Rapidly Drying Sorghum Biomass for Potential Biofuel Production

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ABSTRACT

The Southern U.S. has an ideal climate that may aid in growing large amounts of biomass potentially suitable for biofuel; however, short-term droughts during the growing season may reduce yields. Sorghum may have great potential as an energy crop, because it is capable of high biomass yields and is drought resistant. Sorghum could be integrated into a conservation system as part of a crop rotation. However, sorghum biomass has relatively high moisture content and should be conditioned and dried before transported to reduce costs. Sorghum-sudan hybrid was harvested with two different headers on a self-propelled windrower: a Massey Ferguson 9145 (sickle) and a Massey Ferguson 9185 (disc). The disc header was comprised of two pairs (rear / front) of metal conditioner rollers which compressed the biomass, thus improving the drying process. The roller pairs were used with three different pressures (0, 3500 and 7000 kPa), and with different gaps (0 and 0.02 m). Sorghum biomass samples were collected after harvest and moisture content (%) evaluated daily until they remained constant. Results revealed that the higher pressures and smaller gaps resulted in faster drying of biomass. Thus, the best settings for the disc header were "7000 kPa – 0 m" or "7000 kPa – 0.02 m" which showed, respectively, moisture content levels of 13.6 % and 16.8 % after 14 days. However, when the disc header was set to "0 kPa - 0.02 m", the moisture content was significantly higher (43.2%). These results

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indicate that proper setting of the disc header including properly setting the pressures and gaps are important to achieve optimum drying of biomass.

Keywords: sorghum, biomass, biofuels, moisture, conditioning, USA

1. INTRODUCTION

Growing domestic biomass for bioenergy may help to reduce the amount of oil imported by the United States. The Southern U.S. has an ideal climate that may aid in growing large amounts of biomass; however, short-term droughts during the growing season over the last several years have dramatically reduced production. For these reasons, sorghum may be a reasonable alternative as an energy crop in this region, because it is considered drought resistant (Habyarimana et al., 2004). Sorghum can extract water from deep soil layers with most coming from depths of 0.45- 0.135 m (Farre and Faci 2006).

Additionally, sorghum has been considered a potential bioenergy crop, mostly from a cellulosic standpoint, providing a total maximum dry matter yield of 30.15 tons/ ha in a short time (120 days) and with a maximum mean daily growth rate of 22 g/ m^2 (Loomis and Willians, 1963). Therefore, sorghum could be integrated into a conservation system as part of a crop rotation with typical cash crops (peanuts, cotton), where part of its biomass would be used as a soil cover and any additional amount of biomass would be harvested for potential biofuel production. While much emphasis has been placed on perennials for biofuel production, annual crops, such as sorghum would provide a major source of biomass for cellulosic ethanol production. These annual crops for bioenergy production have largely been ignored in Southeastern U.S.

However, sorghum biomass has relatively high moisture content and should be dried before transported to reduce costs. Cundiff and Worley (1992) found that freshly harvested sorghum stalks had 48 to 76% of fresh weight and contained 42–75 % of whole-plant nonstructural carbohydrate. Thus, sorghum biomass needs to be dried to a moisture content of 15–20 % in order to store it. Moisture content higher than 20 % results in molds and bacteria growth that decreases biomass quantity and quality. On the other hand, moisture content lower than 15 % results in leaf loss decreasing biomass quantity (Wilcke et al., 1999).

Therefore, the objective of the current study was: 1) Compare the drying of sorghum biomass under two different headers on a self-propelled windrower: a Massey Ferguson 9145 (sickle header) and a Massey Ferguson 9185 (disc header), and 2) determine the best setting of the disc header including setting the pressures and gaps.

2. MATERIALS AND METHODS

In order to compare the drying of sorghum biomass under two different headers on a self-propelled windrower: a Massey Ferguson 9145 (sickle header) and a Massey Ferguson 9185 (disc header), and to determine the best setting of the disc header including setting the pressures and gaps, an experiment was begun at the E.V. Smith Research Station, Shorter, AL (85º :53’50” W, 32º:25’22” N) in April, 2008. The soil at the experimental field was classified as fine-loamy, siliceous, semiactive, thermic Aeric Paleaquults included in Lynchburg series. The total field was previously used for with corn sillage before planting sorghum.

2.1 Culture

The sorghum evaluated in this experiment was the Sweet Graze BMR (Brown Midrib Sorghum Sudangrass). It is described as tolerant to drought (0.5 m rainfall requirement during growing season), high sugar content, high forage quality, low lignin content, and with little cold tolerance (Pogue Agri Partners Inc., 2009).
Conventional tillage was applied to the entire experimental area. Seeding rate of 28 kg ha^{-1} and 65 kg ha^{-1} of N was applied during planting. Other applications, such as nutrients and herbicides followed the Auburn University Extension recommendations. Only natural rainfall contributed to crop yields.

2.2 Self-propelled Windrowers

Two different headers on a self-propelled windrower were compared: a Massey Ferguson 9145 and a Massey Ferguson 9185, which are a sickle and a disc header respectively. Figure 1 illustrates both windrowers.

Figure 1. Massey Ferguson 9145 (left); and Massey Ferguson (right).

The disc header was comprised of two pairs (rear / front) of metal conditioner rollers which compressed the biomass, thus improving the drying process. The roller pairs were used with three different pressures (0, 3500 and 7000 kPa), and with different gaps (0 and 0.02 m) combined in 7 different sets. However, the sickle header was also comprised of 2 pairs (rear/front) of conditioners, the front pair being metal and the rear pair being rubber. Table 1 shows all settings applied to both windrowers.

Table 1: Settings applied in both self-propelled windrowers

Self –propelled Windrowers	Treatment Number	Pressure (KPa)	Gap (m) front	Gap (m) rear
Massey Ferguson 9185 – disc header				
	1	0	0	0
	2	3500	0	0
	3	7000	0	0
	4	0	0.02	0
	5	3500	0.02	0
	6	7000	0.02	0
	7	0	0.02	0.02
Massey Ferguson 9145 – sickle header				
	8	standard	standard	

2.3 Field description

The total number of experimental plots was 32 which were composed of 8 different treatments and 4 replications. The treatments were: the 7 different gap/pressure settings of Massey Ferguson 9185 (disc), and the standard setting of Massey Ferguson 9145 (sickle) which were represented in Table 1.
All plots and borders were 5 m wide and 30 m long in which 4 rows were cropped 0.9 m spaced.

2.4 Biomass samples

Sorghum was harvested on October 16, 2008. Biomass samples were collected after harvest and moisture content (%) was evaluated until it remained constant. Samples were collected daily in early afternoon, except for rainy days and subsequent wet days. However, biomass samples were collected 8 times from October, 16th to October 30th, where the collection days were: October 16th, 20th, 21th, 22th, 23th, 28th, 29th, and 30th. All plots were disturbed using a Frontier TD10E hay Tedder on October 28th in order to achieve faster biomass drying.
Three handfuls of biomass subsamples were taken randomly from each plot, and placed in bags where the wet biomass weight was recorded. Biomass samples were dried at 12.8º C until constant weight was achieved. Wet-basis moisture content -M_{wb}(%) was calculated using the following formula:

$$M_{wb}(\%) = \frac{m_{H2O}}{m_{H2O} + m_{dm}} x100$$

where:
M_{wb} (%)= wet-basis moisture content, m_{H2O} = mass of moisture in kg, and m_{dm} = mass of dry matter in kg

2.4 Statistical Analysis

Statistical analyses were performed in a randomized complete block design (RCB) with eight different treatments as shown in Table 1. The predetermined significance level was $P \leq 0.10$ and Fisher's least-significant-difference test (LSD) was performed for means comparisons. The data were analyzed with GLM procedure using software SAS 9.1.

3. RESULTS AND DISCUSSION

3.1 Effect of different MF 9185's roller pressures on sorghum moisture content.

Results showed that higher pressures applied on rollers tended to dry sorghum biomass faster than lower pressures (Fig. 2). For all sampled days, rollers set to 7000 kPa were significantly more effective in drying biomass than rollers set to 0 kPa. This difference in pressure treatments was highest on October 30 (29.8 % vs. 15. 2 %, $P < 0.0025$).

Different results were found when comparing 3500 and 7000 kPa pressures. No significant differences were found between those applied pressures on October 22, 23, 28 and 29. Controversially, October 21 and 30 showed significant differences between different applied pressures. Thus, the last sampled day (October 30) had the highest difference between 3500 and 7000 kPa (24.2 % vs 15.2 %, $P < 0.0460$).

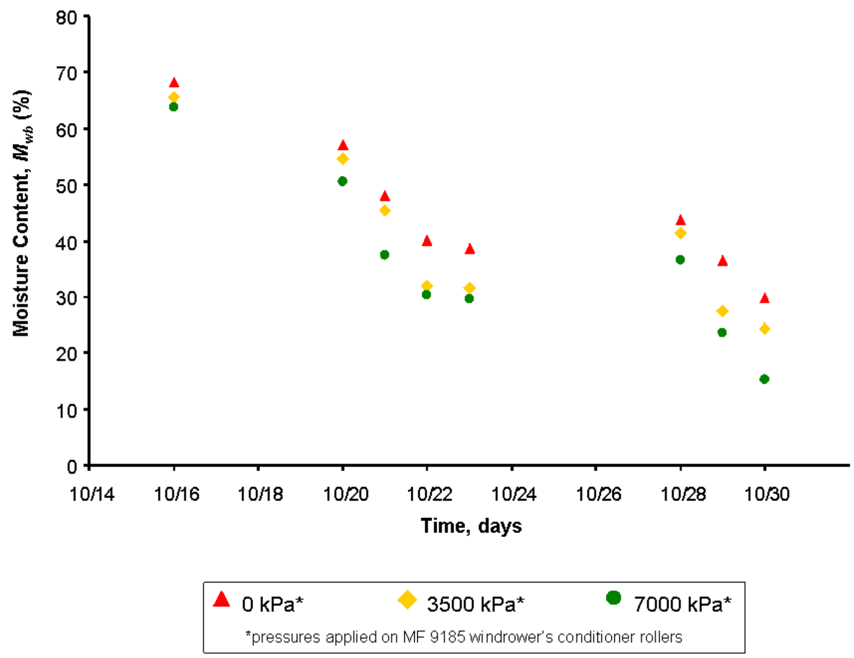

Figure 2. Sorghum moisture content for different disc header pressures for all sampled days

3.2 Effect of different MF 9185's roller gaps on sorghum moisture content.

Sorghum biomass tended to dry fast when rollers were contacting each other (Fig. 3). Comparing two different gap sets: "O m gap front/rear" vs. "0.02 m gap front / 0 m gap rear", all sampled days showed numerically low moisture content values for "0 m gap front and rear" treatments. But, they were significant different on October 23, 28 and 30. Additionally, the last sampled day (October 30) showed averages of 19.8 % and 26.4 %, respectively for "0 m gap front/rear" and "0.02 m gap front / 0 m gap rear" treatments ($P < 0.0712$).

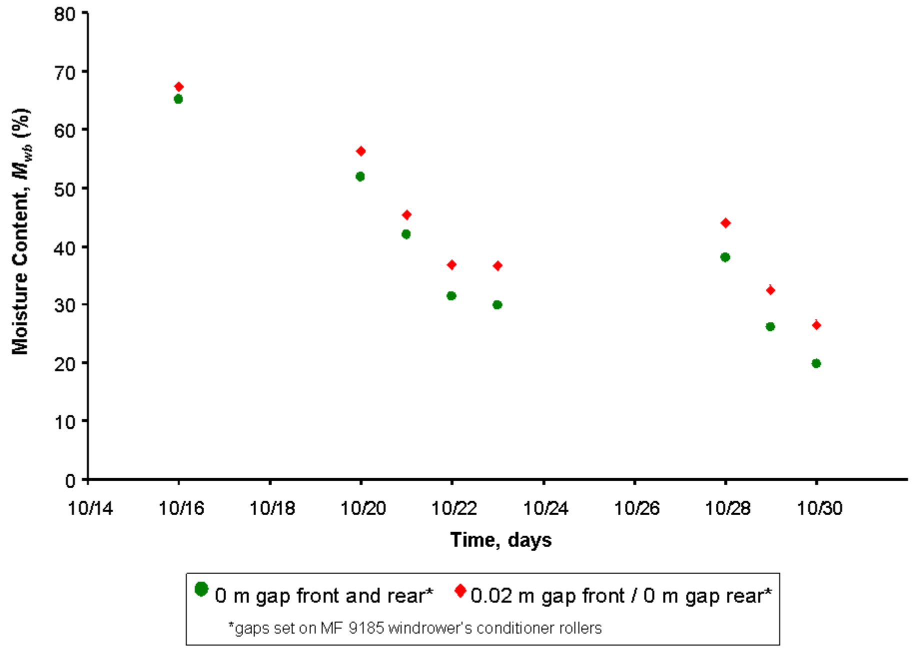

Figure 3. Sorghum moisture content for different disc header gaps in all sampled days

3.3 Interaction of different MF 9185's roller gaps and pressures on sorghum moisture content.

3.3.1 Day: 10/16/2008

Different moisture contents among treatments were observed 5 hours after harvest on October 16.

Treatment 8 showed minimum moisture content (63.5 % ±0.0248) followed by treatments 3 (63.8 % ±0.028), 2 (64.8 % ± 0.024), 5 (66.2 % ±0.029) and 6 (66.1 % ± 0.038), which showed no significant differences among each other. Treatment 1 (67 % ± 0.024) was considered not significantly different from treatments 2, 3, 5, and 6. Thus, treatments 4 (69.8 % ±0.16) and 7 (70.7 % ±0.02) showed highest moisture content (Figure 4). The temperature during October 16th was 20.5 ºC (AWIS Weather Services, Inc., 2009).

MF 9185 showed similar biomass moisture content to MF 9145 when set at 3500 or 7000 kPa; but MF 9185 had higher moisture content when set to 0 kPa. Therefore, higher pressures exposed more plant tissues to atmosphere than low pressures which resulted in faster biomass drying after a short period of time.

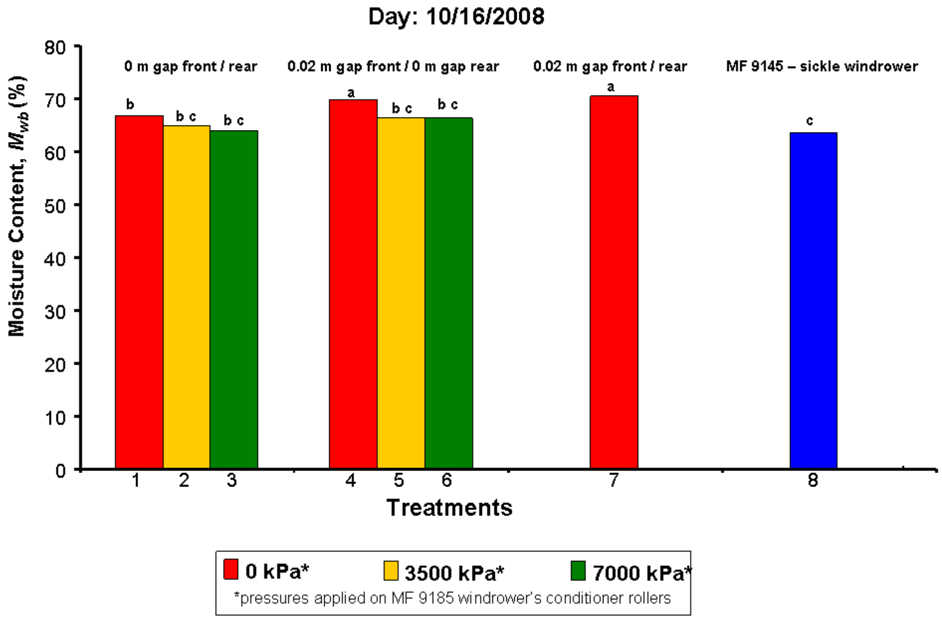

Figure 4. Sorghum moisture content for all treatments on October 16.

3.3.2 Day: 10/23/2008

Seven days after harvest, treatment 3 (27.7 % ±0.053) and 2 (28.5 % ±0.062) showed low values of moisture content followed by treatments 8 (30.9 % ±0.065), 6 (31.6 % ±0.068) and 1 (33.4 % ±0.045), which showed no significant differences among each other. Treatment 5 (34.4 % ±0.075) was considered not significantly different from 1, 6 and 8. Thus, treatments 4 (43.8 % ±0.07) and 7 (56.5 % ±0.03) showed the highest moisture content, but they were not statistically different from each other (Fig. 5). All previous sampling days including October 20, 21 and 22 showed the same trend as October 23. Thus, the average temperature was 17.0 ºC during those 7 days, and 0.008 m of precipitation was recorded on October 18th. (AWIS Weather Services, Inc., 2009).

However, MF 9185 showed similar biomass moisture content to MF 9145 when rollers set to any pressure with 0 m gap, and when rollers submitted on 7000 kPa with 0.02 m gap in front roller. Additionally, moisture content was higher in MF 9185 plots than MF 9145 ones when rollers set with 0 and 3500 kPa or had at least a 0.02 m gap.

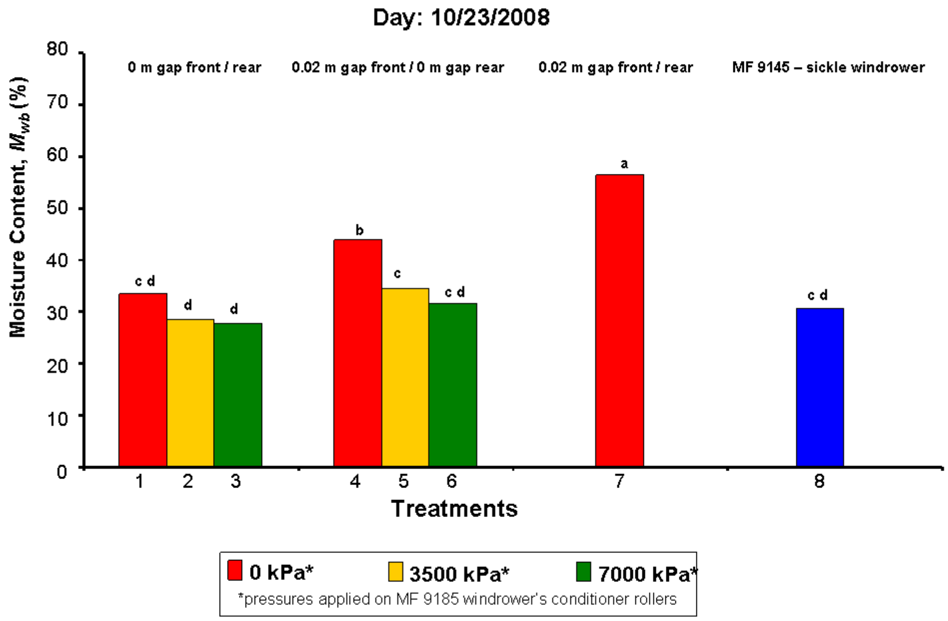

Figure 5. Sorghum moisture content for all treatments on October 23th.

On October 28, the biomass moisture content had an average increment of 0.07 in all experimental plots due to 0.057 m of precipitation on 24th (AWIS Weather Services, Inc., 2009). Consequently, the sorghum biomass in all experimental plots was teddered in order to improve biomass drying.

3.3.2 Day: 10/30/2008

Fourteen days after harvest, biomass from treatment 3 (13.6 % ±0.037) and 6 (16.8 % ±0.054) showed minimum moisture content followed by treatments 2 (21.8 % ±0.044), 1 (24.0 % ±0.058), 8 (24.1 % ±0.039) and 5 (26.6 % ±0.042), which were not significantly different among each other. Treatment 4 (35.6 % ±0.048) was considered not significantly different from 5. Thus, treatments 7 (43.2 % ±0.021) showed the highest moisture content. (Fig. 6). The sampled previous day (October 29) showed the same trend as October 30. Thus, the average temperature from October 24 to 30 was 11.7 ºC (AWIS Weather Services, Inc., 2009).
However, biomass harvested from plots where the MF 9185 was used for harvesting showed 13.6 % and 16.8 % of moisture content for treatments 3 and 6 respectively. It has been recommended that moisture content of biomass samples fall between 15.0 – 20.0 % of moisture content (Wilcke et al., 1999). Therefore, MF 9185 was able to dry sorghum biomass when rollers were set on 7000 kPa with “0 m gap front/rear” and “0.02 m gap front / 0 m gap rear”. Additionally, MF 9145 exceeded the recommended values by still containing 24.1 % moisture after 14 days.

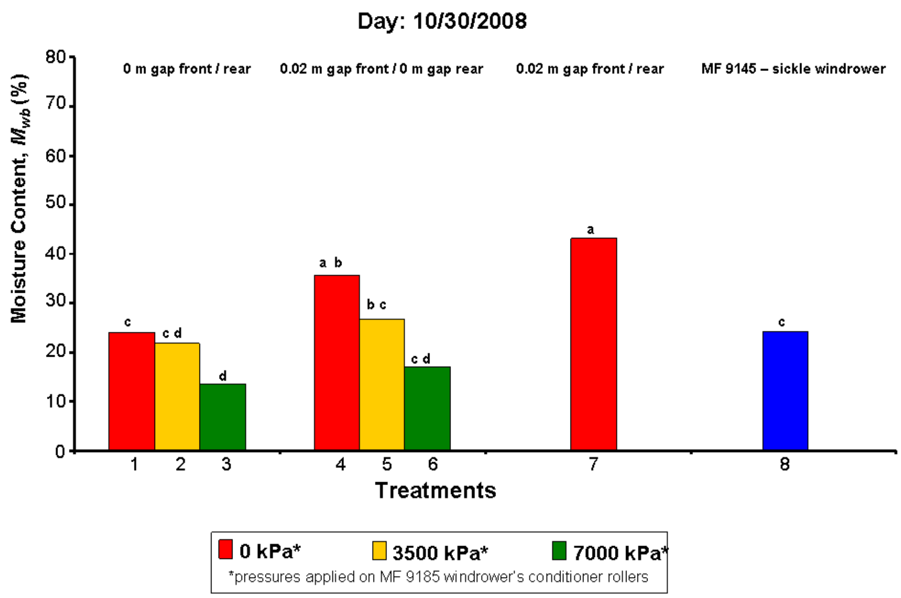

Figure 6. Sorghum moisture content for all treatments on October 30th.

Table 2: Daily average temperature and precipitation during drying period (AWIS Weather Services, Inc., 2009).

Dates	Average Temperature (ºC)	Precipitation (m)
10/16/2008	20.5	0
10/17/2008	22.7	0
10/18/2008	17.2	0.008
10/19/2008	14.4	0
10/20/2008	12.7	0
10/21/2008	13.3	0
10/22/2008	16.6	0
10/23/2008	18.3	0
10/24/2008	15.5	0.057
10/25/2008	13.8	0
10/26/2008	13.8	0
10/27/2008	16.1	0
10/28/2008[†]	8.3	0
10/29/2008	6.1	0
10/30/2008	8.3	0
10/31/2008	12.2	0

[†] plots disturbed using a Frontier TD10E hay Tedder

4. CONCLUSION

1. MF 9185 windrower dried sorghum biomass faster when higher pressures applied on conditioner rollers. However 7000 kPa had significantly reduced moisture content values than 0 and 3500 kPa after 15 days of harvest.
2. No gap between the rollers on the MF 9185 conditioner dried sorghum biomass faster than 0.02 m gap.
3. MF 9185 windrower was considered more efficient in drying sorghum biomass than MF 9145 when conditioner rollers were set with “0 gap front/rear, 7000 kPa”. However, the settings “O m gap front rear, 7000 kPa” and “0.02 gap front / 0 m gap rear, 7000 kPa” reduced moisture content to values lower than 20%, which was considered the maximum moisture content value for storing biomass.

Therefore, it was recommended MF 9185 set with both “O m gap front rear, 7000 kPa” and “0.02 gap front / 0 m gap rear, 7000 kPa” in order to achieve adequate biomass content to storing sorghum biomass for biofuel production. Thus, evaluation of the most economic MF 9185 setting was considered crucial to determine the best setting option.

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