Silage Inoculants – Are They Worth The Money?

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Take Home Messages

- Effectiveness of an inoculant depends on the type and viability of bacteria in the inoculant, the number and types of natural microbes on the forage, method of application, the characteristics of forage ensiled and the type of ensiling practice employed.
- Inoculants can reduce silage shrink, but the optimal response to an inoculant is achieved when it improves silage quality and results in an improvement in the efficiency of milk or meat production.
- The value of inoculants is difficult to predict as efficacy is influenced by several variables. Selecting an inoculant that is backed by research and employing it according to manufacturer's recommendations along with sound ensiling practices is likely to result in the highest economic return.
- Recent work in our laboratory showed that at $2.00 per tonne of treated silage, a 3rd generation inoculant improved fiber digestibility, resulting in a 6% reduction in the cost of gain in beef cattle and a net return of up to $10.70 per head. It is predicted that this 3rd generation inoculant would offer benefits for milk production under similar conditions.
- Ensuring or measuring an economic return with silage inoculants is challenging and they should be looked at as an insurance policy for forage.

Silage Inoculants

Forages represent a significant proportion of the feed costs of dairy production. The generation of high quality silage is therefore important in

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determining the profitability of dairying. Addition of silage inoculants to freshly harvested forage can increase the likelihood of obtaining good quality silage and should be viewed as an insurance policy for forage. First-generation silage inoculants contain homolactic bacteria (LAB) such as *Lactobacillus plantarum* which accelerate the decline in silage pH as a result of an increase in the production of lactic acid. This rapid decline in pH prevents the growth of spoilage bacteria, yeasts and molds as well as stops respiration by forage plant cells, conserving the sugars in silage. This is important as sugars are the most digestible components in silage. This rapid decline in pH also reduces silage shrink during ensiling.

However, upon aerobic exposure of cereal silages, yeast can utilize lactic acid for growth resulting in an increase in silage pH. At this point, both yeast and molds can rapidly utilize the sugars for growth, reducing the nutrient density of the silage. Bunk life of the silage declines with this loss in nutrient density frequently occurring before cows consume the silage.

This problem led to the development of 2nd generation silage inoculants which include bacteria such as *Propionibacteria* spp. and *Lactobacillus buchneri*. Generally, studies have shown that inoculants that contain *L. buchneri* are more effective at improving the aerobic stability of silage than those that contain propionibacteria. *Lactobacillus buchneri* are heterolactic, degrading some of the lactic acid into acetic acid, which inhibits the growth of yeasts and molds, improving silage stability at feed-out (Reich and Kung 2010). Under these conditions the bunk life of the silage can be extended, reducing the likelihood that it will deteriorate before consumption.

The rapid decline in silage pH that is characteristic of 1st generation silage inoculants and the increased production of acetic or propionic acid associated with 2nd generation inoculants does not address one of the main constraints to forage utilization in ruminants - barriers to the digestibility of forage fibre. Studies with 2nd generation inoculants show that they have little impact on fibre digestibility across a range of silages (Rizk et al. 2005). This is because these inoculants lack the enzymes to digest plant cell walls and thus, there is no improvement in ruminal fibre digestibility during ensiling (Adesogan et al. 2009).

Third generation silage inoculants have only recently been introduced to the market. These inoculants are targeted against ferulic acid (FA), a compound that limits the digestion of forage fibre in ruminants (Yu et al. 2005), possibly by inhibiting the attachment and growth (Varel and Jung 1986) of fibrolytic bacteria in the rumen. Ferulic acid also forms linkages with lignin and proteins (Rawel et al. 2010) further reducing the nutritional value of forages. Hydrolysis of these linkages increases the digestibility of fibre in the rumen and as a result may improve milk production. Third-generation inoculants have been shown to improve the fibre digestibility of corn silage (Nsereko et al. 2008;

Kang et al. 2009), but the various variables that may influence this response have not been completely characterized.

■ Factors That Influence The Efficacy of Silage Inoculants

Population of LAB Applied to the Forage

The population of LAB applied should be at least 10% greater than the natural bacteria that are on the forage. Most inoculants are applied at a rate of 100,000 cells per g (CFU/g) of silage, but applying *L. buchneri* at 400,000 to 600,000 CFU/g may further improve its efficacy. Inoculation at rates that are even just 1% less than natural populations can result in these additives having little impact on silage quality (Muck 1989). Consequently, proper application rates are critical to deriving value from inoculants.

Efficiency of Fermentation of the LAB

The amount of fermentation acid produced per unit of sugar fermented by the inoculant LAB should be greater than that of the natural LAB on the forage (Muck 1989).

Nature of the Forage Being Ensiled

The forage should have sufficient substrates (e.g. water soluble carbohydrates) and optimum moisture for fermentation (Muck 1989). Consequently, stage of growth of forage at the time of ensiling impacts the value of inoculants.

Crop-Inoculant Synergy

Some strains of LAB are crop specific; for example, LAB originally isolated from corn may not perform as well if applied to alfalfa (Muck 1996). Crop-specific inoculants (McAllister et al. 1998) may have merit as some inoculants have been shown to lower pH in barley but not in corn silage (Figure 1). Treatment of grass vs. whole-crop wheat with an inoculant containing *L. casei, L. plantarum* and *S. lactis* increased DMI and digestibility of grass, but not whole-crop wheat silage (Charmley et al. 1996).

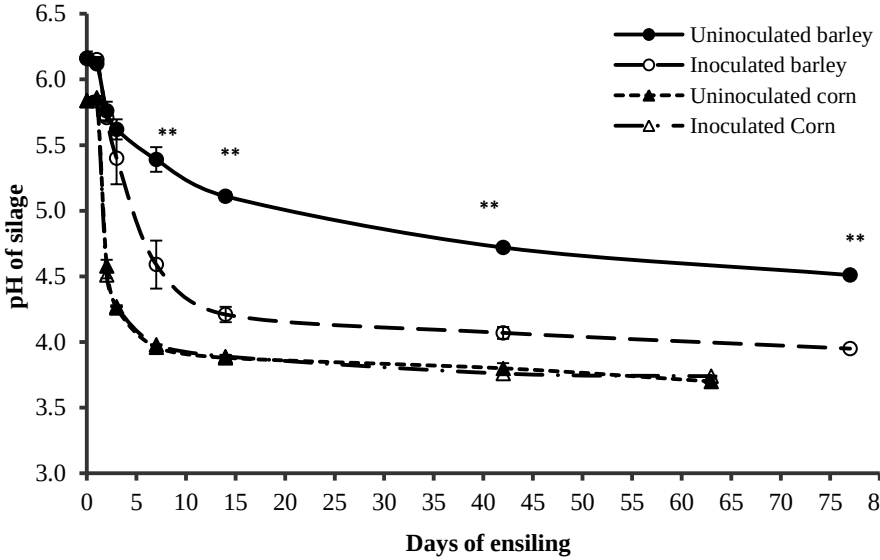

Figure 1. Decline in pH of barley and corn silage ensiled with or without inoculant. Inoculated silages were treated with *Lactobacillus plantarum*, *Enterococcus faecium*, and *Pediococcus acidilactici* at a combined rate of 100,000 CFU/g of forage (Addah et al. 2012a). ** indicate days where the inoculant decreased the pH in barley silage but not in corn silage.

The population and quality of natural microorganisms on forage is highly variable and at times can be too low to guarantee successful fermentation (Merry and Davis 1999). Natural LAB range from 100 to 1,000,000 CFU/g for alfalfa and from 1000 to 1,000,000,000 CFU/g for corn (Bolsen 1992). We have measured populations of up to 1,000,000 CFU/g of LAB on barley (Baah et al. 2011), but under optimal conditions concentrations of LAB are likely even higher. Given the naturally high levels of LAB on forages, especially with cereal silages, it is recommended that that at least 100,000 CFU or higher of LAB be applied per g of forage (Muck 1989). Thus, the production of good quality silage requires that bacteria in the inoculant work in conjunction with natural bacteria in forage. Considering the high degree of variability in the numbers and types of natural bacteria on forage (Merry and Davis 1999), an immediate decline in silage pH is often not observed, contributing to silage shrink. Improper ensiling practices that do not exclude oxygen such as insufficient packing or failing to cover the silage can also increase shrink losses (Muck 1988).

Some production characteristics of the inoculant such as improper packaging and storage conditions, poor viability, unsuitable carriers and the form applied (ie., granule vs. liquid) may also affect the efficacy of silage inoculants (Kung 2009). The addition of other non-microbial additives meant to enhance the

efficacy of silage inoculants such as surface active agents (surfactants) have been used in combination with inoculants to increase bacterial attachment to forage and improve the fermentation of barley silage (Baah et al. 2011).

■ Assessing The Value Of Inoculants Designed To Improve The Aerobic Stability Of Silage

Conventionally, aerobic stability has been defined as the number of hours that the temperature of silage exposed to air remains 1^{o}C (Driehuis et al. 1999) to 2^{o}C (Kung et al. 2004) below ambient temperature. However, the suitability of this method for assessing aerobic stability of silages stored in farm silos has been questioned given that ambient temperature fluctuates widely within a day and across seasons (Borreani and Tabacco 2010). These researchers proposed that using the core temperature of the silage, 20 cm below the face surface, would be a better indicator of silage stability. However, there are obvious practical limitations to this method as coring will further increase the ability of air to penetrate into the silage, leading to aerobic deterioration.

■ Infrared Thermography

Thermal imaging has been used to monitor the quality of agricultural products such as meat, fruit and vegetables (Gowen et al. 2010), and to detect spoilage in grain bins (Manickavasagan et al. 2006). The advantage of thermal imaging is that it provides a real-time quick visual appraisal of the heat distribution across the feed-out face of the silo. Heat emissions from the feed-out face can therefore be used as a measure of the extent of aerobic deterioration of the silage. The lower temperature of barley silage inoculated with *L. buchneri* (Figure 2), suggests that this technique has potential to assess the aerobic stability of silage ensiled in farm-scale systems. It could also prove valuable in assessing management of the silo face with regions that have been exposed to oxygen for too long appearing warmer. In this example, *L. buchneri* increased the production of acetic acid in the silage, creating conditions that were less favorable for the growth of yeasts and molds. Upon exposure to oxygen, this prevented yeast from metabolizing lactic acid and as a result the pH and temperature of inoculated silage remained stable, whereas that of uninoculated silage increased (Figure 3).

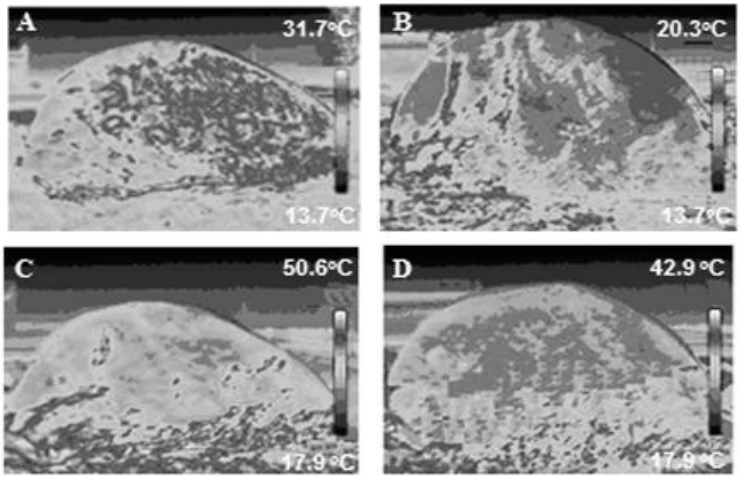

Figure 2. Infrared thermal images of uninoculated and inoculated whole-crop barley silages ensiled in Ag-Bag® silos and exposed to air during feed-out (Addah et al. 2012b). Day 0: A = uninoculated silage; B = inoculated silage. Day 3: C = uninoculated silage; D = inoculated silage. Whole–crop barley silage was treated at ensiling without (uninoculated) or with a mixture of *L. buchneri, L. plantarum and Lactobacillus casei*.

■ Do Silage Inoculants Improve Digestibility Or Meat Or Milk Production?

Even though 1st and 2nd generation inoculants are not expected to improve fibre digestibility of silage, occasional decreases in fibre concentration and increases in feed intake have been observed. Inoculation of perennial ryegrass with *L. plantarum* and *Enterococcus faecium* decreased neutral detergent fiber (NDF) concentration and increased silage intake and feed conversion efficiency as compared to uninoculated silage, with these responses being attributed to favourable shifts in the fermentation products in silage (Sharp et al. 1994).

Keady and Steen (1994) proposed that 1st and 2nd generation inoculants may enhance fibre digestibility by :1) acidic hydrolysis of fibre; 2) the rapid decline in pH preserving sugars that stimulate the activity of fibrolytic bacteria in the rumen and 3) synergistic effects of bacterial enzymes with other enzymes produced during ensiling may improve fibre hydrolysis. Occasionally, silage inoculants have improved digestibility and animal productivity without obvious shifts in fermentation products (Muck 1993; Adesogan et al. 2009). Earlier reports on how 1st generation inoculants could improve animal performance without favourable shifts in fermentation suggested that factors other than

those reflected by traditional silage fermentation traits may account for this response (Kung et al. 1993). A series of experiments by Weinberg et al. (2007) showed that silage inoculants may cause favourable shifts in rumen microbial ecology that improve dry matter (DM) and NDF digestibility.

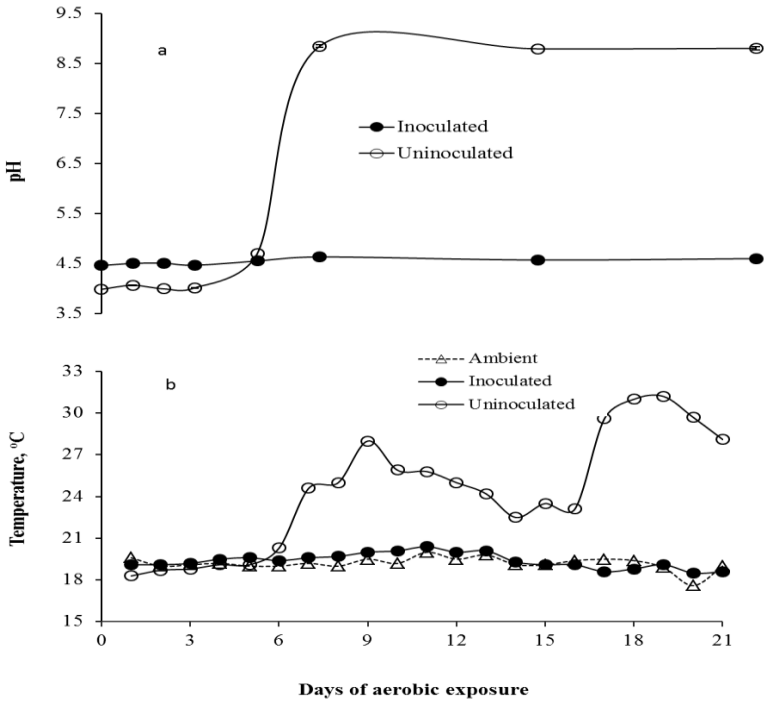

Figure 3. The effect of inoculation on changes in pH (a) and temperature (b) of whole-crop barley silages exposed to air for 21 d (Addah et al. 2012a).

Inoculation of alfalfa with multiple strains of *L. plantarum* failed to cause improvements in intake, ruminal DM, crude protein or fibre digestibilities, or milk production (Rizk et al. 2005). It was proposed that the lack of an improvement in milk production was a reflection that the inoculant failed to improve fibre digestibility. The impact of silage composition on rumen fermentation is more pronounced when silage is included in the diet at a level that is equal to or greater than that of the concentrate. Under these conditions, silage inoculants may be more likely to influence ruminal fermentation and the efficiency of use of the end products from ruminal digestion for milk production and growth. Inoculation of grass silage with *L. plantarum* increased the estimated metabolizable energy content of the diet and shifted the pattern of rumen fermentation towards increased propionic acid and decreased acetic acid (Keady and Steen 1994). As propionic acid

can be used to synthesize glucose, it may offer an energetic benefit to the ruminant host (Ørskov 1977), a response observed by others (Sharp et al. 1994).

It can be inferred from these studies that the frequent inability of most 1st and 2nd generation silage inoculants to improve milk production and growth may reflect their inability to produce fibre digesting enzymes.

There are fewer studies that have examined the ability of 3rd generation inoculants to improve the digestibility of fibre in silage (Table 1). In our previous studies, inoculation of barley silage with a 3rd generation inoculant increased the digestibility of NDF after 24 and 48 h of incubation in the rumen (Addah et al. 2012b). Similarly, inoculation of corn silage with a 3rd generation inoculant improved ruminal fibre digestibility after 48 h of incubation in steers (Nsereko et al. 2008). Neutral detergent fibre digestibility was also improved in one of two corn hybrids by a 3rd generation inoculant (Kang et al. 2009). These results suggest that responses to 3rd generation inoculants also depend on the properties of the forage to which they are applied. Improvements in digestibility are consistent with an improvement in feed efficiency of steers fed barley silage treated with a 3rd generation inoculant (Table 2).

Table 1. Effects of inoculating with a 3rd generation inoculant on in situ ruminal NDF disappearance of corn and barley silages

	Uninoculated	Inoculated	SEM	*P*-value	Reference
NDF disappearance, % of DM					
48 h	52.5	58.3	0.11	0.05	Nsereko et al.(2008)[z]
24 h	22.2	27.6	1.73	0.16	Kang et al. (2009)[z]
48 h	52.3	58.0	1.77	0.03	
24 h	20.0	21.5	1.92	0.01	Addah et al. (2012)[y]
48 h	32.2	35.1	2.05	0.01	

[z]Corn silage was inoculated with a 3rd generation inoculant producing ferulic acid esterase.
[y]Whole-crop barley silage inoculated with a 3rd generation inoculant producing ferulic acid esterase.

Table 2. Effects of 1st or 3rd generation silage inoculants on the growth performance of growing feedlot steers fed whole-crop barley silage diets

Item	Uninoculated	Inoculated	SEM	*P-value*
1st generation[z]				
Dry matter intake[x] (kg/day)	7.13	7.05	0.151	0.359
ADG (kg)	1.43	1.41	0.055	0.655
Gain:feed DM ratio	0.20	0.20	0.005	0.653
3rd generation[y]				
Dry matter intake[x] (kg/day)	7.6	7.1	0.17	0.019
ADG (kg)	1.29	1.31	0.04	0.650
Gain:feed DM ratio	0.17	0.19	0.01	0.027

[z]Inoculated silages were treated with 1st generation inoculant containing *Lactobacillus plantarum, Enterococcus faecium, Pediococcus acidilactici* (Addah et al. 2011).
[y]Whole-crop barley silage treated was 3rd generation inoculant containing *Lactobacillus buchneri, Lactobacillus plantarum and Lactobacillus casei.* The inoculant possessed ferulic acid esterase activity (Addah et al. 2012a).
ADG = average daily gain; DM = dry matter.

■ Economics Of Silage Inoculants

There are few published reports on the effect of inoculants on milk production in dairy cattle. In a series of 19 studies with corn silage, inoculants improved DM recovery by 1.3% and feed efficiency by 1.8% (Bolsen et al. 1992), and in 36 studies measuring milk production, positive responses were observed 47% of the time with an average increase of 1.4 L per day in studies that exhibited a statistical difference (Kung and Muck 1997). Of course, comparisons such as these must be taken in the context that rate of inoculant application, species of bacteria, moisture levels, and diet composition differed markedly across studies.

In a series of 14 lactation studies, the inoculant *L. plantarum* MTD1 improved DM intake by 4.8% and milk production by 4.6% when it was applied to grass, corn or alfalfa (Moran and Owen 1994). A single inoculant from a US manufacturer was used in five lactation studies and in four studies with beef cattle; milk production increased by an average of 0.8 L/d and average daily gain by 11.9% (Kung and Muck 1997). Assuming that inoculants improved DM recovery by 1.25 to 2.5% and milk production by 0.1 L per cow per day, net returns were estimated at US $5.76 and $14.40 per tonne of corn and alfalfa silage, respectively (Bolsen et al. 1999).

Positive animal responses appear to occur more frequently with some inoculants than with others. Unfortunately, the majority of inoculants marketed have never been evaluated in animal studies. Further, the practice of extrapolating results from one product to another is scientifically invalid and likely no better than a random guess of the response that may be achieved. For example, we found that average daily gain and feed efficiency of feedlot cattle were entirely different when alfalfa silage was inoculated with *L. plantarum* alone, as compared with the same strain of *L. plantarum* in combination with *E. faecium* (McAllister et al. 1998). In general, a product for which research exists to support growth or milk production claims is likely more valuable than one without such research.

Cost of forage is one of the most important factors dictating the profitability of dairy and background feedlot operations. Consequently, improvements in aerobic stability, digestibility of fibre and feed efficiency with 3rd generation inoculants could offer greater economic return than inoculants that simply improve the ensiling process. We are not aware of published lactation studies with these inoculants, but we have run experiments using 3rd generation inoculants applied to barley silage that was fed to backgrounding steers. At a cost of $2.00 per tonne of treated silage (Table 3), inoculation of barley silage with a 3rd generation inoculant reduced the cost of gain by 6%, resulting in a net return of $10.70 per head (Table 4). This increase in return on investment could greatly impact the profit margins of feedlot operations during backgrounding.

Table 3. Production cost (variable) of growing steers fed a diet containing silage inoculated with a 3rd generation inoculant for 112 d

Variable Cost	Uninoculated	Inoculated[z]
Inoculant cost ($/tonne silage)	0.00	2.00
Ration cost ($/tonne DM)	125.78	125.29
Initial price of cattle ($/kg live weight)[y]	2.34	2.34
Final price of cattle ($/kg live weight)[x]	2.14	2.14
Yardage ($/head/ day)	0.30	0.30
Animal health ($/day)	11.39	11.39
Interest (%/year)	5.00	5.00
Shipping cost ($/head)	10.00	10.00

[z]Whole-crop barley silage was either not inoculated or inoculated with a 3rd generation inoculant containing *Lactobacillus buchneri, Lactobacillus plantarum* and *Lactobacillus casei* producing ferulic acid esterase.
[y]Weekly livestock review (November 13, 2009), Alberta Agriculture and Rural Development.
[x]Weekly livestock review (March 5, 2010), Alberta Agriculture and Rural Development.

Table 4. Cost-benefit analysis of growing steers fed a diet containing silage inoculated with a 3rd generation inoculant

Profit/loss	Uninoculated	Inoculated[z]	Benefit
Initial cost of cattle ($/head)[y]	567.16	565.88	1.29
Total feed (kg DM/head)[x]	853.44	799.68	-53.76
Total feed cost ($/head)	53.67	50.10	3.57
Total yardage cost ($/head)	33.60	33.60	0.00
Interest cost ($/head)	10.12	10.04	0.07
Miscellaneous cost (bedding; $/head)[x]	5.00	5.00	0.00
Cost of gain ($/kg)	0.672	0.635	0.037
Final cattle value ($/head)[x]	827.97	833.74	5.78
Net benefit ($/head)[w]	192.01	202.73	10.71

[z] Whole-crop barley silage was either not inoculated or inoculated at ensiling with a ferulic acid esterase-producing inoculant containing *Lactobacillus buchneri, Lactobacillus plantarum and Lactobacillus casei*.
[y] Weekly livestock review (November 13, 2009), Alberta Agriculture and Rural Development.
[x] Weekly livestock review (March 5, 2010), Alberta Agriculture and Rural Development.
[w] Based on 112 d on feed.

■ Conclusion

To make good quality silage, one must have an appreciation of the plant and microbial and environmental factors that influence silage fermentation, all of which ultimately dictate the nutrient value and quality of silage. Effectiveness of an inoculant depends on the type and viability of bacteria in the inoculant, the number and types of natural microbes on the forage, method of application, the characteristics of forage ensiled and the type of ensiling practice employed. These factors must be considered as an integrated package, as neglect of any one component can lead to a breakdown in the forage preservation process. Silage inoculants can facilitate the ensiling process, but they are not a replacement for paying attention to the fundamental factors that are the keys to making good quality silage. Advancements in inoculant science have produced inoculants that can improve the aerobic stability of silage and in the case of 3rd generation inoculants, even the digestibility of fibre. Fourth generation inoculants are presently under development with the focus on delivering silage with probiotic properties that could deliver performance of health benefits to the animal. The ecology of ensiling is exceedingly complex making it virtually impossible to absolutely guarantee an ensiling response to inoculants under all conditions. Consequently, inoculants should be viewed as an insurance policy

and one of the factors that can positively sway the odds in favour of making good quality silage.

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