MINISTRY OF AGRICULTURE, FISHERIES AND FOOD

Research and Development

Final Project Report

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Project title	Environmental Impacts of Baled Silage
MAFF project code	**WA 0111**
Contractor organisation and location	ADAS Boxworth Cambridge CB3 8NN
Total MAFF project costs	£ 117,920
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Executive summary (maximum 2 sides A4)

Big-bales account for approximately 20% of total silage made in England and Wales. Under the Control of Pollution Regulations, big-bale silage is subject only to minimal constraints i.e. that it must not be stored or opened within 10m of a watercourse. Limited guidance on avoiding risk of pollution from big-bale silage is given in the Code of Good Agricultural Practice for Protection of Water.

Objectives

The objectives of this project were therefore to establish the effects of dry matter content, height of stacking bales, season when ensiling takes place, wrapping pattern, baler with or without chopping mechanism and incident rainfall on the amounts, pattern and composition of effluent released from wrapped grass silage in round bales. Practical guidelines on reducing pollution risk taking account of these factors were also to be produced. In addition, the effects of siting of heaps of bales on the risks of ground and surface water pollution and the overall risks of ground and surface water pollution compared with other methods of conservation were to be assessed.

Materials and methods

Fieldwork

Over a three year period, a series of experiments was carried out at ADAS Pwllpeiran and ADAS Rosemaund, with mean annual rainfalls of 1700 mm and 600 mm respectively. Swards of predominantly perennial ryegrass were cut with a disc mower/conditioner. The herbage was baled using a Krone KR 125 fixed chamber baler, the same baler being used at each site. Each bale was weighed, cored for dry matter determination and, except for certain treatments in year 3, the bale wrapped using a Kverneland 7515 wrapper with four complete layers of black, 750 mm wide wrap applied with a 50% overlap. For each experiment there were three replicate stacks of bales for each treatment in a randomised block design. Each stack was stored for a minimum of 56 days on specially designed, raised platforms to enable complete effluent collection. In addition, any effluent released at opening was also collected using purpose-built cradles. Over the three years, a total of 108 stacks of bales was monitored.

In year 1 the effects of dry matter at harvest, and season of harvesting were examined. ADAS Pwllpeiran simulated a 2 cut silage system in an upland situation with silage cuts in June and August. ADAS Rosemaund simulated “opportune” harvesting in the lowlands with cuts in Early May and late September/October. There were three target dry matter

contents at each site for each harvest: 150, 200 and 250 g/kg DM. All bales were subsequently stored under cover, in stacks two layers high.

In year 2 the effect of stacking height was assessed. Bales with a target dry matter content of 180 g/kg were stacked as either a single layer or at two bales high whilst bales at a target dry matter content of 220 g/kg were stacked at either two or three bales in height. To assess the effects of rainfall, additional stacks at each height were also stored outside.

In year 3 a series of experiments assessed the effects of additional wrap by applying a further two layers (i.e. four vs. six layers), the effect of chopping herbage during baling, and the effect of storing bales on end as opposed to on their side and the effect of rotating bales through 180° prior to opening.

Desk Studies
Information on current stacking practice was collected on 15 commercial farms**.** The effects of different practices were assessed using data obtained from a previous study on pollution risks from field heaps of silage. Estimates of quantities of silage made and data on silage dry matter contents were used to refine the previous estimates of effluent release from different ensiling methods. Information relating to pollution incidents, siting of bale heaps, and the structural condition of clamp silos/ associated tanks was then drawn together to provide an assessment of water pollution risk from baled silage, relative to that from clamps and field heaps.

Results
Achieving target dry matter content proved difficult on both sites in year 1. Individual bale weight at baling significantly decreased as grass dry matter increased ($P<0.001$).

The pattern of effluent production was very similar to that reported for clamp silage with a peak production at about day three following ensilage, with large quantities arising when grass was harvested at a dry matter content of less than 200 g/kg. As with clamp silage, grass wilted to 250 g/kg DM produced negligible effluent. Despite the data being collected at two sites and over a range of dates, a very close relationship between dry matter content and effluent release during storage was evident ($r^2= 0.973$). Effluent collected at opening followed a similar trend ($r^2= 0.859$) but even at a dry matter content of 150 g/kg the quantity of effluent at opening was relatively small. There were no significant effects of season or site ($P>0.05$).

As dry matter content at ensiling increased , the proportion of weight loss as effluent decreased, concurrent with a small increase in fermentation losses to a maximum figure of around 50 kg/tonne ensiled

For single layer stacks of bales with a dry matter content between 160 and 185g/kg, the total effluent was less than half the quantity produced from a 2 two layer stack (29.6 vs. 64.3 litres/tonne grass ensiled). At these low dry matter contents, considerable mis-shaping of the lower bales occurred in two-layer stacks.

Silage effluent analyses proved variable: however, some trends were apparent. In general, as grass dry matter at baling increased, effluent production decreased but total solids increased. Effluent at opening generally had a higher BOD and higher solids content but in all cases BOD was within the typical range expected for grass silage.

On both sites, storing bales outside resulted in larger volumes of more dilute effluent being collected compared to bales under cover. At Rosemaund, a total of 110 litres/tonne grass ensiled was collected from uncovered stacks which represented a dilution of about 1 in 10. At Pwllpeiran, particularly high rainfall was experienced resulting in over 250 litres/tonne grass ensiled being collected. for stacks of 200g/kg DM and over 350 litres/tonne grass ensiled for stacks of 260 g/kg DM.

Wrapping with six as opposed to four layers, resulted in significantly less effluent from grass ensiled at low dry matter contents both from inside and outside stacks ($P>0.05$). With wilted grass, all stacks of bales receiving four layers of wrap produced effluent, but only one of the three stacks with six layers did so, and for this stack effluent was not seen until three days after ensiling Effluent production and quality were similar for both chopped and unchopped material ($P>0.05$) and although effluent at opening was reduced by rotating the bale, quantities were negligible. Effect of stacking round bales on their ends rather than on their sides was compared, but had no effect on effluent production or analysis.

Conclusions
Fieldwork

- With wet bales, ensiled at below 200 g/kg DM, the majority of the effluent flow takes place in the first 5-10 days. The quantity, pattern and composition of the effluent flow during storage is similar to that of clamp silage at a comparable DM content.

- The majority of effluent (80%) is normally released during storage.
- Wet bales stored outside gave rise to very large volumes of diluted effluent which had a BOD of up to 10,000 mg/l. Large stacks could pose a high risk of pollution if sited so that runoff could reach a drain or watercourse.
- Rainwater ingress to 'dry' bales during storage can result in contaminated runoff.
- The higher the bale stack, the greater the potential effluent production. Bales of less than 200g/kg should be stacked only as a single layer.

Desk Studies

- Groundwater pollution risk is unlikely to be significant unless a big bale heap is built where there are preferred flow pathways through the soil (e.g. through fissured soil).
- The presence of field drains close to a bale stack could provide an easy pathway for effluent to reach surface water, and it appears that not all farmers are aware of this risk.
- The practice of stacking bales on concrete or the use of continuous plastic sheets beneath the heap is likely to accumulate contaminated runoff, giving a risk of point source pollution.
- There is a case for the "10m rule" to be publicised much more forcefully, but there is no clear evidence that the 10m should be extended.
- Relative to bunker silage, the risks of water pollution from big-bale silage are generally very low The estimated total quantities of effluent produced by big bales range from 7-12% of the national total. Numbers of pollution incidents from this source appear to be very low

Recommendations

A series of practical recommendations were drawn up relating to:-

- Wilting to at least 250g/kg dry matter to avoid effluent production.
- Siting of heaps in relation to drains and watercourses
- Size of heaps and suggested restrictions in stacking height when bales are wet
- Increasing numbers of wraps under wet conditions
- Regular bale stack inspection and care when opening bales for feeding.

Recommendations are made for possible future work

All of the objectives were addressed and met in full. The results from this project help to fulfil MAFF's Policy and Research Objectives of developing practical and economic means to reduce silage effluent and slurry production and to provide a sound scientific basis for the Codes of Good Agricultural Practice for the Protection of Water and Air.

Scientific report (maximum 20 sides A4)

1.0 INTRODUCTION

MAFF census figures (1) indicated that, from 1990-1995, big-bale silage accounted for 18% of total silage made in England and Wales. Under the Control of Pollution (Silage, Slurry and Agricultural Fuel Oil) Regulations 1991 (2), all new silos built since that date have to be equipped with perimeter channels and corrosion resistant effluent tanks of a specified capacity. However, big-bale silage is subject only to minimal constraints i.e. that it must not be stored or opened within 10m of a watercourse (which includes ditches and field drains). Limited guidance on avoiding risk of pollution from big-bale silage is given in the Code of Good Agricultural Practice for Protection of Water (3).

Data on numbers of water pollution incidents published by the National Rivers Authority (4) indicate that silage effluent accounts for 8 - 29% of reported incidents, depending on season, but no information is available on whether such incidents arose from big-bale silage. , (5), using data on silage DM content, estimated that in England and Wales from 1992-94, big-bale silage accounted for 18% of the grass silage made, but only 7% of effluent produced. Big bales are a convenient way of ensiling autumn grass(6), however in some years, mean DM content of such silages may be as low as 215g/kg (7), thereby increasing effluent production and water pollution risk. It is generally accepted that, with clamp silage, materials ensiled with DM contents above 280g/kg produce little or no effluent (8). MAFF-funded work (9) has indicated that if wrapped baled silage is made from low DM material, effluent production is comparable with the same material ensiled in a clamp, although more recent data suggest that total effluent flow from wet (200g /kg DM)big bale silage is double that from bunker grass silage ensiled at the same DM content[10]. It has also been shown that increased bale stacking height (9), chopping prior to baling (11) and reducing width of the bale wrap (12) may increase effluent production. This existing information is insufficient to assess water pollution risks from big bale silage relative to other methods, as it does not take account of rainfall effects on bales stacked outside (the most common method of storage), which will dilute and may leach out contaminants. In addition, it does not address the fate of the effluent in the soil once it has left the bales. Experimental work on field heaps of silage made direct on the soil surface concluded that in many circumstances, groundwater pollution risks were low (13).

This project therefore examined whether big-bale silage poses a significant pollution risk to ground or surface water and identified practical, simple measures that farmers and contractors (who bale and wrap an estimated 50% of this silage) can take to minimise the risk of pollution.

2.0 OBJECTIVES

2.1 The overall objective was to assess water pollution risks from silage in large bales, with detailed objectives as follows :-

2.1.1 To establish the effects of the following factors on the amounts, pattern and composition of effluent released from the most commonly used big-bale system i.e. wrapped grass silage in round bales:

(a) Dry matter content at ensiling
(b) Height of stacking
(c) Season when ensiling takes place
(d) Wrapping pattern (number and width of wraps)
(e) Standard baler as opposed to baler with chopping mechanism

2.1.2 To establish the effect of incident rainfall on the amount, pattern of release and composition of effluent and contaminants leached during the storage period from heaps of bales stored in the open.

2.1.3 To establish any inter-relationships between the factors above

2.1.4 To assess the effect of siting of heaps of bales on the risks of ground and surface water pollution

2.1.5 To produce practical guidelines on reducing pollution risk, taking account of factors 2.1.1 to 2.1.4

2.1.6 To assess the risks of ground and surface water pollution from big-bale grass silage in England and Wales relative to other methods of conservation, in particular, clamp silage and field heaps.

2. 2 EXTENT TO WHICH OBJECTIVES WERE MET

All of the objectives above were addressed and met in full. Lack of up-to-date census data on quantities of big bale silage meant that estimates had to be used in addressing objective 2.16.

The results from this project help to fulfil MAFF's Policy and Research Objectives of developing practical and economic means to reduce silage effluent and slurry production and to provide a sound scientific basis for the Codes of Good Agricultural Practice for the Protection of Water and Air.

3.0 MATERIALS AND METHODS

3.1 Field trials on effluent release

Sites
Over a 3 year period, a series of experiments was carried out at ADAS Pwllpeiran and ADAS Rosemaund. These two sites were chosen because of their previous expertise in making big bale silage and their contrasting rainfall. Pwllpeiran in the Cambrian Mountains has a mean annual rainfall of 1700 mm which contrasts with Rosemaund in Herefordshire receiving only 600 mm.

Design
For each experiment there were three replicate stacks of bales for each treatment in a randomised block design. Each stack was stored for a minimum of 56 days on specially designed, raised platforms to enable complete effluent collection. In addition, any effluent released at opening was also collected using a purpose-built effluent collection trough.

Baling and wrapping
Swards of predominantly perennial ryegrass were cut with a disc mower/conditioner with swath boards set to achieve an approximate swath width of 1.3 m (i.e. maximum width for bale pickup). Duplicate samples of herbage were taken from freshly cut swaths using a grab sample technique for chemical analysis of dry matter, water soluble carbohydrate, crude protein, nitrate N and MAD fibre. The herbage was subsequently left undisturbed in the swath until baling.

The herbage was baled according to treatment (having attained target DMs) using a Krone KR 125 fixed chamber baler, the same baler being used at each site. The bale density setting remained constant i.e. density was not adjusted according to herbage dry matter but was set to produce firm bales on the lowest dry matter treatment. In the field, each bale was individually identified in order of baling.

Bales were moved to the storage area as soon as possible after baling, in any case not more than 1 hour after baling. Each bale was weighed, cored for dry matter determination and, except for certain treatments in year 3, bales were wrapped using a Kverneland 7515 wrapper with 4 complete layers of black, 750 mm wide wrap applied with a 50% overlap (i.e. two complete revolutions of the bale on the turntable). Again the same machine was used at each site. During wrapping, an indication of the amount of pre-stretch of wrap that had taken place was measured. Each bale was stacked immediately after wrapping using a twin roller bale handler.

Effluent collection
Total effluent arising was recorded daily for the first 28 days and weekly thereafter from each stack. On days 7, 28 and 50, a sample of fresh effluent was taken for determination of Biological Oxygen Demand (BOD), DM, pH, NO_3-N NH_4-N and water soluble carbohydrate.

Bale opening

Bales were opened at a minimum of 56 days after baling. Each bale was spiked with a bale fork (two tines to prevent the bale from rotating) at one end and lifted vertically. Any effluent was allowed to drain onto the storage platform prior to any further movement of the bale. The bale was then placed over an effluent collection trough and a cut was made through the wrap along the bottom of the bale from end to end. The entire wrap was removed and the bale placed on the trough and allowed to drain for 30 minutes. The total volume of effluent was recorded for each individual bale. A bulked sample of effluent from individual bales of each stack was analysed for DM, pH, BOD, NO_3-N NH_4-N and water soluble carbohydrate. After draining, each bale was weighed and sampled for dry matter content.

Individual experiments
Year 1: the effect of dry matter contents at harvest, and season of harvesting was examined. ADAS Pwllpeiran simulated a 2 cut silage system in an upland situation with silage cuts in June and August. ADAS Rosemaund simulated “opportune” harvesting in the lowlands with a cut in Early May and late September/October.

There were three target dry matter contents at each site for each harvest.

150 g/kg DM to represent direct cut
200 g/kg DM achieved by minimal wilt
250 g/kg DM representing a 24 hour wilt

All bales were subsequently stored under cover, in stacks of five bales, two layers high.

Year 2 The effect of stacking height was assessed. Bales of with a target dry matter content of 180 g/kg were stacked as either a single layer of 5 bales or at two bales high (8 bales stacked as 2 rows of 3 +2) whilst bales at a target dry matter of 220 g/kg were stacked at either two or three bales high (20 bales stacked as 3 rows of 4 +2 rows of 3 +2). In addition, at Rosemaund, stacks of bales one, two, and three high were ensiled at a target dry matter of 220 g/kg. To assess the effects of rainfall, additional stacks at each height were also stored outside.

Year 3 A series of experiments assessed the effects of additional wrap by applying a further two layers (i.e. 4 vs. 6 layers), the effect of chopping herbage during baling, the effect of storing bales on end as opposed to on their side and, using additional commercial funding, evaluation of a new development which effectively increased the pre-stretching of film to allow 6 layers to be applied without increasing the actual quantity of film applied.

Over the three years, a total of 108 stacks of bales was monitored.

3.2 Desk study on the effects of storage method, siting of heaps and soil type on water pollution risks
Information on current stacking practice was collected from 15 farms**.** The effects of different practices were assessed using data obtained from a previous study on pollution risks from field heaps of silage.

3.3 Desk study on risks of ground and surface water pollution relative to other conservation methods
Estimates of quantities of silage made and data on silage dry matter contents were used to refine the previous ADAS estimates of effluent release on a national scale from different ensiling methods (5). Information relating to pollution incidents, siting of bale heaps, and the structural condition of clamp silos/ associated tanks was then drawn together to provide an assessment of water pollution risk from baled silage, relative to that from clamps and field heaps.

4.0 RESULTS

4.1 Year 1, Effect of dry matter content and of harvesting on effluent production

Grass Analyses

Adverse weather conditions delayed first harvests at both Rosemaund and Pwllpeiran which had a detrimental effect on grass quality (Table 1) resulting in a low digestibility and low crude protein and nitrate contents. The second harvests at each site were taken from the same swards and were of higher digestibility: however nitrate contents remained low.

Grass dry matter at ensiling

The grass dry matter at various cuts is summarised in Table 2. Achieving target dry matters proved difficult on both sites. Weather conditions after cutting prevented the 25% DM treatment from being achieved in May and very hot sunny weather caused very rapid wilting in both July and October. Nevertheless a good distribution of dry matter content was obtained over the four cuts to enable objectives to be met.

Table 1 Chemical analyses of grass at ensilage (g/kg DM unless otherwise stated)

Harvest date	**29 May**	**7 July**	**9 September**	**3 October**
Location	**Rosemaund**	**Pwllpeiran**	**Pwllpeiran**	**Rosemaund**
Crude Protein	84	151	195	146
MAD Fibre	316	309	273	291
WS Sugars	173	119	93	89
Nitrate-N (%)	0.01	0.06	0.10	0.03
‘D’ Value (%)	62.0	63.3	67.4	68.9

Table 2 Grass dry matter content achieved at ensiling (g/kg)

DM Target	**150**	**200**	**250**
Cut 1- Rosemaund	148	187	186
Cut 2 - Pwllpeiran	210	248	277
Cut 3 - Pwllpeiran	161	188	221
Cut 4 - Rosemaund	190	265	298

Bale weight changes

The bale weights at ensiling and some 55 days later are shown in Table 3. At baling, bale weight significantly decreased as grass dry matter increased ($P<0.001$). This was consistent for all cuts. Bale weights were higher at Pwllpeiran than at Rosemaund, probably reflecting a variation in operator technique. Dry matter content per bale significantly increased as grass dry matter increased ($P<0.001$) and again this was consistent for all cuts despite a variation between sites. A similar trend was evident for bale weights following the 55 day storage. Bale weight loss during storage decreased as grass DM at baling increased ($P<0.001$): however there was no significant treatment effect on dry matter loss. This suggests that differences in weight loss can be attributed to mainly effluent loss.

Table 3 Effect of wilting on bale weight changes

	Weight at ensiling (kg)			Weight at opening (kg)			Weight loss (kg/tonne)	
	Fresh	DM (g/kg)	Total DM	Fresh	DM (g/kg)	Total DM	Fresh	Dry matter
Cut 1 - Rosemaund								
No wilt	713	148	105	601	148	89	155.9	150
20 hr wilt	644	187	119	600	175	105	63.7	121
34hr wilt	685	186	127	649	169	110	51.8	131
SEM (df)	10.08 (28)	4.41 (28)	2.45 (28)	7.71 (28)	5.37 (28)	3.21 (28)	9.19 (28)	22.37 (28)
CV%	5.7	9.8	8.1	4.8	12.6	12.3	39.3	64.6
	***	***	***	***	**	***	***	
Cut 2 - Pwllpeiran								
No wilt	720	210	151	689	188	129	42.8	143
6 hr wilt	640	248	158	622	227	141	28.9	105
9hr wilt	623	277	173	604	243	147	30.6	148
SEM (df)	10.09 (28)	3.7 (28)	3.12 (28)	9.32 (28)	4.3 (28)	2.99 (28)	2.05 (28)	21.00 (28)
CV%	5.9	5.8	7.5	5.7	7.6	8.3	23.2	61.7
	***	***	***	***	***	***	***	
Cut 3 - Pwllpeiran								
No wilt	879	161	142	764	161	123	130.8	130
6 hr wilt	803	188	151	747	177	132	68.7	121
28 hr wilt	754	221	166	715	204	145	51.4	120
SEM (df)	11.28 (28)	4.4 (28)	3.59 (28)	11.85 (28)	3.9 (28)	2.80 (28)	9.49 (28)	21.50 (28)
CV%	5.4	9	9.1	6.2	8.4	8.1	43.9	67.3
	***	***	***	*	***	***	***	
Cut 4 - Rosemaund								
No wilt	600	190	114	578	180	104	35.3	85
24 hr wilt	519	265	138	514	237	122	9	110
48hr wilt	494	298	147	490	285	139	9.4	50
SEM (df)	7.40 (28)	4.68 (28)	2.80 (28)	7.01 (28)	4.46 (28)	2.64 (28)	2.97 (28)	17.59 (28)
CV%	5.3	7.2	8.2	5.1	7.4	8.4	64.2	83.2
	***	***	***	***	*	***	***	0.007

NS = No significant difference *= P<0.05 **= P<0.01 ***= P<0.001

Effluent production

Figures 1 and 2 show the relationships between herbage dry matter at baling and total volume of effluent collected during storage and at opening respectively from round bales, stacked at two bales high and stored under cover. Despite the data being collected at two sites and over a range of dates, very close relationships (r^2= 0.973 and 0.859 respectively) were evident. There was no significant effects of season or site(P>0.05).

The data from the September cut at Pwllpeiran in particular enabled the effect of grass dry matter on the pattern of effluent production to be compared. Figure 3 shows the mean daily production whilst Figure 4 illustrates the accumulated effluent flow. The pattern of production is very similar to that reported for clamp silage (8) with a peak production at about day three following ensilage. These data show that large quantities of effluent are lost from big bale silage when grass is harvested at a dry matter content of less than 200 g/kg. At 150g/kg DM losses of effluent were 12% of ensiled weight. As with clamp silage, grass wilted to 250 g/kg DM produced negligible effluent.

Figure 1
Effect of grass dry matter on effluent flow from big bale silage

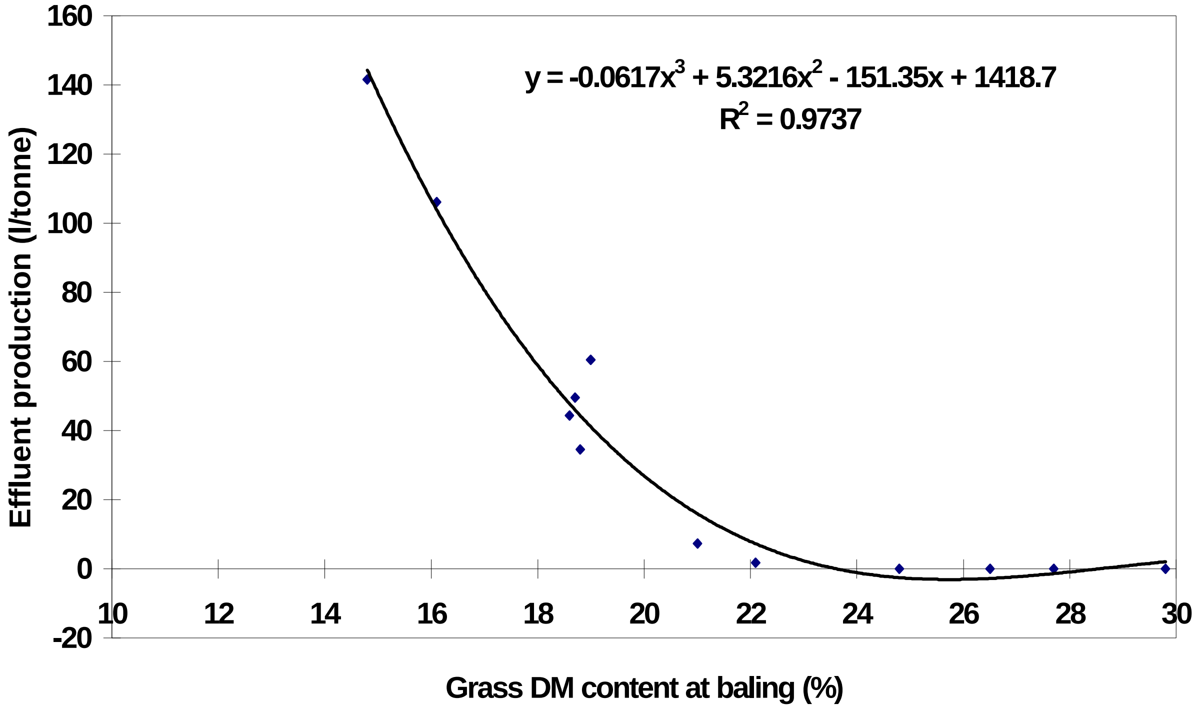


Figure 2
Effect of grass dry matter on effluent at opening from big bale silage

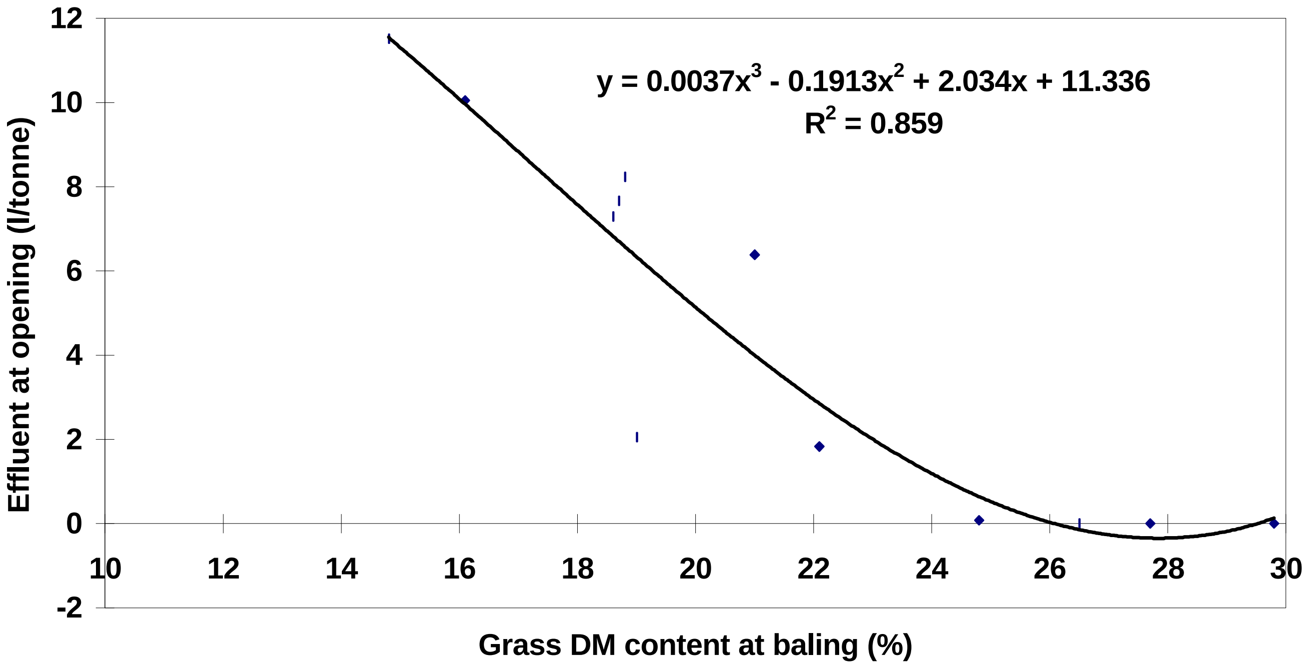


Figure 3
Daily effluent production

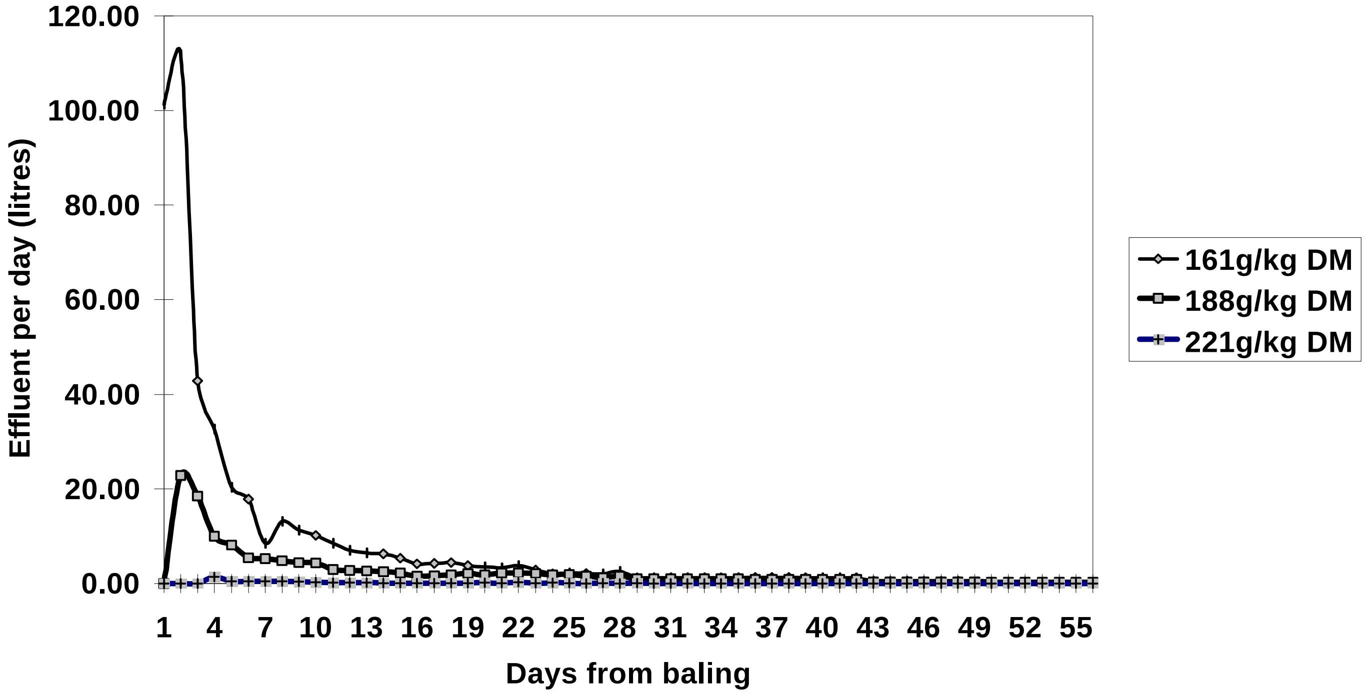
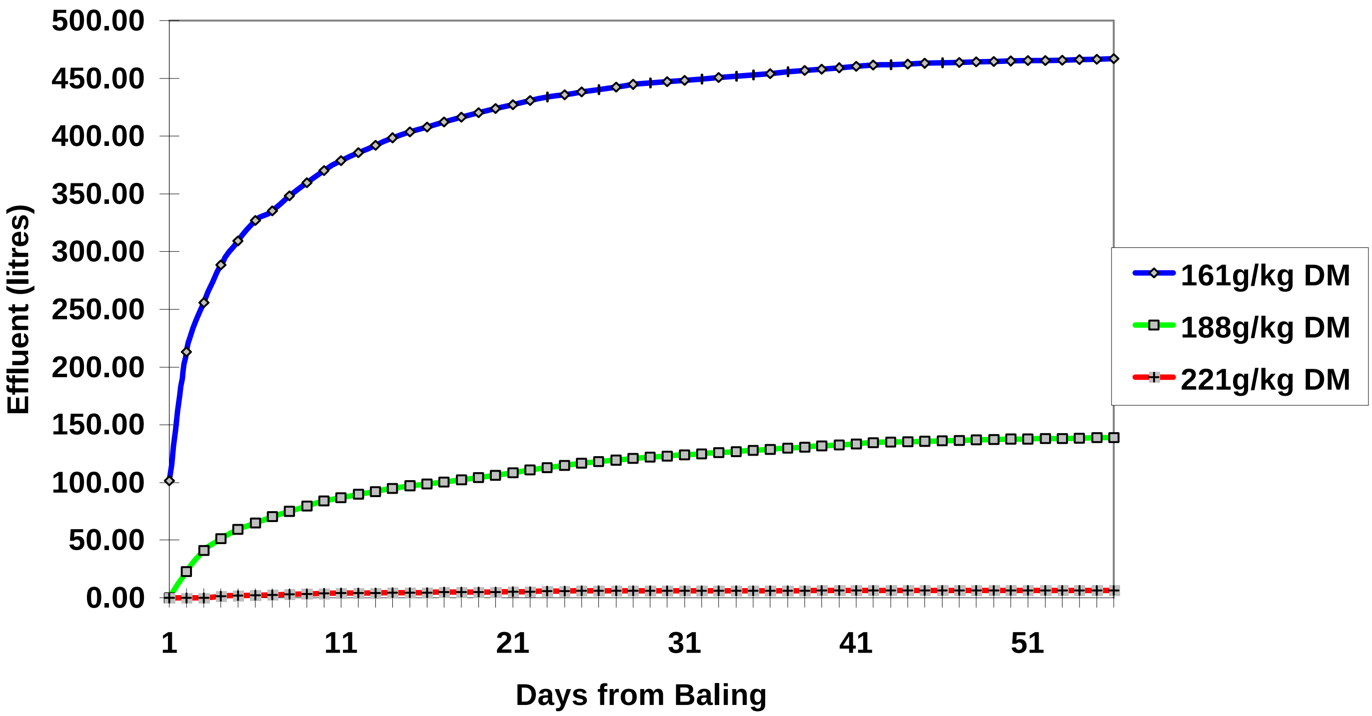
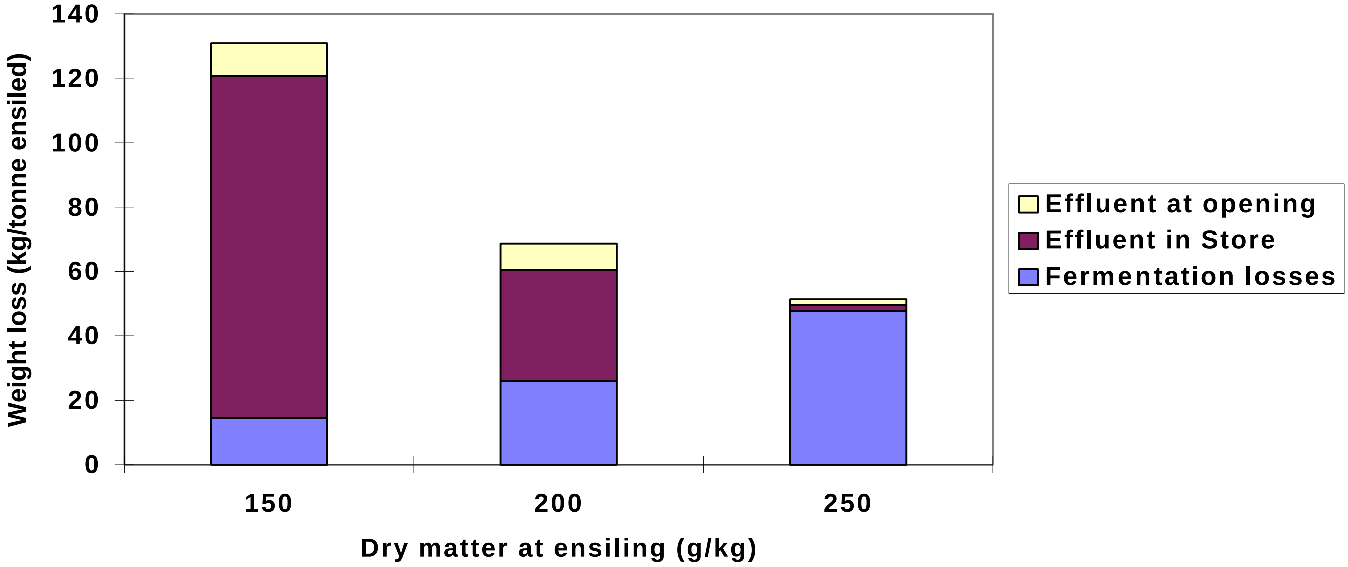


Figure 4
Accumulative effluent production



Effluent collected at opening followed a similar trend, as shown in Figure 2, but even at a dry matter of 150 g/kg the quantity of effluent at opening remained relatively small. The relative contributions to total weight loss are shown in Figure 5. This shows that, as dry matter increased, the proportion of losses as effluent decreased, with a small increase in fermentation losses.

Figure 5
Effect of grass dry matter on source of weight loss in wrapped big bale silage



Effluent analyses
Silage effluent analyses proved variable with total solids from 28.9 to 94.7 g/l and BODs ranging from 11,557 to 81,677 mg/l, However, some trends were apparent. In general, as grass dry matter increased, effluent production decreased but total solids increased. Where stacks were stored under cover, effluent evaporation occurred, particularly during the summer. In addition, for the lower dry matter material, there was a tendency for BOD of effluent to increase during storage. Effluent at opening generally had a higher BOD and higher solids content which might be expected but in all cases BOD was within the typical range expected for grass silage.

Ammonia nitrogen content also increased with dry matter content. nitrate content remained negligible for all treatments and the ammonia content is probably a consequence of microbial activity supported by the higher concentration of nutrients.

4.2 Year 2, Effect of stacking height and outside storage

Grass at ensiling
In year 2, there were two target grass dry matters at each site, 180 and 230 g/kg. At Rosemaund, grass was harvested on 24 June when digestibility was 59% and actual mean dry matters were 192 and 220 g/kg for the two dry matter treatments. At Pwllpeiran, grass was harvested on 21 September at a digestibility of 68% and actual mean dry matters of 198 and 275 g/kg.

Effect of stack height
The effects of stack height on effluent production when bales are stored under cover are shown in Table 4. For stacks of bales with a DM content between 160 and 185g/kg, the total effluent from a single layer stack was less than half the quantity of that produced from a two layer stack (29.6 vs. 64.3 litres/tonne grass ensiled). In addition, at these low dry matter contents, considerable mis-shaping of the bales occurred.

For stacks stored under cover, there were no effects of stack height on total effluent recorded for bales ensiled at more than 200 g/kg dry matter ($P>0.05$), however single layer stacks appeared to yield more effluent at opening. When effluent at opening was compared for bales stored on the bottom layer only of each stack, the differences were greater and significant ($P<0.05$) (4.01, 2.75 and 0.99 litres for stacks of 1, 2 and 3 bales in height respectively).

The effects of storing bales ensiled at two dry matter contents, either under cover or outside in areas of low or high rainfall are shown in Tables 5a and 5b respectively.

At Rosemaund, rainfall during the collection period resulted in a total of about 110 litres/tonne grass ensiled being collected from uncovered stacks compared with 8 litres/tonne when covered. This represented a dilution of about 1 in 10. At Pwllpeiran, particularly high rainfall was experienced resulting in over 250 litres/tonne grass ensiled being collected. for stacks of 200g/kg DM and over 350 litres/tonne grass ensiled for stacks of 260 g/kg DM. Reasons for the greater collection from the stacks of higher dry matter bales is unclear. The high DM bale stacks may have intercepted a larger amount of 'non-vertical' rainfall, as they retained their shape better, resulting in higher stacks than the low DM bales. "Shrinkage" in height was quite substantial for low dry matter bales at 40 to 50 cm per bale reduction from the original height at stacking (25 to 30%). The unexpectedly high rainfall at Pwllpeiran (in excess of 400l/day on one occasion) made total collection impractical. Effluent samples were collected 24 hours after rainfall, hence the higher BOD values shown.

Table 4 Effect of stack height on effluent production from wrapped, big bale grass silage Rosemaund : target dry matter 220g/kg

	Stacking height					
	1	2	3	SEM	d.f.	CV
Dry Matter at ensiling (g/kg)	202	218	233	11.96	4	9.5
Effluent production (l/tonne ensiled)						
- during storage	5.00	8.00	2.20	2.33	4	79.8
- at opening	0.32	0.24	0.16	0.058	4	41.4
- total	5.32	8.24	2.36	2.37	4	77.5
Effluent analyses @ 28 days post baling						
pH	4.9	5.2	5.4	-	-	-
Total solids (g/l)	44.6	51.4	69.0	-	-	-
Nitrate-N (mg/l)	1.07	0.70	0.95	-	-	-
Ammonium-N (mg/l)	617	727	994	-	-	-
Water soluble carbohydrate (%)	0.08	0.16	0.20	-	-	-
BOD (mg/l)	92,100	59,500	92,500	-	-	-

Table 5 (a) Rainfall effects - low rainfall, Rosemaund

	Covered		Uncovered					Significance	
	Low DM	High DM	Low DM	High DM	SEM	d.f.	CV	Storage	DM
Actual DM at baling (g/kg)	192	218	212	221	1.22	6	14.1	NS	NS
Effluent (l/tonne ensiled)									
- during storage	6.4	8.0	111.9	110.4	2.84	6	11.7	NS	***
- at opening	0.5	0.2	*	*	0.053	2	34.2	NS	-
- total	6.9	8.2	111.9	110.4	2.82	6	11.6	NS	***
- adjusted	6.9	8.2	15.3	13.7	2.82	6	62.4	NS	0.13
Total bale weight (kg)	4491	4822	4071	4552	96.8	6	5.3	*	*
BOD at 28 days	88000	59500	1279	1495	-	-	-	-	-

NS = No significant difference *= P<0.05 **= P<0.01 ***= P<0.001

Table 5 (b) Rainfall Effects -high rainfall, Pwllpeiran

	Covered		Uncovered					Significance	
	Low DM	High DM	Low DM	High DM	SEM	d.f.	CV	Storage	DM
Actual DM at baling (g/kg)	197	291	199	264	8.23	6	8.5	***	NS
Effluent (l/tonne ensiled)									
- during storage	4.0	0	263.0	360.1	14.57	6	22.8	0.065	***
- at opening	0.8	0	4.1	5.5	0.61	6	57.3	NS	**
- total	4.8	0	267.1	365.6	15.09	6	23.2	0.071	***
- adjusted	4.8	0	57.1	154	15.09	6	68.6	0.071	**
Total bale weight (kg)	5894	5265	5723	5390	99.7	6	4.4	*	NS
BOD at 28 days	57800	NA	32136	NA	-	-	-	-	-
BOD at opening	32700	NA	30900	NA	-	-	-	-	-

NS = No significant difference *= P<0.05 **= P<0.01 ***= P<0.001

These data also clearly show the effect of DM content at baling, on the weight of each stack. With only 8 bales in a stack, the total weight differed by over 600 kg (10%) between bales of 197 and 291 g/kg DM content. Thus DM content is an important consideration when assessing the weight of grass in a stack of big bales which can then be used to calculate potential effluent from the stack.

4.3 Year 3, Management practices to reduce effluent release from big bales

In the third year, three additional factors were evaluated.

Layers of wrap
Most film wrappers in the UK can be set to achieve different degrees of film overlap. The option chosen normally depends on film width and the crop being ensiled. However the most common method for grass silage for a wrap with a width of 750 mm, is to use a 50% overlap and to complete two revolutions of the bale i.e. apply four layers of wrap. In the final year, the effect of applying wrap for a further revolution i.e. six layers, was examined (Table 6). Each of the treatments was stored both under cover and out-side, in stacks of two bales high, with both direct cut and wilted grass.

At the low dry matter, effluent flowed profusely from all stacks. However total quantity was significantly less from the stacks receiving 6 layers for both inside and outside stacks. With wilted grass, all stacks of bales receiving four layers of wrap produced effluent, but only one of the three stacks with six layers, and for this stack effluent was not seen until three days after ensiling.

Effect of chopping
A number of round balers are now coming onto the market with the ability to chop herbage at baling. This produces a more dense bale, particularly with high dry matter forages, and facilitates feeding. Using a Claas 46 Rotocut baler, bales of chopped and unchopped material were made and effluent release was monitored (Table 7). Effluent production and quality was similar for both treatments (P>0.05).

Table 6 Effect of number of film layers on effluent from big bale grass silage

	Inside 4 layers	Inside 6 layers	Outside 4 layers	Outside 6 layers	SEM	d.f.	CV	Significance In/out	Significance Layer
a) Direct cut grass									
Dry Matter (g/kg)	142	142	141	142	2.96	6	5.1	NS	NS
Wt loss during storage (g/kg)	0.093	0.061	0.165	0.166	0.017	6	33.7	*	NS
Effluent during storage (l/t)	78.8	66.6	293.0	241.0	8.58	6	12.4	***	*
BOD after 7 days (mg/l)	25100	27433	25333	22600	859	6	8.4	NS	NS
BOD after 28 days (mg/l)	29800	23800	27567	23867	1547	6	14.4	NS	0.068
BOD after 56 days (mg/l)	36333	34333	8293	13100	674	6	7.2	***	NS
b) Wilted grass									
Dry Matter (g/kg)	231	224	247	240	7.27	6	7.6	NS	NS
Wt loss during storage (g/kg)	0.079	0.064	0.060	0.075	0.004	4	14.6	NS	NS
Effluent during storage (l/t)	4	1	390	355	19.65	6	25.7	***	NS
BOD after 7 days (mg/l)	20267	0	5600	616	6672	6	247	NS	NS
BOD after 28 days (mg/l)	37200	0	4427	5667	6223	6	129	NS	0.087
BOD after 56 days (mg/l)	33800	17133	4087	2640	7557	6	128	0.084	NS

NS = No significant difference *= P<0.05 **= P<0.01 ***= P<0.001

Effect of stacking position
In Scandinavian countries it is normal practice to store round bales on their ends rather than on their sides. Their bales are however usually of high dry matter content (>300 g/kg) and stored as a single layer stack. It is claimed that the ends have a greater thickness of wrap and are therefore more resilient to damage. Effect of this method of storage was compared, but there were no differences found in effluent production or quality. With bales of lower dry matter content, end storage created problems with stack stability and would not be recommended for bales ensiled at less than 300g/kg, unless stacked in a single layer.

An additional treatment was to examine effluent flow at opening when conventionally stored bales were rotated 180^{o} prior to removing the wrap. This method reduced effluent flow at opening, but did not eliminate it. Much of the effluent flowed round the surface of the bale rather than becoming reabsorbed.

Table 7 Effect of chopping on effluent production from big bale silage

	Conventional	Chopped	SED	d.f.	Sig
Dry Matter (g/kg)	231	226	1.38	4	NS
Fresh weight of stack (kg)	5482	5622	165	4	NS
Dry weight of stack (kg)	1264	1269	61	4	NS
Fresh weigh at opening (kg)	5056	5246	406	4	NS
Weight loss during storage (g/kg)	0.089	0.077	0.065	4	NS
Effluent (litres/tonne fresh grass ensiled)					
	4.03	3.00	3.54	4	NS
At opening	2.90	1.00	1.67	4	NS

4.4. Effects of storage method, siting of heaps and soil type on ground and surface water pollution risk

Collection of information on bale storage methods and siting of heaps
Fifteen sites were visited during the winter of 1998-1999 to collect information on stacking practice, particularly in relation to water pollution risk. Five sites were in the south west, five in the midlands and five in the north. Data were entered on a proforma to facilitate analysis.

Annual bale production per farm ranged from 100-1700 and stack size from 40-1500 bales. Typically, 5-15% of bales were made in the autumn, after September, although on two of the fifteen farms, this was 40-50%.

Stacking was normally on level ground and farmers' criteria for site selection took account of ease of access, and avoiding water courses. Not all considered avoiding land or yard drains. Thirteen of the fifteen farmers claimed to stack bales more than 10m from ditches and watercourses, two, between 2m and 10m. Distance chosen was not apparently affected by wetness of bales.

All farms stacked the majority of their bales on a 'permanent' site, though only one farm stacked on concrete. Twelve of the farms used a hard-core base and 4 used a plastic sheet or bags beneath the stack. Eleven of the farms normally stacked bales three high, three farms stacked two high and one stacked four high. Seven of the farms considered reducing stack height if grass was wet at baling.

Seven farms routinely baited to control rodents and six covered the stacks with netting. Fourteen out of the fifteen farms inspected the stack three times or more, within the first month of stacking. Six farms opened bales at the stack, the remainder either in the field or around yards / buildings.

Previous work on water pollution risk from field heaps
No direct measurements of runoff or groundwater contamination were made in this study. However, experience was gained with a previous project which studied water pollution risks from field heaps of silage made on an unprepared base (WA 0106), and the results of this work have been used as a basis to assess the risks from big bale silage. Under WA 0106, soil analysis for volatile fatty acids (VFAs) was developed as a technique to investigate the fate of silage effluent in soil. The results indicated that the effluent produced was retained in the top 30 cm of the soil profile without any appreciable movement to depth and that soil VFA content declined with time. The use of Teflon soil water samplers indicated that the BOD of soil solution under field silage heaps was relatively low and unlikely to cause a pollution risk.(16)

The ‘Bastiman equation’ (8) shows that above 250g/kg dry matter, little effluent is produced from bunker silage. The mean dry matter of 37 farmers' field heaps studied in 1992/3 was 295 g/kg and 26 farmers' heaps 1993/4, 270 g/kg., i.e. they were generally unlikely to produce large amounts of effluent.

It was concluded that field silage heaps will always present some risk of water pollution, but the risk is not particularly high provided heaps are not built in situations where (a) there are preferred flow pathways through the soil (e.g. through fissured soil) to ground or surface water or (b) where surface runoff directly into watercourses can occur.

Risks from big bale silage

Except for autumn-made silages, dry matter content of big bale silage generally tends to be higher than for field heaps: for example in 1992-4 grass silages in bales were typically 367-389 g/kg dry matter (5), although autumn- made silage may typically be 269g/kg (mean 1983-87) and as low as 213g/kg in some years (6). Amounts of undiluted effluent produced by big bale silage will generally therefore be lower than from field heaps. The majority of stacks are however built in the open, and not covered with a sheet, which gives rise to a larger volume of effluent diluted by rainfall reaching the ground immediately beneath the bale stack. It was concluded that:

- groundwater pollution risk is unlikely to be significant unless the heap is built where there are preferred flow pathways through the soil (e.g. through fissured soil).
- the presence of field drains close to a bale stack could provide an easy pathway for effluent to reach surface water, and it appears that not all farmers are aware of this risk.
- the practice of stacking bales on concrete or the use of continuous plastic sheets beneath the heap is likely to accumulate contaminated runoff, giving a risk of point source pollution. These practices should therefore be discouraged unless adequate effluent containment facilities are provided.
- many bale stacks are built on the same site each year and there is a danger that the surface of the soil (even if covered in hard-core) may become compacted or smeared, thus reducing infiltration rate. There is a potential risk of runoff and surface water contamination from the accumulated dilute effluent /leachate which arises, particularly from large bale stacks, unless they are kept a reasonable distance from ditches. There is therefore a case for the 10m rule to be publicised much more forcefully, as some farmers appear to be unaware of this legislation. (Control of Pollution (Silage , Slurry and Agricultural Fuel Oil Regulations) 1991/1997). There is however no clear evidence that the 10m should be extended to a larger distance.

4.5 Risks of ground and surface water pollution relative to bunker silage and field heaps

Estimated effluent arising from baled and bunker made silage.

This and other studies (9) have shown that, broadly speaking, the Bastiman equation (8) for bunker silage also holds true for big bale silage. Mean dry matter contents of big bale silage are considerably higher than those for grass bunker silage, therefore, overall effluent production per tonne will be less from big bale silage

Haigh (5) calculated that there were considerable year-to-year variations in the quantity of silage effluent produced, largely dependent on weather conditions at ensiling. Grass silage generally accounted for over 99% of the effluent produced. In 1994 (a relatively dry ensiling season) it was estimated that 800 Ml of effluent were produced of which 64 Ml arose from big bale silage.

For the purposes of this project, the figures produced by Haigh (5) have been updated, based on numbers of silage samples in different dry matter ranges submitted to the ADAS laboratories, the Bastiman equation (8), and data on quantities of grass silage made in England and Wales collected annually in MAFF /NAWAD’s December census. As ADAS no longer records which silage samples are acid-treated, figures for 1995-1998 have been calculated using a simplified method compared with that used by Haigh, and may tend to slightly underestimate effluent produced. Unfortunately, 1994 was the last year in which MAFF and WOAD collected separate data on quantities of silage made in big bales. In 1994, big bale silage accounted for 18% of the total grass silage conserved. In the absence of subsequent census figures, extrapolation of previous trends in total grass silage and baled silage tonnages (15) would suggest that in 1999 approximately 22% of the total grass silage tonnage was conserved in the form of big bales. These figures have been used to produce Table 8.

Table 8 Quantities of grass silage in bunkers and bales and estimated effluent arising: England and Wales 1994-1999

Year	Quantities of grass silage made in England and Wales- million tonnes (Source MAFF /NAWAD)				Calculated amounts of effluent arising -million litres (based on ADAS analyses)			
	In bunkers	As bales	Total	% as bales	From bunkers	From bales	Total	% from bales
1994	*27.97*	*6.17*	*34.14*	*18.07*	*736*	*64*	*800*	*8.70*
1995	28.15*	6.52*	34.67	18.80*	658	93	751	12.38
1996	22.73*	5.51*	28.24	19.51*	540	40	580	6.90
1997	23.19*	5.87*	29.06	20.20*	604	60	664	9.04
1998	21.67*	5.73*	27.40	20.91*	566	67	633	10.58

1994 figures = estimates by Haigh(5) * Estimated tonnage and percentage [15]
In addition up to 3.5 Mt of arable and maize silage are made each year.

Pollution incident figures
The Environment Agency (and formerly the National Rivers Authority) produce annual reports of the number of water pollution incidents from different sources. The total numbers of substantiated water pollution incidents caused by silage effluent vary from year to year depending on weather, but overall have shown a substantial decrease in the last 10 years, as seen in Table 9. No separate record was kept of incidents caused by baled silage, though a recently introduced system now allows this to be done. Although national data are not yet available for 1999, for the E.A. South West Region there was a total of 17 pollution incidents caused by silage effluent of which only one was from silage in big bales

Table 9 Total numbers of substantiated water pollution incidents caused by silage effluent: England and Wales.

Year	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
No.	815	245	470	461	220	357	257	148	222	124	112

Condition of bunker silos and effluent storage facilities
The drop in numbers of incidents since 1988 can be attributed to a better awareness of the need to avoid pollution , improved structures resulting from grant aid (now discontinued) and the introduction of the Control of Pollution (Silage, Slurry and Agricultural Fuel Oil) Regulations in 1991. It is arguable that many bunker silos and effluent tanks, installed in the early 80's may have started to deteriorate, and that the general lack of investment within the livestock industry at present will lead to many silos falling into disrepair and posing significant pollution risks.

Overall conclusions.
It is concluded, that relative to bunker silage, the risks of water pollution from big bale silage are generally very low The estimated total quantities of effluent produced by big bales range from 7-12% of the total. Numbers of pollution incidents from this source appear to be very low. Risks from bunker silage may however increase in future if structures are allowed to fall into disrepair. Risks from field silage remain low as reported under WA 0106 (16).

5.0 DISCUSSION

In year 1, the project established valuable baseline data on the effluent production that can be expected from grass ensiled in big round bales, film wrapped and stacked 2 bales high. The relationship obtained had a very high correlation and was suprisingly similar to that reported for clamp silage (8) (17). As found in previous studies on big bales (9), pattern of flow was also similar with a peak flow rate some 2 to 3 days following ensilage. This close correlation was achieved despite data coming from different sites, different seasons and grass of varying digestibility. Above 250g/kg DM no effluent was produced when stacks were stored under cover. A further consideration with big bales is effluent release at opening, and a caution is given in the Code of Good Agricultural Practice for Protection of Water when opening big bales. Again a close correlation was obtained between grass DM at ensiling and effluent release at opening. Generally quantities released per bale were small and even at very low DM the quantity released per bale was small relative to total production. However, the effluent tended to be fairly concentrated with some samples showing high BOD contents. Thus there was an apparent risk from opening bales if released effluent could reach a watercourse.

Storing bales outside appeared to result in some ‘effluent’ release from bales of herbage ensiled at dry matters in excess of 250 g/kg, however quantities were small and it was not envisaged that such bales posed a significant pollution risk. Rainfall *per se* did not appear to exacerbate the problem, indeed with the higher rainfall there was increased dilution which would reduce risk.

Stacking height increased effluent production and particularly impacted on bales of low dry matter herbage. Such bales became misshaped during storage, even when stored as a single layer, due to loss of effluent, fermentation losses and structural changes to the grass. This was increased when such bales were stacked in two or more layers, leading to poor adhesion of film. It would appear from the results obtained, that bales of less than 200g/kg DM content should be stacked only as a single layer, and preferably stacked on end. These findings confirm previous work on the subject by IGER (9). Experience gained during the work indicated that bales should only be stacked in layers of 3 bales high if they are above 250 g/kg DM. For safety reasons, it would not be recommended to stack bales on end if stacks are more than a single layer high, as such stacks are unstable.

For bales ensiled at less than 250 g/kg DM, effluent was significantly reduced, but not prevented, by the application of a further two layers of wrap. Nevertheless, the extra layers would have given greater protection to the ingress of air, thus also helping to reduce spoilage, and would therefore be seen as a beneficial precaution when wrapping low dry matter herbage.

Despite the relatively low quantity of effluent released at opening, rotating bales through 180° prior to removing film did slightly reduce the volume at opening, but such a practice would prove impractical without specialist machinery and the cost of this is generally prohibitive. A practical alternative might be to remove wrap at the feeding site.

6.0 CONCLUSIONS

- With wet bales, ensiled at below 200 g/kg DM, the majority of the effluent flow takes place in the first 5-10 days. The quantity, pattern and composition of the effluent flow during storage is similar to that of clamp silage at a comparable DM content.

- The majority of effluent (80%) is normally released during storage.

- Wet bales stored outside can give rise to very large volumes of diluted effluent which can have a BOD of up to 10,000 mg/l. Large stacks could pose a high risk of pollution if sited so that such runoff could reach a drain or watercourse.

- Rainwater ingress to ‘dry’ bales during storage can result in contaminated runoff.

- The higher the bale stack, the greater the potential effluent production. Bales of less than 200g/kg should be stacked only as a single layer.

- Use of a baler fitted with a chopping mechanism , as compared with a conventional baler, had no significant effect on effluent release from material ensiled a dry matter content of 230g/kg

- For material ensiled at less than 250 g/kg DM, bottom layers of bales tend to lose more effluent than upper layers during storage. Top layers retain more effluent which is subsequently released on opening. Quantity released can be up to 50 l/bale but is generally small (1 to 2 litres).

- Increasing wrap from 4 layers to 6 layers will reduce effluent released during storage

- Some reduction in effluent release can be obtained by turning bales through 180^0 immediately before opening, but this is not a reliable or practical option.
- Siting of heaps is important: the presence of field drains close to a bale stack could provide an easy pathway for effluent to reach surface water. The practice of stacking bales on concrete or the use of continuous plastic sheets beneath the heap is likely to accumulate contaminated runoff, giving a risk of point source pollution.

- Relative to bunker silage, the risks of water pollution from big bale silage are generally very low

7.0 RECOMMENDATIONS

Recommendations, suitable for inclusion in a booklet on minimising water pollution risks from big bale silage, or in revised versions of the Water Code are as follows(with dry matter expressed as %):

- Whenever possible, wilt grass to 25% DM or more before baling, to avoid effluent production.

- When siting heaps, beware of contaminated runoff. Always site heaps at least 10m from a ditch or field drain. Do not stack on concrete or use a plastic sheet beneath the stack unless there are adequate facilities to contain the effluent and rainfall.

- Larger stacks pose a greater risk of runoff and pollution , therefore more care is required with wilting and siting of such stacks

- Reduce stacking height to one bale high if DM is less than 20% and two bales high if bales are between 20 and 25% DM.

- Consider stacking bales on end in a single layer one high if very wet (less than 20% DM).

- Wrapping bales ensiled at less than 20% dry matter with six layers of wrap will reduce effluent loss, reduce bale deformation, and in most cases result in better preservation of bales.

- Inspect bales and the area around them regularly after stacking for signs of effluent release and take appropriate emergency action if it appears that effluent is reaching a drain, ditch or watercourse.

- Take care opening bales, as up to 50 l /bale of effluent retained within the wrap may be released. Be especially careful with opening the top layers of a stack. Ensure that the bales are opened at least 10m from a watercourse, ditch, field drain, or clean water drains around buildings.

8.0 FUTURE RESEARCH REQUIREMENTS

These include:

8.1 Testing the effect of different widths of wrap.

8.2 Testing whether the 10m rule is adequate (some difficulties with experimental techniques needed).

8.3 Testing for pollution beneath heaps .

8.4 Further work on square bales (see separate report on WA0117)and different sizes of balers.

8.4 Alternatives to plastic wrap such as spray-on waxes to reduce effluent and minimise wrap disposal problems.

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