Use of absorbants and inoculants to enhance the quality of corn silage

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Khorvash, M., Colombatto, D., Beauchemin, K. A., Ghorbani, G. R. and Samei, A. 2006. **Use of absorbants and inoculants to enhance the quality of corn silage.** Can. J. Anim. Sci. **86**: 97–107. This study examined whether inoculants and various absorbent materials could be used during ensiling to reduce effluent losses and improve nutritive value of corn silage. Two corn forages were harvested: conventional silage containing 29% dry matter (DM) and low DM silage containing 20% DM. Ninety-six mini-silos (10 cm × 1 m) were each prepared using 2.7 kg of chopped corn forage and one of the following compounds and add rates (fresh basis): no additive (control); 5, 10 or 15% ground barley; 5, 10 or 15% powdered whey; 5, 10 or 15% dried molasses; 1% bentonite; 1% zeolite; 0.5% zeolite plus 0.5% limestone; commercial inoculant containing *Lactobacillus plantarum* and *Propionic bacteria* sp. (Biotal™, Lallemand Animal Nutrition, Rexdale, ON; 2 mg kg^{-1} fresh forage); commercial inoculant containing *Lactobacillus plantarum* and *Pediococcus acidilactici* (Feedtech™, DeLaval, Tumba, Sweden; 24 mg kg^{-1} fresh forage); and 1% zeolite plus Biotal inoculant. Effluent loss from the control low DM silage was high (74 mL kg^{-1}; fresh basis), and was almost completely eliminated ($P < 0.05$) by adding barley (10 and 15%) or zeolite plus either limestone or bentonite during the ensiling process. Effluent loss from the control conventional silage was minimal (14 mL kg^{-1}; fresh weight), and treatments caused no further reduction. For both silages, DM content increased ($P < 0.05$) with the use of barley (10 and 15%), whey (10 and 15%) or molasses. The pH of both silages increased ($P < 0.05$) using molasses or zeolite plus limestone. For both silages, acetic and lactic acid were increased ($P < 0.05$) with the addition of molasses, while zeolite plus limestone increased lactic acid content of conventional silage. For both silages, the addition of ground barley, whey, or Feedtech inoculant improved ($P < 0.05$) or tended ($P < 0.10$) to improve in vitro DM degradability (72 h) of corn silage, whereas degradability decreased ($P < 0.05$) or tended ($P < 0.10$) to decrease using molasses or zeolite plus limestone. High effluent losses that occur when corn forage is ensiled with a low DM content can be reduced by adding barley or zeolite plus either limestone or bentonite as an absorbant. However, of the compounds tested, only barley reduced effluent losses while improving nutritive value of the silage.

Key words: Corn, corn silage, ensiling process, silage additives, silage quality, forages

Khorvash, M., Colombatto, D., Beauchemin, K. A., Ghorbani, G. R. et Samei, A. 2006. **Amélioration de l'ensilage de maïs par l'usage d'absorbants et d'inoculants**. Can. J. Anim. Sci. **86**: 97–107. Les auteurs ont tenté de savoir si on pourrait se servir d'inoculants et de divers matériaux absorbants durant l'ensilage pour diminuer les pertes attribuables aux effluents et améliorer la valeur nutritive du maïs ensilé. Ils ont récolté deux sortes de maïs fourrager à cette fin : du maïs d'ensilage classique, contenant 29 % de matière sèche (MS), et du maïs d'ensilage à faible teneur en MS (20 %). Ils ont ensuite aménagé 96 silos miniatures (10 cm × 1 m) en prenant 2,7 kg de maïs fourrager haché et un des composés que voici, dans les proportions indiquées (poids frais) : aucun additif (témoin); 5, 10 ou 15 % d'orge moulue; 5, 10 ou 15 % de lactosérum en poudre; 5, 10 ou 15 % de mélasse en poudre; 1 % de bentonite; 1 % de zéolite; 0,5 % de zéolite et 0,5 % de chaux; un inoculant commercial de *Lactobacillus plantarum* et de bactéries propioniques (Biotal[MC], Lallemand Animal Nutrition, Niagara-on-the-Lake, Ontario; 2 mg par kg de fourrages frais); un inoculant commercial de *Lactobacillus plantarum* et de *Pediococcus acidilactici* (Feedtech[MC], Delaval, Tumba, Suède; 24 mg par kg de fourrages frais); 1 % de zéolite plus l'inoculant Biotal. L'ensilage à faible teneur en MS employé comme témoin a subi d'importantes pertes sous la forme d'effluents (74 mL par kg; poids frais), pertes qui ont été presque entièrement éliminées ($P <0,05$) par l'addition d'orge (10 et 15 %) ou de zéolite et de chaux ou de bentonite lors de l'ensilage. Les pertes dues aux effluents étaient minimes (14 mL par kg; poids frais) pour l'ensilage témoin ordinaire et aucun traitement ne les a réduites davantage. L'addition d'orge (10 et 15 %), de lactosérum (10 et 15 %) ou de mélasse augmente ($P < 0,05$) la teneur en MS des deux types d'ensilage. Le pH des deux types d'ensilage s'élève ($P < 0,05$) avec la mélasse ou la zéolite et la chaux. L'addition de mélasse accroît ($P < 0,05$) la concentration d'acide acétique et d'acide lactique dans les deux types d'ensilage, alors que l'addition de zéolite et de chaux augmente la concentration d'acide lactique dans l'ensilage ordinaire. Pour les deux ensilages, l'addition d'orge moulue, de lactosérum ou de l'inoculant Feedtech améliore ($P < 0,05$) ou a tendance ($P < 0,10$) à améliorer la dégradation *in vitro* de la MS (72 h) du maïs ensilé, alors que la dégradation de la MS diminue ($P < 0,05$) ou a tendance ($P < 0,10$) à diminuer quand on enrichit l'ensilage de mélasse ou de zéolite et de chaux. Il est possible d'atténuer les importantes pertes dues aux effluents qui surviennent quand on ensile le maïs fourrager à faible teneur en MS en y ajoutant de l'orge ou de la zéolite ainsi que de la chaux ou de la bentonite, comme absorbant. Toutefois, parmi les composants testés, seule l'orge diminue les pertes dues aux effluents tout en améliorant la valeur nutritive de l'ensilage.

Mots clés: Maïs, maïs d'ensilage, ensilage, additifs pour ensilage, qualité de l'ensilage, fourrages

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Abbreviations: ADF, acid detergent fibre; **CP**, crude protein; **DM**, dry matter; **IVDMD**, in vitro dry matter degradability; **N**, nitrogen; **NDF**, neutral detergent fibre; and **VFA**, volatile fatty acid

Corn silage is one of the major sources of forage for dairy cattle in many parts of the world (Food and Agriculture Organization of the United Nations 1997). In Iran, corn silage constitutes about half of the forages fed to cows on commercial dairy farms. However, corn silage grown in Iran is usually planted in July as a second crop; therefore, it does not get sufficient time to mature and it is ensiled with low dry matter (DM) content (20 to 25% DM). Moisture content of corn silage is inversely related to stage of maturity (Bal et al. 1997). It is well established that the optimal DM content of corn silage for use in the diet of dairy cow diets is between 30 and 35% DM (Bal et al. 1996; Phipps et al. 2000). Crops ensiled with low DM content can result in poor-quality silage producing high levels of effluent during the ensiling process (McDonald et al. 1991). Silage effluent represents a loss of valuable forage nutrients and the runoff can pollute surface and ground water (Merriman 1988; Graves and Vanderstappen 1993).

Materials with absorbent properties have been added at the time of ensiling various forages to help reduce DM losses and improve nutritive value (Jones et al. 1990; Ferris and Mayne 1994). Several absorbent feedstuffs, such as rolled barley (Jones et al. 1990), dried sugar beet pulp (Ferris and Mayne 1994), and barley straw (Offer and Al-Rwidah 1989) have been evaluated. Among these, chopped barley straw and sugar beet pulp were shown to be the most consistent and effective effluent absorbants for grass silage (Offer and Al-Rwidah 1989).

While some absorbants reduce effluent losses, they may also reduce nutritive value of the forage. For example, addition of chopped barley straw to grass at the time of ensiling depressed in vitro degradability of the ensiled grass (Woolford et al. 1983; Jones and Jones 1996). In circumstances where corn is ensiled with a low DM content, it is necessary to determine the appropriate type and amount of absorbent material needed to prevent effluent losses from corn forage. Also, there is a need to explore the potential of using other readily available feedstuffs for their capacity to absorb moisture, as well as their effects on forage quality.

In addition to absorbants, some silage additives such as inoculants have been used to improve fermentation and prevent the production of butyric acid in wet silages [< 250 to 300 g DM kg^{-1}; Bolsen et al. (1995), as cited by Kung et al. (2003)]. However, there is limited information on the use of inoculants for low DM corn silage.

The objective of this study was to evaluate the effectiveness of a range of absorbants, including feedstuffs and nonfeed compounds, and inoculants added to corn forage during the ensiling process in minimizing effluent losses and improving nutritive value.

MATERIALS AND METHODS

Harvesting

A hybrid of corn (single cross 704 derived from a cross between B 73 and MO 17/ 11–1 inbred lines provided by Seed and Plant Improvement Institute, Karaj, Iran) was seeded in early June 2001, to produce forage having a DM content representative of corn silage typically harvested in North America (conventional silage containing 29% DM). A replicate of the same hybrid was seeded in early July to produce a forage having a DM content representative of corn silage typically harvested in Iran (low DM silage containing 20% DM). The crops were grown in Isfahan province, Iran (32°32′N, 51°23′E; 1630 m above sea level). Both crops were harvested on 2001 Sep. 08, and ensiled using laboratory silos.

Laboratory Silos and Ensiling Technique

Ninety-six mini-silos were constructed from polyvinyl chloride pipe. Each silo measured 10 cm (diameter) × 1 m (length). A polyvinyl chloride internal end plug, which was chemically welded to one end, formed the silo bottom. An outlet was tapped through the silo wall with copper tubing and fitted with plastic vinyl tubing leading to a sealed plastic bag for effluent collection. About 10 cm of pea gravel was placed on the bottom of each silo to retain the effluent. Two layers of mesh cloth (96 mm in diameter) were placed onto the gravel surface before filling the silo with silage. Mini-silos were designed to collect effluent as described by Alli et al. (1985).

Control silos were prepared in triplicate using approximately 2.7 kg (fresh weight) of chopped corn forage (conventional or low DM silages). Treatment silos were prepared in triplicate for conventional and low DM corn forages by replacing forage with additives (fresh weight basis) as follows: 5, 10 and 15% ground barley; 5, 10 and 15% powdered whey (i.e, the watery part of milk that is separated from the solid curds during the process of making cheese); 5, 10 and 15% dried molasses; 1% bentonite (i.e., an absorbent aluminum silicate clay formed from volcanic ash); 1% zeolite (i.e., a microporous crystalline aluminum silicate mineral) and 0.5% zeolite combined with 0.5% limestone (i.e., calcium carbonate). In addition, several treatments using commercial bacterial inoculant products were used. These included Biotal™ bacterial inoculant containing *Lactobacillus plantarum* and *Propionic bacteria* sp. (Lallemand Animal Nutrition, Rexdale, ON; 2 mg kg^{-1} fresh forage) alone or in combination with 1% zeolite, and Feedtech™ inoculant (*Lactobacillus plantarum* and *Pediococcus acidilactici)* (DeLaval, Tumba, Sweden, 24 mg kg^{-1} fresh forage) without absorbant.

Additives were thoroughly mixed with the corn forage before filling the mini-silos. Both inoculants were mixed in water and applied according to the manufacturer's instructions. The calculated concentrations of lactic acid producing bacteria in the final silages (fresh basis) were 1×10^5 CFU g^{-1} for the Biotal™ product and 6.7×10^{10} CFU g^{-1} for the Feedtech™ product. Silos were packed by manually exerting force to an iron disc (0.5 cm thickness, 9 cm diameter) welded to a metal rod positioned over the forage within the silo. Plastic sheeting was placed onto the packed forage. The mini-silos were sealed by placing an internal end plug onto the plastic sheeting and chemically welding the plugs to the inner silo walls. Silos were stored upright at ambient temperature (20°C) for 92 d.

Effluent and Silage Sample Collection and Analysis

During the first month of ensiling, silage effluent was collected in a plastic bag attached to each mini-silo. After the

92-d ensiling period, silos were opened, the contents were manually mixed and representative subsamples were frozen at –20°C for analysis.

The silage subsamples were prepared for analysis as follows. A representative portion of the sample (15 g) was placed into a blender and 135 g of distilled water was added. The mixture was blended three times for 30 s each. The mixture was then filtered through two layers of cheesecloth. The filtrate was used for the determination of pH, volatile fatty acids (VFA), lactic acid and ammonia nitrogen (N). Subsamples of filtrate were prepared for analysis of VFA and lactic acid by adding 1 mL of 25% (wt/vol) meta-phosphoric acid to 5 mL of filtrate. Another 5 mL of filtrate was combined with 0.4 mL of trichloric acid 65% for analysis of ammonia N. The samples were stored on ice and then stored at –40°C. Before analysis, the samples were thawed overnight at 4°C.

Silage VFA were quantified using gas chromatography (model 5890, Hewlett Packard, Little Falls, DE) with a capillary column (30 m × 0.25 mm i.d., 1 μ phase thickness, bonded PEG; Supelco Nukol, Sigma-Aldrich Canada, Oakville, ON) and flame ionization detection. Crotonic acid was the internal standard. The oven temperature was 100°C for 1 min, which was then ramped by 20°C min^{-1} to 140°C, and then by 8°C min^{-1} to 200°C, and held at this temperature for 5 min. The injector temperature was 200°C, the detector temperature was 250°C, and the carrier gas was helium. Lactate was determined as the methyl ester by gas chromatography (Supelco bulletin 856, Sigma-Aldrich Canada). Silage ammonia N concentration was determined by the Berthelot reaction (Rhine et al. 1998) using a flow analyzer (Astoria Pacific, Clackmas, OR).

A second subsample (200 g) of each silage was dried at 50°C in a forced-air oven for 48 h and DM was determined [Association of Official Analytical Chemists (AOAC) 1995]. Samples were ground using a Wiley Mill (1-mm screen, Arthur H. Thomas, Philadelphia, PA). Analytical DM was determined by drying a 0.5 g sample at 135°C for 3 h (AOAC 1995) and crude protein (CP) was determined using the Kjeldahl method (Kjeltec Auto 1030 Analyzer, Tecator AB, Höganäs, Sweden) using selenium sulphate as a catalyst (AOAC 1975). Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were determined using an ANKOM $^{200/220}$ Fibre Analyser (Ankom Technology Corporation, Macedon, NY) according to the manufacturer's instructions. Sodium sulphite was omitted from the analysis of NDF, while heat stable amylase was included to hydrolyse starch (Van Soest et al. 1991).

In Vitro Degradability

The in vitro degradability of DM (IVDMD), NDF and ADF of silage samples was determined using the ANKOM $^{200/220}$ Daisy II in vitro system (Ankom Technology Corporation, Macedon, NY). Approximately 0.5 g of dried, ground silage sample was placed in each artificial bag (approximately 50 × 50 mm, irregular pore size) and sealed using a heat sealer. Samples from each silo were evaluated in triplicate. A 14-L batch of buffer was prepared according to the method of Goering and Van Soest (1970) containing 35 g Difco Tryptone Peptone (Becton Dickinson, Sparks, MD), 7.0 L H_2O, 0.84 mL micro-mineral solution, 3.5 L rumen buffer, 3.5 L macro-mineral solution and 17.5 mL 0.1% resazurin. The solution was bubbled with O_2-free CO_2 produced by passing anaerobic grade CO_2 through a copper furnace heated to approximately 350°C. After bubbling for 2 to 3 h, cysteine-HCl (4.375 g) and Na_2S (4.375 g) were added to complete the reduction of the buffer. To each 4-L incubation jar, 1600 mL of reduced buffer was added anaerobically, capped and allowed to equilibrate to 39°C in the incubation chambers (vent was sealed with parafilm to preserve reduced state of buffer and unsealed upon addition of rumen fluid).

Rumen contents (fluid and solids) were collected into pre-warmed insulated containers from three ruminally cannulated lactating Holstein cows consuming a corn-silage based total mixed ration. Contents were squeezed through four layers of cheesecloth into pre-warmed insulated containers flushed with CO_2. Added to each incubation jar were: 400 mL of rumen fluid, 24 sample-containing bags and three empty bags used as controls. Jars were closed and placed in the incubation chambers. Bags were removed at 18 and 72 h, gently washed with cold water to remove any contaminating materials and dried at 55°C for 48 h. The 18-h time point was chosen to examine the degradation of the more readily digestible fraction, whereas the 72-h time point was used to examine the extent of degradation.

Statistical Analysis

Data for chemical composition, fermentation characteristics, and degradability were analyzed separately for conventional and low DM silages using the general linear model procedure of SAS (SAS Institute, Inc. 1999). The model included the effect of treatment. When the effect of treatment was significant ($P < 0.05$), Dunnett's test was used to compare the treatments to the control.

RESULTS AND DISCUSSION

Effluent Losses and Chemical Composition

The objective of adding absorbants to forage during the ensiling process is to reduce effluent losses, without decreasing the nutritive value of the silage. High effluent losses from low DM silages have been reported for grass silages (Offer and Al-Rwidah 1989; Ferris and Mayne 1994) and corn silages [Van Der Wel (1993), as cited by Hameleers et al. (1999)]. The effluent loss (74 mL kg^{-1}, Table 1) from the control low DM silage in the present study was less than the value reported by others. Hameleers et al. (1999) reported that effluent losses from corn silages with DM content ranging from 162 to 209 g kg^{-1} were substantial, ranging from 118 to 200 mL kg^{-1}. For grass silage, Fransen and Strubi (1998) observed 180 mL kg^{-1} of effluent while Woolford et al. (1983) subjected grass silage (105 g kg^{-1} DM) to two levels of packing force (3470 and 5490 kg m^{-2}) and observed 322 and 407 mL kg^{-1} of effluent production, respectively. Thus, the low effluent loss from the low DM control silage observed in our study could indicate that the force used during packing was less than that used by others.

Table 1. Chemical composition of low dry matter (DM) corn silage after ensiling with various absorbants and inoculants

Treatment[z]	DM ($g\ kg^{-1}$)	CP ($g\ kg^{-1}$ DM)	NDF ($g\ kg^{-1}$ DM)	ADF ($g\ kg^{-1}$ DM)	Effluent ($mL\ kg^{-1}$ fresh basis)
Control	199	87	618	333	74
Ground barley					
5%	225	96	534*b*	284*b*	42
10%	253*a*	96	449*b*	235*b*	25*b*
15%	290*a*	95	409*b*	200*b*	15*b*
Powdered whey					
5%	209	99	496*b*	258*b*	56
10%	256*a*	105*a*	490*b*	261*b*	43
15%	293*a*	100	370*b*	189*b*	43
Dried molasses					
5%	220	82	507*b*	277*b*	50
10%	247*a*	70*b*	430*b*	241*b*	62
15%	290*a*	70*b*	354*b*	209*b*	53
Bentonite, 1%	224	75	587*b*	339	63
Zeolite					
1%	222	75	560*b*	305*b*	69
1% + inoculant 1[y]	215	80	576*b*	321	11*b*
0.5% + 0.5% limestone	194	89	518*b*	277*b*	25*b*
Inoculant 1[y]	193	85	594	315*b*	55
Inoculant 2[x]	202	88	615	324	45
SEM	6.7	3.7	5.5	5.2	9.4

ADF, acid detergent fibre; CP, crude protein; NDF, neutral detergent fibre; SEM; standard error of the mean.
[z]Treatments were added on a fresh weight basis.
[y]Biotal™ inoculant containing *Lactobacillus plantarum* and *Propionic bacteria* sp. (Lallemand Animal Nutrition, Rexdale, ON; 2 mg kg^{-1} fresh forage)
[x]Feedtech™ inoculant (*Lactobacillus plantarum* and *Pediococcus acidilactici)* (Delaval, Tumba, Sweden; 24 mg kg^{-1} fresh forage).
a Means within each column are significantly higher than the control ($P < 0.05$).
b Means within each column are significantly lower than the control ($P < 0.05$).

Some of the additives used in this study considerably reduced effluent losses from the low DM corn silage (Table 1). Adding ground barley (10 and 15%) or zeolite plus inoculant (Biotal) or zeolite plus limestone to low DM silage reduced effluent loss by 67 to 85%, depending on the treatment. In contrast, the other additives had no effect on effluent losses for the low DM silage. Under the conditions of this study, the most effective feed-type additive for reducing the effluent from low DM corn silage was ground barley (10 and 15%), whereas the best non-feed additive was zeolite with limestone or inoculant (Biotal). There was a synergy between zeolite and inoculant because when either zeolite or inoculant (Biotal) was used alone, effluent losses were similar to those of the control low DM silage.

Bentonite can absorb up to seven times its weight of water and has proven effective as an absorbant at concentrations of 0.5 to 1% (McDonald et al. 1991). However, in this experiment, 1% bentonite had no effect on reducing effluent losses for unknown reasons. It could be that the absorbent properties of sodium bentonite vary depending upon the source. Cook et al. (1980) prepared perennial ryegrass silage using 0.7% bentonite and observed 88 mL kg^{-1} of effluent compared with 131 mL kg^{-1} for control silage. Fransen and Strubi (1998) prepared grass silage with 1% bentonite and found that effluent ranged from 84 to 147 mL kg^{-1} over 3 yr compared with 180 mL kg^{-1} for the control silage. Woolford et al. (1983) ensiled grass with 0.5% bentonite and reported an effluent production of 87 mL kg^{-1} compared with 322 mL kg^{-1} for control silage. In those studies, bentonite reduced the amount of effluent but did not completely eliminate effluent losses even at the highest rates of inclusion (Jones and Jones 1996).

There was no effect of treatment on effluent losses for conventional DM silage (Table 2). The amount of effluent lost from conventional silage was very low (14 mL kg^{-1}). Bastiman [(1976), as cited by McDonald et al. (1991)] reported very little effluent was produced from herbage ensiled with a DM concentration exceeding 250 g kg^{-1}.

The DM concentration of low DM corn silage (199 g kg^{-1}) increased using 10 and 15% ground barley (253 and 290 g kg^{-1}), 10 and 15% powdered whey (256 and 293 g kg^{-1}), and 10 and 15% dried molasses (247 and 290 g kg^{-1}) (Table 1). These same treatments (plus 5% ground barley) also increased the DM content of conventional silage by 34 to 93 g kg^{-1} (Table 2). Increasing the DM content of low and conventional DM silage was due in part to reduced effluent

Table 2. Chemical composition of conventional dry matter (DM) corn silage after ensiling with various absorbants and inoculants

Treatment[z]	DM ($g\ kg^{-1}$)	CP ($g\ kg^{-1}$ DM)	NDF ($g\ kg^{-1}$ DM)	ADF ($g\ kg^{-1}$ DM)	Effluent ($mL\ kg^{-1}$ fresh basis)
Control	271	82	542	290	14
Ground barley					
5%	303*a*	87	486*b*	257*b*	6
10%	321*a*	86	433*b*	226*b*	6
15%	360*a*	95*a*	398*b*	190*b*	1
Powdered whey					
5%	283	91	458*b*	240*b*	14
10%	322*a*	93*a*	384*b*	196*b*	15
15%	350*a*	95*a*	351*b*	182*b*	6
Dried molasses					
5%	289	75	446*b*	240*b*	21
10%	312*a*	75	397*b*	225*b*	22
15%	364*a*	66*b*	323*b*	189*b*	1
Bentonite, 1%	294	73*b*	529	296	9
Zeolite					
1%	287	75	501*b*	267*b*	17
1% + inoculant 1[y]	284	76	524	285	3
0.5% + 0.5% limestone	285	75	482*b*	261*b*	21
Inoculant 1[y]	267	80	526	280	5
Inoculant 2[x]	264	79	449*b*	238*b*	0
SEM	5.7	2.4	6.6	3.7	3.7

ADF, acid detergent fibre; CP, crude protein; NDF, neutral detergent fibre; SEM; standard error of the mean.
[z]Treatments were added on a fresh weight basis.
[y]Biotal™ inoculant containing *Lactobacillus plantarum* and *Propionic bacteria* sp. (Lallemand Animal Nutrition, Rexdale, ON; 2 mg kg^{-1} fresh forage).
[x]Feedtech™ inoculant (*Lactobacillus plantarum* and *Pediococcus acidilactici)* (Delaval, Tumba, Sweden; 24 mg kg^{-1} fresh forage).
a Means within each column are significantly higher than the control ($P < 0.05$).
b Means within each column are significantly lower than the control ($P < 0.05$).

losses, or a trend towards reduced effluent losses (Tables 1 and 2). In some cases, the increased DM content was also due to the dilution effect of adding dry ingredients to moist silage. Similar to our results, Harrison et al. (1994) reported the addition of various levels of rolled barley (5, 10 and 15%) to corn forage increased DM content of the silage. Other researchers have increased the DM of grass silage by incorporating cereal grains (Jones and Jones 1988; Moseley and Ramanathan 1989) or beet pulp (Gordon et al. 1957; Ferris and Mayne 1994). A higher DM content of silage could be important in terms of maintaining high feed intakes by dairy cows, as very moist diets are known to reduce consumption (Lahr et al. 1983).

The CP content of low DM silage was increased ($P < 0.05$) using powdered whey (10%), and decreased ($P < 0.05$) using dried molasses (10 and 15%) (Table 1). The CP content of conventional DM silage was increased ($P < 0.05$) using ground barley (15%) and powdered whey (10 and 15%), and decreased ($P < 0.05$) using dried molasses (15%) and bentonite (1%) (Table 2). The other treatments had no effect on CP content of either silage.

The effect of powdered whey on increasing the CP content of both corn silages was attributed to the higher CP content of powdered whey (96 g kg^{-1}) compared with silage (87 vs. 82 g kg^{-1} DM). Similarly, the CP content of barley was higher than that of silage (101 vs. 82 g kg^{-1} DM; Table 2). Harrison et al. (1994) also found a significant increase in CP content of corn silage when barley (5, 10 and 15%) was added to corn forage (250 g kg^{-1} DM). With other higher protein forages such as grass silage, using barley as an absorbant had no effect on CP content, as expected [O'Kiely (1992), as cited by Fransen and Strubi (1998)].

The effect of dried molasses on decreasing CP content of silage may be related to its effect on increasing pH, because all silages containing dried molasses had a pH above 4 (Tables 3 and 4). After harvesting, rapid proteolysis takes place with the extent of proteolysis during ensiling influenced mainly by pH and temperature (McDonald et al. 1991). It is well known that the rate of pH decline is important in determining the extent of proteolysis. If the rate of pH decline is slow, more protein will be hydrolysed (McDonald et al. 1991). Thus, the higher resulting pH when dried molasses was added during ensiling likely increased proteolysis, thereby decreasing the CP content of the corn silage.

Many of the additives used decreased the fibre content of corn silage due to a dilution effect. Adding ground barley (5, 10 and 15%), powdered whey (5, 10 and 15%), dried molasses (5, 10 and 15%), bentonite (1%), zeolite (1%), zeolite (1%) plus inoculant (Biotal) and zeolite (0.5%) plus

Table 3. Fermentation characteristics of low DM corn silage after ensiling with various absorbants and inoculants

Treatment[z]	Acetic acid (% DM)	Lactic acid (% DM)	Total VFA (% DM)	Ammonia N (% DM)	pH
Control	2.93	10.73	2.93	12.83	3.70
Ground barley					
5%	1.77	8.53	1.78	11.03	3.77
10%	2.30	8.91	2.31	12.24	3.73
15%	1.86	7.33	1.87	11.71	3.72
Powdered whey					
5%	3.34	12.99	3.39	13.14	3.74
10%	3.33	10.45	3.39	10.58	3.81
15%	2.52	10.86	2.58	11.64	3.78
Dried molasses					
5%	4.28*a*	16.14	4.31	15.16	4.26*a*
10%	5.47*a*	17.72*a*	5.71*a*	16.17	5.01*a*
15%	4.51*a*	17.98*a*	4.59	12.46	5.75*a*
Bentonite, 1%	2.80	11.15	2.80	11.00	3.80
Zeolite					
1%	2.85	10.24	2.85	10.6	3.68
1% + inoculant 1[z]	2.41	10.21	2.41	10.16	3.75
0.5% + 0.5% limestone	4.64*a*	14.58	4.74*a*	16.21	5.05*a*
Inoculant 1[z]	2.64	11.84	2.64	13.27	3.75
Inoculant 2[y]	3.20	12.34	3.19	12.41	3.90
SEM	0.507	1.753	0.495	1.264	0.107

SEM; standard error of the mean; VFA, volatile fatty acids.
[z]Treatments were added on a fresh weight basis.
[y]Biotal™ inoculant containing *Lactobacillus plantarum* and *Propionic bacteria* sp. (Lallemand Animal Nutrition, Rexdale, ON; 2 mg kg^{-1} fresh forage).
[x]Feedtech™ inoculant (*Lactobacillus plantarum* and *Pediococcus acidilactici)* (Delaval, Tumba, Sweden; 24 mg kg^{-1} fresh forage).
a Means within each column are significantly higher than the control ($P < 0.05$).
b Means within each column are significantly lower than the control ($P < 0.05$).

limestone (0.5%) significantly ($P < 0.05$) decreased NDF content of low DM silage (Table 1). Similar effects were observed for NDF content of conventional silages, with the exception of Biotal inoculant with and without zeolite, which had no effect on NDF content (Table 2). Due to the lower NDF content of ground barley (19.6%), powdered whey (0%) and dried molasses (6.3%) compared with low DM and conventional corn silages (61.8 and 54.2%, respectively), the addition of these additives reduced NDF content of silage. Many of the treatments also decreased ($P < 0.05$) the ADF content of both low and conventional DM corn silages (Tables 1 and 2). The reduction in fibre (NDF and ADF) content was expected because the proportion of non-fibre carbohydrates in the silage was increased by adding ground barley or powdered whey during ensiling. Various other studies have reported decreases in ADF and NDF content of silages prepared using feed-type absorbants (Jones 1988; Moseley et al. 1989; Ferris and Mayne 1994). The decrease in fibre, and the concomitant increase in non-fibre carbohydrates, is expected to improve the nutritive value of the silage.

Fermentation Characteristics

Corn silage is less prone to spoilage when silage pH is below 4, because growth of most of the undesirable microorganisms is inhibited at low pH (McDonald et al. 1991). In this study using small-scale experimental silos in a laboratory setting, low pH values indicated good fermentation can be achieved for corn silages with a DM content as low as 200 g kg^{-1} DM even without the use of an additive. However, in commercial conditions, it can be very difficult to achieve low pH and good fermentation with low DM silages harvested at an early stage of maturity because of their low content of water-soluble carbohydrates. The pH of silages from forages prepared using with ground barley (5, 10 or 15%), powdered whey (5, 10 or 15%), bentonite, zeolite with and without inoculant (Biotal), or inoculant alone (Biotal and FeedTech) did not differ ($P > 0.05$) compared with the control for either low or conventional DM silages (Tables 3 and 4). The pH of all silages was below 4 excluding those made with dried molasses and zeolite plus limestone.

Molasses has been proven to be an effective silage additive in terms of promoting lactic acid fermentation, reducing silage pH, discouraging clostridial fermentation and proteolysis, and generally decreasing organic matter losses (McDonald et al. 1991). However, in this study the high calcium content (210 g kg^{-1} DM) of the dried molasses used may have reduced its effectiveness. The processing method commonly used in drying molasses includes soaking with

Table 4. Fermentation characteristics of conventional dry matter (DM) corn silage after ensiling with various absorbants and inoculants

Treatment[z]	Acetic acid (% DM)	Lactic acid (% DM)	Total VFA (% DM)	Ammonia N (% DM)	pH
Control	1.78	8.25	1.86	9.99	3.72
Ground barley					
5%	1.60	7.04	1.64	9.18	3.76
10%	1.71	6.88	1.74	9.59	3.71
15%	1.61	6.12	1.63	9.14	3.79
Powdered whey					
5%	1.81	8.55	1.85	9.50	3.81
10%	2.13	9.45	2.16	9.35	3.81
15%	1.99	8.56	2.02	8.10	3.86
Dried molasses					
5%	3.16*a*	13.8*a*	3.22*a*	9.93	4.47*a*
10%	3.52*a*	13.65*a*	3.86*a*	10.03	5.07*a*
15%	5.40*a*	13.06*a*	5.45*a*	6.14*a*	5.55*a*
Bentonite, 1%	1.79	8.63	1.80	5.71*a*	3.87
Zeolite					
1%	1.59	7.41	1.60	6.51*a*	3.81
1% + inoculant 1[y]	1.69	7.81	1.69	7.18*a*	3.76
0.5% + 0.5% limestone	2.59	13.91*a*	2.63	11.84	4.50a
Inoculant 1[y]	2.36	8.69	2.37	10.49	3.76
Inoculant 2[x]	2.15	8.76	2.22	10.17	3.79
SEM	0.343	0.633	0.326	0.645	0.069

SEM; standard error of the mean; VFA, volatile fatty acids.
[z]Treatments were added on a fresh weight basis.
[y]Biotal™ inoculant containing *Lactobacillus plantarum* and *Propionic bacteria* sp. (Lallemand Animal Nutrition, Rexdale, ON; 2 mg kg^{-1} fresh forage).
[x]Feedtech™ inoculant (*Lactobacillus plantarum* and *Pediococcus acidilactici)* (Delaval, Tumba, Sweden; 24 mg kg^{-1} fresh forage).
a Means within each column are significantly higher than the control ($P < 0.05$).
b Means within each column are significantly lower than the control ($P < 0.05$).

calcium carbonate followed by heating, resulting in high levels of calcium. Provided the ensiled crops contain adequate levels of soluble carbohydrates, the lactic acid produced normally releases H^+ ions forming calcium salts of lactate, thereby counteracting the alkalinity of calcium carbonate (McDonald et al. 1991). However, in our study some moulds were observed on the upper side of the mini-silos containing dried molasses when opened after 90-d of fermentation. The high pH of this treatment likely provided a desirable environment for moulds to grow on the surfaces exposed to the air.

For both silages, inclusion of limestone increased the pH above 5 (Tables 3 and 4). Limestone, a calcium salt, is alkaline in nature and has the potential to raise the pH of silage. In some studies with corn, the addition of limestone resulted in higher pH and clostridia-type silages containing high concentrations of butyric acid (McDonald et al. 1991). Similar results were observed with silages treated with zeolite and limestone in our experiment. The lack of effect of bentonite on pH observed in the present study is in contrast to others. Woolford et al. (1983) reported higher pH for silages from perennial ryegrass forage ensiled with bentonite compared with control silage. Everson et al. (1971) and Fransen and Strubi (1998) also found an increase in pH with the addition of 1% bentonite to grass prior to ensiling.

Addition of dried molasses and zeolite plus limestone to low DM silage increased ($P < 0.05$) acetic acid concentration by 46 to 86% compared with the control (Table 3). For the conventional DM corn silage, addition of dried molasses (5, 10 or 15%) increased ($P < 0.05$) acetic acid concentration by 77, 97 and 203%, respectively (Table 4), but the other treatments had no effect on acetic acid or VFA concentration compared with the control. Dried molasses (10 and 15%) also increased ($P < 0.05$) the lactic acid concentration by 65 and 87%, respectively, in low DM silage and by 65 and 58%, respectively, in conventional DM silage compared with the control (Tables 3 and 4). In contrast, the other treatments had no effect on the lactic acid concentration of these silages, except for zeolite plus limestone and 5% dried molasses, which increased lactic acid content of conventional DM silages by about 67% (Table 4). Increased acetic and lactic acid concentrations due to the addition of dried molasses or zeolite plus limestone to corn was attributed to the high pH, which provided a favourable environment for the growth of acetic and lactic acid producing bacteria as well as mould.

In Vitro Degradability

Addition of ground barley (5, 10 and 15%) increased ($P <$ 0.05) 18-h IVDMD of low DM (Table 5) and conventional

Table 5. In vitro degradability of dry matter (DM) and fibrous components of low DM corn silage after ensiling with various absorbants and inoculants

	DM ($g\ kg^{-1}$ DM)		NDF ($g\ kg^{-1}$ DM)		ADF ($g\ kg^{-1}$ DM)		Hemicellulose ($g\ kg^{-1}$ DM)		Cellulose ($g\ kg^{-1}$ DM)	
Treatment[z]	18 h	72 h	18 h	72 h	18 h	72 h	18 h	72 h	18 h	72 h
Control	439	654	242	535	207	516	277	541	221	567
Ground barley										
5%	492*a*	692*a*	215	523	198	502	235	567	211	600
10%	541*a*	712*a*	176	469	134*b*	452	232	513	152	586
15%	579*a*	751*a*	198	494	132*b*	445	264	549	151	587
Powdered whey										
5%	531*a*	721*a*	228	541	176	514	286	549	199	620
10%	549*a*	730*a*	245	548	206	520	289	585	229	625
15%	670*a*	814*a*	291	596	247	566	338	658	261	676
Dried molasses										
5%	426	620	176*b*	528	143*b*	507	218	510	155	613
10%	460	594*b*	175*b*	530	115*b*	454	254	575	136*b*	607
15%	506*a*	598*b*	151*b*	479	98*b*	422	227	601	115*b*	585
Bentonite, 1%	465	667	278	559	262	531	301	603	338*a*	666
Zeolite										
1%	471	682	213	525	185	503	248	427	220	651
1% + inoculant 1[z]	469	659	239	514	227	497	254	536	258	622
0.5% + 0.5% limestone	412	604*b*	179*b*	488	137*b*	453	229	534	172	599
Inoculant 1[z]	457	673	229	545	194	522	270	547	224	593
Inoculant 2[y]	486*a*	698*a*	316*a*	598	269	573	369a	622	294	619
SEM	19.6	12.5	25.4	27.3	23.3	29.6	30.3	50.3	29.5	84.6

ADF, acid detergent fibre; NDF, neutral detergent fibre; SEM; standard error of the mean.
[z]Treatments were added on a fresh weight basis.
[y]Biotal™ inoculant containing *Lactobacillus plantarum* and *Propionic bacteria* sp. (Lallemand Animal Nutrition, Rexdale, ON; 2 mg kg^{-1} fresh forage).
[x]Feedtech™ inoculant (*Lactobacillus plantarum* and *Pediococcus acidilactici)* (Delaval, Tumba, Sweden; 24 mg kg^{-1} fresh forage).
a Means within each column are significantly higher than the control ($P < 0.05$).
b Means within each column are significantly lower than the control ($P < 0.05$).

(Table 6) silage compared with the control. The positive effect of added barley on IVDMD persisted until 72 h of incubation for low DM silage (Table 5), but only the highest level of barley (15%) improved 72-h IVDMD of conventional silage (Table 6). Similarly, Harrison et al. (1994) found that the addition of rolled barley (5, 10 and 15%) to corn silage increased starch content and IVDMD. Fransen and Strubi (1998) reported that the IVDMD of grass silages with rolled barley (10%) was greater compared with control silages. Similarly, Moseley et al. (1989) showed that inclusion of rolled barley at rates of 2.5 and 5% to ensiled ryegrass-clover increased IVDMD.

The increase in IVDMD resulting from barley was likely due to the increased concentration of starch, as there were no improvements in NDF, ADF, cellulose, or hemicellulose degradability (Tables 5 and 6). In fact, for low DM silages, 10 and 15% ground barley reduced ADF degradability at 18-h (Table 5). Reduced ADF degradability of silage containing ground barley, coupled with the improvement in IVDMD, indicates that increased concentration of starch resulted in less than optimum growth of fibrolytic bacteria early in the incubation, which was responsible for reduced ADF disappearance compared with the control silage. However, this effect was not evident at 72-h, because the more readily available carbohydrates would have been previously digested. These results are in agreement with Moseley et al. (1989) who found no significant effect on ADF or NDF degradability when grass silage (160 g kg^{-1} DM) was ensiled with rolled barley (5%).

Addition of powdered whey (5, 10 and 15%) increased ($P < 0.05$) 18-h and 72-h IVDMD of low DM (Table 5) and conventional silage (Table 6) compared with the control. This improvement in IVDMD is attributed to the high concentration of readily fermentable carbohydrate (lactose) in powdered whey. This observation agrees with previous studies in which whey or lactose was added to alfalfa-brome haylage (Dash et al. 1974) and sunflower silage (Schingoethe et al. 1980).

The highest level of dried molasses (15%) increased ($P < 0.05$) 18-h IVDMD of both low DM (506 vs. 439 g kg^{-1} DM, Table 5) and conventional (532 vs. 494 g kg^{-1} DM, Table 6) DM silages. However, concurrent with increased IVDMD, degradability of all fibrous components decreased ($P < 0.05$). The increase in IVDMD observed at 18-h due to added molasses could have been due to added sugars that had not been fermented during ensiling, which would have been rapidly degraded in vitro. This increase in IVDMD was short term; IVDMD at 72-h of incubation decreased ($P <$

Table 6. In vitro degradability of dry matter (DM) and fibrous components of conventional DM corn silage after ensiling with various absorbants and inoculants

	DM ($g\ kg^{-1}$ DM)		NDF ($g\ kg^{-1}$ DM)		ADF ($g\ kg^{-1}$ DM)		Hemicellulose ($g\ kg^{-1}$ DM)		Cellulose ($g\ kg^{-1}$ DM)	
Treatment[z]	18 h	72 h	18 h	72 h	18 h	72 h	18 h	72 h	18 h	72 h
Control	494	701	238	547	189	516	293	582	214	600
Ground barley										
5%	535*a*	709	227	506	190	468	268	549	198	589
10%	570*a*	732	216	486	171	452	266	524	181	586
15%	606*a*	755*a*	240	507	161	440	311	568	173	593
Powdered whey										
5%	559*a*	737*a*	229	536	188	491	273	569	210	618
10%	634*a*	777*a*	255	529	201	486	310	574	211	619
15%	659*a*	800 *a*	251	557	203	507	322	611	227	654
Dried molasses										
5%	473	643*b*	173*b*	514	135	470	216	565	144	610
10%	473	611	157*b*	463*b*	94*b*	414*b*	238	526	113*b*	564
15%	532*a*	641*b*	119*b*	487	39*b*	434*b*	193*b*	606	59*b*	614
Bentonite (1%)	490	696	234	544	201	501	274	599	251	670
Zeolite										
1%	521	718	232	538	196	498	271	584	244	656
1% + inoculant 1[y]	508	696	231	521	202	490	265	558	233	638
0.5% + 0.5% limestone	459*b*	634	169*b*	483	158	433*b*	180*b*	538	187	591
Inoculant 1[y]	505	711	229	544	144	522	307	569	161	618
Inoculant 2[x]	548*a*	713	216	505	208	473	222	540	233	601
SEM	14.6	11.8	15.5	20.9	19.0	20.5	23.3	23.5	33.0	105.2

ADF, acid detergent fibre; NDF, neutral detergent fibre; SEM; standard error of the mean.
[z]Treatments were added on a fresh weight basis.
[y] Biotal™ inoculant containing *Lactobacillus plantarum* and *Propionic bacteria* sp. (Lallemand Animal Nutrition; 2 mg kg^{-1} fresh forage).
[x]Feedtech™ inoculant (*Lactobacillus plantarum* and *Pediococcus acidilactici)* (Delaval, Tumba, Sweden; 24 mg kg^{-1} fresh forage).
a Means within each column are significantly higher than the control ($P < 0.05$).
b Means within each column are significantly lower than the control ($P < 0.05$).

0.05) or numerically decreased for all levels of molasses added to both silages. Decreased IVDMD of both silages at 72-h of incubation corresponded to numerically lower degradation of fibrous components for low DM silages (Table 5), and a combination of lower ($P < 0.05$) and numerically lower fibre degradation for conventional silages (Table 6) which is consistent with the high pH (Tables 3 and 4) and mould growth observed for these silages. High pH of the silage resulted in an increase in the population of undesirable microorganisms, and consequently, nutritive value (e.g., IVDMD and fibre degradability) of the silage declined.

Feedtech inoculant was very effective for low DM silages, increasing ($P < 0.05$) 18- and 72-h IVDMD compared with the control (Table 5). This inoculant also increased the 18-h IVDMD of conventional forage, but no effect on IVDMD was observed at 72-h (Table 6). The improvements in IVDMD indicate the potential for beneficial effects resulting from using an inoculant based on *Lactobacillus sp*. and appears to be associated with an increase in digestibility of the fibre fraction. This is in agreement with Harrison et al. (1994) in which IVDMD of wilted lucerne silage (234 g kg^{-1} DM) increased from 518 to 551 g kg^{-1} DM ($P < 0.05$) with the addition of lactic acid bacteria. In contrast, Biotal inoculant, also based on *Lactobacillus sp*., was not effective for either silage. The reasons for this apparent contradiction in response may be due to differences in lactic acid producing bacteria concentration (1×10^5 CFU g^{-1} for the Biotal™ vs. 6.7×10^{10} CFU g^{-1} for the Feedtech™) or viability of the product.

Addition of zeolite with limestone decreased ($P < 0.05$) 72-h IVDMD of low DM silage and 18- h IVDMD of conventional silage compared with control silages. For low DM silage, the decrease in IVDMD corresponded to numerical reductions in degradation of fibre components, and for conventional forage, decreases ($P < 0.05$) in NDF and hemicellulose degradation. Zeolite alone had no effect on IVDMD or fibre degradation, thus the negative effect of zeolite combined with limestone was attributed to the limestone.

Bentonite had no effect on IVDMD of low DM or conventional silage in contrast with Cook et al. (1980) who reported that digestibility of organic matter was reduced by bentonite (0.7 and 2.1%) inclusion to perennial ryegrass (172 g kg^{-1} DM) in feeding trials with sheep. Addition of bentonite increased ($P < 0.05$) 18-h cellulose degradation, but no other fibrous component was increased. Thus, the effects of bentonite on fibre degradation were negligible.

CONCLUSIONS

Crops ensiled with low DM content can result in poor-quality silage, producing high levels of effluent during the ensiling process. Absorbants and inoculants added to corn forage during the ensiling process have the potential to reduce effluent and improve the nutritive value of silage. However, not all the additives studied were equally effective. In our study, the most effective feed-type additive for reducing effluent losses was ground barley, added at 10 to 15% of the silage fresh weight, whereas the best non-feed additives were zeolite (added at 0.5%) with limestone (added at 0.5%) and zeolite (added at 1%) with a bacterial inoculant. In terms of improving silage quality (measured as in vitro dry matter degradability), ground barley (5 to 15%), powdered whey (5 to 15%) and a commercial inoculant (Feedtech) were most effective. However, of the additives evaluated, only ground barley reduced effluent losses while improving nutritive value of low DM corn silage.

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Alli, I., Thiffault, C. and Baker, B. 1985. A device for monitoring silage effluent produced in laboratory silos. J. Dairy Sci. **68:** 3355–3359.

Association of Official Analytical Chemists. 1975. Official methods of analysis. 12th ed. AOAC, Washington, DC.

Association of Official Analytical Chemists. 1995. Official methods of analysis. 14th ed. AOAC, Washington, DC.

Bal, M. A., Coors, J. G. and Shaver R. D. 1996. Impact of maturity of corn for use as silage in the diets of dairy cows on intake, digestion, an milk production. J. Dairy Sci. **80**: 2497–2503.

Bolsen, K. K., Ashbell, G. and Wilkinson, J. M. 1995. Silage additives. Pages 32–54 *in* R. J. Wallace and A. Chesson, eds. Biotechnology in animal feeds and animal feeding. VCH, New York, NY.

Bastiman, B. 1976. Factors affecting silage effluent production. Exp. Husb. **31**: 40–46.

Cook, J. E., Wilkinson, J. M. and Woolford, M. K. 1980. Addition of sodium bentonite to unwilted grass: effects on effluent production and nutritive value of silage. Anim. Prod. **30:** 467.

Dash, S. K., Voelker, H. H., Muller, L. D. and Schingoethe, D. J. 1974. Dried whey as an additive for reconstituted alfalfa hay silage. J. Dairy Sci. **57**: 314–318.

Everson, R. A., Jorgensen, N. A. and Barrington, G. P. 1971. Effect of bentonite, nitrogen source, and stage of maturity on nitrogen redistribution in corn silage. J. Dairy Sci. **54:** 1482–1490.

Ferris, C. P. and Mayne, C. S. 1994. The effects of incorporating sugar-beet pulp with herbage at ensiling on silage fermentation, effluent output and in-silo losses. Grass Forage Sci. **49:** 216–228.

Food and Agriculture Organization of the United Nations. 1997. FAOSTAT database, Agricultural production, Crops primary, Rome. [Online] Available: http://faostat.fao.org/faostat/collections [2005 Oct. 10].

Fransen, S. C. and Strubi, F. J. 1998. Relationships among absorbants on the reduction of grass silage effluent and silage quality. J. Dairy Sci. **81:** 2633–2644.

Goering, H. K. and Van Soest, P. J. 1970. Forage fibre analysis. Agricultural Handbook no. 379. ARS-USDA, Washington, DC.

Gordon, C. H., Irvin, H. M., Melin, C. G., Wiseman, H. G. and McCalmont, J. R. 1957. Some experiments in preservation of high-moisture hay-crop silage. J. Dairy Sci. **40:** 789–799.

Graves, R. E. and Vanderstappen, P. J. 1993. Environmental problems with silage effluent. Pages 291–299 *in* Silage production from seed to animal. Proc. Natl. Silage Prod. Conf., Syracuse, NY. Northeast Reg. Agric. Eng. Ser. Coop. Ext. Cornell Univ., Ithaca, NY.

Hameleers, A., Leach, K. A., Offer, N. W. and Roberts, D. J. 1999. The effects of incorporating sugar beet pulp with forage maize at ensiling on silage fermentation and effluent output using drum silos. Grass Forage Sci. **54:** 322–335.

Harrison, J. H., Kincaid, R. L., Loney, K. A., Riley, R. E. and Cronrath, J. 1994. Fermentation and nutritive value of *Zea mays* and lucerne forage ensiled with added rolled barley. Grass Forage Sci. **49:** 130–137.

Jones, D. I. H. 1988. The effect of cereal incorporation on the fermentation of spring- and autumn-cut silages in laboratory silos. Grass Forage Sci. **43:** 167–172.

Jones, D. I. H., Jones, R. and Moseley, G. 1990. Effect of incorporating rolled barley in autumn-cut ryegrass silage on effluent production, silage fermentation and cattle performance. J. Agric. Sci. (Camb.) **115:** 399–408.

Jones, R. and Jones, D. I. H. 1988. Effect of absorbants on effluent production and silage quality. Pages 47–48 *in* B. A. Stark and J. M. Wilkinson, eds. Silage effluent. Chalcombe Publ., Marlow, UK.

Jones, R. and Jones, D. I. H. 1996. The effect of in-silo effluent absorbants on effluent production and silage quality. J. Agric. Eng. Res. **64:** 173–186.

Kung, L., Jr., Stokes, M. R. and Lin, C. J. 2003. Silage additives. Page 305 *in* D. R. Buxton, R. E. Muck, and J. H. Harrison, eds. Silage science and technology. Agronomy Monograph, No. 42. ASA, Madison, WI.

Lahr, D. A., Herby, D. E., Johnson, D. G., Linn, J. G. and Lindquist, R. G. 1983. Effects of moisture content of complete diets on feed intake and milk production in dairy cows. J. Dairy Sci. **66**: 1891–1900.

McDonald, P., Henderson, A. R. and Heron, S. J. E. 1991. The biochemistry of silage. 2nd ed. Chalcombe Publ., Marlow, UK.

Merriman, R. P. 1988. Water pollution by silage effluent. Pages 5–15 *in* B. A. Stark and J. M. Wilkinson, eds. Silage effluent. Chalcombe Publ., Marlow, UK.

Moseley, G. and Ramanathan, V. 1989. The effect of dry feed additives on the nutritive value of silage. Grass Forage Sci. **44:** 391–397.

Offer, N. W. and Al-Rwidah, M. N. 1989. The use of absorbant materials to control loss from grass silage: experiments with drum silos. Res. Dev. **6:** 71–76.

O'Kiely, P. 1992. The effects of ensiling sugar beet pulp with grass on silage composition, effluent production and animal performance. Iri. J. Agric. Food Res. **31**: 115–128.

Phipps, R. H., Sutton, J. D., Beever, D.E. and Jones, A. K. 2000. The effect of crop maturity on the nutritional value of maize silage for lactating dairy cows. 3. Food intake and milk production. Anim.Sci. **71**: 401–409.

Rhine, E. D., Sims, G. K., Mulvaney, R. L. and Pratt, E. J. 1998. Improving the Berthelot reaction for determining ammonium in soil extracts and water. Soil Sci. Soc. Am. J. **62:** 473–480.

SAS Institute, Inc. 1999. SAS/STAT user's guide. Version 8, SAS Institute, Inc., Cary, NC.

Schingoethe, D. J., Skyberg, E. W. and Rook, J. A. 1980. Chemical composition of sunflower silage as influenced by addition of urea, dried whey and sodium hydroxide. J. Anim. Sci. **50**: 625–629.

Van Der Wel, C. 1993. Inkuil verliezen by snijmais. [Ensiling losses in forage maize.] Rapport No 146, Proefstation voor de Rundvee Hourderij, Schapenhouderij en Paardenhouderij, Lelystad, the Netherlands.

Van Soest, P. J., Robertson, J. B. and Lewis, B. A. 1991. Methods for dietary fibre, neutral detergent fibre, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. **74:** 3583–3597.

Woolford, M. K., Wilkinson, J. M. and Cook, J. E. 1983. Investigations on the effect of sodium bentonite and other moisture absorbants on the production of effluent from grass silage. Anim. Feed Sci. Technol. **8:** 107–118.