Effect of rainfall and swath density on dry matter and composition change during drying of switchgrass and corn stover

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Abstract

During field drying, crops can be subjected to rainfall losses due to leaching, respiration and mechanical treatments. The objective of this study was to measure the impact of rainfall amount (8 to 75 mm) and crop density (0.8 to 2.6 (corn stover), 1 to 3.2 (switchgrass) kg [DM] m⁻²) on dry matter and composition change of corn stover (CS) and switchgrass. CS and switchgrass lost 0.3 to 4.7% and 0.2 to 2.8% as leaching loss from 8 to 75 mm of rainfall, respectively. After the incubation period of 48 h, the dry matter loss increased to 7.2 to 9.8% (CS) and 2.6 to 6.1% (switchgrass) from 8 to 75 mm of rainfall, respectively. Water soluble portion of CS and switchgrass was more severely affected than the fibre portion. Corn stover, being more exposed to rainfall in low density (LD) swaths, lost 56.7% ash content, compared to 19% in high density (HD) swaths. In CS, a significant decrease of K (10.2 to 63.8%) and Mg (5.6 to 41.7%) was observed with greater reductions in LD swaths compared to HD swaths. Similarly, a significant decrease in K (6.2 to 23.0%) and Mg (5.1 to 17%) content was observed in switchgrass but it was less prominent than CS.

Keywords. Rainfall loss, leaching loss, dry matter loss, extractive loss, mineral change, fibrechange.

1. Introduction

Evaluating and quantifying various sources of loss during the biomass supply chain is crucial for the economical production of biofuels. A considerable loss of 15 to 30% dry matter or yield has been reported for different crops during harvesting operations (Kallis, Susini, & Oakey, 2013; Sultana & Kumar, 2012; Valtere, Kirsanovs, & Zandeckis, 2015). Crops are often dried in windrows (Fig. 1) to decrease the moisture content for safe storage as well as reduced transportation costs (Khanchi et al., 2013). In general, crops dried in low density swaths intercept

more solar radiation and lose moisture quicker than high density windrows. Density of swaths can be controlled by adjusting windrow forming shields located on the back of the mower conditioner or by using tedders, which spread the crop in the field. The common sources of dry matter loss during field drying include plant and microbial respiration, rain damage, or mechanical loss due to shattering or dropping of crop material by the machinery.

The equipment used, time of harvest, harvesting operations followed, and weather conditions influence the extent of losses during the harvesting process (Rotz, 1995). Losses caused by rain vary widely and dependent on crop and environmental factors. Direct loss due to rainfall includes leaf loss and leaching loss. Leaf loss is caused by the impact of raindrops on the crop, which removes some leaves from the stems and thus are not picked up by the baler. Leaching loss occurs when the soluble portion of the crop is washed into the soil. Both losses result in loss of dry matter from the biomass. The leaching loss is often quantified together with respiration loss. Plant tissues continue their normal respiration process after harvest until the moisture is reduced to below 30% (Wood & Parker, 1971). A rain event during field drying increases the moisture content of the crop and thus escalates the loss caused by respiration. Microflora present on the plant surface become active as the moisture content is increased due to rain. The weather conditions after rainfall also govern total dry matter loss. If drying conditions are favourable, the moisture content of the crop drops quickly, limiting the damage caused by rain and microbial respiration. However, under unfavourable drying conditions, dry matter loss of up to 50% has been reported from conditioned crops (Rotz, 1995). The effect of rainfall amount and crop characteristics are difficult to measure and control in field conditions under natural rainfall. Artificial rain showers offer much more control and flexibility for performing experiments. However, experiments which use artificial rain showers tend to show lower losses than natural

rainfall due to the difference in rainfall duration and the kinetic energy of raindrops (Rotz, 1995).

Fig 1. Switchgrass handling steps from harvest to transportation to a biorefinery

It is also important to quantify the constituents lost during rainfall. Rainfall leaches the more soluble portion and can remove some of the minerals or ash in the biomass. The constituents that get dissolved as water soluble extractives include inorganic salts, non-structural sugars, gums, starches, colouring matter and tannins (Sluiter, Ruiz, Scarlata, & Templeton, 2008; Thammasouk, Tandjo, & Penner, 1997). Cold water (23 °C) removes tannins, gums, sugar, and colouring matter from lignocellulosic biomass. Hot water (100 °C) extractions can remove starch in combination to constituents removed with cold water (Sluiter, Ruiz, Scarlata, & Templeton, 2008; Thammasouk, Tandjo, & Penner, 1997). It is crucial to minimise the dry matter lost during the post-harvest supply of biomass to biorefineries as it can significantly increase the cost of fuel produced from biomass.

Researchers have studied the diverse factors which influence the loss caused by rainfall during field drying of forage crops. Kormos and Chestnutt (1968) evaluated the effect of rainfall amount, mechanical treatment, and stage of maturity on dry matter loss from ryegrass and white clover. They reported that after a one-day wilting period, dry matter loss increased from 2.9% to 4.6% with an increase in rainfall amount from 6 to 25 mm, respectively. However, the loss was not significantly influenced by the frequency of rain or duration of the wilting period prior to the

rainfall event. Additionally, more losses were observed inconditioned grass (4.6%) compared to unconditioned grass (2.4%) and the extent of loss was dependent on the degree of laceration. Grass lying in higher densities also suffered losses of 3.0 %, compared to 1.6% when the grass was spread in thinner layers. Fonnesbeck, Hernandez, Kaykay, and Saiady(1986) estimated the yield and nutrient losses due to rainfall on field drying alfalfa hay. They reported dry matter loss of 4.6% and 9.7% from rainfall amounts of 5 and 20 mm, respectively. They also reported that 20 mm of simulated rainfall reduced available carbohydrates from 27.3% to 24.3% and soluble ash from 9.5% to 9.0%. Models for leaf and leaching loss were also developed by Rotz(1995) and McGechan (1989) based on past data collected for forage crops. Numerical relationships were established between leaching loss, crop moisture content, amount of rainfall, concentration of soluble cell content, runoff rainfall, and conditioning factors. These studies confirm that rainfall had a significant impact on dry matter and chemical composition of the agricultural crops. However, there is minimal information available on losses occurring during a rainfall event from switchgrass and corn stover. The quality parameters for the bioenergy crops also vary from the crops that are utilized for animal feed purposes. Therefore, it is crucial to investigate rainfall losses in the supply chain to get realistic costs for delivering biomass to biorefineries. The specific objective of this study is to estimate the impact of rainfall amount and crop density on dry matter loss and compositional changes from switchgrass and CS.

2. Materials and method

2.1. Crop collection:

CS and switchgrass were collected from agricultural farms owned by Iowa State University in Boone, IA, USA with geographical coordinates of (41°58'37"N 93°46'14"W) and (42°00'37"N, 93°44'43"W), respectively. CS was collected and packed as round bales after a

99 single pass harvest operation in which CS was directly fed into a round baler after harvest
 100 without making any ground contact. Immediately after harvest, samples were collected from
 101 several round bales randomly located in the field. Samples were filled in plastic bags and stored
 102 in a cold storage at 5 °C until they were kept under an artificial rain shower for analysis.

103 Before frost, switchgrass was harvested manually a day before the experiment and stored
 104 in cold storage at 5 °C until subjected to the rainfall treatment. After frost, the samples were
 105 harvested when weather permitted and surplus samples were stored in cold storage at 5 °C until
 106 further analysis. The detailed sample collection schedule and initial moisture content for CS and
 107 switchgrass is presented in Table 1.

Table 1. Dates of corn stover and switchgrass collection with variation in initial moisture content. The range of dry matter density and rainfall tested during the experiments is also shown below

Corn Stover collection date	Moisture content at harvest (%)	Switchgrass collection date	Moisture content at harvest (%)
17th Aug 2013	31.2	7th Nov 2013	40.5
		11th Nov 2013	31.1
		14th Nov 2013	21.0
		18th Nov 2013	22.1
		10th Feb 2014	13.1
		13th Feb 2014	13.1
		17th Feb 2014	13.0
Range of dry matter density tested during the rainfall experiments			
Crop	Low dry matter density (LD)	Medium dry matter density (MD)	High dry matter density (HD)
		(kgm ⁻²)	
Corn Stover	0.8	1.3	2.6
Switchgrass	1.0	1.6	3.2

Range of rainfall amount tested during the experiment

Rain fall (mm) 8, 25, 50, 75

2.2. Experimental plan, design, and analysis:

A 4×3 factorial design with four levels of rainfall amount and three levels of swath density was used for experimentation (Table 1). The experiment was repeated three times between 24th October 2013 and 10th March 2014. During the experiments, switchgrass and CS were placed into low (LD), medium (MD) and high density (HD) windrows under the artificial rain shower. The rainfall simulator used in this study was similar to that developed by Norton and Savabi (Norton & Savabi, 2010) and is discussed in detail in their paper under the development of the portable continuously variable intensity linear simulator. The height of the nozzles were set to 2.4 m and the pressure in each line was 41 kPa.

The dry density of switchgrass placed in LD, MD, and HD windrows were 0.97, 1.6, and 3.2 kg m⁻², respectively. Similarly, dry density of CS placed in LD, MD and HD windrows were 0.8, 1.3 and 2.6 kg m⁻², respectively. Although, the experimental setup and design were similar for both switchgrass and CS experiments, they were performed on separate occasions and were independent of each other.

Switchgrass and CS samples were placed on 75.7 l storage capacity plastic containers with a layer of muslin cloth and wire mesh under the crop sample, respectively. Rain water applied using the rainfall simulator passed through the crop, muslin cloth, and wire mesh, and then was collected in the storage container. Wire mesh provided the strength to hold the crop above the container and the muslin cloth simulated a saturated soil layer as well as helped retain the fines from dropping into the runoff water collected in the storage container. Different densities were

simulated by adding varying amounts of crop material to the same surface area. The switchgrass and CS were subjected to four levels of rainfall amount (8, 25, 50 and 75 mm) using the rainfall shower. All experiments were conducted at a moderate rainfall intensity of 8 mm hr⁻¹. During each experiment, two trays of LD, MD, and HD swath were kept under the rainfall shower. After subjecting switchgrass and CS to rainfall treatment, trays were left undisturbed for 48 h at 21 °C and 60% Rh (incubation period) to simulate the field drying period after a rainfall event. After the incubation period of 48 h, one tray was weighed and kept in an oven at 103 °C for 24 h for dry matter loss analysis and the other was dried at a lower temperature of 60 °C for 72 h and used for compositional analysis (ASAE, 2003). Losses were measured by the following methods: 1) measuring the total solids in the runoff water collected in the storage container (leaching loss), 2) measuring the loss in the water soluble portion of switchgrass by measuring the water soluble extractives before the rainfall treatment and after the 48 h incubation period, and 3) measuring the dry matter loss after the incubation period of 48 h. The leaching (LL), water soluble extractive (WSEL), and dry matter (DML) loss were calculated in percent by Eq. 1, 2 and 3, respectively.

$$LL = \frac{TS_{runoff}}{DM_i} \times 100 \quad (1)$$

$$WSEL = \frac{WSE_i - WSE_f}{WSE_i} \times 100 \quad (2)$$

$$DML = \frac{DM_i - DM_f}{DM_i} \times 100 \quad (3)$$

TS_{runoff} is total solids in runoff water, DM_i and DM_f are the initial and final dry matter content, and WSE_i and WSE_f are the initial and final water soluble extractive content, respectively. To calculate total solids in runoff water, a small portion of runoff water (190 ml) was dried at 60 °C to constant weight ($ODW_{190\text{ ml}}$) and then it was multiplied by the total volume of runoff water

collected in the container given by Eq.4.

$$TS_{runoff} = \frac{ODW_{190\ ml}}{190} \times volume\ of\ runoff\ water \quad (4)$$

WSE of biomass in the initial and final sample was measured by the Soxhlet method and the samples were extracted with HPLC grade water for 10 h (Sluiter, Ruiz, Scarlata, & Templeton, 2008). Before and after rainfall treated and incubated samples were also subjected to compositional analysis of mineral, ash, and fibre content. The samples for compositional analysis were sent to Agsource Laboratories in Umatilla, OR, USA. Dried samples were ground to 1 mm using a knife mill and then passed through a 1.0 mm screen before the samples were subjected to water soluble extractives, ADL (Acid Detergent Lignin), ADF (Acid Detergent Fibre), minerals, and ash (Jung & Lamb, 2004; Sluiter et al., 2008) analysis. Hemicellulose content is often calculated as the difference between NDF and ADF fraction whereas, cellulose is calculated as the difference between ADF and ADL fraction (Jung & Lamb, 2004). Lignin found in cell walls was determined by using standard ADL procedures (Mertens, 1992; Van Soest, Robertson, & Lewis, 1991). Ash content was measured by following National Renewable Energy Laboratory (NREL) Laboratory Analytical Procedures (LAP) for determination of ash in biomass (Sluiter et al., 2008). Mineral analysis was performed using both wet chemistry and spectrometry techniques explained in detail by Jones and Case (1990). The change in mineral, ash and fibre content after the rainfall and incubation period given in Tables 3, 4, 5 and 6 was calculated by Eq.5.

$$\% \ Change = \frac{C_i \times DM_i - C_f \times DM_f}{C_i \times DM_i} \times 100 \quad (5)$$

Where C_i and C_f are the initial concentration before rainfall treatment and final concentration

after the incubation period of the constituent being analysed for change.

2.4. Statistics

Leaching loss, extractive loss, dry matter loss, and compositional changes were analysed by split plot design using PROC Mixed in SAS 9.4 (SAS Institute, 2015). Rainfall level, swath density, and interaction of rainfall and swath density were treated as fixed effects and replication, and interaction of replication with rainfall level were treated as random effects.

3. Results and discussion:

3.1. Leaching loss:

Generally, greater leaching loss is expected with increasing rainfall amounts. In the present study, when the rainfall amount increased from 8 to 75 mm, leaching loss increased by 93% and 85% in switchgrass and CS, respectively. Crop manipulation techniques such as crop conditioning and drying the crop in varying swath densities impacted the losses during rainfall events. In the present study, switchgrass had 25% and 43.8% greater leaching loss when placed in MD and LD swaths compared to HD swaths, respectively (Table 2). Similarly, a significant effect of swath density was observed in which CS placed in LD swaths had 43.3% greater leaching loss compared to HD swaths. Switchgrass and CS placed in LD swaths were highly exposed to rainfall, whereas, top layers in HD swaths provide protection to the underlying layers. During harvest, a conditioning treatment is often applied to crops to increase the drying rate. These mechanical operations break the outer layer of the biomass and expose the soluble components to leaching loss.

Collins (1983) also reported a leaching and respiration loss of 3.6 to 4.3% from untreated alfalfa which increased to 4.9 to 6.3% after 25mm of rainfall and a 96 h incubation period. A model

developed by Rotz(1995) estimated leaching losses of 2.2, 6.8 and 13% from 8, 25 and 50 mm of rainfall, respectively. The data used to develop the model by Rotz(1995) included both leaching and respiration loss because they were difficult to measure separately (Rucker & Knabe, 1977). However, in the present study leaching loss includes only the soluble solids leached out after the rainfall and thus, are less than reported losses in other studies.

Table 2. Influence of rainfall amount and swath density on leaching, extractive and dry matter loss from switchgrass

		Switchgrass			Corn Stover		
Rainfall amount	Density	Leaching Loss ^Z	WSE ^α Loss	Dry Matter loss	Leaching Loss	WSE ^α Loss	Dry Matter loss
(mm)		(%)*					
8	LD	0.3 ^a	2.9 ^{bcd}	3.2 ^a	0.6 ^a	0.6 ^c	9.4 ^a
8	MD	0.2 ^a	2.0 ^d	2.6 ^a	0.3 ^a	1.9 ^{bc}	8.8 ^a
8	HD	0.1 ^{ab}	2.2 ^{cd}	2.0 ^a	0.5 ^{ab}	2.0 ^c	7.7 ^a
25	LD	0.8 ^{ab}	2.5 ^{cd}	2.7 ^a	2.4 ^b	3.9 ^{ab}	9.8 ^a
25	MD	0.6 ^{abc}	4.3 ^{abc}	1.9 ^{ab}	1.9 ^{cb}	3.9 ^{ab}	8.4 ^a
25	HD	0.4 ^{bc}	3.6 ^{abcd}	4.6 ^{ab}	1.4 ^{cb}	3.8 ^{ab}	9.3 ^a
50	LD	1.9 ^{bcd}	4.1 ^{abcd}	5.6 ^{abc}	4.2 ^{cb}	4.2 ^a	8.0 ^a
50	MD	1.3 ^{bcd}	4.1 ^{abcd}	4.1 ^{abc}	1.5 ^{cb}	4.5 ^a	9.8 ^a
50	HD	0.6 ^{bcd^e}	5.5 ^a	3.7 ^{abcd}	2.6 ^{bcd}	4.4 ^a	7.8 ^a
75	LD	3.7 ^{cde}	5.0 ^{ab}	6.4 ^{bcd}	4.7 ^{cd}	5.0 ^a	8.0 ^a
75	MD	2.5 ^{cde}	5.1 ^{ab}	5.9 ^{ebcd}	2.8 ^{cde}	4.5 ^a	7.3 ^a
75	HD	2.3 ^{de}	4.2 ^{abcd}	6.1 ^{ecd}	2.3 ^{cde}	3.5 ^{ab}	7.2 ^a
Influence of swath density on leaching, extractives and dry matter loss from switchgrass. Data are pooled over rainfall amount							
	LD	1.6 ^a	3.6 ^a	4.5 ^a	3.0 ^a	3.4 ^a	8.8 ^a

MD	1.2 ^{ab}	3.8 ^a	3.6 ^a	1.6 ^b	3.7 ^a	8.6 ^a
HD	0.9 ^b	3.9 ^a	4.1 ^a	1.7 ^b	3.2 ^a	8.0 ^a

Influence of rainfall amount on leaching, extractives and dry matter loss from switchgrass. Data are pooled over swath density

8	0.2 ^c	2.3 ^c	2.6 ^c	0.5 ^c	1.2 ^b	8.6 ^a
25	0.6 ^{bc}	3.5 ^b	3.1 ^c	1.9 ^b	3.9 ^a	9.1 ^a
50	1.3 ^b	4.5 ^{ab}	4.5 ^b	2.8 ^{ab}	4.4 ^a	8.5 ^a
75	2.8 ^a	4.7 ^a	6.1 ^a	3.3 ^a	4.3 ^a	7.5 ^a

^ZMeans within columns followed by different letters are significantly different at the 95% confidence level. LD, MD, and HD is defined as low density, medium density and high density, respectively. ^aWSE is the water soluble extractive content, *Leaching loss, extractive loss, and dry matter loss were calculated by formulae given in Eqs.1, 2, and 3, respectively

3.2. Water soluble extractive (WSE) loss:

During rainfall, the water-soluble portion of biomass, generally termed as water soluble extractives, are more severely affected than the fibre portion. In this study, the extractives loss also included respiration losses caused by microbial spoilage during the incubation period in addition to the direct leaching loss discussed previously.

Switchgrass had an initial WSE content of 15.7% before frost, which reduced to an average initial WSE content of 11.0% after frost. This change in initial WSE content was due to an increase in maturity of crop and frost could have caused some variability in the final results.

Switchgrass lost 2-fold more WSE at a rainfall amount of 50 and 75 mm compared to 8 mm and were statistically different (Table 2). Constituents such as organic acids, inorganic anions and cations, and oligomeric and free sugars have been reported in the water soluble extractive portion of switchgrass (Chen, Mowery, Sevcik, Scarlata, & Chambliss, 2010). Chen et al. (2010) reported an extractive content of 15% in switchgrass and free sugars (i.e. monomeric sugars plus sucrose) were 18 to 27% of the dry weight of the water-soluble material.

Averaged over densities, CS also lost 3.5-fold more WSE at and above 25 mm rainfall compared to 8 mm. This can be due to the extensive conditioning of CS which facilitated leaching and respiration losses as inner tissues were exposed to rainfall and microbial growth. Being highly conditioned, CS settled into a dense swath with minimum aeration between the crop tissues. The protection offered by top layers in HD swaths during rainfall might be annulled by high respiration loss during the incubation period. In another study on CS, water-soluble extractives varied from 14.2% (NREL ID: Kramer 33A14) to 26.7% (NREL ID: 2302-115) of the oven dry weight of different CS varieties (Kormos & Chestnutt, 1968). Monosaccharides, glucose, and fructose constituted 30-46% of the dry weight of water-soluble materials extracted from corn stover varieties (Kormos & Chestnutt, 1968). These results have significant technical and economic implication on biomass for the bioethanol conversion process.

3.3. Dry matter loss

While WSE loss reflected loss in the water-soluble portion of biomass and dry matter loss estimated losses in the overall dry matter of switchgrass and CS. On average, switchgrass lost 2.6 and 3.1% of dry matter at 8 and 25 mm of rainfall compared to 4.5 and 6.1% at 50 and 75 mm of rainfall, respectively (Table 2). Kormos and Chestnutt(1968) reported a dry matter loss of 2.9, 3.7 and 4.6% at 6.4, 13 and 25 mm after one day of wilting from ryegrass and white clover, respectively. Fonnesbeck, Hernandez, Kaykay, and Saiady(1986) also reported a dry matter loss of 4.6 and 9.7% from alfalfa hay from a rainfall amount of 5 and 20 mm, respectively which illustrates that dry matter loss can vary significantly with crop type.

CS also lost 7.2 to 9.8% dry matter after the rainfall and incubation period of 48 hours. However, no statistical difference was observed between the treatments. The trend observed during leaching loss was not carried over to dry matter loss which could be due to microbial respiration

as discussed in the previous section. Even a small amount of rainfall was enough to encourage microbial growth on conditioned CS samples. The air movement was minimal due to the collapsed structure of the swath. This kept the CS samples wet throughout the incubation period. Dry matter loss from the crop is also dependent on the duration of the incubation period. Collins (1983) reported a dry matter loss of 53.8% from alfalfa at rainfall and incubation periods of 62 mm and 96 hours, respectively. Dry matter loss from CS can also vary with changes in duration or environmental conditions during the drying period. Dry matter loss in CS is expected to be greater than fine stem crops such as switchgrass which form an airy swath structure after harvesting.

3.4. Mineral and ash content change

3.4.1 Minerals

During rainfall, soluble minerals also leach with other water soluble components of biomass. After the rainfall event, P, K, and Mg concentration in switchgrass decreased whereas, S, and Ca concentration increased slightly (Table 3). A significant influence of swath density was observed in K and Mg concentration after the rainfall treatment in switchgrass. K concentration decreased by 23% in LD swaths compared to 6.2% in HD swaths. Similarly, Mg content decreased by 17% in LD swaths compared to 5.1% in HD swaths. Additionally, a significant effect of rainfall amount was observed on K content, with greater reductions at higher rainfall amounts. Switchgrass lost 6.3% K at 8mm rainfall compared to 22.3% at 75 mm. A more prominent effect of rainfall was observed on CS than switchgrass. CS lost 51.3% K content placed in exposed LD swaths compared to 28.2% in HD swaths (Table 4). Similarly, a reduction of 27.4, 19.5 and 14.2 % in Mg content was observed when placed in LD, MD and HD swaths, respectively. The rainfall amount also significantly affected the magnitude of K content

261 leached during rainfall. A loss of 18.6% was observed at 8 mm compared to 51.2% at 75 mm of
262 rainfall from CS. As discussed previously, switchgrass and CS stems are highly exposed to
263 rainfall in LD swaths, resulting in greater losses of soluble constituents. P, K, and Mg are also
264 highly soluble in water (Mertens, 1992) therefore, these are expected to leach during rainfall. K,
265 Mg and Ca ions were also detected in CS and switchgrass water extractives by Chen, Mowery,
266 Scarlata, and Chambliss (2007). They found that K^+ is the major cation that was contained in the
267 water extractive of CS and varied from 4.0 to 10.9% of the dry weight of water extractives.

Table 3. Final ash and mineral content left in switchgrass after the rainfall treatment and percent change in composition compared to initial values

Rainfall (mm)	Density	Ash	S	P	K	Ca	Mg	Ash change	S change	P change	K change	Ca change	Mg change
% db ^Z								% ^{Z,*}					
8	LD	5.6 ^a	0.049 ^{ab}	0.039 ^a	0.20 ^a	0.44 ^{abc}	0.14 ^{abc}	9.6 ^a	-16.1 ^d	3.5 ^a	14.2 ^{abc}	-6.1 ^a	-4.5 ^{cde}
8	MD	6.8 ^a	0.046 ^{ab}	0.038 ^a	0.20 ^a	0.42 ^{bc}	0.15 ^{ab}	4.2 ^a	-8.8 ^{bcd}	6.4 ^a	18.0 ^{abc}	-4.7 ^a	-10.5 ^e
8	HD	6.6 ^a	0.048 ^{ab}	0.048 ^a	0.25 ^a	0.45 ^{abc}	0.15 ^{abc}	10.0 ^a	-13.0 ^{cd}	1.9 ^a	-2.8 ^c	-13.7 ^a	-7.4 ^{de}
25	LD	5.1 ^a	0.043 ^b	0.054 ^a	0.26 ^a	0.44 ^{bc}	0.13 ^{cdef}	16.7 ^a	10.9 ^a	7.3 ^a	15.7 ^{abc}	-1.3 ^a	16.5 ^{ab}
25	MD	5.3 ^a	0.046 ^b	0.056 ^a	0.27 ^a	0.44 ^{abc}	0.13 ^{abcd}	15.6 ^a	4.8 ^{ab}	3.3 ^a	16.5 ^{abc}	-1.0 ^a	12.9 ^{abc}
25	HD	6.3 ^a	0.055 ^a	0.040 ^a	0.26 ^a	0.41 ^c	0.15 ^a	9.6 ^a	-11.7 ^{cd}	6.4 ^a	17.0 ^{abc}	8.4 ^a	4.8 ^{bcde}
50	LD	6.4 ^a	0.050 ^{ab}	0.042 ^a	0.19 ^a	0.52 ^{abc}	0.11 ^g	15.3 ^a	-1.3 ^{abc}	3.8 ^a	35.5 ^a	7.0 ^a	28.8 ^a
50	MD	7.5 ^a	0.052 ^{ab}	0.041 ^a	0.22 ^a	0.52 ^{abc}	0.12 ^{defg}	9.7 ^a	-5.4 ^{bcd}	7.0 ^a	24.9 ^{ab}	4.6 ^a	19.8 ^{ab}
50	HD	7.8 ^a	0.052 ^{ab}	0.052 ^a	0.25 ^a	0.52 ^{abc}	0.13 ^{abcd}	9.6 ^a	-7.1 ^{bcd}	1.9 ^a	10.2 ^{bc}	5.6 ^a	10.9 ^{abcd}
75	LD	6.7 ^a	0.053 ^{ab}	0.048 ^a	0.22 ^a	0.56 ^a	0.11 ^{fg}	10.5 ^a	-12.2 ^{cd}	5.4 ^a	36.4 ^a	-4.8 ^a	27.0 ^a
75	MD	7.2 ^a	0.050 ^{ab}	0.049 ^a	0.19 ^a	0.54 ^{ab}	0.12 ^{efg}	10.2 ^a	-6.6 ^{bcd}	2.3 ^a	29.6 ^{ab}	-1.0 ^a	23.8 ^a
75	HD	6.5 ^a	0.054 ^{ab}	0.049 ^a	0.25 ^a	0.54 ^{ab}	0.13 ^{bcde}	15.2 ^a	-14.4 ^{cd}	1.9 ^a	10.7 ^{bc}	-1.9 ^a	12.1 ^{abc}
Influence of swath density on the mineral content of switchgrass. Data are pooled over rainfall amount													
	LD	6.0 ^a	0.049 ^b	0.046 ^a	0.22 ^b	0.49 ^a	0.12 ^b	13.0 ^a	4.6 ^{ab}	5.0 ^a	23.0 ^a	-1.3 ^a	17.0 ^a
	MD	6.7 ^a	0.048 ^b	0.046 ^a	0.22 ^b	0.48 ^a	0.13 ^b	9.9 ^a	-4.0 ^a	4.8 ^a	22.3 ^a	-0.5 ^a	11.5 ^{ab}

HD	6.8 ^a	0.052 ^a	0.047 ^a	0.25 ^a	0.48 ^a	0.14 ^a	11.1 ^a	-11.6 ^b	3.0 ^a	6.2 ^b	-0.41 ^a	5.1 ^b
Influence of rainfall amounts on the mineral content of switchgrass. Data are pooled over swath density												
8	6.3 ^a	0.048 ^a	0.042 ^a	0.22 ^a	0.43 ^a	0.14 ^a	7.9 ^a	-12.6 ^b	4.0 ^a	6.3 ^b	-8.2 ^a	-7.5 ^b
25	5.6 ^a	0.048 ^a	0.050 ^a	0.26 ^a	0.43 ^a	0.14 ^a	14.0 ^a	1.4 ^a	5.7 ^a	16.4 ^{ab}	2.1 ^a	11.4 ^a
50	7.2 ^a	0.052 ^a	0.045 ^a	0.21 ^a	0.52 ^a	0.12 ^b	11.5 ^a	-4.6 ^{ab}	4.2 ^a	23.5 ^a	5.7 ^a	19.9 ^a
75	6.8 ^a	0.052 ^a	0.048 ^a	0.22 ^a	0.55 ^a	0.12 ^b	12.0 ^a	-11.1 ^b	3.2 ^a	22.3 ^a	-2.6 ^a	20.9 ^a

^ZMeans within columns followed by different letters are significantly different at the 95% confidence level. LD, MD, and HD is defined as low density, medium density, and high density, respectively. *% change is calculated by formulae, $\% \text{ Change} = \frac{C_i \times DM_i - C_f \times DM_f}{C_i \times DM_i} \times 100$, where, C and DM are the concentration and dry matter of the constituent being analysed, and subscripts *i* and *f* are the initial and final values

Table 4. Final ash and mineral content left in corn stover after the rainfall treatment and percent change in composition compared to initial values

Rainfall (mm)	Density	Ash	S ^Z	P	K	Ca	Mg	Ash change	S change	P change	K change	Ca change	Mg change
% db ^Z								% ^{Z,*}					
8	LD	4.6 ^b	0.06 ^a	0.05 ^a	0.61 ^{abc}	0.45 ^{bcd}	0.20 ^a	54.1 ^a	-16.4 ^a	-40.1 ^a	30.9 ^{cdef}	3.6 ^{abc}	6.3 ^b
8	MD	4.4 ^b	0.05 ^a	0.05 ^a	0.80 ^a	0.38 ^d	0.19 ^a	55.3 ^a	-1.7 ^a	-33.9 ^a	10.2 ^g	17.2 ^a	10.2 ^b
8	HD	8.3 ^a	0.06 ^a	0.06 ^a	0.75 ^{ab}	0.40 ^{cd}	0.19 ^a	14.1 ^b	0.1 ^a	-48.3 ^a	14.6 ^{fg}	12.8 ^a	5.6 ^b
25	LD	4.2 ^b	0.06 ^a	0.06 ^a	0.44 ^{cd}	0.47 ^{abc}	0.14 ^{ab}	59.8 ^a	-9.8 ^a	-41.7 ^a	49.0 ^{abc}	2.7 ^{abc}	33.0 ^{ab}
25	MD	3.8 ^b	0.06 ^a	0.06 ^a	0.68 ^{abc}	0.41 ^{cd}	0.15 ^{ab}	61.9 ^a	-37.6 ^a	-45.2 ^a	20.0 ^{efg}	11.7 ^a	24.7 ^{ab}
25	HD	7.6 ^a	0.06 ^a	0.05 ^a	0.67 ^{abc}	0.40 ^{cd}	0.16 ^{ab}	23.9 ^b	-13.0 ^a	-40.7 ^a	22.7 ^{defg}	13.6 ^a	22.6 ^{ab}
50	LD	4.4 ^b	0.07 ^a	0.06 ^a	0.33 ^d	0.54 ^a	0.15 ^{ab}	55.1 ^a	-21.5 ^a	-58.7 ^a	61.7 ^{ab}	-16.5 ^c	28.7 ^{ab}
50	MD	3.8 ^b	0.07 ^a	0.06 ^a	0.53 ^{bcd}	0.46 ^{bcd}	0.18 ^{ab}	62.1 ^a	-23.4 ^a	-59.4 ^a	39.2 ^{cde}	1.7 ^{abc}	14.5 ^{ab}
50	HD	9.5 ^a	0.07 ^a	0.06 ^a	0.57 ^{abcd}	0.44 ^{bcd}	0.19 ^a	11.3 ^b	-6.7 ^a	-50.8 ^a	34.0 ^{cdef}	4.9 ^{ab}	6.3 ^b
75	LD	4.2 ^b	0.07 ^a	0.05 ^a	0.31 ^d	0.51 ^{ab}	0.12 ^b	57.8 ^a	-35.8 ^a	-25.1 ^a	63.8 ^a	-10.6 ^{bc}	41.7 ^a
75	MD	4.2 ^b	0.06 ^a	0.04 ^a	0.44 ^{cd}	0.47 ^{abc}	0.14 ^{ab}	57.2 ^a	-35.1 ^a	-18.0 ^a	48.2 ^{bc}	-2.2 ^{abc}	28.8 ^{ab}
75	HD	7.5 ^a	0.06 ^a	0.04 ^a	0.50 ^{bcd}	0.43 ^{cd}	0.16 ^{ab}	26.8 ^b	-21.8 ^a	-17.4 ^a	41.5 ^{bc}	5.1 ^a	22.4 ^{ab}
Influence of swath density on mineral content of corn stover. Data are pooled over rainfall amount													
	LD	4.3 ^b	0.07 ^a	0.05 ^a	0.42 ^b	0.49 ^a	0.15 ^c	56.7 ^a	-20.9 ^a	-41.4 ^a	51.3 ^a	-5.2 ^b	27.4 ^a

MD	4.0 ^b	0.06 ^a	0.05 ^a	0.61 ^a	0.43 ^b	0.17 ^b	59.1 ^a	-24.5 ^a	-39.1 ^a	29.4 ^b	7.1 ^a	19.5 ^b
HD	8.2 ^a	0.06 ^a	0.05 ^a	0.62 ^a	0.42 ^b	0.18 ^a	19.0 ^b	-10.3 ^a	-39.3 ^a	28.2 ^b	9.1 ^a	14.2 ^c

Influence of rainfall amount on mineral content of corn stover. Data are pooled over swath density

8	5.8 ^a	0.06 ^a	0.05 ^{ab}	0.72 ^a	0.41 ^b	0.19 ^a	41.1 ^a	-6.0 ^a	-40.8 ^{ab}	18.6 ^c	11.2 ^a	7.3 ^a
25	5.2 ^a	0.06 ^a	0.05 ^a	0.60 ^{ab}	0.43 ^b	0.15 ^a	48.5 ^a	-20.1 ^{ab}	-42.6 ^{ab}	30.5 ^{bc}	9.4 ^a	26.8 ^a
50	5.9 ^a	0.07 ^a	0.06 ^a	0.48 ^{bc}	0.48 ^a	0.17 ^a	42.8 ^a	-17.2 ^{ab}	-56.3 ^b	45.0 ^{ab}	-3.3 ^a	16.5 ^a
75	5.3 ^a	0.06 ^a	0.05 ^b	0.42 ^c	0.47 ^a	0.14 ^a	47.3 ^a	-30.9 ^b	-20.2 ^a	51.2 ^a	-2.6 ^a	31.0 ^a

^Z Means within columns followed by different letters are significantly different at the 95% confidence level. LD, MD, and HD is defined as low density, medium density, and high density, respectively. *% change is calculated by formulae, $\% \text{ Change} = \frac{C_i \times DM_i - C_f \times DM_f}{C_i \times DM_i} \times 100$, where, C and DM are the concentration and dry matter of the constituent being analysed, and subscripts *i* and *f* are the initial and final values

Similarly, K^+ and Mg^{2+} ions, constituted about 5.3 to 7.3% and 1.0 to 1.9% of the dry weight of water extractives from switchgrass, respectively (Chen et al., (2010). Chen et al. (2007) reported that Ca^{+2} was the other major cation lost during extraction and was 1.2 to 1.7% of the dry weight of water extractives. However, in the present study, significant increases of 5.2% in LD swaths and 3.3 and 2.6% increases at rainfall amounts of 50 and 75 mm were observed in CS. These increases might have come from the supply water used to simulate rainfall during the experiments. Minerals such as Mg (1.5 mg100g^{-1}), Ca (3.9 mg100g^{-1}), Na (6.8 mg100g^{-1}), Cu (0.008 mg100g^{-1}), K (0.5 mg100g^{-1}) were reported in the Midwest water supply (Pehrsson, Patterson, & Perry, 2008). Small changes in S, P, and other micronutrients (B, Zn, Mn, Cu, Fe, Na) were observed but no significant effect of rainfall amount or swath density was observed (results presented as supplementary material in Tables A & B).

3.4.2 Ash

In switchgrass, rainfall decreased the ash content by 4.2 to 16.7% but the treatments were not statistically different. LD swaths showed the maximum decrease of 13% as being more exposed to rainfall but, it was also not significantly different than a reduction of 9.9% and 11.1% observed in MD and HD swaths, respectively.

Being highly conditioned, the effect of rainfall was more pronounced in CS and ash content decreased by 11.3% to 62.1% (Tables 3). Ash content of 4.3% was left in LD swaths compared to 8.2% in HD swaths and were significantly different from each other. Ash content above 5% is not desirable in biomass for thermochemical processes (Tanger, Field, Jahn, DeFoort, & Leach, 2013). Harvesting techniques such as single pass harvest is encouraged to keep the ash content low. Ash and mineral content in biomass also negatively affect the thermochemical conversion equipment. The elements Na, K, Mg, Ca, Cl, S and Si produce problems such as slag formation

(a liquid phase formed at elevated temperatures) and deposits during thermochemical processes.

Although silica in the plant tissue may be low, contamination with soil during the harvesting process increases the silica content and thus leads to operational difficulties. High mineral content in biomass also decreases oil yield and increases the production of char and gas products during pyrolysis (Tanger, Field, Jahn, DeFoort, & Leach, 2013).

3.5. Change in fibre components

3.5.1 Plant cell wall

Plant cell wall (NDF) or fibre portions are insoluble in boiling water, so little to no change is expected after rainfall (Fonnesbeck, Hernandez, Kaykay, & Saiady, 1986). Most of the changes are due to leaching of the soluble portions which indirectly increase the fibre content even though there is no actual change in fibre. Averaged over densities, plant cell wall content varied from 71.4 to 72.6% (Table 5) in the rain treated switchgrass and 74.3 to 74.7% (Table 6) in CS which showed that rainfall had no significant effect on plant cell wall content.

3.5.2 Lignin

In switchgrass, an increase of 6.2% was observed at the higher rainfall amount of 75 mm, and it decreased at other rainfall amounts. A significant effect of swath density was also observed but the differences were small with little practical significance. However, swath density significantly affected the lignin content in CS after rainfall. Lignin increased by 13.8% and 21.3% in LD and MD swaths compared to 3.2% in HD swaths. For alfalfa, Fonnesbeck et al (1986) reported an increase of 8.5% and 14.3% from 5 and 20 mm of rainfall, respectively. An increase of 4.3 to 17.6% was also reported by Collins (1983) from red clover treated with 25 to 62 mm of rainfall. A greater increase in lignin content in LD and MD swaths indicates that more soluble components were lost from LD and MD swaths when compared to HD swaths. The impact of

lignin on fuel conversion is different for biochemical and thermochemical conversion technologies. In the biochemical process, minimising the lignin content increases hydrolysis and fermentation yields (Miles et al., 1996).

3.5.3 Cellulose

Averaged over swath densities, cellulose varied from 41.7 to 42.5% in rainfall treated CS samples. No significant difference in rainfall amount or swath densities was observed. Changes were small and were not identified with any trend. A change of 3.5 to 6.6% (CS) and 0.8 to 3.6% (switchgrass) was observed from initial values which were consistent with other studies (Rotz, 1995). Fannesbeck et al. (1986) reported a change of 5.2% to 12.9% in cellulose content after 5 and 20 mm of rainfall from alfalfa.

3.5.4 Hemicellulose

Hemicellulose decreased by 4.1% to 7.6% (CS) and 0.6 to 11.3% (switchgrass) in water treatment samples but no consistent trend was noted. A decrease of 7.4% hemicellulose content was also observed in square switchgrass bales stored outside without any protection for 6 months (Fannesbeck, Hernandez, Kaykay, & Saiady, 1986). It was found that under adverse conditions, hemicellulose content is more severely affected than the cellulose content. Grohmann et al. (1981) and Thammasouk, Tandjo, and Penner, (1997) reported that the rate of cleavage of β -xylans (major components of hemicellulose) is 5 times higher than β -glucans (a major component of cellulose). However, in the present study, the decrease in hemicellulose content was small and is of little practical significance.

Table 5. Final extractives and fibre content left in switchgrass after the rainfall treatment and percent change in composition compared to initial values

Rainfall (mm)	Density	Extractives ^a	Plant cell wall	Cell wall constituents			Plant cell wall change	Cell wall constituents		
				Lignin	Cellulose	Hemi cellulose		Lignin change	Cellulose change	Hemicellulose change
				(^o) ^Z			(^o) ^{Z,*}			
8	LD	7.8 ^a	71.8 ^a	6.2 ^b	38.7 ^a	26.9 ^{ab}	2.0 ^a	14.3 ^a	-1.4 ^a	2.6 ^{ab}
8	MD	8.8 ^a	72.7 ^a	6.7 ^{ab}	39.7 ^a	26.3 ^{abc}	0.3 ^a	6.4 ^a	-4.6 ^a	4.1 ^{ab}
8	HD	7.6 ^{ab}	73.1 ^a	6.8 ^{ab}	39.4 ^a	26.9 ^{ab}	-1.1 ^a	5.4 ^a	-4.8 ^a	1.4 ^{ab}
25	LD	10.9 ^{ab}	72.6 ^a	6.9 ^{ab}	38.5 ^a	27.2 ^a	2.4 ^a	5.6 ^a	2.5 ^a	0.6 ^b
25	MD	9.1 ^{abc}	73.5 ^a	7.0 ^{ab}	39.6 ^a	26.8 ^{abc}	0.4 ^a	2.5 ^{ab}	-1.2 ^a	1.3 ^{ab}
25	HD	9.7 ^{bc}	72.5 ^a	7.0 ^{ab}	39.8 ^a	25.7 ^{abc}	4.4 ^a	4.3 ^{ab}	1.3 ^a	7.9 ^{ab}
50	LD	7.6 ^{bc}	72.2 ^a	6.4 ^b	38.2 ^a	27.6 ^a	3.2 ^a	7.1 ^a	2.7 ^a	2.0 ^{ab}
50	MD	7.6 ^{bc}	72 ^a	6.5 ^{ab}	38.5 ^a	27.1 ^{ab}	1.9 ^a	3.8 ^{ab}	0.4 ^a	2.3 ^{ab}
50	HD	6.2 ^{bcd}	70.9 ^a	6.7 ^{ab}	39.6 ^a	24.5 ^c	3.1 ^a	0.2 ^{ab}	-3.1 ^a	11.3 ^a
75	LD	6.2 ^{cd}	71.2 ^a	6.3 ^b	39.0 ^a	25.9 ^{abc}	1.9 ^a	-1.1 ^{ab}	1.2 ^a	4.4 ^{ab}
75	MD	6.2 ^{cd}	70.9 ^a	6.2 ^b	39.9 ^a	24.8 ^{bc}	2.7 ^a	2.3 ^{ab}	-1.8 ^a	8.7 ^{ab}
75	HD	7.1 ^{cd}	72.1 ^a	7.6 ^a	40.0 ^a	24.5 ^c	0.1 ^a	-19.7 ^b	-1.8 ^a	9.1 ^{ab}
Influence of swath density on the changein extractives, ash and fiber content of switchgrass. Data are pooled over rainfall amount										
	LD	8.2 ^a	71.9 ^a	6.5 ^b	38.6 ^a	26.9 ^a	2.4 ^a	6.5 ^a	1.0 ^a	2.4 ^b

MD	7.9 ^a	72.3 ^a	6.6 ^{ab}	39.4 ^a	26.3 ^{ab}	1.3 ^a	3.8 ^{ab}	-1.8 ^b	4.1 ^{ab}
HD	7.6 ^a	72.2 ^a	7.0 ^a	39.7 ^a	25.4 ^b	1.6 ^a	-2.5 ^b	-2.4 ^b	7.4 ^a
Influence rainfall amount on the change in extractives, ash and fibre content of switchgrass. Data are pooled over swath density									
8	8.1 ^b	72.6 ^a	6.6 ^a	39.3 ^a	26.7 ^a	0.4 ^a	8.7 ^a	-3.6 ^a	2.7 ^a
25	9.9 ^a	72.9 ^a	7.0 ^a	39.3 ^a	26.6 ^a	2.4 ^a	4.1 ^a	0.8 ^a	3.3 ^a
50	7.2 ^{bc}	71.7 ^a	6.5 ^a	38.8 ^a	26.4 ^{ab}	2.8 ^a	3.7 ^a	0.0 ^a	5.2 ^a
75	6.5 ^c	71.4 ^a	6.7 ^a	39.7 ^a	25.1 ^b	1.5 ^a	-6.2 ^a	-0.8 ^a	7.4 ^a

^z Means within columns followed by different letters are significantly different at the 95% confidence level. ^a Extractive change presented in Table 2. LD, MD, and HD is defined as low density, medium density, and high density, respectively. *% change is calculated by formulae, $\% \text{ Change} = \frac{C_i \times DM_i - C_f \times DM_f}{C_i \times DM_i} \times 100$, where, C and DM are the concentration and dry matter of the constituent being analysed, and subscripts *i* and *f* are the initial and final values

Table 6. Final extractives and fibre content left in corn stover after the rainfall treatment and percent change in composition compared to initial values

Rainfall (mm)	Density	Extractives ^a	Plant cell wall	Cell wall constituents			Plant cell wall change	Cell wall constituents		
				Lignin	Cellulose	Hemi cellulose		Lignin change	Cellulose change	Hemicellulose change
				(%) ^Z			(%) ^{Z,*}			
8	LD	7.8 ^a	71.8 ^a	6.2 ^b	38.7 ^a	26.9 ^{ab}	2.0 ^a	14.3 ^a	-1.4 ^a	2.6 ^{ab}
8	MD	8.8 ^a	72.7 ^a	6.7 ^{ab}	39.7 ^a	26.3 ^{abc}	0.3 ^a	6.4 ^a	-4.6 ^a	4.1 ^{ab}
8	HD	7.6 ^{ab}	73.1 ^a	6.8 ^{ab}	39.4 ^a	26.9 ^{ab}	-1.1 ^a	5.4 ^a	-4.8 ^a	1.4 ^{ab}
25	LD	10.9 ^{ab}	72.6 ^a	6.9 ^{ab}	38.5 ^a	27.2 ^a	2.4 ^a	5.6 ^a	2.5 ^a	0.6 ^b
25	MD	9.1 ^{abc}	73.5 ^a	7.0 ^{ab}	39.6 ^a	26.8 ^{abc}	0.4 ^a	2.5 ^{ab}	-1.2 ^a	1.3 ^{ab}
25	HD	9.7 ^{bc}	72.5 ^a	7.0 ^{ab}	39.8 ^a	25.7 ^{abc}	4.4 ^a	4.3 ^{ab}	1.3 ^a	7.9 ^{ab}
50	LD	7.6 ^{bc}	72.2 ^a	6.4 ^b	38.2 ^a	27.6 ^a	3.2 ^a	7.1 ^a	2.7 ^a	2.0 ^{ab}
50	MD	7.6 ^{bc}	72 ^a	6.5 ^{ab}	38.5 ^a	27.1 ^{ab}	1.9 ^a	3.8 ^{ab}	0.4 ^a	2.3 ^{ab}
50	HD	6.2 ^{bcd}	70.9 ^a	6.7 ^{ab}	39.6 ^a	24.5 ^c	3.1 ^a	0.2 ^{ab}	-3.1 ^a	11.3 ^a
75	LD	6.2 ^{cd}	71.2 ^a	6.3 ^b	39.0 ^a	25.9 ^{abc}	1.9 ^a	-1.1 ^{ab}	1.2 ^a	4.4 ^{ab}
75	MD	6.2 ^{cd}	70.9 ^a	6.2 ^b	39.9 ^a	24.8 ^{bc}	2.7 ^a	2.3 ^{ab}	-1.8 ^a	8.7 ^{ab}
75	HD	7.1 ^{cd}	72.1 ^a	7.6 ^a	40.0 ^a	24.5 ^c	0.1 ^a	-19.7 ^b	-1.8 ^a	9.1 ^{ab}
Influence of swath density on change in in extractives, ash and fibre content of corn stover. Data are pooled over rainfall amount										
	LD	6.8 ^a	74.0 ^b	6.0 ^a	41.6 ^a	26.4 ^a	5.7 ^a	-13.8 ^b	7.4 ^a	6.6 ^a

MD	6.4 ^a	75.2 ^a	6.2 ^a	42.3 ^a	26.6 ^a	3.4 ^b	-21.3 ^b	4.9 ^{ab}	5.1 ^a
HD	7.1 ^a	74.1 ^{ab}	5.3 ^b	42.6 ^a	26.2 ^a	4.2 ^{ab}	-3.2 ^a	3.9 ^b	5.7 ^a
Influence rainfall amount on change in in extractives, ash and fibre content of corn stover. Data are pooled over swath density									
8	8.3 ^a	74.3 ^a	5.6 ^a	42.3 ^a	26.3 ^a	4.6 ^a	-9.6 ^a	5.0 ^a	6.2 ^a
25	6.4 ^b	74.3 ^a	5.8 ^a	42.2 ^a	26.3 ^a	6.0 ^a	-10.1 ^a	6.6 ^a	7.6 ^a
50	6.1 ^b	74.7 ^a	6.2 ^a	41.7 ^a	26.8 ^a	3.9 ^a	-20.0 ^a	6.4 ^a	4.1 ^a
75	6.2 ^b	74.4 ^a	5.7 ^a	42.5 ^a	26.2 ^a	3.3 ^a	-11.6 ^a	3.5 ^a	5.3 ^a

^z Means within columns followed by different letters are significantly different at the 95% confidence level. ^aExtractive change presented in Table 2. LD, MD, and HD is defined as low density, medium density, and high density, respectively. *% change is calculated by formulae, $\% \text{ Change} = \frac{C_i \times DM_i - C_f \times DM_f}{C_i \times DM_i} \times 100$, where, C and DM are the concentration and dry matter of the constituent being analysed, and subscripts *i* and *f* are the initial and final values

Dry matter losses due to rainfall directly influence the economics of biofuel production and should be considered in determining the biomass supply cost to biorefineries. The dry matter lost during rainfall must be supplemented by harvesting more biomass to meet the demand of biorefineries. Rainfall losses can be minimised by placing the crop in narrow windrows so that the underlying layers can be protected by the top layers. However, to minimise respiration loss after a rainfall event, the crop must be dried in wide swaths to intercept maximum solar radiation. But, these operations will increase the overall cost of harvesting and supplying the biomass to biorefineries. The cost advantage achieved by saving the dry matter during a rainfall event should be compared with the cost of subsequent field operations applied to minimise the loss.

4.0 Conclusion

This study demonstrated the effect of rainfall amount and swath density on dry matter loss and compositional changes during the field drying of switchgrass and CS. Significant changes in the soluble portion were observed with more losses from LD swaths compared to MD, and HD swaths. Dry matter losses up to 6% in switchgrass and 9% in CS were observed after rainfall treatments. Rainfall removed both desirable (water soluble carbohydrates) and undesirable (minerals, ash) components from the biomass. Water soluble carbohydrates can be easily fermented to ethanol by the biochemical conversion process and therefore, should be protected during the drying period. Small changes in the fibre portions were observed which were primarily due to a decrease in the soluble portion of biomass rather than actual changes in the fibre. Minerals K and Mg, which are water soluble, decreased after rainfall and both rainfall amount and swath density significantly affected the final concentration.

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Appendix A

Table A. Final micronutrients concentration left in switchgrass after the rainfall treatment and percent change in concentration compared to initial values

Rainfall (mm)	Density	B	Zn	Mn	Cu	Fe	Na	B change	Zn change	Mn change	Cu change	Fe change	Na change
ppm ^Z							% * ^Z						
8	LD	5.7 ^{ab}	9.0 ^a	12.6 ^a	2.8 ^a	98.9 ^{ab}	475.0 ^a	-48.0 ^{ab}	1.7 ^{ab}	-2.8 ^{abc}	14.0 ^a	8.3 ^a	-86.7 ^a
8	MD	4.6 ^b	8.7 ^a	10.5 ^a	2.9 ^a	86.7 ^b	381.0 ^a	-10.8 ^{ab}	1.8 ^{ab}	11.8 ^{abc}	8.2 ^a	18.4 ^a	-73.4 ^a
8	HD	5.5 ^{ab}	11.8 ^{ab}	12.4 ^{ab}	3.2 ^{ab}	106.0 ^{ab}	261.7 ^a	-45.6 ^{ab}	-27.7 ^{bc}	-1.1 ^{abc}	7.5 ^a	-6.4 ^a	-3.7 ^a
25	LD	5.7 ^{ab}	9.7 ^{ab}	10.1 ^{ab}	3.1 ^{ab}	92.5 ^{ab}	305.0 ^a	-36.6 ^{ab}	11.4 ^{ab}	32.9 ^{abc}	5.4 ^a	21.5 ^a	-7.7 ^a
25	MD	5.5 ^{ab}	8.4 ^{abc}	8.7 ^{abc}	2.7 ^{abc}	106.4 ^{ab}	282.0 ^a	-19.4 ^{ab}	22.6 ^a	39.2 ^{ab}	4.4 ^a	14.4 ^a	-3.5 ^a
25	HD	5.8 ^{ab}	10.3 ^{abc}	8.0 ^{abc}	3.3 ^{abc}	90.7 ^{ab}	472.7 ^a	-21.4 ^{ab}	8.6 ^{ab}	46.6 ^a	3.6 ^a	24.7 ^a	-53.5 ^a
50	LD	6.4 ^{ab}	10.7 ^{abc}	9.9 ^{abc}	3.1 ^{abc}	166.6 ^a	437.7 ^a	-12.0 ^{ab}	3.3 ^{ab}	34.7 ^{ab}	1.3 ^{ab}	0.3 ^a	-123.5 ^a
50	MD	5.4 ^{ab}	10.4 ^{abc}	10.6 ^{bc}	3.3 ^{abc}	119.0 ^{ab}	453.3 ^a	3.8 ^{ab}	4.7 ^{ab}	28.3 ^{abc}	-1.7 ^{abc}	27.0 ^a	-113.9 ^a
50	HD	6.2 ^{ab}	10.9 ^{abc}	10.3 ^{bc}	3.2 ^{abc}	123.9 ^{ab}	339.0 ^a	-13.7 ^{ab}	0.2 ^{ab}	31.3 ^{abc}	-3.2 ^{abc}	23.7 ^a	-82.1 ^a
75	LD	12.0 ^a	14.8 ^{abc}	27.0 ^{bc}	4.4 ^{abc}	156.3 ^{ab}	373.7 ^a	-129.9 ^b	-39.2 ^c	-74.6 ^c	-5.6 ^{abc}	-16.1 ^a	-69.4 ^a
75	MD	4.3 ^b	10.9 ^{abc}	10.1 ^{bc}	3.2 ^{abc}	123.0 ^{ab}	377.7 ^a	19.3 ^a	-2.7 ^{abc}	33.7 ^{ab}	-39.0 ^{bc}	4.1 ^a	-71.1 ^a
75	HD	11.3 ^{ab}	13.5 ^{abc}	25.2 ^{bc}	4.3 ^{abc}	146.0 ^{ab}	341.7 ^a	-117.1 ^{ab}	-26.3 ^{bc}	-64.5 ^{bc}	-43.4 ^c	-10.1 ^a	-55.8 ^a
Influence of swath density on micronutrient concentration of switchgrass. Data are pooled over rainfall amount													
	LD	7.5 ^a	11.0 ^a	14.9 ^a	3.4 ^a	128.6 ^a	397.8 ^a	-56.6 ^a	-5.7 ^a	-2.5 ^a	-5.8 ^a	3.5 ^a	-71.8 ^a

MD	4.9 ^a	9.6 ^a	10.0 ^a	3.0 ^a	116.6 ^a	373.5 ^a	-1.8 ^a	6.6 ^a	28.2 ^a	4.4 ^a	16.0 ^a	-65.5 ^a
HD	7.2 ^a	11.6 ^a	14.0 ^a	3.5 ^a	108.8 ^a	353.8 ^a	-49.5 ^a	-11.3 ^a	3.1 ^a	-10.7 ^a	8.0 ^a	-48.8 ^a

Influence of rainfall amount on micronutrient concentration of switchgrass. Data are pooled over swath density

8	5.3 ^a	9.8 ^b	11.9 ^{ab}	3.0 ^b	97.2 ^b	372.6 ^a	-34.8 ^a	-8.1 ^{ab}	2.6 ^{ab}	2.7 ^a	6.8 ^{ab}	-54.6 ^{ab}
25	5.7 ^a	9.5 ^b	8.9 ^b	3.0 ^b	96.5 ^b	353.2 ^a	-25.8 ^a	14.2 ^a	39.6 ^a	5.6 ^a	20.2 ^a	-21.6 ^a
50	6.0 ^a	10.6 ^{ab}	10.2 ^b	3.2 ^{ab}	136.5 ^{ab}	410.0 ^a	-7.3 ^a	2.7 ^a	31.4 ^a	4.1 ^a	17.0 ^{ab}	-106.5 ^b
75	9.2 ^a	13.0 ^a	20.8 ^a	4.0 ^a	141.8 ^a	364.3 ^a	-75.9 ^a	-22.7 ^b	-35.1 ^b	-28.5 ^b	-7.4 ^b	-65.4 ^{ab}

^Z Means within columns followed by different letters are significantly different at the 95% confidence level. LD, MD, and HD is defined as low density, medium density and high density, respectively. *% change is calculated by formulae, $\% \text{ Change} = \frac{C_i \times DM_i - C_f \times DM_f}{C_i \times DM_i} \times 100$, where, C and DM are the concentration and dry matter of the constituent being analysed, and subscripts *i* and *f* are the initial and final values

Appendix B

Table B. Final mineral content left in corn stover after the rainfall treatment and percent change in composition compared to initial values

Rainfall (mm)	Density	B	Zn	Mn	Cu	Fe	Na	B change	Zn change	Mn change	Cu change	Fe change	Na change
ppm ^Z								% ^{Z,*}					
8	LD	7.2 ^{ab}	12.2 ^b	11.0 ^a	3.1 ^a	68.2 ^a	286.7 ^{ab}	-16.4 ^a	-18.0 ^{ab}	12.2 ^a	-1.7 ^a	-22.3 ^{ab}	-46.3 ^{ab}
8	MD	6.2 ^b	11.8 ^b	11.3 ^a	3.2 ^a	46.9 ^a	249.7 ^b	-1.7 ^a	-14.4 ^a	10.1 ^a	-5.9 ^a	15.6 ^a	-28.5 ^a
8	HD	6.0 ^b	14.4 ^{ab}	15.5 ^a	3.3 ^a	59.2 ^a	448.0 ^{ab}	0.1 ^a	-41.7 ^{ab}	-30.3 ^a	-8.8 ^a	-8.8 ^{ab}	-134.4 ^{ab}
25	LD	7.0 ^{ab}	14.1 ^b	12.8 ^a	3.2 ^a	79.9 ^a	306.3 ^{ab}	-9.8 ^a	-31.9 ^{ab}	12.6 ^a	-0.5 ^a	-38.0 ^{ab}	-51.7 ^{ab}
25	MD	18.0 ^a	22.0 ^a	13.4 ^a	5.3 ^a	85.3 ^a	303.7 ^{ab}	-37.6 ^a	-110.4 ^c	-19.6 ^a	-69.3 ^a	-53.4 ^{ab}	-55.7 ^{ab}
25	HD	7.0 ^{ab}	15.4 ^{ab}	12.8 ^a	3.3 ^a	67.4 ^a	494.3 ^{ab}	-13.0 ^a	-47.7 ^{abc}	5.7 ^a	-8.0 ^a	-20.3 ^{ab}	-154.4 ^{ab}
50	LD	7.3 ^{ab}	18.7 ^{ab}	10.2 ^a	3.7 ^a	96.2 ^a	444.7 ^{ab}	-21.5 ^a	-83.9 ^{bc}	15.5 ^a	-22.4 ^a	-77.5 ^{ab}	-128.9 ^{ab}
50	MD	7.6 ^{ab}	14.4 ^{ab}	12.6 ^a	3.8 ^a	90.3 ^a	455.3 ^{ab}	-23.4 ^a	-38.7 ^{ab}	-11.7 ^a	-24.2 ^a	-63.4 ^{ab}	-132.3 ^{ab}
50	HD	13.9 ^{ab}	18.6 ^{ab}	9.4 ^a	4.5 ^a	99.8 ^a	293.7 ^{ab}	-6.7 ^a	-84.9 ^{bc}	19.6 ^a	-51.6 ^a	-89.8 ^b	-53.8 ^{ab}
75	LD	8.4 ^{ab}	13.8 ^b	9.3 ^a	3.5 ^a	83.6 ^a	534.3 ^a	-35.8 ^a	-35.5 ^{ab}	36.5 ^a	-13.9 ^a	-51.5 ^{ab}	-174.4 ^b
75	MD	8.2 ^{ab}	12.1 ^b	11.4 ^a	3.4 ^a	77.5 ^a	456.0 ^{ab}	-35.1 ^a	-19.5 ^{ab}	22.3 ^a	-12.8 ^a	-40.9 ^{ab}	-138.3 ^{ab}
75	HD	7.3 ^{ab}	15.6 ^{ab}	9.7 ^a	3.4 ^a	85.7 ^a	394.0 ^{ab}	-21.8 ^a	-52.1 ^{abc}	36.2 ^a	-11.0 ^a	-56.3 ^{ab}	-106.7 ^{ab}
Influence of swath density on mineral content of corn stover. Data are pooled over rainfall amount													
	LD	7.5 ^a	29.7 ^a	10.8 ^a	3.4 ^a	82.0 ^a	393.0 ^a	-20.9 ^a	-42.3 ^a	19.2 ^a	-9.6 ^a	-47.3 ^a	-100.3 ^a

MD	10.0 ^a	15.1 ^a	12.2 ^a	3.9 ^a	75.0 ^a	366.2 ^a	-24.5 ^a	-45.7 ^a	0.3 ^a	-28.1 ^a	-35.5 ^a	-88.7 ^a
HD	8.6 ^a	16.0 ^a	11.9 ^a	3.6 ^a	78.0 ^a	407.5 ^a	-10.3 ^a	-56.6 ^a	7.8 ^a	-19.9 ^a	-43.8 ^a	-112.3 ^a

Influence of rainfall amount on mineral content of corn stover. Data are pooled over swath density

8	6.5 ^a	12.8 ^b	12.6 ^a	3.2 ^a	58.1 ^b	328.1 ^a	-6.0 ^a	-24.7 ^a	-2.7 ^a	5.5 ^a	-5.2 ^a	-69.7 ^a
25	10.7 ^a	17.1 ^a	13.0 ^a	3.9 ^a	77.5 ^{ab}	368.1 ^a	-20.1 ^{ab}	-63.3 ^{ab}	-0.4 ^a	-25.9 ^a	-37.2 ^{ab}	-87.3 ^a
50	9.6 ^a	17.3 ^a	10.7 ^a	4.0 ^a	95.4 ^a	397.9 ^a	-17.2 ^{ab}	-69.1 ^b	7.8 ^a	-32.7 ^a	-76.9 ^b	-105.0 ^a
75	8.0 ^a	13.8 ^{ab}	10.1 ^a	3.4 ^a	82.3 ^{ab}	461.4 ^a	-30.9 ^b	-35.7 ^{ab}	31.6 ^a	-12.6 ^a	-49.5 ^{ab}	-139.8 ^a

^z Means within columns followed by different letters are significantly different at the 95% confidence level. LD, MD, and HD is defined as low density, medium density, and high density, respectively. *% change is calculated by formulae, $\% \text{ Change} = \frac{C_i \times DM_i - C_f \times DM_f}{C_i \times DM_i} \times 100$, where, C and DM are the concentration and dry matter of the constituent being analysed, and subscripts *i* and *f* are the initial and final values