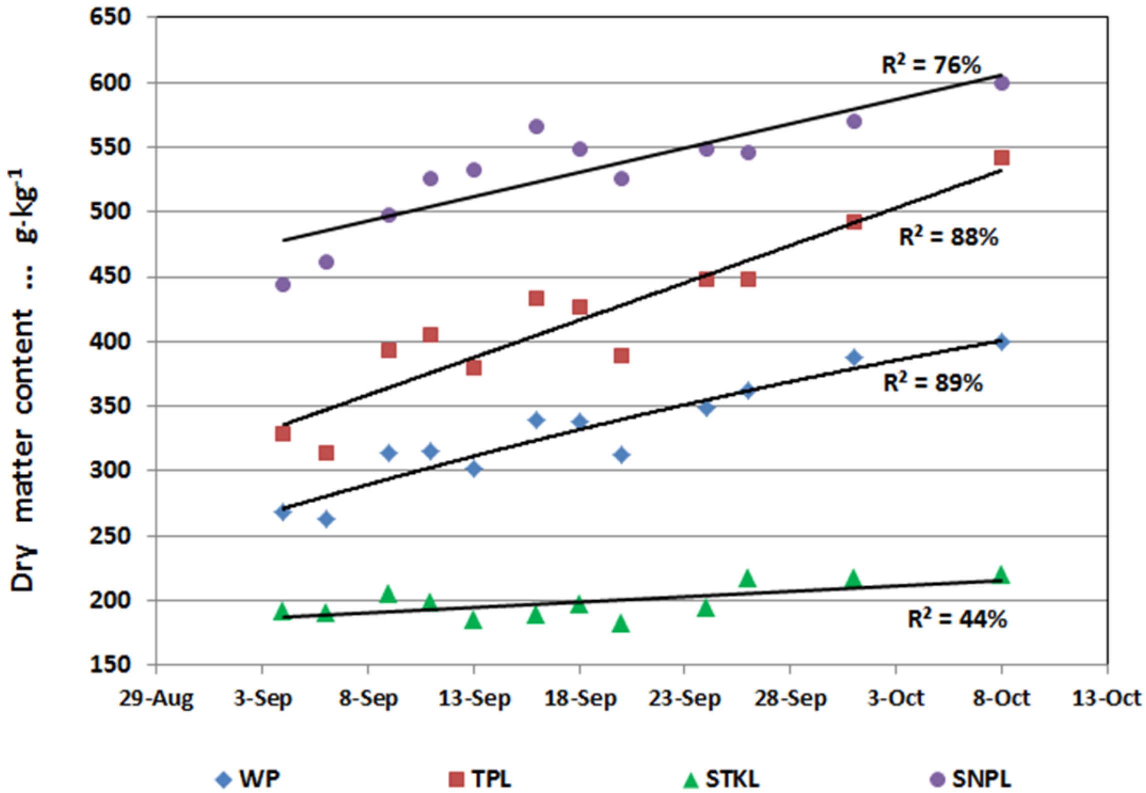

Figure 2. Dry matter content of plant fractions that made up whole-plant, snaplage, toplage, and stalklage (WP, SNPL, TPL, and STKL, respectively) during the 2013 harvest period, determined by hand sampling and averaged across the two fields harvested in subsequent machine experiments.

8 September to 8 October 2013 (fig. 2). This was later than normal in Wisconsin due to spring weather conditions that delayed planting (table 1) and subsequent crop maturity. SNPL harvest DM range is typically 550 to 650 $g \cdot kg^{-1}$ (Lardy and Anderson, 2010), a range which occurred after 23 September, 15 days after WP harvest began. The DM content of TPL increased more rapidly than WP or SNPL because of the greater concentration of the top-stalk and leaf fractions, which dry more rapidly during senescence than other plant fractions (Shinners and Binversie, 2007). Therefore, TPL harvest may have to occur more rapidly to insure that the desired DM range is achieved, but TPL harvest can begin earlier than WP harvest. The stalk fractions that would make up STKL had the lowest DM content and dried the slowest during senescence, so techniques like field wilting and/or silage inoculation may be required to achieve adequate silage conservation without clostridial fermentation if direct harvest of the STKL is planned.

In 2013, harvesting TPL by the addition of stalk cut-off knives to the ES header increased yield by 41% and decreased DM content by 131 $g \cdot kg^{-1}$ compared to harvesting SNPL (table 2). Slightly more than 80% of the total harvested mass was collected in the first operation using the modified header. It was hypothesized that the HC configuration would collect the ear, all of the leaves, and the entire stalk above the cut-point; the TPL configuration (with 4 knives on 6-row header) would collect the ear, two-thirds of leaves and two-thirds of the stalk above the cut-point; and the SNPL configuration the ear only. Based on the hand harvested yields and these assumptions for fractions harvested; the theoretical yields of the SNPL, TPL and HC configurations should have been 61%, 78%, and 89% of the whole-plant DM, respectively. The actual yields were 54%, 77%, and 87% of the available DM. The lower than expected SNPL yield was attributed to observed grain loss from shelling at the SPFH feedrolls.

In 2014, adding four stalk cut-off knives in the forward or rearward positions to the six-row ES header increased overall yield by 27% and 18% and decreased DM content by 82 and 57 $g \cdot kg^{-1}$, respectively, compared to harvesting SNPL (table 2). On a per-row basis, the forward and rearward knife positions increased yield by 0.88 and 0.60 $Mg\ DM \cdot ha^{-1}$, respectively. The position of the knife had a significant effect on stalk height; DM content; and TPL yield because the forward knife position cut the stalk sooner, resulting in less stalk engagement with the snapper rolls and greater yield of the higher moisture stalk below the ear.

Averaged across both years, STKL yield following TPL harvest was 28% greater when windrowing was used, rather than direct harvest (table 2). It was observed that the WPU was able to collect more leaves than the RC header, resulting in greater STKL yield. Windrowing STKL following TPL resulted in about the same DM yield as reported from post-combining corn stover harvest using conventional techniques (Shinners et al., 2007). Harvesting STKL following SNPL produced greater yield than STKL following TPL because most of the leaves and upper portion of the stalk were available for STKL harvest with the former method.

Table 2. Fractional yield (dry basis) and DM content of corn harvested with a self-propelled forage harvester configured with different headers and operating conditions.

Harvest Description[a]	First Harvest Operation: Stalk Height (cm)	First Harvest Operation: DM Content ($g \cdot kg^{-1}$)	First Harvest Operation: Yield ($Mg \cdot ha^{-1}$)	Stalklage Harvest: Number of Oper.[b]	Stalklage Harvest: DM Content ($g \cdot kg^{-1}$)	Stalklage Harvest: Yield ($Mg \cdot ha^{-1}$)	Total Yield ($Mg \cdot ha^{-1}$)	Yield Compared to WP[c] (%)
Trials Conducted on 23 Sept., 29 Sept., and 7 Oct. 2013								
TPL[d]	115 b	422 b	17.6 c	1	266 b	3.4 c	21.1 bc	-8
				2	360 a	4.3 b	21.8 ab	-5
SNPL	130 a	553 a	12.5 d	2	367 a	7.4 a	19.9 c	-13
HC	100 c	406 b	20.5 b	1	237 b	2.5 d	23.0 a	0
WP	25 d	377 c	23.0 a				23.0 a	
Significance[e]	<0.0001	<0.0001	<0.0001		<0.0001	<0.0001	<0.0001	
Trial Conducted on 24 Sept. 2014								
TPL - Forward[f], [d], [b]	115 c	459 c	16.7 c	1	310 b	3.9 d	20.6 ab	-6
				2	398 a	4.7 cd	21.4 ab	-2
TPL - Rear[f], [d], [b]	130 a	484 b	15.6 d	1	311 b	4.2 cd	19.8 ab	-9
				2	406 a	5.9 ab	21.5 ab	-2
SNPL[d], [b]	120 b	541 a	13.2 e	1	359 ab	5.2 bc	18.4 c	-16
				2	340 ab	6.7 a	19.9 bc	-9
HC	65 d	436 c	19.2 b				19.2 c	-12
WP	25 e	393 d	21.9 a				21.9a	
Significance[e]	<0.0001	<0.0001	<0.0001		0.0007	<0.0001	<0.0001	
					Averaged by Header Type			
TPL - Forward[f]					354 a	4.3 c		
TPL - Rear[f]					359 a	5.0 b		
SNPL					349 a	5.9 a		
Significance[e]					0.8296	0.0006		
					Averaged by No. of Oper.			
				1	327 b	4.4 b		
				2	381 a	5.8 a		
Significance[e]					0.0004	0.0001		

[a] TPL - toplage; SNPL - snaplage; HC - high-cut; WP - whole-plant (table 1).
[b] One operation - STKL harvested from standing stalks with RC header.
Two operations - standing stalks harvested with windrower and then STKL harvested with WPU on SPFH.
[c] Difference in combined yield from first operation plus STKL harvest compared to WP.
[d] STKL harvested in 1 or 2 operations following these first harvest operations.
[e] Means within a column with different markers (a–d) differ using Tukey's test at $P < 0.05$.
[f] Forward and rearward indicate position of stalk cut-off knives (table 1).

However, this method resulted in the greatest overall yield reduction compared to WP because the ear-snapper rolls often shattered the wet stalks resulting in pieces too small to be collected. In 2014, windrowing STKL resulted in significantly greater yield and DM content than the direct harvesting STKL. Windrowing may be needed to achieve the required DM range to achieve adequate silage conservation. The method of first operation harvest significantly affected STKL yield but not DM content.

If the target DM content to promote good fermentation of STKL is 350 $g \cdot kg^{-1}$, all windrowed STKL treatments would have been ready to harvest the day after TPL harvest (data not presented). In 2014, the standing stalks reached this DM content one to four days after TPL or SNPL harvest (fig. 3). It was observed that the standing stalks following SNPL (i.e., no cut-off knives) were split open due to considerable stalk engagement with the snapper rolls, and this conditioning likely contributed to the faster drying rate. The least snapper roll engagement occurred when the forward positioned knives (TPL) were used, resulting in the slowest drying rate.

In 2013, HC cut height was 105 cm compared to 40-70 cm in other HC studies (Neylon and Kung, Jr., 2003; Wu and Roth, 2005). Compared to WP, HC silage increased starch content by 49 $g \cdot kg^{-1}$ and decreased NDF by 58 $g \cdot kg^{-1}$ (table 3), which were nearly two-fold greater than reported in these earlier studies due to the cut-height differences. In 2014, HC cut height was 65 cm, but starch content was still 56 $g \cdot kg^{-1}$ greater and NDF 47 $g \cdot kg^{-1}$ less

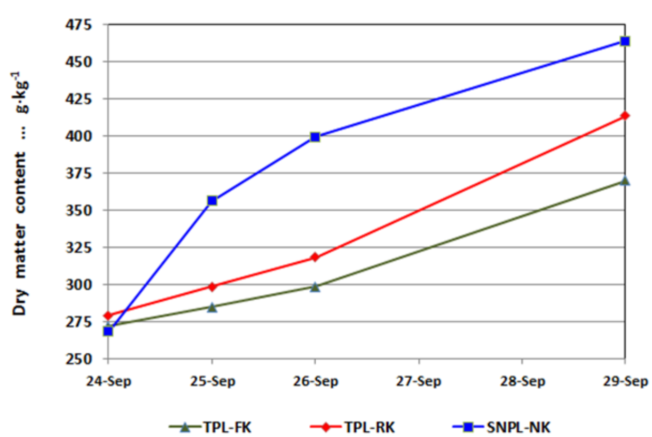

Figure 3. Dry matter content of standing stalks following snaplage (SNPL) or toplage (TPL) harvest on 24 Sept. 2014 with ear-snapper header equipped with no cut-off knives (SNPL–NK); four rearward knives (TPL–RK) or four forward knives (TPL–FK).

Table 3. Compositional analysis of material harvested on the first harvest operation and then ensiled in mini-silos.

Harvest Description[a]	Constituent,[b] g DM · (kg DM) $^{-1}$				
	CP	NDF	Lignin	Starch	Ash
		Trials Conducted on 23 Sept., 29 Sept., and 7 Oct. 2013			
TPL	89 a	321 b	31 c	430 b	31 b
SNPL	88 a	195 c	22 d	586 a	17 c
HC	89 a	345 b	34 b	388 c	34 ab
WP	82 b	403 a	40 a	339 d	37 a
Significance[c]	0.0005	< 0.0001	< 0.0001	< 0.0001	< 0.0001
		Trial Conducted on 24 Sept. 2014			
TPL - Forward[d]	82 ab	229 bc	27 c	485 b	29 ab
TPL - Rear[d]	82 ab	199 c	26 c	520 b	26 b
SNPL	84 a	86 d	18 d	634 a	7 c
HC	78 ab	253 b	30 b	470 b	31 ab
WP	75 b	300 a	33 a	414 c	36 a
Significance[c]	0.0199	< 0.0001	< 0.0001	< 0.0001	< 0.0001

[a] TPL - toplage; SNPL - snaplage; HC - high-cut; WP - whole-plant (table 1).
[b] CP-crude protein; NDF - neutral detergent fiber.
[c] Means within a column with different markers (a–d) differ using Tukey test at P < 0.05.
[d] Forward and rearward indicate position of stalk cut-off knives (table 1).

than WP. In both 2013 and 2014, SNPL starch and NDF concentrations were comparable to those reported in previous studies (Mahanna, 2008; Akins and Shaver, 2014).

We hypothesized that the nutrient composition of TPL would be between SNPL and HC (table 3). TPL yielded starch concentrations much higher than previously published HC studies, yet much lower than reported in previous SNPL studies (Neylon and Kung, Jr., 2003; Wu and Roth, 2005; Mahanna, 2008; Akins and Shaver, 2014). When harvesting TPL, the ES header had stalk cutoff knives on four of six rows, resulting in greater yield of the leaves and upper-stalk in these rows, while only collecting ears on the two remaining rows. Greater leaf and upper-stalk concentration produced TPL with significantly lower NDF than WP (> 70 g·kg^{-1} difference), but significantly greater than that of SNPL (>120 g·kg^{-1} difference). The greater concentration of upper-stalk and leaves diluted the TPL starch content compared to SNPL (>110 g·kg^{-1} difference), but TPL starch content was significantly greater than WP (>70 g·kg^{-1} difference). Positioning the stalk cut-off knives rearward 16 cm reduced stalk and leaf capture by 1.1 Mg DM·ha^{-1}, so NDF was numerically lower and starch concentration was numerically greater compared to the forward knife position (2014 data; table 2).

Windrowed STKL treatments had greater CP (2013 only) and lower NDF and lignin content than the direct harvested STKL treatments (2014 data, table 4) as a result of greater leaf yield from windrowing (table 2). Windrowing and using the WPU on the SPFH captured more leaf and upper-stalk. These fractions have greater

Table 4. Compositional analysis of stalklage material harvested after the first harvest operation and then ensiled in mini-silos.

Harvest Description[a]	Constituent[b], g DM · (kg DM) $^{-1}$				NDFD[c], g · (NDF kg) $^{-1}$		
	CP	NDF	Lignin	Ash	24 h	30 h	48 h
			Trials Conducted on 23 Sept., 29 Sept., and 7 Oct. 2013				
Direct-cut after TPL	36 bc	721 a	75 a	46 a	114 b	188 c	249 b
Windrowed after TPL	43 b	702 a	71 a	46 a	164 a	229 b	308 a
Windrowed after SNPL	53 a	685 a	65 b	49 a	185 a	262 a	347 a
Direct-cut after HC	31 c	720 a	77 a	45 a	104 b	172 c	226 b
Significance[d]	< 0.0001	0.1220	< 0.0001	0.1143	< 0.0001	< 0.0001	< 0.0001
			Trial Conducted on 24 Sept. 2014				
First Harvest Method[e]							
TPL - Forward[f]	51 a	717 a	68 a	65 a	122 a	230 a	358 a
TPL - Rear[f]	54 a	715 a	67 a	70 a	119 a	230 a	356 a
SNPL	53 a	711 a	64 a	66 a	127 a	245 a	376 a
Significance[d]	0.3888	0.8748	0.3836	0.4589	0.6921	0.2429	0.4079
STLK Operations[g]							
Direct-cut	53 a	729 a	74 a	63 b	86 b	193 b	304 b
Windrowed	52 a	700 b	59 b	72 a	159 a	276 a	422 a
Significance[d]	0.8963	0.0043	< 0.0001	0.0184	< 0.0001	< 0.0001	< 0.0001

[a] TPL - toplage; SNPL - snaplage; HC - high-cut; STKL – stalklage (table 1).
Direct-cut - STLK harvested from standing stalks with row-crop header.
[b] CP-crude protein; NDF - neutral detergent fiber
Windrowing - standing stalks harvested with windrower and then STLK harvested with windrow pick-up on forage harvester.
[c] NDFD - fraction of NDF digested after 24, 30 or 48 h incubation
[d] Means within a column with different markers (a–d) differ using Tukey's test at P < 0.05.
[e] Data averaged across STKL harvest method (direct-cut and windrowing).
[f] Forward and rearward indicate position of stalk cutoff knives (table 1).
[g] Data averaged across first harvest operations.

fiber digestibility than other tissues comprising the STKL, which resulted in an overall increase in the fiber digestibility (NDFD) for the windrowed treatments in both years of the study. Corn leaves and stalks (i.e., corn stover) increase in NDF and decrease in CP and fiber digestibility with maturity (Darby and Lauer, 2002). The STKL, due to its concentration of the lower-stalk, was both high in NDF and the NDF was highly lignified (~9% of NDF) compared to reported values for the non-grain portions of the plant harvested for silage in the early-fall (Hunt et al., 1992; Burken et al., 2013). However, STKL was of similar or better nutrient composition (CP and NDF) than reported values for corn stover harvested in the late-fall after grain harvest (Lee et al., 2007; Huang et al., 2012; Shreck, 2013; Li et al., 2014), despite the concentration in the STKL of the least digestible plant tissues. This would suggest when the lowest quality tissues are harvested at an earlier maturity (i.e., STKL following TPL compared to stover after grain harvest) that using STKL instead of wheat straw or corn stover in the dairy ration may improve animal performance. Based on the achieved STKL nutrient composition, it would be competitive with post grain harvest stover as maintenance feed for dry cows, heifers, and beef animals.

Preservation of material harvested in the first operation and stored in mini-silos was very good with losses typically less than 2% of DM (data not reported). In 2013, the pH of all the silages was greater than expected given the measured values of lactic and acetic acid (table 5). Lactic acid has a pKa of 3.86, so the moderate, but significant amounts that were produced in these silages (15 to 31 $g \cdot kg^{-1}$) would be expected to result in lower pH than were measured. In 2014, the pH of all silages were at levels expected given the total acids produced. In 2013, silos were stored over the winter in an unheated room which might have reduced the biological activity and limited fermentation.

In both years, the type of first pass harvest operation significantly affected the level of fermentation as quantified by total fermentation products. This was likely due to how harvest affected the DM content as total fermentation products were linearly related to DM (R^2 = 98%). Inoculation of silages did not affect the total acids produced but did shift fermentation acid dominance from lactic to acetic acid. The inoculant used was a combination of homofermentative (*L. Pediococcus*) and heterofermentative (*L. buchneri*) bacterial species with the latter helping to boost acetic acid production. Acetic acid is a better inhibitor of yeasts and molds than lactic acid (Muck, 2010).

In both years, the SNPL treatment had significantly lower total fermentation products than other treatments (table 5). The SNPL lactic and acetic acid production were similar to those reported by Atkins and Shaver (2014). Treatments that included more stover had greater moisture (table 2) and NDF (table 4) which resulted in increased lactic and acetic acid production, and their associated lower pH. Substrates for silage fermentation are mainly water soluble carbohydrates and some structural carbohydrates, primarily hemicellulose (Pahlow et al., 2003). Silage preservation normally depends upon lactic acid bacteria overwhelming competitors and fermenting these sugars to lactic acid (Muck and Shinners, 2001). Most lactic acid bacteria lack the capability to degrade starch, thus starch is a minor source of fermentation substrate (Weinberg and Muck, 1996). The dilution of stover with grain resulted in more mass, but the fermentable microbial substrates did not increase proportionally. The grain also has greater DM

Table 5. Fermentation products and pH of material harvested on the first harvest operation and then ensiled in mini-silos.

Harvest Description[a]	DM Content ($g \cdot kg^{-1}$)	pH	Lactic $g \cdot (kg\ DM)^{-1}$	Acetic $g \cdot (kg\ DM)^{-1}$	Ethanol $g \cdot (kg\ DM)^{-1}$	Total FP[b] $g \cdot (kg\ DM)^{-1}$
Trials Conducted on 23 Sept., 29 Sept., and 7 Oct. 2013						
TPL	442 b	4.75 bc	24.0 ab	7.6 a	4.3 a	38.9 a
SNPL	559 a	5.30 a	15.3 b	4.1 b	3.3 ab	23.6 b
HC	405 bc	4.82 b	27.4 ab	9.6 a	4.4 a	46.3 a
WP	387 c	4.40 c	31.2 a	8.9 a	2.4 b	44.3 a
Significance[c]	< 0.0001	< 0.0001	0.0044	0.0021	0.0005	0.0070
Trial Conducted on 24 Sept. 2014						
Harvest						
TPL - Forward[d]	458 bc	4.14 ab	25.8 bc	19.2 a	5.3 a	53.2 b
TPL - Rear[d]	481 b	4.13 ab	24.6 bc	14.5 b	4.6 ab	46.4 c
SNPL	534 a	4.01 b	21.8 c	11.3 b	3.6 b	38.6 d
HC	436 c	4.24 a	27.0 ab	19.7 a	5.2 a	55.0 b
WP	390 d	4.20 a	31.0 a	22.1 a	5.2 a	61.7 a
Significance[c]	< 0.0001	0.0012	0.0002	< 0.0001	0.0012	< 0.0001
Inoculant						
None	467 a	4.01 a	33.5 a	10.1 b	4.1 b	50.5 a
Inoculated[e]	453 b	4.28 b	18.6 b	24.7 a	5.4 a	51.5 a
Significance[c]	0.0252	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.3586

[a] TPL - toplage; SNPL - snaplage; HC - high-cut; WP - whole-plant (table 1).
[b] Total fermentation products including unreported propionic; butyric; succinic; and formic acids. Total of the unreported acids was less than 3.0 and 1.0 $g \cdot kg^{-1}$ DM in 2013 and 2014, respectively. Butyric acid was undetected in all treatments.
[c] Means within a column with different markers (a–e) differ using Tukey's test at P < 0.05.
[d] Forward and rearward indicate position of stalk cutoff knives (table 1).
[e] Bacterial inoculant - Pioneer 11C33 with *L. buchneri* and *L. plantarum*.

content, therefore its inclusion reduces the overall moisture content and water activity of the silage. Thus, as grain concentration increases, the level of fermentation generally will decrease and that was the case in this study and that conducted by Atkins and Shaver (2014). Adding stalk cut-off knives to create TPL silage produced a more fermentable product than SNPL because it had greater moisture and fermentable substrate.

All the STKL treatments fermented very well with low DM losses (average of less than 2%, data not reported), low pH, and high total fermentation products (table 6). STKL fermentation was more robust than that of most of the first harvest materials, likely due to differences in DM content and substrate concentration. There were few significant differences in fermentation characteristics between STKL treatments, but wilted treatments had greater DM content and consequently numerically lower (2013) or significantly lower (2014) total fermentation products. Since STKL represented less than 20% of the total harvested mass (table 2), STKL would likely have a much slower silo feedout rate than TPL. Therefore, a strong STKL fermentation is important to prevent excessive aerobic spoilage.

If silage is too moist and pH decline is not sufficient, clostridial bacteria may ferment lactic to butyric acid and amino acids to ammonia (Weinberg and Muck, 1996). This secondary clostridiall fermentation results in greater pH, loss of silage DM, and reduced silage palatability. Clostridial bacteria are inhibited by a combination of low water activity (high DM) and low pH (McDonald, 1981). Despite the low STKL DM content of the treatments harvested from standing stalks, there was no evidence that clostridial fermentation produced butyric acid. Evidently, the STKL pH was low enough to suppress clostridial growth. An additional factor that assists clostridial growth is their proteolytic ability that produces ammonia, raising the pH and enhancing further clostridial growth. However, STKL had low CP (table 4), which made it more difficult for clostridial to produce a secondary fermentation. In 2013, the mini-silos were in storage for a long enough period for secondary fermentation to occur, but they were stored in an unheated room over the winter months and the low temperature may have suppressed clostridial activity. However, in 2014 the mini-silos were stored in a heated room long enough for secondary fermentation to occur (177 days), but levels of butyric acid were undetectable in all samples analyzed.

We hypothesized that the degree of kernel processing may increase with decreasing non-grain material passing through the crop processor. The geometric-mean-particle-size (GMPS) of the silages was not significantly different (data not presented) but kernel particle-size was significantly impacted by the type of harvest operation (table 7). Kernel GMPS was well correlated with both yield of the non-grain fraction (R^2 = 99%) and the material NDF content (R^2 = 87%). No attempt was made to maintain

Table 6. Fermentation products and pH of stalklage material harvested after the first harvest operation and then ensiled in mini-silos.

Harvest Description[a]	DM Content ($g \cdot kg^{-1}$)	pH	Lactic $g \cdot (kg\ DM)^{-1}$	Acetic	Ethanol	Total FP[b]
Trials Conducted on 23 Sept., 29 Sept., and 7 Oct. 2013						
Direct-cut after TPL	264 a	4.16 a	39.0 a	15.6 a	1.8 a	61.3 a
Windrowed after TPL	336 a	4.02 a	31.9 a	10.9 a	1.2 a	46.7 a
Windrowed after SNPL	350 a	4.03 a	36.3 a	11.6 a	1.3 a	52.5 a
Direct-cut after HC	233 a	3.79 a	43.8 a	17.5 a	2.8 a	67.2 a
Significance[c]	0.2480	0.7478	0.8397	0.0761	0.7614	0.5243
Trial Conducted on 24 Sept. 2014						
First Harvest Method[d]						
TPL - Forward[e]	356 a	4.34 a	38.7 a	22.7 a	2.7 a	64.1 a
TPL - Rear[e]	363 a	4.37 a	37.4 a	21.1 a	2.5 a	60.9 a
SNPL	358 a	4.28 a	39.6 a	19.5 a	0.9 b	59.9 a
Significance[c]	0.8086	0.1552	0.6689	0.0853	< 0.0001	0.1859
Inoculant[f]						
None	362 a	4.29 a	42.6 a	17.5 b	1.3 b	61.4 a
Inoculated[g]	356 a	4.37 b	34.5 b	24.7 a	2.7 a	61.9 a
Significance[c]	0.5325	0.0294	0.0002	< 0.0001	< 0.0001	0.8137
STLK Operations[h]						
Direct-cut	329 a	4.35 a	38.7 a	23.7 a	2.6 a	65.0 a
Windrowed	389 b	4.31 a	38.4 a	18.5 b	1.4 b	58.3 b
Significance[c]	< 0.0001	0.2291	0.8593	< 0.0001	0.0003	0.0010

[a] TPL - toplage; SNPL - snaplage; HC - high-cut; STKL - stalklage (table 1).
Direct-cut - STLK harvested from standing stalks with row-crop header.
Windrowing - standing stalks harvested with windrower and then STLK harvested with windrow pick-up on forage harvester.
[b] Total fermentation products including unreported propionic; butyric; succinic; and formic acids.
Total of the unreported acids was less than 5.0 and 1.0 $g \times kg^{-1}$ DM in 2013 and 2014, respectively. Butyric acid was undetected in all samples.
[c] Means within a column with different markers (a–c) differ using Tukey's test at P < 0.05.
[d] Data averaged across both types of operations to harvest STLK and inoculant used.
[e] Forward and rearward indicate position of stalk cutoff knives (table 1).
[f] Data averaged across both first harvest and STLK harvest operations.
[g] Bacterial inoculant - Pioneer 11C33 with *L. buchneri* and *L. plantarum*.
[h] Data averaged across both inoculants used and first harvest operation.

Table 7. Geometric-mean-particle-size (GMPS) and estimated surface area of kernels after first harvest operations on 24 Sept. 2014.[a]

Harvest Description[b]	GMPS[b] (mm)	Estimated Surface Area[c] ($cm^2 \cdot kg^{-1}$)
TPL - Forward[d]	2.2 c	35,497 bc
TPL - Rear[d]	2.1 cd	39,631 b
SNPL	1.8 d	48,750 a
HC	2.5 b	30,817 cd
WP	2.8 a	25,332 d
Significance[e]	<0.0001	<0.0001

[a] Crop processing roll clearance was 3 mm.
[b] TPL - toplage; SNPL - snaplage; HC - high-cut; WP - whole-plant (table 1).
[c] Geometric-mean-particle-size as determined by ASABE Standard S319.4
[d] Forward and rearward indicate position of stalk cut-off knives (table 1).
[e] Means within a column with different markers (a–d) differ using Tukey test at P < 0.05.

similar mass-flow-rate across all treatments, so the kernel GMPS results could have been influenced by differences in overall mass-flow-rates. This hypothesis deserves greater study because of the impact starch particle-size has on dairy cattle performance.

Discussion

TPL had greater starch and lower NDF than WP silage, and because the bottom stalk was not harvested, the NDF would likely be more digestible. TPL would likely be used to replace both WP silage and some of the corn grain in the dairy ration. As a ration ingredient, TPL would have greater digestibility and lower physically effective fiber than WP silage. If used directly in place of WP silage, this could result in rumen acidosis (Plaizier et al., 2008), so careful balancing of effective fiber would be needed. The greater total diet NDF and the improved NDF digestibility should result in more energy in the ration being derived from fiber. Having TPL supply more of the corn grain will result in a starch that is more digestible, as earlier harvest corn grain that is fermented produces improved starch digestibility compared to dry ground corn (Benton et al., 2005).

The STKL was very high in NDF and the NDF was more lignified (table 4) which may limit its use to dry cow and heifer rations where ruminal fill to limit intake is desirable. It could also be reincorporated with TPL in feeding some later lactation animals. STKL is a feed source that is low in calcium, making it desirable in a dry cow ration (Goff, 2008). The high physically effective fiber also is beneficial in dry cow rations to keep the rumen full and prevent displaced abomasum. Because STKL is harvested separately from the corn silage and has a high indigestible NDF content, it makes it a good candidate for chemical treatments to enhance its digestibility rates. For instance, Shrek (2013) treated corn stover with CaO to enhance NDF digestibility.

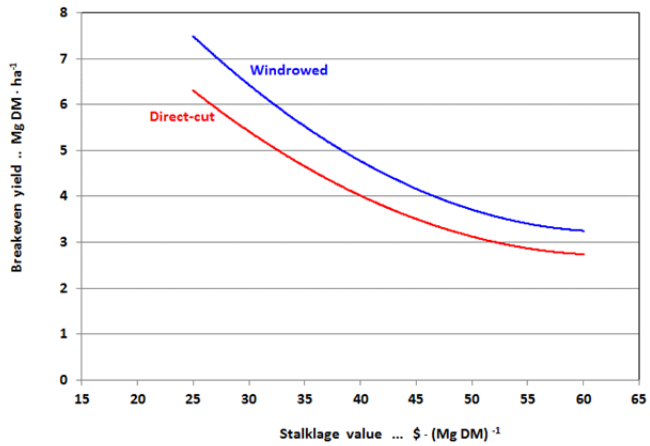

Figure 4. Breakeven yield as a function of STKL value for the two STKL harvest methods used in this study. Average cost for harvest, transport and storage were $160 and 190·ha^{-1}, for direct-cut or windrowed methods, respectively.

Stalklage yield and value are relatively low compared to other forages, with corn stover likely its closest comparison. Harvest and storage costs must be less than the STKL value to justify its harvest. Custom rates for Wisconsin were used to estimate STKL harvest, hauling and packing costs (USDA-NASS, 2014). Average estimated costs for windrowing stalks were $30·ha^{-1}. Average costs for chopping, hauling and packing were estimated at $160·ha^{-1}. Stalklage value was varied between $25-60·(Mg DM)$^{-1}$ which bracketed the 2014 auction prices for corn stover in the Midwest. Breakeven yield was calculated using these estimates (fig. 4). To economically justify direct-cut harvest of STKL following SNPL or TPL (2014 data, table 2), its value must exceed $31 or $40·(Mg DM)$^{-1}$, respectively. When harvesting STKL by windrowing after SNPL or TPL, its value would need to exceed $29 or $41·(Mg DM)$^{-1}$, respectively. The greater yields produced by windrowing STKL would only slightly offset the operations added cost. The current feed value of corn stover was estimated at $65 ·(Mg DM)$^{-1}$ (Edwards, 2014) so harvesting STKL should be justified under the scenarios explored in this study.

Conclusions

Fractional harvest of corn silage was shown to be a practical alternative to traditional WP corn silage or SNPL, and was achieved with easily adopted modifications to the ES header. The TPL nutrient composition was between WP and SNPL, resulting in a ration ingredient that will likely have greater digestibility than WP silage due to differences in NDF concentration and fermentation should improve starch digestibility compared to dry ground grain. Harvesting STKL after TPL resulted in a high-fiber, low-energy roughage feed that could be used as an economical alternative ration component for dry cows, heifers and beef animals.

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