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Effect of Inoculants on the Ensiling of Corn Stover

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Abstract. *Four different varieties of corn stover were harvested and ensiled over a range of dry matter (DM) contents from approximately 30 to 60% DM with and without the use of lactic acid bacterial inoculants. Stovers ensiled as harvested (45 to 58% DM) ensiled well with no additive. Similarly stovers rehydrated to 40% DM ensiled well and were stable over 90 d. Stovers rehydrated to 30% DM initially ensiled well (21 d) but experienced secondary fermentations by 90 d. It appears that ensiling stover at 30% DM may result in occasional clostridial activity that could reduce the recovery and quality of the stover for downstream uses. All three inoculants tested were successful in affecting ensiled stover quality in all trials even when the inoculant application rates were less than 1% of the natural lactic acid bacterial population. The homofermentative inoculant shifted fermentation to lactic acid, and reduced pH relative to the untreated control particularly in stovers above 45% DM. The two inoculants with L. buchneri shifted fermentation toward acetic acid and 1,2-propanediol. These two inoculants would help to guarantee the stability of stover in transit between the farm and bioprocessing plant.*

Keywords. Corn stover, silage, inoculant, lactic acid bacteria

Introduction

Corn stover is a potentially attractive source of biomass for conversion to ethanol or lactic acid. A key issue in developing such an industry is preservation of the stover between harvest and processing at a bioconversion facility. One alternative is ensiling whereby lactic acid bacteria ferment some of the stover sugars to lactic acid and other products.

Ensiling the stover on farms is attractive for several reasons. First, storage of the stover would be distributed across many farms until needed at the processing plant. Second, ensiling should permit preservation of the stover across a wide range of moisture or dry matter (DM) contents. Third, the products of ensiling should help to stabilize stover and minimize spoilage between the farm and utilization at the processing plant. Finally, ensiling could potentially provide an opportunity for pretreating the stover, possibly reducing downstream processing costs.

Because whole-plant corn ensiles readily, the stover fraction might be expected to ensile well. However, whole-plant corn silage is made typically while the plant is still active, laying down starch in the kernels. Stover harvest for biomass uses is likely to occur at grain harvest when the stover is brown, relatively dry and difficult to compact, and lower in sugars, conditions less conducive to successful ensiling.

Recent work does suggest that the stover is ensilable. Corn stover was ensiled at field-scale in a bag silo and in wrapped round bales with low losses (Shinners and Binversie, 2004). Ren et al. (2006) reported on ensiling stover with and without cell-wall degrading enzymes in mini-silos and at pilot-scale. These results indicate that stover can be ensiled successfully. However, additional work is needed to investigate ensilability over a wider range of corn varieties, DM contents and harvesting conditions.

One potential aid to ensiling is the application of lactic acid bacterial inoculants to the stover at ensiling. These bacterial inoculants are the most commonly used silage additives in the U.S. Two types exist: homofermentative lactic acid bacteria to ensure a rapid fermentation of sugars to lactic acid and a low silage pH and *Lactobacillus buchneri*, a heterofermentative lactic acid bacteria, to raise acetic acid concentrations and inhibit spoilage by yeasts and molds. The latter type may be useful in keeping the stover from heating during transport between the farm and bioprocessing plant.

The objectives of the study reported here were to investigate the ensilability of various corn stover sources ensiled at different DM contents with and without inoculant treatments, both homofermentative and *L. buchneri* inoculants.

Materials and Methods

Stover Sources

Corn stover was obtained from various fields at the University of Wisconsin Arlington Agricultural Research Station on four dates in fall 2005. On October 11, an experimental single-pass stover and grain harvester producing three fractions [grain, stalk, ear (primarily husk and cob)] (Shinners et al., 2006b) was used to harvest Pioneer 34M93[1], a 110-d, Bt and LibertyLink

[1] Names of products are included for the benefit of the reader and do not imply endorsement or preferential treatment by the USDA, Agricultural Research Service or the University of Wisconsin-Madison.

Figure 1. Single-pass stover and grain harvester used for the October 11 trial.

variety. The head of the harvester cut the whole plant. The ear was separated from the stalk. The stalk was chopped and blown into a wagon being pulled beside the harvester (Figure 1). The ear proceeded through the combine portion of the harvester. The ear residue after grain removal was chopped and blown into a trailing wagon. We ensiled separately both the stalk and ear fractions. For stover used on subsequent dates, corn was harvested with a single-pass, split-stream harvester that harvested the corn grain and stover in separate streams (Shinners et al., 2006a,b; Figure 2). The grain combine used a whole-plant corn head from a forage harvester to capture the entire plant at a height of 10-15 cm. The stover fraction was chopped and transported from the rear of the harvester into a trailing wagon. On October 20, Agri-Gold A6333 Bt, a 104-d, Bt, LibertyLink and Roundup Ready hybrid was harvested. It was ensiled at two DM contents, as-harvested and rehydrated to approximately 30% DM. On November 3, a 112-d brown mid-rib (BMR) hybrid, Mycogen F697, was harvested. It was ensiled at three DM contents, as-harvested and rehydrated to approximately 30 and 40% DM. On November 4, a 106-d, high starch, Bt and LibertyLink hybrid, Pioneer 35Y67, was harvested. It was also ensiled at three DM contents, as-harvested and rehydrated to approximately 30 and 40% DM.

Ensiling

Stover was frozen (-20°C) on the day of harvest. The stover was ensiled within three weeks of harvest. On the day before ensiling, the stover was moved to a refrigerator overnight, and final

Figure 2. Single-pass stover and grain harvester used for October 20, November 3, 4 trials.

thawing was done at room temperature on the day of ensiling. Prior to ensiling, the DM content of the stover was estimated using microwave oven. When stover was ensiled at more than one DM content, the stover was divided in half or thirds depending on the number of DM treatments. The portions to be rehydrated for the lower DM contents were weighed and laid out on a plastic sheet. Distilled water in an amount calculated to achieve the desired DM content was sprinkled on the stover and thoroughly mixed into the stover by hand. The rehydrated stover was allowed to absorb moisture for at least an hour prior to ensiling and was periodically mixed by hand to achieve a uniform blending of water and stover. All DM levels were ensiled on the same day.

Vacuum-sealed bags (28 x 35 cm) and a Minipack Best Vac sealer (Doug Care Equipment, Springville, CA) were used to ensile the stover, 24 bags for each DM content of a particular stover. The amount ensiled in each bag was set to approximately 100 g DM. Six bags were uninoculated, six bags were treated with a homofermentative lactic acid bacterial corn silage inoculant (Biomax 5, Chr. Hansen Biosystems, Milwaukee, WI), six with *Lactobacillus buchneri* (11A44, Pioneer Hi-Bred, Johnston, IA), and six with a combination product (*L. buchneri*, *L. plantarum*, *E. faecium*; 11C33, Pioneer Hi-Bred). Inoculated treatments applied original product at the rate specified by the manufacturer. However, all inoculants were diluted more than normal so that all inoculated treatments received 1 g diluted inoculant/100 g crop, applied by a hand sprayer. The uninoculated control was sprayed with distilled water at 1 g/100 g crop. After vacuum sealing of all bags, bags were vacuumed sealed in a second bag of the same size to provide a double layer of plastic film. Bags were stored at room temperature (~22°C). At 21 d, three bags of each treatment were frozen (-20°C) until opened for analysis. The remainder were frozen at 90 d.

Analyses

Fresh stover, minimum of two samples per DM, were analyzed for DM content by oven drying at 55°C for 72 h (ASAE Standards, 2003), pH, and lactic acid bacteria (Rogosa agar; Muck, 1989). Inoculants were analyzed for lactic acid bacteria. Silages were analyzed for pH, fermentation products via HPLC (Muck and Dickerson, 1988), and DM content. Fresh stover and silages will be analyzed for ash, crude protein, neutral detergent fiber, acid detergent fiber and potential ethanol yield. Those results will be reported at a later time.

Analysis of variance was performed using the GLM procedure in SAS (SAS Institute, Cary, NC). Significant differences were declared for $P < 0.05$. Differences among means were tested using LSMEANS with the PDIFF option.

Results

Fresh Stover

Characteristics of the stover ensiled are shown in Table 1. Except for the stalk fraction harvested on 11 October, the stover as harvested was between 50 and 60% DM. Rehydrating based on microwave oven estimates of DM concentration was reasonably accurate in achieving the target concentrations of 30 and 40%. The populations of lactic acid bacteria on the stover were generally high with the exception of the Agri-Gold stover harvested on 20 October.

Table 1. Characteristics of the stover at ensiling.

Harvest Date	Variety	Type	DM, %	pH	Lactic Acid Bacteria, log_{10}(cfu/g)*
11 Oct 2005	Pioneer 34M93	Stalk	45.3	5.94	8.18
		Ear	51.0	6.28	5.56
20 Oct 2005	Agri-Gold	Stover	57.8	6.41	4.75
	A6333 Bt	Rehydrated stover	30.6	6.78	5.02
3 Nov 2005	Mycogen F697	Stover	51.2	6.22	7.58
		Rehydrated stover	29.6	7.42	8.65
		Rehydrated stover	39.5	6.49	8.65
4 Nov 2005	Pioneer 35Y67	Stover	53.7	7.01	6.00
		Rehydrated stover	32.5	6.87	6.49
		Rehydrated stover	37.5	6.46	7.30

* cfu - colony-forming units

The populations of lactic acid bacteria supplied by each of the three inoculants were consistent over the four ensiling dates (Table 2). The minimum application rates guaranteed by the Biomax 5, 11A44 and 11C33 inoculants were 5.00, 5.04 and 5.08 log_{10}(colony-forming units [cfu]/g stover), respectively. Consequently the actual application rates were higher than the minimum guaranteed rates in all cases. While these rates were above minimum values, the inoculant

bacteria in most of the cases had to compete with a greater natural lactic acid bacterial population, comparing the values in Table 2 with those in Table 1. With the Pioneer 34M93 stalk and the Mycogen stover, the natural population was more than 100 times greater than that supplied by the inoculants, providing stiff challenges for the inoculants to dominate fermentation.

Table 2. Rate of inoculant application [log_{10}(cfu/g stover)]* at ensiling.

	Inoculant		
Harvest Date	Biomax 5	11A44	11C33
11 Oct 2005	5.31	5.90	5.59
20 Oct 2005	5.39	5.41	5.41
3 Nov 2005	5.45	5.78	5.72
4 Nov 2005	5.24	5.79	5.69

* cfu - colony-forming units

Ensiled Stover

The ensiled ear residue harvested on 11 October fermented well with no additive (Table 3). Fermentation in the control treatment was not finished at 21 d, with pH declining an additional 0.23 units at 90 d. Traces of butyric acid were measured in all three control silages at 90 d. The Biomax 5 reduced pH compared to the control because of the higher production of lactic acid. The *L. buchneri* strain in both 11A44 and 11C33 was evident by the elevated levels of acetic acid and 1,2-propanediol in those treatments compared to the control treatment. Both compounds increased between 21 and 90 d in those two treatments. The increase in acetic acid was most likely the reason for the higher pH at 90 d in the 11A44 and 11C33 treatments compared to the pH of the control.

Table 3. Characteristics (g/kg DM except as noted) of the ensiled Pioneer 34M93 ear residue.

Treatment	DM, %	pH	Lactic Acid	Acetic Acid	Propionic Acid	Butyric Acid	Ethanol	1,2-Propanediol
21 d								
Control	50.4	4.34	16	9	0	0	7	0
Biomax	50.4	4.01	23	7	0	0	5	0
11A44	49.4	4.39	6	14	0	0	5	7
11C33	49.6	4.30	9	14	0	0	4	7
90 d								
Control	51.1	4.11	18	9	0	1	6	0
Biomax	52.4	3.96	24	9	0	0	7	0
11A44	51.0	4.27	7	25	0	0	7	11
11C33	50.6	4.32	5	25	0	0	8	12
s.e.	0.35	0.014	2.2	1.4	NS	0.1	0.8	0.6

The ensiled corn stalks harvested on 11 October also ensiled well without treatment (Table 4) achieving a low pH at 21 d with no significant change in fermentation quality at 90 d. In spite of the high natural lactic acid bacterial population, all three inoculants affected fermentation. The homofermentative Biomax 5 produced a lower pH and higher lactic acid concentration than the control. The inoculant with only *L. buchneri*, 11A44, produced the highest pH and highest acetic acid and 1,2-propanediol concentrations. The combination inoculant, 11C33, produced a pH and acetic acid and 1,2-propanediol concentrations intermediate between the control and 11A44.

Table 4. Characteristics (g/kg DM except as noted) of the ensiled Pioneer 34M93 stalk residue.

Treatment	DM, %	pH	Lactic Acid	Acetic Acid	Propionic Acid	Butyric Acid	Ethanol	1,2-Propanediol
21 d								
Control	44.5	4.14	49	17	0	0	13	0
Biomax	43.5	4.04	46	12	0	0	12	0
11A44	44.1	4.29	38	25	0	0	14	9
11C33	43.8	4.18	33	17	0	0	10	3
90 d								
Control	45.8	4.10	43	16	0	0	9	0
Biomax	45.5	4.04	60	17	0	0	9	0
11A44	45.3	4.34	26	32	0	0	10	16
11C33	44.6	4.25	30	28	0	0	9	11
s.e.	0.47	0.021	4.0	1.7	NS	NS	1.1	0.7

The driest stover ensiled was the Agri-Gold A6333 Bt harvested on 20 October. Without inoculant, the stover fermented slowly and was not below pH 5.0 until after 21 d (Table 5). All three inoculants reduced pH more rapidly than the control; 11A44 had the slowest rate of decline of the three inoculants. At 90 d, the Biomax 5 treatment had the lowest pH and highest lactic acid concentration. The inoculants with *L. buchneri* had the highest acetic acid and 1,2-propanediol concentrations. All silages had low levels of propionic acid.

The rehydrated Agri-Gold stover fermented to a low pH at 21 d (Table 6) and appeared to undergo a *L. buchneri*-type fermentation between 21 and 90 d as evidenced by a loss of lactic acid and increases in pH, acetic acid and 1,2-propanediol. The Biomax 5 treatment was not significantly different ($P > 0.05$) from the control treatment in pH or fermentation products although there was a trend toward more lactic acid and less acetic acid than the control. The *L. buchneri* containing inoculants had the highest pH values and acetic acid concentrations. In these treatments 1,2-propanediol was highest at 21 d while propionic acid increased between 21 and 90 d.

Table 5. Characteristics (g/kg DM except as noted) of the 58% DM ensiled Agri-Gold A6333 Bt stover.

Treatment	DM, %	pH	Lactic Acid	Acetic Acid	Propionic Acid	Butyric Acid	Ethanol	1,2-Propanediol
21 d								
Control	59.6	5.18	13	8	6	0	8	0
Biomax	60.2	4.44	31	8	2	0	4	0
11A44	58.7	4.71	17	15	5	0	8	4
11C33	58.7	4.58	21	14	4	0	6	4
90 d								
Control	64.7	4.76	15	8	4	0	4	0
Biomax	60.2	4.31	36	12	3	0	4	0
11A44	61.5	4.52	16	22	4	0	7	7
11C33	61.8	4.52	17	23	3	0	5	7
s.e.	1.38	0.040	2.6	2.1	0.7	NS	0.9	0.6

Table 6. Characteristics (g/kg DM except as noted) of the rehydrated (30% DM) and ensiled Agri-Gold A6333 Bt stover.

Treatment	DM, %	pH	Lactic Acid	Acetic Acid	Propionic Acid	Butyric Acid	Ethanol	1,2-Propanediol
21 d								
Control	27.2	3.98	53	18	1	0	8	1
Biomax	29.3	4.03	47	15	1	0	6	0
11A44	28.3	4.38	27	28	3	0	8	8
11C33	27.1	4.25	31	24	2	0	8	7
90 d								
Control	30.9	4.14	30	35	4	0	6	9
Biomax	32.5	4.04	38	24	1	0	4	7
11A44	27.0	4.35	13	50	7	0	9	4
11C33	29.0	4.37	7	45	8	0	9	2
s.e.	NS	0.047	3.5	4.2	1.1	NS	1.1	1.4

The BMR stover (Mycogen F697) fermented rapidly in both the control and Biomax 5 treatments to a low pH at 21 d with no significant changes in fermentation characteristics at 90 d (Table 7). Biomax 5 had a higher lactic acid concentration at 21 d and a lower pH at 90 d than the control but otherwise the two treatments were similar. The *L. buchneri* containing treatments performed similarly, achieving a pH below 4.30 at 21 d with measurable levels of 1,2-propanediol and with an increase in pH, acetic acid and 1,2-propanediol between 21 and 90 d.

Table 7. Characteristics (g/kg DM except as noted) of the 51% DM ensiled Mycogen F697 stover.

Treatment	DM, %	pH	Lactic Acid	Acetic Acid	Propionic Acid	Butyric Acid	Ethanol	1,2-Propanediol
21 d								
Control	53.8	4.13	34	15	0	0	4	0
Biomax	53.4	4.12	48	18	0	0	4	0
11A44	51.5	4.27	31	22	0	0	6	7
11C33	50.2	4.28	28	19	0	0	5	5
90 d								
Control	56.1	4.19	44	19	0	0	5	0
Biomax	53.5	4.12	50	17	0	0	4	0
11A44	53.1	4.40	26	35	0	0	6	12
11C33	54.2	4.39	27	32	0	0	5	11
s.e.	0.71	0.023	4.2	1.7	NS	NS	0.5	0.8

The pH values of the rehydrated (both 30 and 40% DM) BMR stover at 21 d (Tables 8, 9) were similar to those of the as-harvested ensiled stover. The *L. buchneri* containing treatments with the exception of 11C33 at 30% DM were approximately 0.10 pH units higher than the control and Biomax 5 treatments. However, there were no significant differences in fermentation products among treatments at 21 d for either rehydrated condition. At 90 d, the 30 and 40% DM ensiled stovers behaved differently. At 30% DM, pH and acetic acid concentrations increased for all treatments compared to values at 21 d. The biggest shifts occurred with 11A44, including

Table 8. Characteristics (g/kg DM except as noted) of the rehydrated (30% DM) and ensiled Mycogen F697 stover.

Treatment	DM, %	pH	Lactic Acid	Acetic Acid	Propionic Acid	Butyric Acid	Ethanol	1,2-Propanediol
21 d								
Control	28.1	4.15	45	21	0	0	5	1
Biomax	28.4	4.16	40	20	0	0	5	1
11A44	28.1	4.27	41	25	0	2	6	0
11C33	28.9	4.19	37	20	0	0	5	1
90 d								
Control	27.8	4.23	34	30	0	6	5	4
Biomax	27.9	4.25	40	30	0	6	6	4
11A44	27.8	4.49	17	41	4	3	8	5
11C33	28.0	4.38	25	33	0	1	6	7
s.e.	NS	0.042	5.0	3.2	0.2	NS	0.5	1.5

Table 9. Characteristics (g/kg DM except as noted) of the rehydrated (40% DM) and ensiled Mycogen F697 stover.

Treatment	DM, %	pH	Lactic Acid	Acetic Acid	Propionic Acid	Butyric Acid	Ethanol	1,2-Propanediol
21 d								
Control	38.8	4.12	41	17	0	0	4	1
Biomax	38.8	4.12	37	16	0	0	4	0
11A44	38.3	4.20	35	18	0	0	5	1
11C33	38.8	4.20	40	20	0	0	5	1
90 d								
Control	40.0	4.08	45	34	0	0	6	7
Biomax	39.8	4.07	54	31	0	0	5	4
11A44	38.4	4.35	28	39	0	0	7	16
11C33	38.9	4.34	30	32	0	0	5	11
s.e.	NS	0.012	5.2	2.4	NS	NS	0.6	2.1

a reduction in lactic acid. All four treatments had evidence of clostridial activity with low levels of butyric acid. At 40% DM, there was a significant decrease in pH from 21 to 90 d in the control and Biomax 5 treatments and a significant increase for the 11A44 and 11C33 treatments. Acetic acid and 1,2-propanediol increased in all four treatments. However, the largest increases came with 11A44. Lactic acid increased between 21 and 90 d only in the Biomax 5 treatment.

Table 10. Characteristics (g/kg DM except as noted) of the 54% DM Pioneer 35Y67 ensiled stover.

Treatment	DM, %	pH	Lactic Acid	Acetic Acid	Propionic Acid	Butyric Acid	Ethanol	1,2-Propanediol
21 d								
Control	54.5	4.58	25	12	0	0	3	0
Biomax	49.1	4.08	44	12	0	0	4	0
11A44	47.1	4.23	34	27	0	0	6	17
11C33	46.5	4.16	40	20	0	0	4	6
90 d								
Control	56.4	4.33	28	13	0	0	2	1
Biomax	50.6	4.02	41	12	0	0	3	0
11A44	47.5	4.23	30	34	0	0	6	23
11C33	48.3	4.14	34	29	0	0	4	11
s.e.	1.14	0.027	2.8	1.7	NS	NS	0.6	1.0

Fermentation of the Pioneer 35Y67 stover was slowest in the control treatment (Table 10). The control treatment had the highest pH at 21 d, and pH in this treatment declined another 0.25 pH units by 90 d. In contrast, the pH values of the inoculated treatments were not significantly different between 21 and 90 d. However, the *L. buchneri* treatments did increase in acetic acid and 1,2-propanediol between 21 and 90 d.

The rehydrated Pioneer 35Y67 fermented similarly over the first 21 d whether at 30 or 40% DM (Tables 11 and 12). The pH values for the control and Biomax 5 treatments were less than 4.0 whereas those for the *L. buchneri* treatments were generally 0.10 pH units or more higher. The highest lactic-to-acetic acid ratio occurred in the Biomax 5 treatment and the lowest occurred in the 11A44 treatment at both DM contents. By 90 d, pH increased in all treatments at 30% DM due to reductions in lactic acid and increases in acetic acid. Increases in 1,2-propanediol between 21 and 90 d occurred for all treatments with the highest concentrations in the *L. buchneri* treatments. In contrast at 40% DM, pH between 21 and 90 d remained similar for the control and Biomax 5 treatments; nonsignificant differences in lactic and acetic acid concentrations were observed. For the same time period, pH rose in the *L. buchneri* treatments along with significant increases in acetic acid and 1,2-propanediol.

Table 11. Characteristics (g/kg DM except as noted) of the rehydrated (30% DM) and ensiled Pioneer 35Y67 stover.

Treatment	DM, %	pH	Lactic Acid	Acetic Acid	Propionic Acid	Butyric Acid	Ethanol	1,2-Propanediol
21 d								
Control	31.8	3.96	59	19	0	0	5	2
Biomax	30.8	3.94	54	15	0	0	4	0
11A44	31.3	4.14	46	26	0	0	6	9
11C33	30.4	4.15	41	22	0	0	5	8
90 d								
Control	33.4	4.26	30	37	0	0	5	16
Biomax	31.5	4.14	37	29	0	0	4	12
11A44	32.6	4.40	20	40	0	0	8	23
11C33	32.2	4.47	16	43	0	0	7	23
s.e.	0.70	0.037	4.2	2.2	NS	NS	0.5	1.2

Table 12. Characteristics (g/kg DM except as noted) of the rehydrated (40% DM) and ensiled Pioneer 35Y67 stover.

Treatment	DM, %	pH	Lactic Acid	Acetic Acid	Propionic Acid	Butyric Acid	Ethanol	1,2-Propanediol
21 d								
Control	37.3	3.97	57	19	0	0	5	0
Biomax	36.9	3.93	61	17	0	0	4	0
11A44	36.3	4.10	42	27	0	0	6	14
11C33	35.8	4.01	52	21	0	0	4	5
90 d								
Control	38.4	3.96	51	21	0	0	4	3
Biomax	38.8	3.92	63	20	0	0	4	1
11A44	37.1	4.24	33	40	0	0	7	23
11C33	36.3	4.11	42	32	0	0	5	13
s.e.	0.51	0.012	4.7	2.1	NS	NS	0.4	0.6

Discussion

Ensiling Untreated Stover

The untreated stover, when ensiled as harvested (45 to 58% DM), fermented well and appeared stable over the 90 d of storage. This included the stover fractions (ear and stalk, Tables 3 and 4). The untreated stover that was above 50% DM fermented slowly, and fermentation was not complete at 21 d. This was indicated by lower pH and/or increases in fermentation products at 90 d.

Rehydrating the stover to approximately 30% DM resulted in a much faster fermentation and a lower pH (Tables 6, 8 and 11). Primary fermentation appeared finished at 21 d. However, some secondary fermentation from either lactic acid bacteria or clostridia occurred in all three cases. In the case where pH at 21 d was not below 4.0, the ensiled stover contained butyric acid at 90 d, indicating clostridial activity. In the other two cases, pH increased between 21 and 90 d while lactic acid concentrations decreased and acetic acid and 1,2-propanediol increased. These changes, particularly the increase in 1,2-propanediol, suggest that naturally-present *L. buchneri* were active in these stovers.

Rehydrating the stover to approximately 40% DM resulted in low pH values by 21 d, and pH was slightly lower (but not always significantly) at 90 d (Tables 9, 12). This suggested a more stable fermentation. However, both control stover silages at 40% DM had low levels of 1,2-propanediol at 90 d, indicative of the activity of naturally-present *L. buchneri*.

Overall, the results suggest that untreated stover ensiles well. This was true over four different varieties and a range of DM concentrations. However, at 30% DM the potential for clostridial activity is possible, and did occur in one of three trials. This is unlikely to be a cause for concern if stover is being harvested concurrently with grain harvest. Under such conditions, stover DM concentration is unlikely to be less than 40%.

Effect of Inoculants on Ensiling of Stover

A homofermentative inoculant like Biomax 5 should drop silage pH more rapidly and potentially to a lower value than an untreated silage. Our experimental design was not really set up to measure differences in the speed of fermentation. However, in the driest conditions (the five trials where the stover was not rehydrated), the pH of the Biomax 5 treatment at 21 d was lower than the pH in the control treatment in four of five trials. In the one case where the two treatments had similar pH, the Biomax 5 treatment had significantly more lactic acid than the control. Thus the Biomax 5 treatment affected fermentation in all five cases even though the natural population of lactic acid bacteria was more than 10 times greater than the Biomax 5 application rate in two of the five trials.

In the rehydrated stovers, the Biomax 5 inoculant most often had no significant effect on lowering pH relative to that in the control except for the 40% DM Pioneer 35Y67 stover. At 90 d, the pH of Biomax 5 treatments of both rehydrated DM contents of Pioneer 35Y67 were lower than the respective pH values of the control. At 90 d, there was a consistent tendency for the Biomax 5 treatment to have a higher lactic-to-acetic acid ratio than the control. Consequently, there was evidence that the inoculant did affect fermentation even though the magnitudes of effects were not as great as observed for the drier, as-harvested trials.

The two Pioneer inoculants contained *L. buchneri*, a heterofermentative lactic acid bacteria that should increase the aerobic stability of silages by increasing acetic acid, an inhibitor of yeasts and molds. A key product of *L. buchneri* activity is 1,2-propanediol. Another lactic acid bacteria, *L. diolivorans*, can utilize 1,2-propanediol, producing propionic acid, an even stronger inhibitor of yeasts and molds (Krooneman et al., 2002). The 11A44 inoculant contained only *L. buchneri* whereas 11C33 contained both homofermentative lactic acid bacteria and *L. buchneri*. The latter product should ensure both a rapid early fermentation and a later accumulation of acetic acid to keep the silage from spoiling and heating when exposed to air.

The 11C33 inoculant most often did not have a lower pH than the control at 21 d. Only in three of the driest stovers (Tables 3, 5 and 10) did 11C33 reduce pH significantly over the control. In two of those cases, 11A44 had an intermediate pH between 11C33 and the control. In the other trials both of the *L. buchneri* inoculants had evidence at 21 d that the *L. buchneri* was beginning to shift fermentation toward acetic acid and/or 1,2-propanediol.

At 90 d, both 11C33 and 11A44 had significant increases in acetic acid compared to 21 d. In most trials there was a significant increase in 1,2-propanediol. The one exception was the 30% DM Agri-Gold stover, where there was a significant increase in propionic acid with both inoculants. This was most likely due to naturally present strains of *L. diolivorans* in the stover at ensiling. Overall both inoculants showed evidence of *L. buchneri* working consistently in all trials even in cases where the natural population was more than 100 times the number of bacteria applied by the inoculants.

Conclusions

Four different varieties of corn stover were harvested and ensiled over a range of DM contents from approximately 30 to 60% DM with and without the use of lactic acid bacterial inoculants. Stovers ensiled as harvested (45 to 58% DM) ensiled well with no additive. Similarly stovers rehydrated to 40% DM ensiled well and were stable over 90 d. Stovers rehydrated to 30% DM initially ensiled well (21 d) but experienced secondary fermentations by 90 d. It appears that ensiling stover at 30% DM may result in occasional clostridial activity that could reduce the recovery and quality of the stover for downstream uses. All three inoculants tested were successful in affecting ensiled stover quality in all trials even when the inoculant application

rates were less than 1% of the natural lactic acid bacterial population. The homofermentative inoculant shifted fermentation to lactic acid, and reduced pH relative to the untreated control particularly in stovers above 45% DM. The two inoculants with *L. buchneri* shifted fermentation toward acetic acid and 1,2-propanediol. These inoculants would help to guarantee the stability of stover in transit between the farm and bioprocessing plant.

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