Understanding the Effects of Drought Stress on Corn Silage Yield and Quality

Gonzalo Ferreira
Department of Dairy Science
Virginia Tech

Summary

Uncontrolled environmental factors can affect DM yield and composition of corn whole-plant for silage. The spring and summer drought of 2012 reduced corn yields substantially when compared to 2011. In Virginia, drought stress affected DM yields and composition differently, depending on the region. The extremely low DM yield observed for the Southern Piedmont region in 2012 (2.0 ton DM/acre) could be attributed to the severe drought suffered that year. However, from the perspective of water status, the Southern Piedmont region had similar water status at the same fenological state than the Shenandoah Valley region, suggesting that factors other than drought stress also affected DM yield in the Southern Piedmont in 2012. Analysis of maximum temperatures showed that heat stress had a major effect on kernel development in the Southern Piedmont but not in the Shenandoah Valley. Therefore, in the Southern Piedmont region, heat stress exacerbated the effects of drought, reducing substantially DM yields and kernel development. Crop management practices, such as hybrid selection and planting date, should be considered to avoid high temperature stress during silking and kernel development.

Introduction

Whole-plant corn silage is a major ingredient in diets for dairy cattle. Therefore, producing high yielding and good quality forage is critical for minimizing production costs in dairy farming systems. Different management practices or genotype selections can affect yield and quality of corn whole-plant for silage. Whole-plant DM yields can be increased with higher planting densities (Cusicanqui and Lauer, 1999; Ferreira et al., 2014) or nitrogen fertilization rates (Roth et al., 2013). Increasing corn plant density likely increases fiber concentration and decreases in vitro DM digestibility of corn whole-plant (Cusicanqui and Lauer, 1999) due to a lower grain to stover ratio (Roth et al., 2013). Delaying harvesting time also increases DM yields and reduces fiber concentration of corn whole-plant (Bal et al., 1997; Ma et al., 2006), although nutrient utilization can be diminished if kernel processors are not utilized when chopping at late maturity stages (Ferreira and Mertens, 2006). Increasing cutting height at harvesting reduces fiber and lignin concentrations of corn whole-plant (Kung et al., 2008), although this reduces DM yields by 7.4 to 16.7% (Wu and Roth, 2003; Kung et al., 2008). With regard to genotype selection, planting corn hybrids with the brown midrib 3 mutation results in whole-plant corn silages with greater in vitro NDF digestibility (Oba and Allen, 2000; Taylor and Allen, 2005), although

[1]Contact at: 175 W Campus Drive, 2100 Litton-Reaves Hall (0315), Blacksburg, VA 24061, (540) 231-1965, FAX: (540) 231-1965; Email: gonf@vt.edu; Twitter: @DairyMgntVT.

DM yield is typically inferior for these hybrids (Lee and Brewbaker, 1984; Bal et al., 2000).

Despite these multiple controlled factors, uncontrolled environmental factors can affect DM yield and composition of corn whole-plant for silage (NeSmith and Ritchie, 1992; Çakir, 2004; Ferreira et al. 2014). This paper will discuss how abiotic stresses affect yield and composition of corn for silage.

"2012…One of the Worst Agricultural Calamities in the U.S."

The spring and summer drought of 2012 will be remembered as one of the "worst agricultural calamities" in the United States (USDA, 2013). The drought of 2012 reduced the national corn grain and silage yields by 16.2 and 16.3%, respectively, when compared to 2011 (USDA, 2013).

Corn hybrid performance trials completed at different locations across the state of Virginia (Behl et al., 2011; Behl et al., 2012) showed that climate affected DM yields differently. Indeed, whole-plant DM yields from the same corn hybrids ranged from 1.9 to 8.0 ton/acre in 2012 and from 5.1 to 8.1 ton/acre in 2011 (Table 1). Based on rainfalls (Table 2), we would have not expected the second lowest DM yield (5.6 ton/acre) in the Southern Piedmont region for 2011, the site-year with the greatest amount of rainfalls (Table 2). Rainfalls in the Shenandoah Valley region were not abundant in either year. Therefore, lower DM yield in the Southern Piedmont region may reflect inferior soil quality or fertility compared to the Shenandoah Valley region. The Virginia Agricultural Land Use Evaluation System (Donohue et al., 1994) recognizes this fact and estimates the yield potential of the soil at the Shenandoah Valley region to approximately 15% higher than the yield potential at the Southern Piedmont. Therefore, the extremely low DM yield observed for the Southern Piedmont region in 2012 (2.0 ton/acre) should be attributed to the severe drought suffered that year. However, precipitations in the Shenandoah Valley region were not much more abundant than for the Southern Piedmont region that year [262 and 228 mm (10.5 and 9.1 inches), respectively; Table 2). This observation suggests that factors other than drought stress also affected DM yield in the Southern Piedmont region in 2012.

Corn Composition

Dry matter concentration of the corn silage varied substantially among site-years (Table 3). The high variation for DM concentration among site.years is attributed to the low DM concentration (25.3%) observed for the Southern Piedmont region in 2012, likely due to the a reduced proportion of grain component in the whole plant. Similarly to DM concentration, CP concentration varied substantially among site-years (Table 3). The high variation for CP concentration among site-years is attributed to the high CP concentration (10.9% CP) observed for the Southern Piedmont region in 2012. In agreement with the observed DM concentration, a greater proportion of vegetative tissues in the whole plant, due to a reduced grain component, can explain the observed high concentration of CP for the Southern Piedmont region in 2012.

Neutral detergent fiber also varied substantially among site-years (Table 3). The NDF concentration in 2012 was substantially lower for the Shenandoah Valley region (43.0%) than for the Southern Piedmont region (56.6%), indicating that corn crops were affected differently despite summer drought. Fiber concentration in whole-plant corn silage is highly and negatively correlated to starch concentration (Ferreira and Mertens, 2005). Unfortunately, starch concentrations were not reported in these hybrid tests, but it is likely that kernel development explains the difference in NDF concentrations between these regions for 2012. An inferior kernel development for the Southern Piedmont region during 2012 is also supported by the low DM concentration (25.3%) and the relatively high CP concentration (10.9%) of the whole-plant (Table 3).

Timing of Rainfalls

After obtaining climate data, cumulated rainfalls were plotted against growing-degree days (Figure 1). Surprisingly, the Southern Piedmont region had greater cumulative rainfalls than the Shenandoah Valley region for the same stage of development of the crop. From the perspective of water status, these observations suggest that the Southern Piedmont site had similar water status at similar fenological state than the Shenandoah Valley site. These observations suggest that differences in NDF concentration between the Southern Piedmont and Shenandoah Valley regions should be attributed to factors beyond water status.

Heat Stress and Kernel Development

Heat stress during kernel development can greatly affect corn grain yield (Hanft and Jones, 1986; Cheikh and Jones, 1994). Kernel development is divided by a lag phase with little kernel growth and a linear growing phase with major accumulation of DM. The lag phase, which starts immediately after pollination and lasts 10 to 12 days after pollination, is critical for kernel development (Cheikh and Jones, 1994). The endosperm is the structure of the corn kernel that contains starch granules. Cell division of the endosperm cells during the lag phase determines the capacity of the endosperm to accumulate starch within the grain (Cheikh and Jones. 1994). Cheikh and Jones (1994) cultured corn kernels in vitro at different temperatures and observed that heat stressed kernels [i.e., kernels cultured at 35°C (95°F)] accumulated 18 to 75% less DM than non-stressed kernels [i.e., kernels cultured at 25°C (77°F)]. Reduced DM accumulation can be related to reductions in starch synthesis within the endosperm when kernels are subjected to temperatures greater than 35°C (95^{o}F) (Hanft and Jones, 1986). In addition to reduced kernel growth, Cheikh and Jones (1994) reported 23 to 97% kernel abortion when subjected to heat stress.

The date at which pollination occurred was estimated (Figure 2) under the assumption that silking occurred at 1400 growing-degree days (Neild and Newman, 1987). In 2011, maximum temperatures were below 35°C (95^{o}F) throughout the whole critical period of kernel development for the Southern Piedmont region (Figure 2A). In the Shenandoah Valley region, maximum temperatures were above 35°C (95^{o}F) for only a few days during the critical period of kernel development (Figure 2B). Based on these observations, heat stress would have not affected kernel development. In 2012, however, the Southern Piedmont region had maximum daily temperatures above 35°C (95^{o}F) for an extended period (11 days) right after silking (Figure 2C), whereas maximum daily temperatures were 7.1 ± 2.3°C lower in the Shenandoah Valley region around silking (Figure 2D). It is therefore likely that heat stress had a major effect on kernel development in the Southern Piedmont region but not in the Shenandoah Valley region. Therefore, in the Southern Piedmont region, heat stress exacerbated the effects of drought, reducing substantially DM yields and kernel development.

Implications

The observations from this study have major practical implications. In the first instance, heat stress may affect the nutritional composition of corn silage, even in crops with adequate water status. Similar to the data reported in this study, Ferreira (unpublished data) observed concentrations of 28.1% DM, 11.6% CP, and 59.9% NDF for corn silage originated from an irrigated corn field suffering heat stress immediately after pollination, suggesting that silage quality is not ensured exclusively by water status.

Dairy farmers, agronomists, and dairy consultants should also not overlook the regional temperatures when planning a strategy to ensure forage stocks for dairy farms. In regions with high summer temperatures, choosing early maturity corn hybrids or delaying planting date should be considered to avoid high temperature stress during silking and kernel development. With regard to harvesting management, monitoring daily temperatures might help to better decide whether harvesting and chopping should be anticipated when drought occurs. High temperatures around pollination might be considered as an indicator that silage yield or quality would not increase or improve substantially after a relieving rain.

Finally, planting alternative forages, such as Sorghum species, should also be considered to minimize the risk associated to growing corn in regions with high summer temperatures (Aydin et al., 1999; Amer et al., 2011). Sorghum species are characterized for having greater resistance to drought stress than corn. Compared to corn, Sorghum species usually require a delayed planting date, therefore escaping the high summer temperatures during kernel development.

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Table 1. Dry matter yield (ton/acre) of silage from 8 corn hybrids tested at the Southern Piedmont and Shenandoah Valley regions in the State of Virginia.

	Southern Piedmont		Shenandoah Valley	
Hybrid	2011	2012	2011	2012
A	5.5	2.3	7.6	6.1
B	5.9	2.1	5.1	8.0
C	5.5	2.0	6.6	7.7
D	5.9	1.9	7.2	5.9
E	5.6	2.2	5.9	5.2
F	5.9	2.0	8.1	4.2
G	5.1	1.9	7.0	5.2

Table 2. Planting and silage harvesting dates, and rainfalls of experimental corn plots at the Southern Piedmont and Shenandoah Valley regions in the State of Virginia during 2011 and 2012.

	Southern Piedmont		Shenandoah Valley	
	2011	2012	2011	2012
Planting date	April 18	April 10	May 6	May 21
Harvesting date	August 31	July 17	August 24	September 12
Growing period, days	136	119	111	125
Rainfalls, mm[1]	501	228	280	262
April	12.7	71.9	0	0
May	103.4	65.8	86.1	61.2
June	92.2	27.2	82.6	37.1
July	138.9	62.7	34.0	65.8
August	153.7	0	77.7	78.5
September	0	0	0	19.8

[1]1 mm = 0.04 inches.

Table 3. Composition of 8 corn hybrids harvested as silage and tested at the Southern Piedmont and Shenandoah Valley regions in the State of Virginia during 2011 and 2012.

	Dry Matter, %				Crude Protein, % of DM				Neutral Detergent Fiber, % of DM			
	Southern Piedmont		Shenandoah Valley		Southern Piedmont		Shenandoah Valley		Southern Piedmont		Shenandoah Valley	
Hybrid	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
A	39.6	28.2	32.2	37.4	8.6	10.3	8.0	7.4	51.2	58.4	52.8	42.3
B	34.8	26.9	33.5	34.5	8.8	10.5	8.1	7.5	49.9	55.7	50.5	44.9
C	33.1	23.8	30.2	34.2	8.6	11.5	7.9	6.7	52.5	55.4	54.7	41.8
D	38.7	24.9	31.4	28.2	8.2	10.7	7.2	7.2	47.6	58.8	55.5	42.6
E	34.2	21.1	30.6	28.1	9.6	11.5	7.8	6.9	50.1	55.6	54.5	45.3
F	40.5	27.5	36.1	48.8	8.4	10.9	7.7	6.9	57.7	55.9	51.4	40.3
G	38.2	27.4	35.3	39.7	8.4	10.2	7.0	6.8	51.4	57.6	50.6	42.4
H	36.8	22.5	31.1	32.4	9.1	11.4	8.0	7.2	51.2	55.5	52.1	44.5
Average	37.0	25.3	32.6	35.4	8.7	10.9	7.7	7.1	51.5	56.6	52.8	43.0

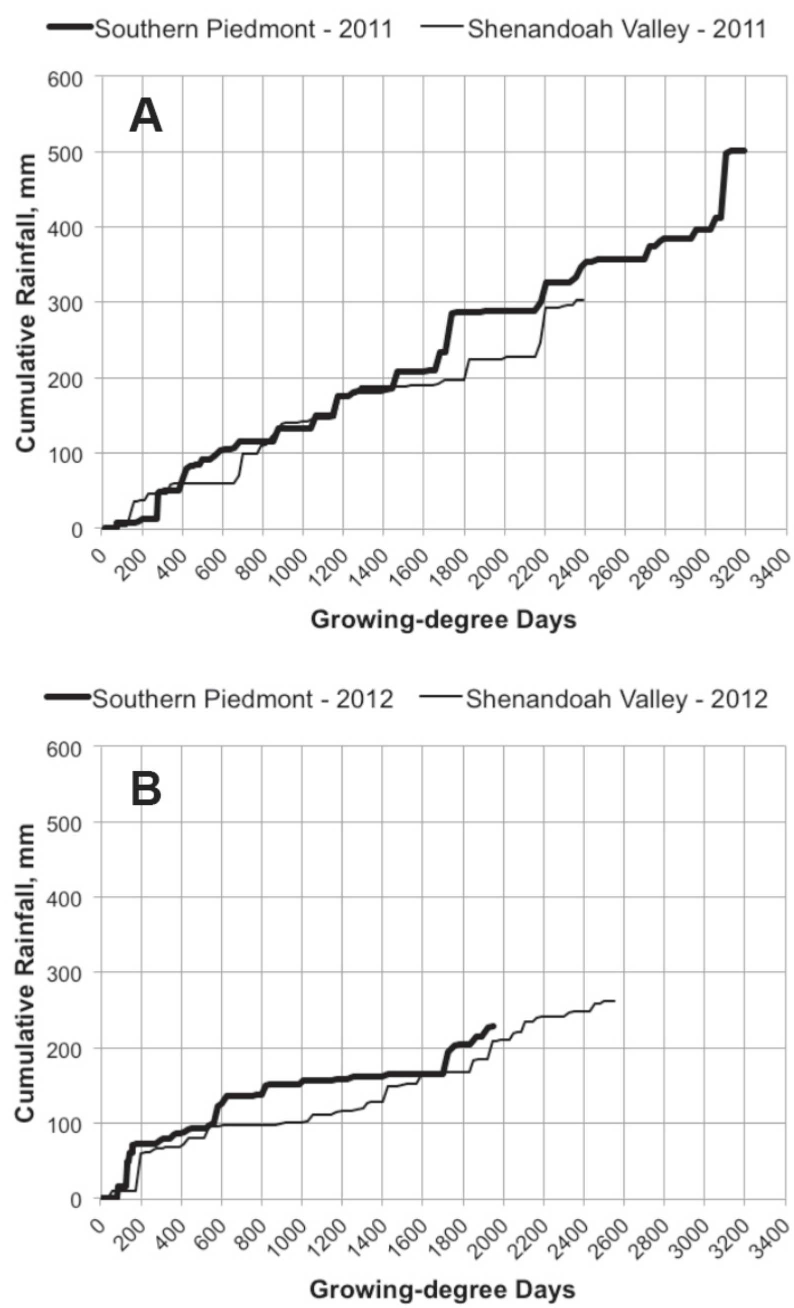

Figure 1. Cumulative rainfalls (1 mm = 0.04 inches) at different growing-degree days of corn crops grown at 2 regions during 2011 (A) and 2012 (B) in the State of Virginia. Thick and thin lines represent the cumulative precipitations for the Southern Piedmont and Shenandoah Valley regions, respectively.

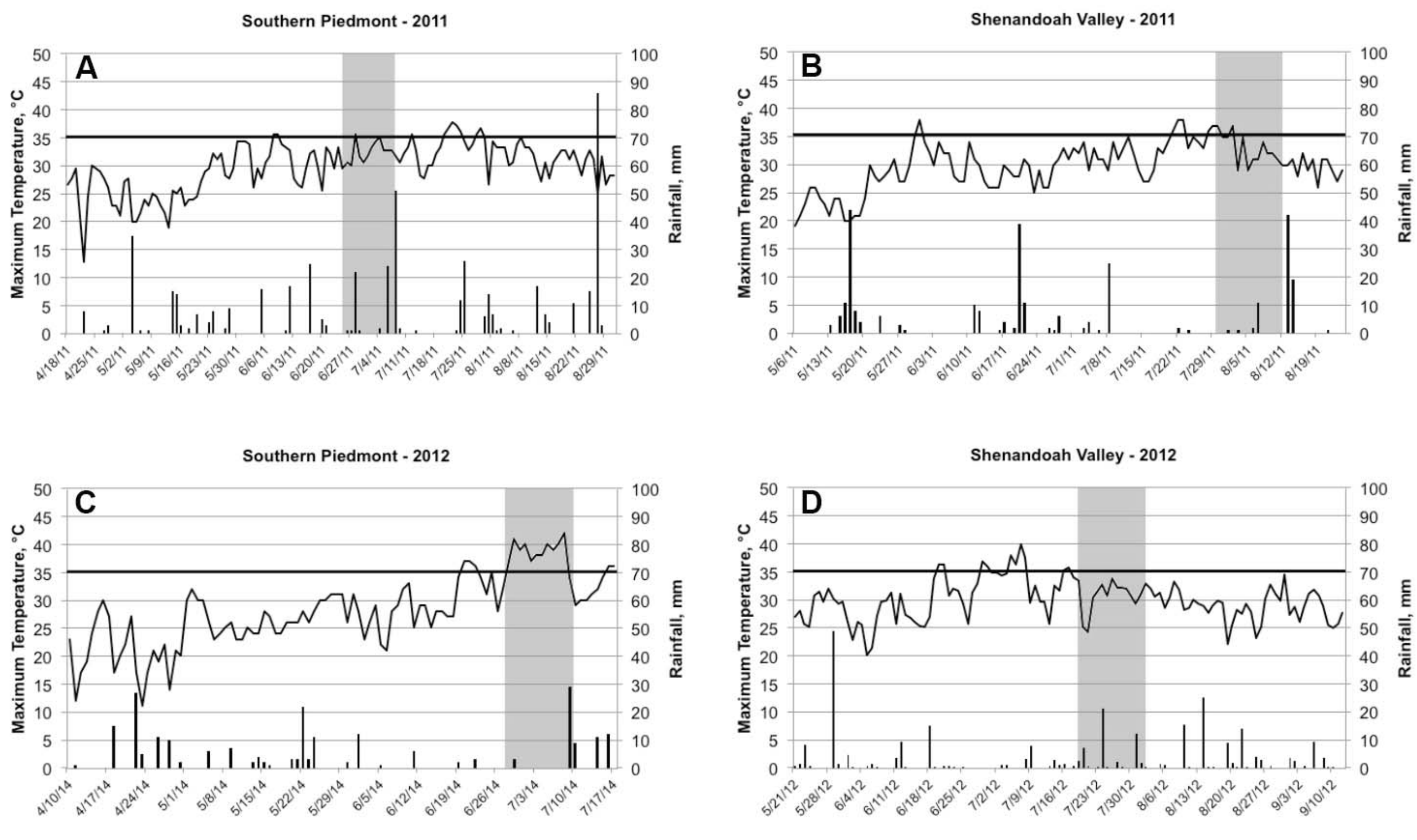

Figure 2. Daily maximum temperatures (line) and rainfalls (columns; 1 mm = 0.04 inches) during the crop cycle at 2 regions during 2011 and 2012 in the state of Virginia. The shaded region represents the critical stage for kernel development. The thick horizontal line represents the threshold temperature for heat stress (>35°C; 95°F). Prolonged heat stress after silking occurred only in the Southern Piedmont region during 2012 but not in other site-years.