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Conservation characteristics of grass and dry sugar beet pulp co-ensiled after different degrees of mixing

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The objective of this experiment was to quantify the effects of the degree of mixing of dry molassed sugar beet pulp (BP) with grass on silage conservation characteristics. Herbage from a timothy *(Phleum pratense)* sward was precision chopped and treated with a formic acid based additive (3 l/t grass). Units of 50 kg grass, without or with 2.5 kg BP were randomly allocated among four replicates on each of seven treatments. The treatments were (1) no BP (NONE), (2) BP evenly mixed through the grass (EVEN), (3) BP evenly mixed through the lower 25 kg grass (LOWH), (4) BP evenly mixed through the lower 12.5 kg grass (LOWQ), (5) 0.625 kg BP mixed through the top 25 kg grass and 1.875 kg SBP mixed through the lower 25 kg grass (25/75), (6) BP placed in 0.5 kg layers beneath each 10 kg grass (LAYR), and (7) BP placed in a single layer under all of the grass (BOTM). Laboratory silos were filled and sealed, and stored at 15 °C for 163 days. Effluent was collected and weighed from each silo throughout the ensilage period. At opening, silage composition and aerobic stability measurements were made. Total outflow of effluent was reduced ($P<0.001$) by the addition of BP; LAYR had a greater effect ($P<0.001$) than any of the other treatments. Effluent dry matter (DM) concentration was highest ($P<0.05$) for BOTM and lowest ($P<0.01$) for NONE. All treatments underwent similar lactic-acid dominant fermentations. Incorporation of BP with grass increased silage DM concentration ($P<0.001$), *in vitro* DM digestibility ($P<0.05$) and water soluble carbohydrate ($P<0.001$) concentration and reduced acid detergent fibre ($P<0.001$) concentration. Aerobic stability was similar across treatments and aerobic deterioration at 192 h was higher ($P<0.05$) for LOWQ, 25/75, LAYR and BOTM than

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for NONE. In conclusion, the incorporation of BP increased silage DM digestibility but had relatively little effect on fermentation or aerobic stability. Placing BP in layers gave the largest and most sustained restriction in effluent output.

Keywords: silage effluent; silage conservation characteristics

Introduction

Preventing effluent loss often poses a major challenge when making grass silage in north western Europe. Silage effluent has a higher biological oxygen demand (BOD) than pig or cattle slurry, or domestic sewage (Spillane and O'Shea, 1973) and farmers are required to prevent it causing pollution. In addition, effluent production represents a loss of dry matter (DM) from the silo. As effluent DM is a valuable source of highly digestible nutrients including soluble carbohydrates, nitrogenous components, organic acids and mineral elements (Patterson and Walker, 1979), its retention within the silo stores more nutrients for the animal. Effluent flow through silage depends on the moisture concentration of the herbage at ensiling, on other characteristics of the herbage ensiled (species and maturity; chop length and type), use of additives and on the vertical pressure applied (McDonald, 1973). Effluent will only discharge from the silo if it can move to the bottom of the silo and then find an exit (Woolford, 1978).

One method of retaining effluent within the silo is to bind the forage moisture *in situ* by incorporating a drier material at ensilage. Both feed and non-feed materials have been employed as effluent absorbents including cereals, such as barley and oats (Jones, 1988b), fibrous materials such as barley straw (Haigh, 1998) and sugar beet pulp (Offer and Al-Rwidah, 1989a, b; O'Kiely, 1992; Ferris and Mayne, 1994), proprietary ingredients, such as Sweet 'n' Dry (Moore and Kennedy, 1994), newspaper and the colloidal clay, bentonite (Fransen and Strubi, 1998). Much of the research on absorbents has focused on sugar beet pulp due to its own high feeding value and high effluent retention capacity compared with other feed ingredients (Offer and Al-Rwidah, 1989a). Inclusion of dried sugar beet pulp with grass at harvesting has been shown to reduce effluent production (O'Kiely, 1992; Ferris and Mayne, 1994; Moore and Kennedy, 1994), improve the fermentation characteristics and nutritive value of the silage (Offer and Al-Rwidah, 1989a; O'Kiely, 1992; Moore and Kennedy, 1994) and reduce in-silo losses (Ferris and Mayne, 1994; Moore and Kennedy, 1994).

Jones (1988a) found that the maximum reduction in effluent outflow in farm silos occurred when beet pulp was thoroughly mixed with grass by hand. Spreading beet pulp in layers with a fertiliser spreader was adjudged to create lateral drainage channels across the silo, which increased drainage and reduced the absorption of effluent. However, since effluent tends to concentrate more in the lower layers of silage, benefits may accrue from placing beet pulp in the lower horizons, and in particular, close to where the effluent exits the silo. The objective of this experiment, carried out using laboratory silos, was to quantify the effects of the degree of mixing of dry molassed sugar beet pulp nuts with grass on silage conservation characteristics, with particular emphasis on effluent production.

Materials and Methods

Silage preparation

Herbage from a timothy *(Phleum pratense)* sward was cut on the 9 November and harvested without wilting using a precision-chop harvester (Pottinger, Mex VI). The chopping knife and feed roller speeds were chosen, according to the manufacturer's instructions, to give a chop length of 19 mm. Harvesting took place early in the morning when a heavy dew was present on the grass, ensuring sufficiently wet grass to release a significant flow of effluent throughout the ensilage period. An additive based on formic acid (Add SafeR, composed of 70 g ammonia and 640 g formic acid per 1 kg, supplied by Interchem Ltd, Cherry Orchard Ind. Est., Dublin 10) was applied to the grass during harvesting (above and behind the chopping drum) at a rate of 3 l/t grass. Grass was thoroughly hand mixed and sampled (n=6) for chemical analysis. A batch of 75 kg of dry molassed sugar beet pulp nuts (BP) was obtained, hand mixed and sampled (n=4) for chemical analysis.

Units of 50 kg grass, without or with 2.5 kg BP, were allocated at random to the following additive treatments, with 4 replicates per treatment:

1. No BP added (NONE)
2. BP evenly mixed through all the grass (EVEN)
3. BP evenly mixed through the lower 25 kg grass (LOWH)
4. BP evenly mixed through the lower 12.5 kg grass (LOWQ)
5. BP evenly mixed in two halves of the grass – 0.625 kg BP through the top 25 kg grass and 1.875 kg BP through the lower 25 kg (25/75)
6. BP placed in layers through the grass – 0.5 kg layer of BP beneath each 10 kg grass (LAYR)
7. BP placed in a single layer under the grass (BOTM)

The treatments were ensiled in 2 m high, cylindrical plastic-pipe silos as described by O'Kiely (1991). The grass for each replicate was mixed thoroughly and grass for each of the seven treatments in that replicate was weighed into individual plastic boxes before being mixed with the BP, as appropriate. A similar procedure was followed for the four replicates and ensured a similar duration prior to silo filling for each treatment, and that no loss of liquid occurred prior to silo filling. Similar packing procedures were used for each silo to ensure similar compaction within and among treatments. Two water bags (10 kg each) were placed into the top of each silo to help create anaerobic conditions and exert vertical pressure on the ensiled material. Silos were stored at 15 °C for 163 days. Effluent was collected and weighed from each silo on days 2, 4, 9, 14, 28, 42, 56, 80, 100, 120, 140 and 163. The effluent retained by the six BP treatments was determined as the difference from the effluent output of NONE. Effluent retention rate for each BP treatment was calculated by dividing the effluent retained by the weight of BP ensiled.

Chemical analysis

Grass samples were stored at −18 °C for 24 h and were subsequently thawed and processed through a bowl chopper (Muller, Type MKT 204 Special, Saarbrücken, Germany). From each sample, a 200 g subsample was dried at 98 °C for 16 h for DM determination. A further sub-sample was dried at 40 °C for 48 h, ground through a Wiley mill (1 mm mesh sieve) and analysed for *in vitro* DM digestibility (DMD), ash, total N, water soluble carbohydrates (WSC), neutral detergent fibre (NDF), acid detergent fibre (ADF) as described by Cummins *et al.* (2008). Buffering capacity was determined by the method of Playne and McDonald (1966).

Dry BP nut samples were crushed to allow thorough drying in the oven. From each sample, a 200 g sub-sample was dried at 98 °C for 16 h for DM determination. A further sub-sample was dried at 40 °C for 48 h, ground through a Wiley mill (1 mm mesh sieve) and analysed for *in vitro* DMD, ash, NDF, ADF, total N and WSC.

During the ensilage period, effluent DM concentration (total dissolved solids) was estimated using a refractometer, while pH was estimated using an Orion SA720 pH meter and electrode.

On opening the silos, the density of the silage was estimated using the height of the silage in the silo, the internal radius of the silo and the mass of the silage in the silo. The contents of each silo were fully mixed and a representative sample was taken and processed through a bowl chopper (Muller, Type MKT 204 Special, Saarbrücken, Germany). Duplicate sub-samples were dried at 85 °C for 16 h for DM determination. This DM value was later corrected for lost volatiles according to Porter and Murray (2001). A further sub-sample was dried at 40 °C for 48 h, ground through a Wiley mill (1 mm mesh sieve) and analysed for *in vitro* DMD, ash, WSC, NDF and ADF. Silage juice was mechanically expressed and retained for measurement of pH, lactic-acid, volatile fatty acids (VFA), ethanol and ammonia-N (NH_3-N) as described by Cummins *et al.* (2008). Fermentation products (FP) were calculated as the sum of lactic acid, VFAs and ethanol.

Aerobic stability

Aerobic stability of each silage was assessed for 8 days at 20 °C using an automated temperature recording system. Duplicate samples (6 kg each) from each silo were placed in polythene-lined polystyrene (2.5 cm thick) containers (59 cm × 39 cm × 22 cm) with a polystyrene lid fitted loosely on top. Temperature was assessed by means of thermocouples placed in the middle of the silage in each box and recorded every hour by a data logger (SQ ELTEK 80T, Eurolec Instrumentation Ltd., Dundalk, Co. Louth, Ireland). Containers of water stored beside the silage acted as reference temperatures to which all silage temperatures were compared. Indices of aerobic stability were time (h) to temperature rise by >2 °C and >5 °C, the maximum temperature rise (°C) and the time (h) to maximum temperature rise. Indices of aerobic deterioration were the accumulated temperature rise to 120 and 192 h (°C).

Statistical analysis

Silage composition and aerobic stability data were subjected to analysis of variance using the general linear model procedures of SAS (SAS, 2002–2003) with means separated using Duncan's multiple range test (Steel and Torrie, 1960) in SAS. For each of the aerobic stability measurements, the means of the duplicate samples were used in the analysis. Effluent output data were analysed according to a repeated measures design in SAS. The model used had fixed effects for treatment, day and treatment*day interaction and silo as a random term.

Results

Chemical composition of grass and BP

The composition of the grass and BP are given in Table 1. The grass ensiled had a low DM and high N concentration. The chemical composition of the BP contrasted sharply to that of the grass in terms of its higher DM, *in vitro* DMD and WSC values and its lower total N concentration.

Silage effluent

Total outflow of effluent was reduced (P<0.001) by co-ensilage with BP, and LAYR had a larger impact (P<0.001) than

Table 1. Average (s.d.) chemical composition of grass and sugar beet pulp as ensiled

	Grass	Beet pulp
Dry matter (DM) (g/kg)	152 (0.5)	894 (0.6)
pH	5.4 (0.78)	4.8 (0.10)
In vitro dry matter digestibility (g/kg DM)	638 (27.6)	897 (2.4)
Composition of DM (g/kg)		
Ash	96 (7.2)	99 (1.5)
Total nitrogen	27 (0.4)	17 (0.3)
Water soluble carbohydrates	130 (14.4)	258 (3.9)
Neutral detergent fibre	498 (4.7)	284 (1.8)
Acid detergent fibre	282 (3.8)	157 (1.0)
Buffering capacity (mEq/kg DM)	460 (12.2)	352 (6.3)

any of the other BP treatments (Table 2 and Figure 1). These effects were manifested on accumulated effluent output at each sampling time after Day 2. From Day 28 to 80, there was a greater output of effluent ($P<0.001$) for EVEN, LOWH, LOWQ and 25/75 than for LAYR or BOTM. Between Day 80 and 163, BOTM had a similar ($P>0.05$) effluent output to EVEN, LOWH, LOWQ and 25/75 and a greater ($P<0.001$) effluent output than LAYR. Corresponding with its lower effluent output, LAYR had a higher ($P<0.001$) effluent retention rate than the other treatments. BOTM had a higher ($P<0.05$) effluent DM value than all other treatments. The EVEN and 25/75 treatments had similar ($P>0.05$) DM values as had LOWH and LAYR ($P>0.05$) while NONE had the lowest ($P<0.01$) effluent DM value. On a DM basis, LAYR also produced a lower ($P<0.001$) total effluent loss than NONE, LOWH, LOWQ or BOTM. Silage DM recovery was lower ($P<0.01$) for LOWQ and BOTM than for NONE, EVEN, 25/75 or LAYR, and was lower for LOWRH than 25/75 ($P<0.05$). Silage density increased ($P<0.05$) with the addition of BP, and amongst the BP silages, 25/75 had a higher ($P<0.05$) density value than BOTM.

Silage aerobic stability

LOWQ, 25/75 and BOTM had a shorter ($P<0.05$) times to temperature rise by 2 or 5 °C than LOWH with the other treatments being intermediate (Table 2). NONE, EVEN and LOWH had a longer ($P<0.05$) time to maximum temperature rise occurred than LOWQ, 25/75 or BOTM while 25/75 had a higher ($P<0.05$) accumulated temperature rise to 120 and 192 h than NONE, EVEN or LOWH.

Chemical composition of the silage

All treatments were well preserved as indicated by their low pH values, relatively low concentrations of NH_3-N and butyric acid, and high contribution of lactic-acid to total fermentation products (FP) (Table 3). Incorporation of BP with the grass increased ($P<0.001$) silage DM concentration. Treatments EVEN, LOWH, LOWQ and 25/75 had DM concentrations that did not differ from one another ($P>0.05$), and all had higher ($P<0.01$) values than BOTM. LAYR had a lower ($P<0.05$) DM value than either EVEN or 25/75 but had a higher ($P<0.05$) value than BOTM. Addition of BP increased ($P<0.05$) silage DMD values while ADF concentrations followed the opposite trend ($P<0.001$). Both NONE and BOTM had a higher ($P<0.001$) NDF concentration than EVEN, LOWH, LOWQ, 25/75 or LAYR, while LOWQ had a higher ($P<0.05$) value than 25/75. BOTM had a higher ADF concentration than EVEN, LOWH, LOWQ, LAYR ($P<0.01$) or 25/75 ($P<0.001$).

Table 2. Effect of co-ensiling grass and dry sugar beet pulp on total effluent output, dry matter (DM) recovery and aerobic stability

	Treatment							s.e.d.	Significance
	NONE	EVEN	LOWH	LOWQ	25/75	LAYR	BOTM		
Effluent output (g/kg grass)	162^{a}	107^{b}	116^{b}	111^{b}	105^{b}	71^{c}	105^{b}	9.4	***
Effluent retention rate[1] (kg/kg)	–	1.10^{b}	0.92^{b}	1.02^{b}	1.15^{b}	1.84^{a}	1.14^{b}	0.137	***
Effluent dry matter (DM) (g/kg)	54.1^{e}	73.8^{d}	92.9^{c}	110.2^{b}	78.2^{d}	93.5^{c}	125.9^{a}	6.45	***
Total effluent DM loss[2] (g/kg)	58.0^{b}	52.2^{bc}	71.1^{a}	80.7^{a}	54.1^{bc}	43.6^{c}	82.3^{a}	5.69	***
Silage DM recovery[3] (g/kg)	862^{ab}	853^{ab}	845^{bc}	832^{cd}	871^{a}	862^{ab}	816^{d}	10.1	***
Silage DM density (kg/m^3)	124^{c}	143^{ab}	143^{ab}	141^{ab}	145^{a}	140^{ab}	135^{b}	4.1	***
Aerobic stability									
Time to temperature rise by 2 °C (h)	138^{ab}	115^{abc}	145^{a}	93^{c}	100^{bc}	108^{abc}	92^{c}	19.0	*
Time to temperature rise by 5 °C (h)	153^{a}	134^{ab}	162^{a}	109^{b}	110^{b}	130^{ab}	105^{b}	19.5	*
Max. temperature rise (°C)	10	15	10	17	18	15	13	3.3	
Time to maximum temperature rise (h)	172^{a}	172^{a}	175^{a}	133^{bc}	123^{c}	163^{ab}	119^{c}	17.4	**
Accumulated temperature rise to 120 h	4.6^{bc}	5.6^{bc}	4.3^{c}	17.2^{ab}	23.3^{a}	12.1^{abc}	16.0^{abc}	6.41	*
Accumulated temperature rise to 192 h	19.3^{d}	34.6^{bcd}	24.0^{cd}	60.2^{ab}	73.1^{a}	50.7^{abc}	54.5^{abc}	15.26	**

[1] Effluent retained/beet pulp added.
[2] Total effluent DM/grass DM ensiled.
[3] Total silage volatile corrected DM/total DM ensiled.
[abcd] Within a row, values not sharing a common superscript are significantly different ($P<0.05$).

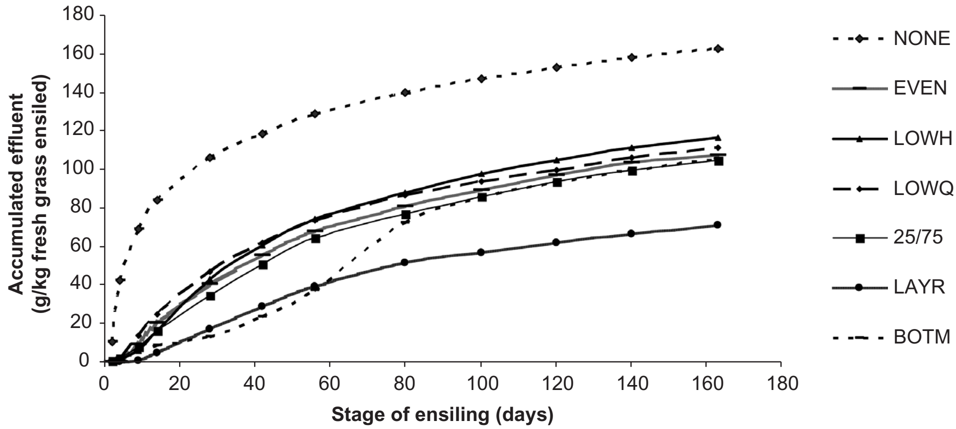

Figure 1. The temporal pattern in accumulated effluent output (least square means); s.e.d. 6.19.

Silage WSC concentration was increased (P<0.001) with the addition of BP. In line with the similar pH values, similar concentrations of lactic-acid were found for all treatments. LOWQ, 25/75 and BOTM had lower (P<0.01) acetic acid concentrations than NONE, while LOWQ and BOTM had lower (P<0.05) values than EVEN. Although significant treatment effects on propionic and butyric acid concentrations were recorded, all values were low and the scale of effects was small. Ethanol concentration was increased (P<0.05) by EVEN, 25/75, LAYR and particularly by LOWH. Total fermentation products were lower (P<0.05) for BOTM compared to NONE. When lactic acid was expressed as a proportion of FP, similar concentrations were recorded across treatments. Inclusion of BP reduced (P<0.01) NH_3-N concentration, with 25/75 having a greater (P<0.05) effect than EVEN or LOWQ.

Discussion

Herbage composition

Wet conditions pre harvest meant that the grass ensiled had surface moisture and this was reflected in an overall DM concentration of only 152 g/kg. This ensured a significant flow of effluent throughout the ensilage period. The low DM and WSC concentrations and moderately high buffering capacity of the grass presented a considerable risk that the NONE and EVEN silages would experience considerable and limited clostridial activity, respectively, with the other treatments showing intermediate effects (O'Kiely and Muck, 1998). Such major confounding effects of the general standard of preservation would have made the treatment effects on effluent outflow difficult to interpret. The application of a moderate rate of a formic-acid based additive facilitated an extensive, lactic-acid dominant fermentation in all the ensiled grass, with relatively little residual WSC remaining. This therefore permitted treatment effects on fermentation be determined within an environment dominated by lactic-acid bacterial activity. Furthermore, the formic-acid based additive was likely to facilitate more rapid cell lysis and thus effluent outflow, thereby increasing the opportunity to

Table 3. Effect of co-ensiling grass and dry sugar beet pulp on silage composition after 163 days ensilage

	Treatment							s.e.d.	Significance
	NONE	EVEN	LOWH	LOWQ	25/75	LAYR	BOTM		
Dry matter (DM) (g/kg)	162[d]	183[a]	182[ab]	179[ab]	184[a]	178[b]	173[c]	2.2	***
pH	3.97	3.87	3.93	3.93	3.87	3.96	3.98	0.040	
In vitro dry matter digestibility (g/kg)	593[b]	652[a]	634[a]	642[a]	628[a]	644[a]	653[a]	14.7	**
Composition of DM (g/kg DM)									
Ash	97[b]	95[b]	97[b]	101[a]	101[a]	102[a]	102[a]	1.3	***
Neutral detergent fibre	448[a]	411[bc]	418[bc]	420[b]	405[c]	415[bc]	443[a]	6.5	***
Acid detergent fibre	270[a]	247[c]	250[c]	249[c]	240[d]	247[c]	256[b]	2.0	***
Water soluble carbohydrate	10.5[b]	14.9[a]	14.4[a]	15.3[a]	14.9[a]	14.6[a]	15.4[a]	0.42	***
Fermentation characteristics (g/kg DM unless otherwise stated)									
Lactic-acid	135	136	128	128	137	130	124	6.3	
Acetic acid	28.0[a]	26.8[ab]	26.1[abc]	23.8[cd]	24.4[bcd]	26.1[abc]	23.1[d]	1.27	**
Propionic acid	2.4[a]	1.3[e]	1.6[cde]	1.6[cd]	1.5[de]	1.9[bc]	2.2[ab]	0.17	***
Butyric acid	0.4	0.6	0.6	0.8	0.3	1.0	0.2	0.31	
Total volatile fatty acids	32[a]	29[b]	28[bc]	26[bc]	26[bc]	29[ab]	25[c]	1.4	**
Ethanol	24[c]	34[ab]	40[a]	30[bc]	34[ab]	34[ab]	23[c]	3.6	**
Fermentation products[1] (FP) (g/kg DM)	192[ab]	199[a]	196[ab]	184[bc]	197[ab]	193[ab]	173[c]	6.6	*
Lactic acid relative to FP	0.71	0.68	0.66	0.70	0.69	0.67	0.72	0.020	
Ammonia-N (g/kg N)	110[a]	98[b]	92[bc]	100[b]	87[c]	94[bc]	96[bc]	4.6	**

[1] Fermentation products = lactic-acid + VFAs + ethanol.
[abcd] Within a row, values not sharing a common superscript are significantly different ($P<0.05$).

detect treatment effects (Pedersen, Olsen and Guttormsen, 1973).

Silage effluent and DM recovery

The quantity of effluent produced in the absence of BP is in agreement with the findings of Peters and Weissbach (1977) who estimated effluent output based on both the DM concentration of the herbage ensiled and the vertical pressure. Although the inclusion of BP at a standard rate of 50 kg/t grass reduced the total production of effluent, considerable quantities of effluent were still produced. It was calculated, using the same effluent retention rate as pertained for 50 kg BP/t grass, that a further 97, 126, 109, 91, 39 and 92 kg of BP/t of grass would have been required to absorb all the effluent in the EVEN, LOWH, LOWQ, 25/75, LAYR and BOTM treatments, respectively. Compared with NONE, effluent flow from the BP treated silages was most markedly reduced during the first 28 days following ensiling, with effluent production reduced by proportionately 0.7. Since most effluent is released within 2 to 3 weeks of ensiling (O'Kiely, 1990), this reduction in effluent flow after ensiling could greatly facilitate effluent management on farms. However, the marked increase in effluent DM concentrations for the BP treatments, suggesting a significant loss of soluble contents from the BP, would elevate effluent BOD considerably, so great care would be necessary in ensuring that such effluent is prevented from reaching surface or ground water. The higher effluent DM values of the BP treated silages compared with NONE are in accordance with findings from Ferris and Mayne (1994). This apparent loss of digestible nutrients from the BP via effluent is a finding that merits further investigation. The effluent retention rates of 0.9 to 1.8 kg per 1 kg BP are in general agreement with previous findings (O'Kiely, 1989; O'Kiely, 1991). In an experiment using larger scale (10 t) pit silos, Offer and Al-Rwidah (1989b) found similar effluent retention rates to those observed in the present study when molassed dry sugar beet shreds were mixed with low DM grass (148 g/kg) at inclusion rates of 60 kg/t grass.

Due to the relatively intimate contact between BP and forage in EVEN, LOWH, LOWQ and 25/75, these treatments initially gave a large restriction in effluent outflow relative to NONE. However, once the BP in the former treatments became saturated, subsequent effluent outflow was similar to NONE. The slower initial outflow of effluent for BOTM may have the same explanation as the movement of water through alternating saturated and dry layers in a column of soil (Smith and Smith, 1998). It is proposed that the effluent formed a capillary fringe that moved slowly downwards from the saturated grass through the unsaturated BP layer at the base of the silo. Once this BP layer became saturated, which appears to have occurred after about 56 days of ensilage, the head of effluent resulted in a rapid discharge of effluent such that by day 80 of ensilage, the surplus effluent previously retained within the forage passed through the saturated BP and exited at the bottom of the silo. Thereafter, effluent outflow occurred at a similar rate to EVEN, LOWH, LOWQ and 25/75. The same principle of forage and BP layers achieving a state of equilibrium before effluent was released to the bottom of the silo is also applicable to LAYR. In the latter case, the capillary fringe moved from each overlying saturated forage layer into the unsaturated BP layer below. Again, as each layer became saturated, equilibrium was reached and the surplus effluent was then slowly released either to the underlying forage (for four of the layers) or to the space beneath the bottom layer. However, the head of vertical pressure that existed above each layer of BP in this treatment was initially much smaller than that in BOTM. This likely resulted in a slower rate of saturation of the BP and a considerably longer delay (more than 163 days ensilage) before all of the surplus effluent trapped within the forage might exit to the bottom of the silo. This is the most probable explanation for the lower effluent output for LAYR compared to the other treatments. An additional explanation could be offered by the hypothesis that the air spaces between the BP nuts in the LAYR and BOTM treatments allowed the nuts to expand and hold more moisture.

While DM recovery rates were high across all treatments, addition of BP had an inconsistent effect on silage DM recovery with NONE having a higher DM recovery than treatments where the BP was concentrated in the lower quarter of the silo (LOWQ and BOTM). In line with these findings, both LOWQ and BOTM had numerically higher accumulated effluent DM losses than the other treatments, reflecting the loss of soluble, digestible nutrients from the BP. It is likely that under the prevailing conditions of high volumes of effluent production, more effluent passed through these BP nuts than for the other treatments due to their position towards the bottom of the silage. As a consequence, much of their soluble contents would have been leached and thus, lost in the effluent. The current results contrast with those of O'Kiely (1992) and Fransen and Strubi (1998) who both recorded higher DM recoveries for BP treated silages than for untreated silages when preservation was satisfactory. This apparent discrepancy reflects the lower output of effluent with the drier herbages in these other experiments which, together with their more even distribution of BP nuts through the silage, meant that relatively little surplus effluent was available to remove solubles from the BP and leach them in the effluent.

Silage chemical composition

The DM concentration of herbage ensiled without addition of BP increased from 152 to 162 g/kg during ensilage, mainly reflecting water loss via effluent. The corresponding decline in DMD (638 to 593 g/kg) is in accord with the report by Rotz and Muck (1994) and reflected mainly the losses of soluble nutrients in effluent as well as losses associated with the extensive fermentation. The decrease in NDF (498 to 448 g/kg DM) and in ADF (282 to 270 g/kg DM) reflect enzymatic and in particular acid hydrolysis of structural carbohydrates during ensilage (Jones, Hatfield and Muck, 1992), with hemicellulose concentration appearing to undergo the major decline. The fermentation characteristics of NONE, as shown by a low pH and low concentrations of WSC, total volatile fatty acids and ethanol, together with the high lactic-acid concentration indicate that the ensiled herbage underwent an extensive, lactic-acid dominant fermentation.

The larger numerical decline in mean DMD (based on the calculated DMD of the mixture at ensiling) during ensilage for treatments where grass and BP were co-ensiled compared to NONE (55 v. 45 g/kg) was surprising and reflects the sizeable loss of nutrients via effluent in some of the treatments involving BP. However, in comparison with NONE, addition of BP increased DM digestibility by an average of 49 g/kg as a result of its higher digestibility relative to grass and its ability to absorb and retain effluent. This increase in DM digestibility was higher than that found by Offer and Al-Rwidah (1989a) and O'Kiely (1992) for similar BP inclusion rates. The slightly higher WSC and the lower ADF concentrations in the BP treated silages compared with NONE are consistent with the inclusion of a feedstuff which is higher in WSC and lower in ADF than the grass.

Although significant treatment effects were recorded for a number of fermentation variables, many of these were so small as to be of little biological importance. The addition of BP to very wet formic-acid treated grass, resulting in an increase in mean silage DM concentration from 162 to 180 g/kg, did not alter silage pH but did affect the extent of fermentation for BOTM as reflected by its lower concentration of FP compared to NONE. Overall treatment effects on the proportion of FP contributed by lactic-acid were non significant while treatment effects on acetic acid and ammonia-N were modest in scale. Thus, none of the BP treatments markedly altered the extent or direction of fermentation. This agrees with Offer and Al-Rwidah (1989b) who found similar fermentation characteristics for untreated silage and silage incorporating molassed BP shreds under conditions where the untreated silage underwent an extensive lactic-acid dominant fermentation.

Other characteristics

In general, the relative stability of the silages when exposed to air agrees with the report by McDonald *et al*. (1962) for extensively fermented low DM silages. The similar aerobic stability found across treatments is reflective of the similar fermentation characteristics. However, the generally greater extent of aerobic deterioration when BP was co-ensiled with grass, particularly when measured over 192 h, indicates that once silages eventually started to deteriorate after exposure to air, the higher concentration of respirable substrate for the BP treatments supported more extensive respiration. The reason for the differences in aerobic deterioration between BP treatments is not evident.

Practical implications

It is believed that the effluent production from the 2 m high plastic pipe silos used in this present experiment equate to the quantities produced in conventional horizontal silos of similar height. For example, O'Kiely (1991) recorded total effluent production from untreated silage in these silos that was intermediate between the predictions of Zimmer (1967) and Sutter (1957) for grasses of similar wetness.

The main attractions, for farmers, of co-ensiling BP with grass are to aid silage preservation (if grass is difficult to preserve), slow and reduce effluent output, and increase silage nutritive value. The present experiment indicates that where grass that will readily undergo an extensive lactic-acid dominant fermentation is being ensiled, the degree of mixing of BP with grass has relatively minor impacts on the overall standard of preservation. However, where grass is difficult to preserve due to low WSC and/or high buffering capacity, then it would be expected that even mixing of BP throughout the grass should supply additional fermentable substrate more evenly, facilitating the production of a more homogenously well-preserved silage.

Where effluent reduction is a major requirement, the addition of BP will slow and reduce effluent output. The present experiment suggests that in walled silos, spreading BP in layers will be optimal provided each layer of BP is continuous and is in contact with the walls. In contrast, in an unwalled bunker silo, some effluent may flow past the edges of each layer of BP and thus escape retention within the silo. In such circumstances, it might be expected that even mixing of

BP with grass might lead to similar or improved effluent retention compared to layering the BP.

The results from the present experiment suggest that the evenness of mixing BP with grass will have little impact on silage nutritive value under circumstances where silage preservation would have been satisfactory when no BP was added. However, under less favourable conditions, where BP could lead to a major improvement in silage preservation, then even mixing of BP with grass should be preferable in terms of its impact on silage nutritive value, as described above.

Finally, in terms of the potential number of animal feed days provided by a given quantity of grass and BP dry matter pre-ensiling, concentrating the BP towards the bottom of the silo would seem the least desirable option due to the lower recovery rate of ensiled DM.

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