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Drying, Harvesting and Storage Characteristics of Perennial Grasses as Biomass Feedstocks

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Abstract. Reed canarygrass and switchgrass were established on 4 ha plots so that crop drying rate, baling rate, bale density, storage losses, and quality changes could be determined. In a single-cut system, switchgrass yield was 8% greater than reed canarygrass in the second year of production. Reed canarygrass yield was 14% greater in a two cutting system than a single cut system. Initial moisture at cutting was 58 to 47% (w.b.) for reed canarygrass and 66 to 46% (w.b.) for switchgrass. When crop yield was similar, switchgrass tended to dry faster than reed canarygrass. When crop was placed in a wide-swath by tedding, it was possible to achieve baling moisture (< 20% w.b.) in a single day. Bale density averaged 163 kg DM/m^3 with no significant differences between crops or type of wrap (twine or net). Dry bales stored outdoors for 9 and 11 months averaged 3.4, 7.7, 8.3, and 14.9% DM loss for bales wrapped with plastic film, net wrap, plastic twine, and sisal twine, respectively. Bales stored indoors averaged 3.0% DM loss. The most uniform biomass feedstock was generated by storing indoors or ensiling in a tube of plastic film. Preservation by ensiling in a tube of plastic film produced average DM losses of 1.1%. Baling and then ensiling without field wilting was successful.

Keywords. Biomass, biomass collection; biomass harvest; grasses, switchgrass, reed canarygrass

Introduction

In North America, the main feedstock for fuel ethanol is currently corn grain. New enzyme hydrolysis and fermentation technologies are being developed to produce ethanol from cellulosic biomass such as grasses, straw and wood. The energy balance for these materials has the potential to be much more favorable than with corn grain (Farrell et al., 2006). Often mentioned as a biomass feedstock is switchgrass (Panicum virgatum L.) which is a warm-season (C4) perennial grass. Switchgrass is a course-stemmed plant that grows 1 to 2 m tall with yields between 8 and 20 t DM/ha (Huisman, 2003). Switchgrass is established by seed, has a low nutrient demand, efficient water use and good persistence. Another potential perennial grass that could serve as a biomass feedstock is reed canarygrass (Phalaris arundinacea L.). Reed canarygrass is a cool-season (C3) grass adapted to much of the northern half of North America, so it may be better suited as a biomass crop than switchgrass in northern climates. It begins growth in early spring with growth peaking in mid-June and declining in mid-August. Although there has been much research concerning agronomic practices related to these species, there has not been a great deal of work related to harvest, drying, packaging and storing of these materials in a systems approach.

One production variable that needs to be considered with perennial grasses to be used as biomass feedstocks is cutting frequency. Since high forage quality for livestock production is not required, it may be more economical to harvest once per year after the growing season. Wright (1990) reported that switchgrass and reed canarygrass cut twice per year produced a 47 and 31% greater DM yield, respectively, than a single cut system. In Oklahoma, harvest frequency was the most important factor affecting yields over a two year study with average DM yields of 16.3, 14.7, and 12.9 Mg/ha/yr for three, two, and one cutting per year, respectively (Thomason et al., 2004). Two switchgrass cultivars yielded more on average with two cuttings rather than one, with 36% greater for an upland cultivar harvested twice per year (Fike et al., 2006). Two harvests per year may increase yields in some cultivars, but a single annual harvest maximizes yields in other cases (Parrish and Fike, 2005). If two harvests are taken, more N must be applied to compensate for the N removed in the midseason harvest. Taking more than two harvests per year often adversely affects long-term productivity and persistence (Parrish and Fike, 2005). In Sweden, reed canarygrass DM yield decreased with more than two cuts per year (Geber, 2002). Whether increased yields from two harvests per season are enough to justify the expense of an extra trip over the field remains to be determined.

Estimating costs for harvesting perennial grasses as biomass feedstocks requires data concerning baling productivity and bale density. Perennial grasses cut once or twice per year have yields much greater than those typically experienced with forage crops, so conventional hay harvesting equipment may not adequately handle the crop volume. Bale density was not dependent upon switchgrass yield and round bale density was reported as 136 kg DM/m^3 (Bransby and Sladden, 1996). Baling productivity for a Class IV round baler was 9.2 Mg DM/h in this study. Type of wrap used was not identified.

Another important aspect of the production system for perennial grasses is the physical and chemical condition of the grasses after a period of conservation. Losses of switchgrass DM in round bales stored outside on crushed rock were 2 – 4% of DM over an 8.5-month period in Indiana (Johnson et al., 1991). Twine wrapped bales stored outside on the ground lost up to 15% of DM during this period. Loses of switchgrass DM ranged from 5 to 13% for bales stored outdoors over 12 months (Sanderson et al., 1997). Switchgrass bales exposed to 650 mm of precipitation showed a significant loss of extractives in both the rind (11%) and the core (8%) of the bale (Wiselogel et al., 1996).

<u>Objectives</u>

The objectives of this research were to establish plots of switchgrass and reed canarygrass in a northern US location and compare yields and stand persistence; to collect production data relative to crop drying rate, baling rate and bale density; and to investigate storage losses and quality changes in these crops using a variety of round bale storage schemes.

<u>Materials and Methods</u>

<u>Crop Establishment</u>

Both reed canarygrass and switchgrass plots were established in the spring of 2004. The previous crop was corn. Primary and secondary tillage was conducted with a chisel plow (20 cm depth) and a field cultivator (3 cm depth), respectively. The reed canarygrass (Palaton variety) was seeded with a Brillion[1] Sure Stand seeder at the rate of 16.8 kg/ha on April 30th, 2004. The reed canarygrass was cut and biomass disposed on June 29th, 2004. No herbicides have been applied to this crop. Granular urea was top dressed at the rate of 90 kg/ha in April of 2005 and 2006. The switchgrass (Shawnee variety) was planted with the same seeder on May 29th, 2004 at 16.8 kg/ha. Drive 75DF herbicide (585 ml AI/ha) was applied one day after planting. The switchgrass growth was halted by application of 2,4-D (2,350 ml AI/ha) on July 9th, 2004. A tank mix of Pursuit DG (105 ml AI/ha) and Banvel (585 ml AI/ha) were applied on May 19th, 2006 for weed control. Granular urea was top dressed at the rate of 90 kg/ha in April of 2005 and 2006.

<u>Crop Drying Rate</u>

The first drying trial used both reed canarygrass and switchgrass and was conduced on October 9th – 11th, 2004. The crop was cut and conditioned with a John Deere[1] model 4990 disk cutterbar windrower (4.5 m cut width) equipped with urethane conditioning rolls. The yield was 4.1 and 5.9 Mg DM/ha for the reed canarygrass and

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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 or the USDA–ARS.

switchgrass, respectively. The crop was placed in either swaths or windrows that were approximately 60 and 30% of cut width, respectively. Four replicate swaths or windrows were formed. A single sample of material was collected from each replicate right after cutting and periodically during the daylight hours during the next few days. For each replicate sample, about 0.5 m of material was collected across the full width and depth of the swath or windrow, placed in a container and transported to the farmstead to be size-reduced by chopping. No sample was taken immediately adjacent to a previous sample to eliminate edge effects. The chopped material was mixed and then three sub-samples collected and oven dried for 24 h at 103ºC as per ASAE Standard: S358.2 (ASAE, 2004).

The second drying trial used only reed canarygrass and was conducted on July 14th – 15th, 2005 when the yield was 6.3 Mg DM/ha. The treatments and procedures were the same as described above with the exception of a tedded treatment that created a swath that was as wide as the cutting platform (wide-swath). The final drying trial again used both reed canarygrass and switchgrass and was conducted on August 29th and 30th, 2005 when the yield was 8.3 and 9.0 Mg DM/ha, respectively. The three swath width treatments and all data collection procedures were the same as described above.

The drying data was analyzed assuming that the data fit the following exponential drying rate model (Rotz and Chen, 1985):

$$\frac{M}{M_0} = e^{-kt} \tag{1}$$

where:

M	=	dry basis moisture at the end of the time interval,
M_0	=	dry basis moisture at the beginning of the time interval,
k	=	drying constant (h^{-1})
t	=	length of time interval (h)

For each day and treatment, the drying constant was then transformed based on the least square linear regression model of several data points (Greenlees et al., 2000):

$$k = \frac{n\sum t_i \ln \mu_i - (\sum t_i)\sum \ln \mu_i}{n\sum t_i^{\,2} - (\sum t_i)^2} \tag{2}$$

where:

k	=	transformed drying rate constant (h-1)
n	=	number of observations in each day
t_i	=	actual drying time between each observation
μ_i	=	dry basis moisture content

A daily transformed k-value was calculated for each treatment and an average drying constant also determined over the period of the study. A single factor analysis of variance was conducted on all the experiments to determine statistically significant differences in the treatment averages for each day. A two-way analysis of variance was used to block confounding effects of different days when analyzing the data for the multiple days of a test. Statistical differences were based on a least significant difference (LSD) with a probability of 95%.

Baling Productivity and Yield

Reed canarygrass was cut on July 14th, August 29th, and October 27th, 2005 in plots of approximately 2 ha each. The October cutting was re-growth from the July cutting. Switchgrass plots of 2 ha each were also cut on the latter two dates. The crop was cut with the same equipment described above and placed in swaths at 60% of cut width. A few hours before baling, a single rotor rotary rake was used to narrow the swath into a windrow of appropriate width for the baler pick-up. Baling took place after two or three days of field curing. A few bales were formed the day of cutting to produce bales for ensiling for the storage study (see below). Bales were formed by an experienced round bale operator with a John Deere[1] model 7820 tractor and model 567 round baler (157 W x 160 cm D). The baler was operated as fast as possible without plugging the pick-up and the belt tension set to maximum. The variable density core option was not activated so belt tension was the same throughout bale formation. Bales were wrapped with either twine or net.

Baling productivity was defined as the total time required from start of bale formation of one bale until the start of the next bale. All bales were wrapped using 8 cm twine spacing plus six end wraps or 2½ layers of net, respectively. The bale monitor/controller automatically started the wrapping sequence after the desired bale diameter had been reached and controlled the entire wrapping process. Wrapping time was defined as the time from initiation of the wrapping cycle to the time when hay began to enter the baler for the next bale. The baler was equipped with a bale ejector so no backing was required. The center-to-center distance between adjacent swaths was measured at many locations to quantify average cutting width. The distance between each bale was measured with a land wheel to the nearest 0.5 m, allowing calculation of baling speed and crop yield. The vertical and horizontal diameter of all bales was measured to the nearest 1 cm to allow calculation of bale density. Each bale was weighed to the nearest 0.5 kg on a 1,800 kg capacity platform scale. The bales were then radially bored twice from either side to a depth of roughy 50 cm using a 5 cm diameter boring tube. The bore samples were combined, mixed and then split into four sub-samples. Two sub-samples were used for moisture determination and were oven dried at 103ºC for 24 h and the other two samples reserved for chemical compositional analysis and were oven dried at 65ºC for 72 h (ASAE Standard S358.2, 2005).

Bale Storage

Five treatments were considered in the storage study. Four involved outdoor storage of bales wrapped with sisal twine, plastic twine, net wrap or wrapped circumferentially with plastic film. The latter treatment was first wrapped with net and then wrapped in three layers of white 1 mil plastic film. The film was wrapped with a typical tube wrapper without laying the wrap over the bale edges. Outdoor stored bales placed on directly on sod with the bales spaced about 20 cm apart. Rows of bales were spaced about 2 m apart on a gentle slope in lines running roughly east to west. The fifth treatment used net wrap bales stored indoors in a completely enclosed shed. The final storage treatment used bales formed late on the day of cutting and then wrapped in a continuous tube of six layers of white 1 mil plastic film and preserved by ensiling.

Five replicate bales of reed canarygrass bales were formed on July 15th, 2005 using four of the treatments described above. Yield was not sufficient to include dry bales wrapped circumferentially in plastic film. Five replicate bales each of reed canarygrass and switchgrass were formed on August 29th, 2005 using all five treatments described above. Bale weight, volume and moisture were determined using the procedures described above.

The reed canarygrass bales formed on July 15th were removed from storage on June 7th, 2006. First, a moisture profile was made using a conductance-type moisture sensor (Delmhorst model F2000). The sensor probe was inserted roughly parallel to the longitudinal axis of the bale to a depth of 25 cm from either end of the bale. Measurements were taken at 5, 10, 15, 20, 30 and 50 cm from the bale surface and also at the approximate center of the bale. Measurements were taken at the 3, 6, 9 and 12 o'clock radii on one end of the bale and at the 1:30, 4:30, 7:30 and 10:30 radii on the other. Therefore, a total of 50 moisture measurements were made from each bale.

Before a bale was moved, the width, height, and diagonal diameters were measured to the nearest 1 cm. All bales were then weighed as previously described. If a portion of the bale was left on the ground when it was lifted, this material was collected by hand and weighed to the nearest 0.05 kg on a 45 kg capacity scale. Sub-samples of the material left on the ground were collected to determine oven dry moisture. After the bale had been lifted, bottom length in contact with the soil was measured to the nearest 1 cm on both sides and middle of the bale. Five bore samples for moisture (5 cm diameter) were taken from the rind of the bale to a depth of 20 cm. Samples were taken at the 1:30, 4:30, 7:30, and 10:30 positions on the bale. Samples were also taken at the 3:00 or 9:00 positions, with one sample each used for moisture or chemical composition analysis. On two bales, the first sample (1:30) was taken 20 cm from the east face of the bale and each subsequent sample taken 20 cm away so that samples were taken in a spiral pattern. On the remaining three bales, the first sample was taken 20 cm from the west bale face. All bore samples were oven dried individually and the moistures averaged and defined as the moisture of the rind of the bale. Two additional bore samples, one each at the 3:00 and 9:00 positions, were taken from a depth of 20 to 50 cm. These bore samples were each split into two sub-samples, one each for moisture and chemical composition analysis. This moisture was defined as the core moisture. The bale was then tipped and four bore samples taken from the bottom of the bale to a depth of 20 cm. Two bore samples were used for moisture determination and two for chemical composition. This moisture was defined as the bottom moisture. All moisture samples were oven dried at 103°C for 24 h (ASAE Standard S358.2, 2005). Samples for chemical composition analysis were oven dried at 65°C for 72 h and then analyzed using wet laboratory methods by the USDA US Dairy Forage Research for crude protein (CP), acid-detergent fiber (ADF), neutral-detergent fiber (NDF).

To determine the DM in the bale after the storage period, the overall volume adjusted bale moisture was calculated by first using the dimensions described above to calculate the volume of the rind, core and base of the bale (fig. 1). The volume adjusted moisture of the bale was determined by:

$$M_a = \frac{\left(M_r \bullet V_r \quad + \quad M_c \bullet V_c \quad + \quad M_b \bullet V_b\right)}{V_t} \qquad (3)$$

where:

M	=	wet basis moisture content
V	=	volume of bale section
i	=	subscript indicating rind (r), core (c), base (b) or volume adjusted total (a)

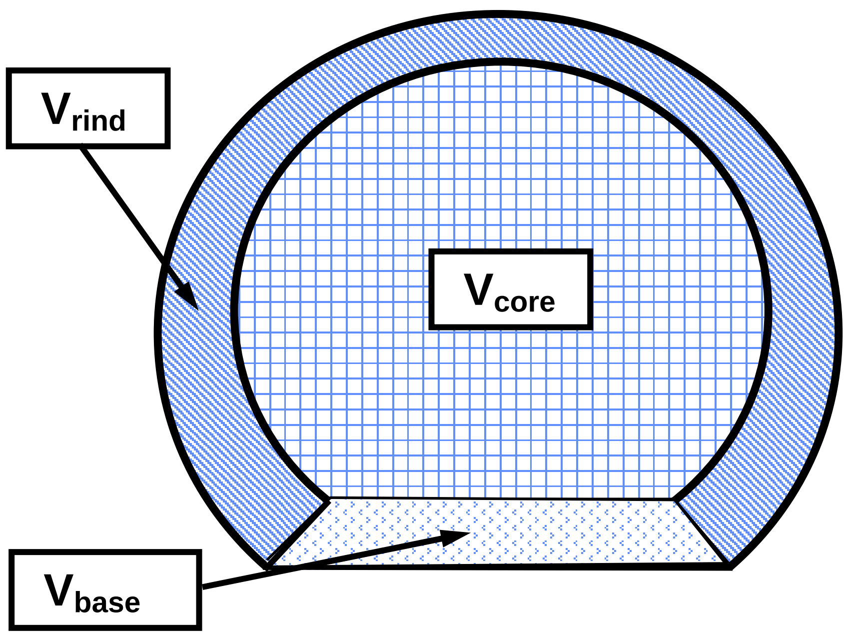

Figure 1. Locations of the volume of the rind, core and base of the bale used to calculate the volume adjusted bale moisture for bales removed from storage.

Bales wrapped in a plastic film tube and preserved by ensiling were removed from storage at the same time as the dry bales. As bales were removed from storage they were weighed using the same equipment and procedure as described above. Bales were bored to a depth of about 50 cm in three locations using the same boring device described above. Two samples each were taken from each side at the 3:00 and 9:00 positions and also on the bottom of the bale. All samples were combined, mixed and then separated into seven sub-samples. One sub-sample was placed in a plastic bag and frozen for later determination by the USDA US Dairy Forage Research Center of pH, lactic acid, acetic acid and ethanol using high performance liquid chromatography (Muck and Dickerson, 1988). The six remaining sub-samples were oven dried at 65ºC for 72 h for moisture determination. Two of the sub-samples were used for chemical compositional analysis using the wet laboratory procedures described above.

Results

Field Drying

Weather conditions during the three drying studies were considered good for the time of year (table 1) with no precipitation. The first year fall drying rates were similar to the second year summer drying rates despite the better drying conditions of the latter season (tables 1 and 2). These differences were likely due to differences in yield between the two cuttings (table 2). Like perennial forage crops, reed canarygrass and switchgrass dried more quickly when it was placed in a wide-swath (table 2). In October 2004, the drying rate difference between these two crops was most likely due to differences in crop yield. In August 2005 when yield was similar between the two biomass grasses, there were no significant differences in drying rate between the two crops. Tedding significantly increased the drying rate of both crops (figs. 2 and 3). It was observed that the tedder was not able to uniformly spread the crop the full width of the cutting platform due to the high yield of the crop. The tedder used was intended to treat hay crops where yields are typically not in excess of 4.5 Mg DM/ha. It was observed that the tedded swath had less material at the edges than at the center. In the August 2005 study, yields were greater than 8 Mg DM/ha and the tedder was not able to uniformly distribute a crop with this high yield. The drying rate constants reported here are greater than those reported for alfalfa or grass crops (Rotz, 1995; Greenlees et al., 2000; Shinners et al., 2006 a,b) despite the fact that the biomass grasses had yields over twice that of typical forages. There were several observed differences between these biomass crops and typical forage crops. First, reed canarygrass was 58 to 47% and switchgrass was 66 to 46% (w.b.) moisture at cutting (table 3), considerably drier at cutting than typical forage crops. These grasses were very mature, with a height of about 1.5 m at cutting with a large, stiff stem. The swath or windrow was very well formed and because of the low initial moisture they did not slump into the stubble as often observed with high-moisture forages. These well formed structures probably aided in rapid drying due to ease of air movement through the cut crop. These mature crops also vary large leaf area, which also promoted rapid drying. In all cases studied, the crop was below 20% (w.b.) moisture early in afternoon of the third day of drying.

Table 1. Average ambient conditions during the daytime drying period when samples were collected for the three different drying rate experiments conducted in 2004 and 2005.

Date	Ambient temperature ° C	Solar radiation W / m^2	Wind speed m/s	Relative humidity %
2004				
October 9th	18	518	4.4	39
" 10th	16	495	2.4	50
" 11th	14	448	2.6	58
2005				
July 14th	30	548	4.0	50
" 15th	29	718	2.6	46
August 29th	26	615	3.2	53
" 30th	21	456	4.0	72
" 31st	22	587	2.9	61

Table 2. Yield and drying rate of biomass crops as affected by swath width and date.

	Reed canarygrass				Switchgrass				
	Yield	Drying constant			Yield	Drying constant			LSD*
	Mg DM/ha	Tedded	Swath	Windrow	Mg DM/ha	Tedded	Swath	Windrow	(P = 0.05)
October, 2004	3.58		0.229_{d}	0.183_{c}	5.15		0.157_{b}	0.116_{a}	0.020
July, 2005	6.27	0.235_{b}	0.207_{ab}	0.194_{a}					0.025
August, 2005	8.29	0.185_{cd}	0.147_{bc}	0.101_{a}	8.96	0.201_{d}	0.154_{bc}	0.102_{a}	0.041
October, 2005#	3.14				8.96				

* – Averages with different subscripts in the same row are significantly different at 95% confidence.

– October cutting of reed canarygrass was a second cutting of crop cut in July, so total yield for two cuttings was 9.41 Mg DM/ha.

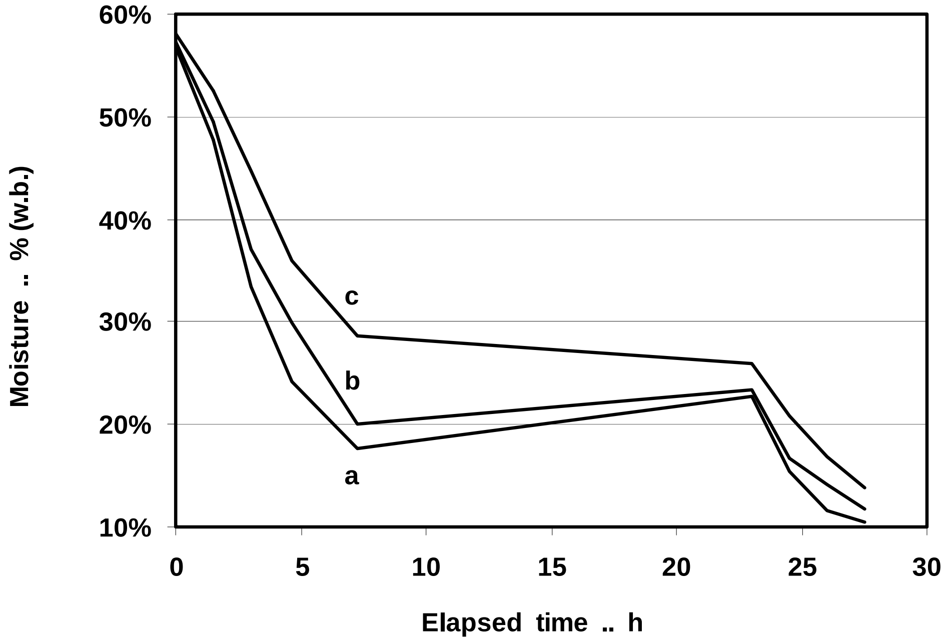

Figure 2. Drying rate of reed canarygrass cut on July14th 2005 and placed in (a) wide-swath, (b) swath and (c) windrow.

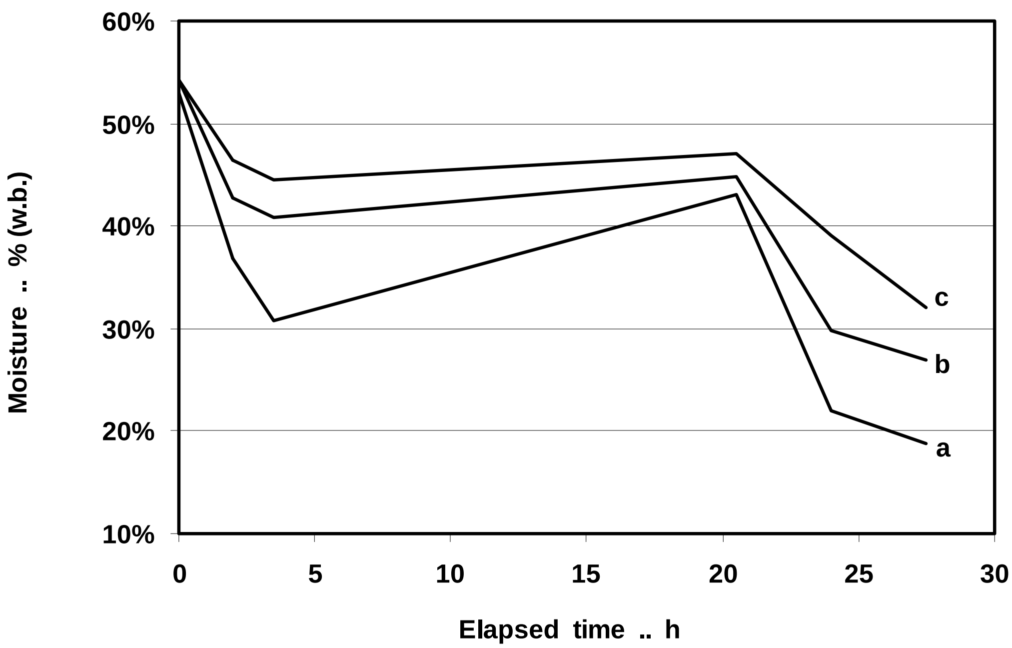

Figure 3. Drying rate of reed canarygrass cut on August 29th 2005 and placed in (a) wide-swath, (b) swath and (c) windrow.

Table 3. Crop moisture, bale density and baling productivity for reed canarygrass and switchgrass.

	Reed canarygrass				Switchgrass			
	Crop moisture				Crop moisture			
	At cutting	At baling	Bale density	Baling productivity	At cutting	At baling	Bale density	Bale productivity
	% w.b.	% w.b.	kg DM/m^3	Mg DM/h	% w.b.	% w.b.	kg DM/m^3	Mg DM/h
July 2005	55.7							
Net wrap		11.4	152					
Twine		11.3	154					
LSD (P = 0.05)		1.7	4					
August 2005	52.4				66.2			
Net wrap		15.1	168	13.4_b		22.6	165	17.7_b
Twine		15.2	171	8.3_a		22.3	166	13.5_a
LSD (P = 0.05)		2.2	5	2.5		3.4	5	1.7

Baling Productivity and Yield

Compared to wrapping with twine, wrapping with net increased baling productivity by 31 to 61% for reed canarygrass and switchgrass, respectively (table 3) because the time to wrap with twine was three to four times greater than with net wrap. Net wrap covered the entire width of the bale at once while the twine had to be spiral wound around the bale, which resulted in the bale being turned about 4 and 25 revolutions during net, and twine wrapping, respectively. Similar productivity differences were found with alfalfa and alfalfa/grass bales (Shinners et al., 2002). Productivity ranged from 8.3 to 13.5 and 13.5 to 17.7 kg DM/h for twine and net wrap, respectively (table 3). Alfalfa baling productivity with the same model baler was 11.6 and 15.3 kg DM/h for twine and net wrap, respectively (Shinners et al., 2002). It was observed that the baler productivity was limited with reed canarygrass and switchgrass because the physical volume of the raked windrow overwhelmed the open area of the baler pick-up, causing crop to pile up in front of the pick-up. Forage crops for animal use are typically cut three to four times per growing season to produce acceptable feed quality. This cutting frequency produces yields much less than those that were experienced with biomass crops cut only once or twice per growing season. Future modifications to the baler pick-up and throat may be needed to handle the high yield and physical volume of crops for biomass feedstocks. Baling productivity was greater for switchgrass than reed canarygrass (table 3). It was observed that the volume of the windrows was greater for reed canarygrass than for switchgrass, which meant that ground speed had to be less for the former crop to prevent crop piling up ahead of the pick-up.

Bale density was not affected by type of wrap or crop (table 3). Density of alfalfa and alfalfa/grass bales averaged 174 kg DM/m^3 over four cuttings (Shinners et al., 2002) which was similar to those found with the perennial biomass grasses. Truck weight and volume legal restrictions limit bale density to about 210 kg DM/m^3, depending upon bale moisture, bale-size and local regulations. The dry density of bales of perennial biomass grasses need to be increased by 20 to 35% to minimize shipping cost.

In the second year of production, switchgrass yield was not affected by cutting date as yields were the same in August as in October (table 2). Reed canarygrass yield was 14% greater with a two cutting system (July, October) compared to a single cut system (August).

Storage

Precipitation during the storage was 702 and 535 mm for bales first stored in July and August 2005, respectively, which was near average for this location. When stored on sod, sisal twine bales had greater DM loss than plastic twine bales primarily because the sisal twine rotted and the bale lost integrity (tables 4 and 6). This allowed greater moisture infiltration that produced a trend for slightly higher moisture in the rind of sisal twine bales. The lack of twine restraint also caused a greater fraction of the bale to be in contact with the sod and significantly increased the moisture in the bottom of the bale (table 4 and 6). It was observed that the material sloughed from bottom of the twine bales and subsequently recovered by hand was very contaminated with soil and of quite poor quality. If this material were assumed impractical to recover, then DM loss would have increased by an average of X percentage units over the three trials.

Previous research had shown that net wrapped bales of alfalfa averaged 4.0 percentage units less DM loss than those wrapped in plastic twine (Shinners et al., 2002). In that study, net wrapped bales had lower moisture in the rind and core than plastic twine wrapped bales. In this research, moisture in the rind and core were statistically similar for the two treatments and these two fractions of the bale made up roughly 40 and 50%, respectively, of the total bale volume. The biomass grasses were very mature when baled and both had large diameter stems that dominated the total DM. This relatively low leaf:stem ratio did not produce a good thatch with either twine or net wrap, so water infiltration during precipitation may have been similar for both wrap types. Soluble components would have made up a smaller fraction of the total DM in the very mature biomass crops compared to an alfalfa crop harvested for animal feed, so DM loss from leaching would have had less impact with the biomass crops.

Storing bales indoors significantly reduced DM loss compared to all other treatments (table 4 and 6). The moisture of the hay in the rind, core and base were significantly lower than all other treatments, which contributed to the lower DM loss because biological activity was less. Bales stored indoors were also not subject to leaching losses during precipitation. The most consistent biomass feedstock occurred with bales stored indoors. Losses of DM were similar between the plastic film wrapped and indoor stored bales (table 6). The stretch film wrapped bales had much higher moisture in the base than the indoor stored treatments, but this fraction only made up roughly 10% of the bale volume. The plastic film kept the moisture within the bale that collected in a thin layer at the base of the bale, but the film prevented rain from penetrating the bale and leaching soluble components, which lowered potential DM loss compared to other treatments. It was observed that there were some rather large patches of green algae formed at the outside of some of the film wrapped bales, which reduced the aesthetic appeal of the bales.

Losses from bales of switchgrass were greater than reed canarygrass bales because the latter averaged 22.5% moisture compared to 15.2% for the former (table 6). These differences were particularly evident with the bales wrapped in film and stored indoors, showing the importance of baling as dry as possible to reduce biological activity.

In all trials, the bales preserved by ensiling had a very pleasant odor when removed and only minor incidences of mold were observed. The bales were observed to be uniform in appearance and physical characteristics. Loss of DM from respiration averaged 1.1% for the 16 ensiled bales. Losses from respiration would have resulted in a rise in moisture because stiochiometrically 60% of the mass of the respired carbohydrates would have remained in the bale as H_2O (Pitt, 1990). The average absolute difference between the final and initial bale moisture was 0.2 percentage units, indicating very low levels of loss from respiration. There was little evidence of moisture equalization within the tube. Two adjacent bales that were several percentage units different in moisture when they were placed in the tube would typically be removed with the same moisture difference. There was no trend for higher losses with bales that were lower in moisture, within the range from 28.5 to 50% moisture (w.b.).

Losses of chopped forage stored in tower, bunk or bag silos have been reported to range from 5 to 20% (Pitt, 1990; Muck and Rotz, 1996; Muck and Holmes, 2000). Losses with wrapped bale silage have been reported to be less than this, typically in the range of 3 to 12% (Huhnke et al., 1997; Shinners et al., 200; and Kennedy, 1987). It is well known that attempting to ensile low moisture (< 40% moisture) chopped forage can cause high levels of DM loss, excessive heating and even silo fires (Pitt, 1990; Muck, 1988). In this study, DM loss with low moisture wrapped bales were less than 2.1% in all three trials (table 5). A major factor contributing to high DM losses of chopped forage in silos is the inability to exclude oxygen, especially at low moistures (Pitt, 1990; Muck, 1988). Preserving low moisture biomass in wrapped bales was very successful, even though there was little fermentation (see below) because the tight plastic film prevented oxygen penetration. Many of the studies cited above determined DM loss over a relatively short period of storage, typically 2 to 6 months. In this study, DM losses were less than 2.1% even after 11 months in storage, showing the viability of long-term preservation of biomass grasses by ensiling in wrapped bales. The bales formed in October 2005 were baled directly behind the windrower with no field wilting. The excellent preservation of these bales shows that a single-pass harvesting system that combines cutting and baling could be successful if the bales are preserved by ensiling.

Fermentation products were lower and pH higher for the low moisture bales (table 5). A pH of greater than 6.5 is generally recognized as evidence of spoilage even if mold formation is not observed (Pitt, 1990). None of the bales had a pH greater than 6.0. The trend of higher pH and lower fermentation products with lower moisture forages has been reported with laboratory silos (Muck, 1990), grass silage bales (Huhnke et al., 1997) and alfalfa silage bales (Nicholson et al., 1991; Shinners et al., 2002). Although lactic and acetic acid production was low, the presence of undesirable butyric acid was almost non-existent, similar to results reported by Huhnke et al. (1997) and Shinners et al. (2002). The low levels of fermentation products and relatively high pH of the low moisture bales indicate that very little fermentation actually took place. However, DM losses were quite low, indicating that low moisture forage can be very well preserved without much fermentation as long as the plastic film limits oxygen.

Table 4. Moisture distribution, overall bale moisture and DM loss for dry bales of reed canarygrass bales stored from July 2005 to June 2006.

Treatment	Moisture .. % w.b.					DM loss % of total
		Out of storage				
	Into storage	Rind	Core	Base	Volume adjusted total	
Sisal twine	11.3	21.7_c	14.3_a	59.5_d	25.1_d	14.9_c
Plastic twine	11.3	23.2_c	15.1_{ab}	36.2_b	20.1_c	7.5_b
Net wrap	11.6	20.5_{bc}	16.2_b	46.0_c	20.6_c	7.7_b
Inside	11.6	16.6_{ab}	15.1_a	14.7_a	15.7_a	2.6_a
LSD* (P = 0.05)	0.9	3.9	1.0	3.5	1.7	1.3

* – averages in columns with different subscripts are significantly different at 95% confidence.

Table 5. Final storage data crops ensiled in film wrap tube

	Moisture .. % w.b.				Fermentation products .. % of DM			
	Into storage	Out of storage	DM loss % of total	pH	Lactic acid	Acetic acid	Butyric acid	Ethanol
Reed canarygrass*	33.9	34.3	0.3	5.91	0.25	0.19	0.00	0.41
Switchgrass#	49.0	49.5	1.9	4.93	1.03	0.68	0.00	0.97
Reed canarygrass#	35.8	37.5	2.1	5.38	0.65	0.54	0.00	0.72
Switchgrass^	46.6	46.1	1.0	5.22	0.93	0.42	0.00	0.71
Reed canarygrass^	45.7	44.6	0.5	5.15	0.93	0.54	0.00	0.83

* – Ensiled in July 2005 and removed in June 2006

\# – Ensiled in August 2005 and removed in June 2006

^ – Ensiled in October 2005 and removed in June 2006

Table 6. Moisture distribution, overall bale moisture and DM loss for dry bales of switchgrass and reed canarygrass stored from August 2005 to June 2006.

Treatment	Moisture .. % w.b.					DM loss % of total
		Out of storage				
	Into storage	Rind	Core	Base	Volume adjusted total	
Switchgrass						
Sisal twine	23.7	22.6_{c}	15.5	63.3_{d}	22.9_{d}	15.4_{c}
Plastic twine	21.0	20.1_{bc}	14.9	29.1_{b}	18.1_{b}	9.3_{b}
Net wrap	21.8	17.5_{ab}	15.4	32.2_{b}	17.6_{b}	9.0_{b}
Film wrap	21.3	20.2_{bc}	14.8	53.6_{c}	20.4_{c}	5.7_{a}
Inside	24.7	15.2_{a}	14.0	19.3_{a}	14.9_{a}	4.9_{a}
LSD* (P = 0.05)	4.4	3.7	0.9	6.8	1.7	2.6
Reed canarygrass						
Sisal twine	15.3_{ab}	24.5_{c}	15.7_{c}	64.4_{d}	24.4_{d}	14.5_{c}
Plastic twine	15.0_{a}	23.7_{c}	15.1_{bc}	38.0_{b}	20.7_{c}	8.1_{b}
Net wrap	17.3_{b}	20.2_{bc}	15.3_{bc}	38.6_{b}	19.4_{c}	6.5_{b}
Film wrap	14.2_{a}	19.3_{b}	15.2_{bc}	52.2_{c}	20.1_{c}	1.1_{a}
Inside	15.0_{a}	14.8_{a}	13.4_{a}	15.6_{a}	14.1_{a}	1.6_{a}
LSD* (P = 0.05)	2.0	2.7	0.9	6.0	1.5	3.0

* – averages in columns with different subscripts are significantly different at 95% confidence.

Conclusions

- In a single-cut system, switchgrass yield was 8% greater than reed canarygrass in the second year of production. Reed canarygrass yield was 14% greater in a two cutting system than a single cut system.

- Initial moisture at cutting was 58 to 47% (w.b.) for reed canarygrass and 66 to 46% (w.b.) for switchgrass. When crop yield was similar, switchgrass tended to dry faster than reed canarygrass.

- When the crops were placed in a wide-swath by tedding, it was possible to achieve baling moisture (< 20% w.b.) in a single day. Drying rate constants for these crops were greater than those reported for forage crops like alfalfa or forage grasses.

- Bale density averaged 163 kg DM/m^3 with no significant differences between crops or type of wrap (twine or net). The bale density was only slightly less than those reported for alfalfa or forage grasses.

- Baling productivity was 47% greater with switchgrass compared to reed canary-grass because the former crop more easily fed into the baler throat. Baling with net wrap improved baling productivity by 46% compared to baling with twine.

- Over two trails with storage periods of 9 and 11 months, dry bales stored outdoors averaged 3.4, 7.7, 8.3, and 14.9% DM loss for bales wrapped with plastic film, film, net wrap, plastic twine and sisal twine, respectively. Bales stored indoors averaged 3.0% DM loss. Differences in DM loss between reed canarygrass and switchgrass were likely due to differences in initial moisture.

- No matter the type of wrap, bales stored outdoors on sod had higher moisture in the rind and base than the core. The most uniform biomass feedstock was generated by storing indoors or ensiled in a tube of plastic film.

- Preservation by ensiling bales in a tube of plastic film produced average DM losses of 1.1%. Baling and then ensiling without field wilting was successful.

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