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IMPROVED TECHNOLOGIES FOR BALED SILAGE

Grange and Oak Park Research Centres

Project No. 4621

Beef Production Series No. 50

End of Project Report

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Improved Technologies For Baled Silage

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Background

A previous report in 1999 (Beef Production Series No. 11 - Teagasc, End of Project Report for ARMIS 4284) summarised findings from a collaborative research project jointly conducted by the Teagasc Research Centres at Grange and Oak Park. This joint research initiative has continued, and has also involved the invaluable contribution of colleagues in both the Botany and Environmental Resource Management departments of University College Dublin. This present report summaries the findings of the more recent research on baled silage.

Contents

The contents of this report are presented under the following headings:

1. CHARACTERISTICS OF BALED SILAGE ON IRISH FARMS – A SURVEY

The data presented here are based on a survey conducted during the autumn-winter period of 1999 by the National Farm Survey unit in Teagasc. The sample of 1028 farms are considered representative of a population of 123,400 farms throughout Ireland. These farms conform to the standard European Union definition of being bigger than two economic size units (ESU's).

Scale of silage. Silage is made on 86% of Irish farms, ranging from virtually all dairy farms to only half of specialised tillage farms. The 1.24 million ha silage can be estimated to produce an annual total of approximately 4.6 million tonnes edible silage dry matter per year. Thus the land area and tonnage of herbage involved are very considerable, making it our second most important agricultural crop after grass for grazing. About 30% of the total farmland represented in this survey, or 34% of the area of farms that make silage, are harvested for silage. However, as many fields are cut more than once each year for silage, the absolute proportion of farmland used for silage-making is lower than the latter values.

Harvester type. Baled silage is now made on most farms in Ireland, and occurs on a higher proportion of farms than all other systems of silage harvesting combined. Baled, precision-chop and single-/double-chop silage are made on 73, 32 and 9% of farms, respectively, corresponding to 85, 37 and 10% of farms where silage is made. Clearly some farms are using more than one silage-making system. A different perspective emerges however when the relative significance of the different harvester systems is considered in terms of the national area of land harvested for silage (Table 1). Precision-chop harvesters are then the most important, accounting for 56% of the area harvested for silage, compared to round balers and single-/double-chop harvesters which are used to harvest 35 and 9% of the total silage area, respectively.

Farming enterprise significantly impacts on the types of harvester predominating on farms (Table 1). Precision-chop harvesters account for the largest area of silage made on dairy farms whereas baled silage accounts for most of the silage made on beef and sheep farms. However, on many farms, but particularly on dairy farms, both precision-chop and baled silage systems are used. In a general sense, the latter reflects the precision-chop harvester being used for first-cut silage and the baler being used either for the second cut or to opportunistically harvest grass that is occasionally surplus to grazing requirements.

Precision-chop silage is made to a relatively minor extent on small sized farms, but dominates the area harvested on large farms (Table 2). In contrast, although baled silage is found on most farms irrespective of size, it accounts for most of the area harvested on small sized farms and only a relatively small proportion of the area on large farms.

Most silage is now made within systems where mowing and harvesting are separate operations (Table 1) Only about one-tenth of silage is made with direct-cut systems such as single or double-chop harvesters.

Table 1. Harvester type used for making silage in the main farming enterprises

	Dairying	**Beef**	**Sheep**	**All Systems**
% of farms making silage				
- precision-chop	66	23	13	37
- single/double-chop	10	11	8	10
- baler	78	88	94	85
% of national silage area				
- precision-chop	71	37	25	56
- single/double chop	8	9	11	9
- baler	21	52	63	35
Average area (ha/farm/year)				
- precision chop	20.3	13.2	10.9	17.4
- single/double chop	13.6	6.7	7.7	9.7
- baler	5.1	4.8	3.9	4.8
Number of farms making silage				
- conventional[1] silage only	8000	6600	800	16200
- baled silage only	9200	34900	10500	56100
- both silages	19300	11900	2200	34400
Percentage of silage-making farms				
- conventional silage only	22	12	6	15
- baled silage only	25	65	78	53
- both silages	53	22	16	32
Silage area per farm (ha)				
- conventional silage only	25.5	13.1	11.6	19.6
- baled silage only	6.9	5.0	4.1	5.1
- both silages	21.8	14.4	11.9	18.5
Ryegrass dominant swards(%silage area)				
- conventional silage only	47	38	35	44
- baled silage only	28	17	26	21
- both silages	45	40	28	43

[1]single, double and precision-chop combined

Table 2. Harvester type used in silage making within different farm size categories

	Farm size (ha) category					
	<10	**10 to < 20**	**20 to <30**	**30 to <50**	**50 to <100**	**≥100**
Number of farms making silage	9100	29200	25800	24800	14400	3400
Area of silage (ha)	23594	146338	212181	354310	364427	138406
% of silage harvested in first cut	80	81	76	72	66	63
% of farms making silage						
Precision-chop	4	15	34	55	71	70
Single/double-chop	4	10	12	11	10	11
Baler	96	94	83	80	75	70
% of area of silage made :						
Precision-chop	4	19	40	58	76	74
Single/double-chop	5	13	12	8	5	12
Baler	91	68	48	34	19	14

Precision-chop harvesters generally harvest much larger areas (17.4ha) within individual farms compared to single-/double chop (9.7ha) or baler (4.8) systems. This has major implications in terms of efficiencies of machinery, fuel and labour use, administration etc.

Virtually all baled silage is made as cylindrical 'round' bales and wrapped in black plastic stretch film. It is important that opportunities for damage to occur to this plastic wrap are minimised so that an anaerobic environment is maintained in the bale through to feed-out, thereby preventing mould growth. The results in Table 3 indicate that most bales are wrapped at the site of baling rather than at the place of storage. The former presents an increased opportunity for damage to occur to the plastic wrap due to (a) wildlife piercing the plastic wrap before the bales are removed from the field and (b) physical damage to the wrap while the wrapped bales are being transported to the storage area. Although a minority of bales are transported to the place of storage before being wrapped, this practice is progressively more common as farm size increases. Thus, for the farm size categories < 20 ha, 20 ha to < 100 ha and equal to or above 100 ha, the proportion of bales transported to the place of storage before being wrapped was 26, 33 and 38% respectively.

Table 3. Location of wrapping baled silage as influence by the main farming enterprises

	Dairying	**Beef**	**Sheep**	**All systems**
% area for baled silage				
- wrapped at site of baling	59	78	61	69
- wrapped at place of storing	41	22	39	31

Among those farms where baled silage was fed, 42% of farmers acknowledged that they had mould on some of their baled silage and considered that it was present on about 11% of their bales. These proportions were fairly constant across farming enterprises. In contrast, only 7% acknowledged any mushroom-type growth on any of their bales, considering such to be present on approximately 10% of their bales. Farm size did not appear to be obviously related to mould or mushroom growth on baled silage. Data from another survey involving on-farm investigations of bales by personnel trained in identifying the presence of the mushroom-type fungus *Schizophyllum commune* suggest the above acknowledged incidences may be underestimates.

The survey reports the silage making practices during 1999. However, information on feeding baled silage or on mould/mushroom-type growth on baled silage refer to what occurred during the preceding winter. One particularly interesting finding was that among farms where only conventional silage was made (i.e. farms where baled silage was not made) during 1999, baled silage was fed on 43% of these farms during the preceding winter. It is likely that a significant amount of this was purchased and imported onto the farm, possibly reflecting the fodder shortage situation of the previous season. In these circumstances, 25% of these “conventional silage” farmers acknowledged that some of the bales were mouldy, considering the mould to be present on about 43% of the bales. The corresponding values for the presence of mushroom-type growth were 53% and 6%.

The survey indicates that virtually no additives are used in making baled silage in Ireland (less than 0.5% of the area of baled silage was treated with an additive).

Trends. Economic and social influences together with technological and market opportunities combine to maintain a state of change in our ruminant production systems. This in turn is reflected in changes in the role of silage and in the associated technologies and practices underpinning it.

Table 4. Trends in silage making, harvester type and additive use

	1991-92	**1996**	**1999**
Average total silage area (ha/farm)	11.0	11.3	11.6
- % first cut	-	72	71
Harvester system (% silage area)			
- single plus double-chop	40	17	9
- precision-chop	37	51	56
- round baler	23	32	35
Silage additive (% silage area)			
- none	58	73	84
- formic acid	4	3	2
- sulphuric acid	10	3	1
- molasses	20	8	4
- biological	8	12	8

Direct-cut (single and double-chop) harvesting systems have markedly diminished in national importance since 1991/92, being progressively replaced by precision-chop and to a lesser extent round baler systems. These changes parallel an increase in the considerable role of contractors in silage-making and major new capital investments by them. In some cases, these changes in harvesting systems have facilitated an increased interest in field wilting.

Silage making practices will continue to change in responses to market forces. The substantial replacement of hay by baled silage that was evident in some years may be partially reversed if the costs of making baled silage continue to rise. This may be facilitated by EU farm extensification schemes and by the greater mechanisation feasible with big (round) bale hay now compared to heretofore.

Summary

- Silage is made on 86% of Irish farms. Although the overall scale of silage production continues to rise slightly, the proportion of beef and sheep farms with silage is increasing.
- First cut silage accounts for about 70% of the area harvested for silage
- Baled silage is made on 85% of farms that make silage, but precision-chop systems harvest 56% of the total area of silage.
- Baled silage is wrapped mainly at the site of baling in the field rather than at the place of storage.
- The extent of mould and particularly mushroom growth on baled silage is probably underestimated by farmers.
- Virtually all baled silage and almost three-quarters of conventional silage is made without the application of a silage additive. The trend towards less additive being used appears to be ongoing. Where additives are used, biological additives predominate.
- Only 38% of silage is made from ryegrass dominant swards.
- Larger sized farms place greater reliance on ryegrass swards and precision-chop forage harvesters. They are also more likely to use silage additives, particularly biological additives, compared to small sized farms.

Acknowledgements. The considerable input of the staff of the National Farm Survey in collecting and collating the data summarised in this document is acknowledged.

2. MECHANISATION IN THE FIELD

The two issues dealt with in this section are field losses of grass dry matter (Experiment 1) and improved systems for handling bales (Experiment 2).

Field losses (Experiment 1)

The mechanical processes involved in the field harvesting of baled silage differ from those in conventional forage harvesting. Mowing and tedding/raking operations can be similar. There is scope for mechanical loss of forage from the bale chamber during the bale forming process and at the point of bale ejection. While there has been research on losses from balers working in hay, there is no information relating to baled silage. A previous feeding experiment, where total quantities of baled and conventional forage were weighed from known areas, suggested the possibility of higher field losses with baled silage. The objective of this trial carried out at Oak Park was to evaluate the level of mechanical field losses which occur with baled silage.

Materials and Methods. A field trial designed to measure the quantity and location of physical losses from balers and to compare these with losses from a forage harvester was established. The two most common types of baler, roller (R) and chain and slat (C+S) types represented by Claas 46 and Krone RP1250 models, were evaluated with (C), and without (UC), bale chopping mechanisms engaged, using either grass that was wilted for just 2 days (SW) or 6 days (LW) in a factorial design. All loss measurements were carried out on a per-bale basis with 6 bales allocated to each treatment on a random basis within the experimental area. A conventional precision-chop harvester (JF850) was also used on both types of grass to harvest similar quantities of grass to that of each of the baler treatments. The grass used for the trial was a first harvest, predominantly ryegrass sward. It was mown with a conventional 2.1 m, 2-drum mower and raked into swaths suitable for baling on the evening before baling using a rotary tedder. Drying conditions during the long wilting period were poor, resulting in the dry matter content of SW and LW grass being 23.1% and 28.4%, respectively.

Physical losses associated with the baling operation were measured in three areas. Pick-up-losses, i.e. the material remaining on the stubble following grass pick-up by the baler, was measured by carefully raking 1 m^2 sections of the swath after baling (3 per bale). Bale chamber losses were measured by attaching a collection box beneath the baler chamber. The accumulated loss from each bale was collected and weighed. Ejection loss material was carefully raked and weighed when each bale was dropped. Samples for DM measurement were taken for each weighing. Loss measurement for the forage harvester was restricted to pick-up losses and fine material collection downwind of the harvester using a 10 m^2 collection sheet.

Results and Discussion . The source of the physical losses and the influence of wilting period, baler type and chop level are indicated in Tables 5 to 7. The data is presented in these tables as percentage loss, i.e. the recorded loss material as a percentage of the recorded harvested material.

Table 5: Baled silage mechanical field losses (%) with short and long wilting periods

	Short wilt	**Long wilt**	**F-prob**	**SED**
Chamber loss	0.31	0.17	<0.001	0.03
Drop loss	0.04	0.02	0.001	0.005
Pick-up loss	0.65	0.67	NS	0.14
Total loss	1.00	0.86	0.048	0.07

Table 6: Baled silage mechanical field losses (%) with roller and chain and slat balers

	Roller	**Chain and slat**	**F-prob**	**SED**
Chamber loss	0.24	0.24	NS	0.03
Drop loss	0.03	0.03	NS	0.005
Pick-up loss	0.59	0.73	NS	0.14
Total loss	0.86	1.0	NS	0.07

Table 7: Baled silage mechanical field losses (%) with chopped and unchopped bales

	Un-chopped	Chopped	F-prob	SED
Chamber loss	0.15	0.33	<0.001	0.03
Drop loss	0.02	0.03	0.035	0.005
Pick-up loss	0.66	0.67	NS	0.14
Total loss	0.83	1.03	0.006	0.07

Table 8: Precision-chop harvester mechanical field losses (%) vs baler losses

	P. chop	Baler (C+S, C)	Baler (R, UC)	F-prob	SED
Pick-up losses	0.60	0.73	0.59	NS	0.12
Total losses	0.60[1]	1.12	0.80	<0.001	0.11

[1]Fine material loss was negligible but other chute losses not recorded

All recorded baler losses were low, being approximately 1% or less of the harvested material. Unusually, mechanical losses were lower with the extended-wilt material (Table 5). The low DM content and matted swath following broken weather probably explains this. Non-mechanical field losses over the wilting period were not recorded. Baler type did not affect mechanical losses (Table 6). As expected, the use of an on-baler chopper did increase chamber and drop loss, although its effect on overall mechanical losses was small (Table 7). When compared with two of the baler treatments, measured losses from the conventional forage harvester were lower, as fine material losses were negligible (Table 8). It should be noted that the experiment did not facilitate measurement of losses which occur due to inaccurate direction of grass from the harvester into the trailer.

Conclusion. It is concluded that mechanical losses from the baled silage system are unlikely to lead to significant differences in efficiency between baled and conventional harvesting systems.

New systems for handling bales (Experiment 2)

Ensiling forage using the baled silage system can be time consuming and labour intensive. Consequently, for larger quantities of silage the system is at a considerable disadvantage compared to conventional silage and, for smaller quantities, considerable labour is required relative to the amount of silage conserved. The level of labour is determined by the need to collect, transport and store individual 1.2 m x 1.2 m round bales of silage. Typically, bales are collected and transported using single bale carriers mounted on the rear linkage of a tractor. Occasionally, bales are loaded by tractor loader onto a conventional trailer or a purpose-built bale trailer. Self-loading trailers are also available. The objective of this work carried out at Oak Park was to examine the work rate of two self-loading bale trailers and to compare that with a single mounted bale transporter and a tractor carrying two bales; one on a front loader and one on a rear carrier. The systems evaluated were: single bale carrier (A); two-bale carrier (B); four-bale self-loading trailer (C); and five-bale self-loading trailer (D).

Normal work-study practice was used to time the various components of the working cycle of the four transport systems. Each system was timed over 7 work cycles during which bales were collected from paddocks and transported to the storage area. The average bale weight was 847 kg and all bales were transported before they were wrapped with film.

The distance from the three paddocks to the bale area varied but transport speed data was used to standardise the transport distance to 250 m for comparative analysis. The performance of the tested systems is illustrated in Figs. 1, 2 and 3. The overall time for the transport cycle and the time for the cycle components for each system is given in Fig. 1. Transport and bale unloading sections of the work cycle differed little for each of the systems, even though the number of bales handled per cycle was different. However, bale loading in the field varied markedly, with the trailed transporters taking proportionally longer to load bales than the mounted bale carriers.

This is illustrated more clearly in Fig. 2, where the results are presented on a per-bale basis. The trailed self-loading units required accurate driving when loading, compared to the more manoeuvrable mounted units. In Fig. 3, the work rates for the tested systems are presented for a range of transport distances. The data for this was calculated by adding additional time for road transport (at 25 km/h) to the measured data. This clearly shows the improvement in performance of the trailed transporter systems compared to the single or double bale system, as transport distance increases. Self-loading trailers can considerably reduce the labour requirement of baled silage systems.

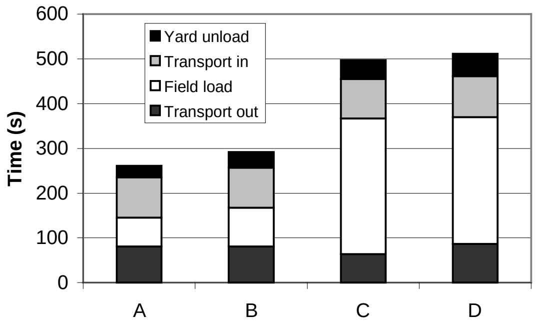


Fig. 1. Bale transport, time per cycle.

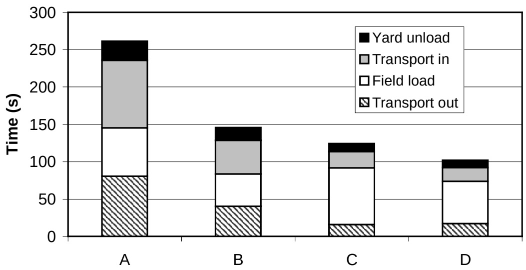


Fig. 2. Bale transport, time per bale.

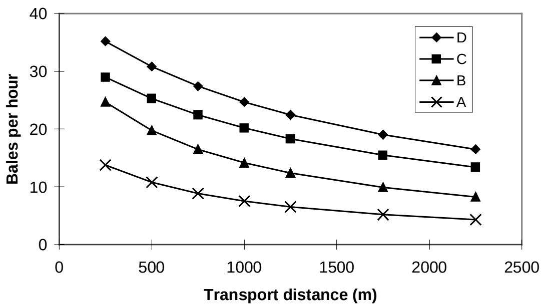


Fig. 3. Transport systems workrates.

3. FORAGE AND PLASTIC

Six experiments were conducted and are reported on in this section. Experiments 3 and 8 were located at Grange while Experiments 4 to 7 were all located at Oak Park. The overall objectives of the first five experiments were (a) to identify the optimal forage and bale characteristics for effective conservation, (b) to simultaneously determine the appropriate type and quantity of plastic film that should be applied, the effect of the manner in which it was applied or the influence of how the wrapped bale was subsequently handled, and (c) understand the dynamics of the gaseous environment within the wrapped bale throughout ensilage under the differing conditions imposed. In the case of Experiment 8, the aim was to quantify the influence of a range of additives with different modes of action on conservation characteristics of baled silage.

Experiment 3: Baled silage conservation characteristics as influenced by forage dry matter concentration, bale density and the number of wraps of plastic wrap used

Although the principles governing the preservation of baled silage are the same as for the more conventional flail or precision-chop silages, the practices by which it is currently made and stored mean that its final conservation characteristics differ from those of conventional silage. Thus, baled silage is generally baled at a higher dry matter (DM) concentration, stored at a lower bulk density and has a thinner plastic barrier protecting it from oxygen compared to conventional silages. Baled silage has 6 to 8 times the surface area in contact with the plastic film compared to conventional bunker silage, and about half of the silage volume is within 15 cm of the plastic film. As anaerobiosis is the most critical requirement of ensilage, the effects of the plastic film, bale density and forage DM concentration present particular risks to quantitative and qualitative conservation losses and, in particular, to mould growth and development. This experiment quantified the effects of forage DM concentration, bale density and the number of wraps of plastic film used on baled silage conservation characteristics.

Materials and Methods. A *Lolium perenne* dominant grass sward was cut on 25 May with a mower conditioner set to place wide windrows on the stubble. These windrows were tossed after 23 and 47 h wilting. Twenty-four, 48 and 72 h after mowing, 54 bales were made (Claas Rollant 46 Roto Cut) with the slicing blades engaged, with the baler being set at a high or low density setting for alternate bales. Bales were tied with netting, transported to the storage area, sampled and weighed. In sequence individual bales were then wrapped (McHale 991 BE) with 2, 4 or 6 layers of black plastic stretch film (Silawrap, Volac), giving 9 bales per treatment, and stored on their round sides on a grass base for 295 days.

Results. The mean (s.d.) weight of low and high density bales for each of the low, medium and high wilted treatments was 560 (55.0) and 708 (39.0) kg, 521 (63.2) and 638 (32.2) kg, and 427 (35.1) and 507 (16.7) kg, respectively. The mean (s.d.) composition of the grass at ensiling was crude protein 171 (16.5) g/kg DM, *in vitro* DM digestibilty 744 (21.7) g/kg and ash 100 (10.3) g/kg DM for the low wilted treatment. The corresponding values for the medium wilted treatment were 172 (15.8) g/kg DM, 754 (17.9) g/kg and 102 (16.8) g/kg DM, and for the high wilted treatment were 171 (10.0) g/kg DM, 733 (19.9) g/kg and 98 (36.5) g/kg DM. The conservation characteristics of the silages are summarised in Table 9.

Baled silage wrapped in only 2 layers of plastic film was badly preserved, had an inferior digestibility and the bale surface exhibited extensive aerobic rotting. Substantial benefits accrued from increasing the amount of film to 4 layers, while 6 layers brought relatively little further benefit.

Where adequate plastic film was used (4 or 6 layers) extending wilting restricted fermentation, but had minor effects on preservation, digestibility, surface rotting and mould development. Correspondingly, silage preservation, digestibility and surface mould were not influenced by bale density when adequate polythene was used.

Where inadequate plastic film was used, medium wilted bales exhibited the greatest surface area of mould, but the lowest extent or depth of surface rotting. High wilted bales had the greatest depth of surface mould penetration. Correspondingly, increasing bale density was associated with an increase in the proportion of the bale surface that was mouldy or rotted.

Conclusions. A minimum of 4 layers of the type of plastic stretch film used were required to conserve baled silage adequately. Under the prevailing conditions, relatively small benefits accrued from progressing to 6 layers of film. Once adequate plastic film was used, neither the extent of wilting nor bale density markedly altered silage preservation or digestibility.

Table 9. Individual treatment effects of bale dry matter concentration, bale density and number of layers of plastic film on the conservation characteristics of the bales.

Dry matter	Low DM						Medium DM						High DM							
Density	Low			High			Low			High			Low			High			SEM	Sig
No. layers wrap	2	4	6	2	4	6	2	4	6	2	4	6	2	4	6	2	4	6		
Mould patch area on bales																				
(% visible surface of bale)																				
- bale end	1.1	1.7	0.1	11.6	0.2	1.3	11.3	4.0	1.9	12.7	2.5	0	20.4	1.3	4.7	18.5	5.5	2.6	2.63	***
- bale barrel	0.9	4.9	0.8	2.0	2.7	3.5	7.7	6.8	3.0	22.9	7.0	2.9	32.1	1.1	2.1	32.3	3.1	2.5	3.85	***
- total	1.0	3.6	0.5	5.7	1.7	2.6	9.1	5.7	2.6	18.9	5.4	1.8	27.5	1.1	3.1	26.9	4.0	2.6	2.71	***
Mould patch depth on bale (cm)																				
- bale end	1.1	2.2	1.1	5.8	1.3	0.8	6.9	4.7	2.2	8.3	3.9	0.7	10.0	2.2	3.2	9.4	3.1	2.4	1.09	***
- bale barrel	1.5	8.4	2.2	3.0	5.0	4.8	6.6	7.4	2.4	8.9	6.4	2.0	10.0	2.4	3.4	8.9	3.4	4.6	1.07	***
Interspersed mould flocking through bale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-
Aerobically rotted bale surface																				
(% visible surface of bale)																				
- bale end	84	0	0	83	1	0	33	0	0	72	19	0	68	0	1	82	3	0	7.2	***
- bale barrel	92	0	0	86	0	0	27	1	0	90	24	0	64	0	0	90	11	0	6.8	***
- total	89	0	0	85	0	0	29	0	0	83	22	0	66	0	0	87	8	0	6.5	***
Aerobically rotted depth on bale (cm)	54	0	0	54	2	0	19	1	0	60	14	1	45	0	2	54	1	0	3.9	***
Dry matter (g/kg)	169	225	228	179	221	244	287	249	265	234	259	278	368	396	377	368	390	407	11.2	***
pH	6.8	4.4	4.3	6.2	4.4	4.3	5.4	4.5	4.3	7.2	4.6	4.4	5.8	4.7	4.7	5.7	5.0	4.5	0.38	***
Ash (g/kg DM)	134	112	112	136	114	108	121	115	117	139	119	118	122	112	115	116	108	113	6.6	NS
Dry matter digestibility (g/kg)	626	697	706	608	706	740	725	717	721	643	706	709	683	705	729	712	735	718	16.6	***
Organic matter digestibility (g/kg)	604	688	697	579	694	730	728	714	715	616	700	704	672	698	725	705	728	715	19.9	***
Crude protein (g/kg DM)	187	178	176	192	176	165	166	171	180	181	179	175	172	165	164	168	163	168	5.0	***
Ammonia-N (g/kg N)	276	130	135	185	128	120	143	141	139	200	145	134	136	96	99	134	109	89	23.5	***
Lactic acid (g/kg DM)	39	69	78	35	75	78	52	65	75	34	68	65	37	46	48	41	44	44	4.3	***

Experiment 4: The influence of the number of layers of film cover and film colour on silage preservation, gas composition and mould growth on big bale silage

Baled silage is a significant forage conservation system in Ireland, being used on 82% of all silage-making farms, and accounting for 32% of the forage area conserved as silage[1]. The barrier to gas movement which the stretch film forms is of particular importance in ensuring satisfactory silage preservation. When preserved in round bales, 50% of the forage is within a 17 cm distance of the film barrier. In Ireland, standard wrapping practice is to use 4 layers of 25 μm black film. The objective of the trial described here was to determine the effects of using different levels of film cover and different film colours, on silage preservation, bale gas composition and mould growth on baled silage.

Materials and Methods. Three different levels of film cover (nominally 2, 4 and 6 layers) and five different film colours (black, clear, green, light green and white) were applied to bales in a 3 x 5 factorial design with 6 replications per treatment. The grass ensiled was a first-harvest, predominantly perennial ryegrass sward which was wilted to a dry matter concentration of approximately 300 g/kg. The grass was baled with a 1.2 m x 1.2 m chopper baler (Krone KR 130). The bales were transported to the storage area where they were wrapped with either 2, 4 or 6 layers of each of the five films (IP Europe). The bales were placed singly in a net-protected storage area. Concentrations of O_2, N_2 and CO_2 were measured at five different times during the storage period. Samples were taken from a bale sampling port placed in one of the flat ends of the bales approximately 20 cm from the top of the bale. Samples were taken with 20 ml syringes for subsequent analysis in a gas chromatograph fitted with Molecular sieve 5A and Poropak Q columns[2]. Following a 9-month storage period, the bales were cored for silage analysis, and the extent of mould development on the bale surface was estimated.

Results and Discussion. Silage composition and mould assessment data for the main effects are given in Tables 10 and 11. There were no significant interactions recorded. The level of film cover had a significant effect on silage digestibility, pH and ammonia-N concentration. The most significant effect was on mould development, however, where the 2 layer cover resulted in high levels of mould development and 6 layers of cover resulted in less mould. Interestingly, film colour did not influence any of the measured silage or mould parameters significantly. It is possible that the prevailing temperate climate did not necessitate the use of reflective films.

The gas composition results for the main effect of layers are presented in Figs. 4, 5 and 6. Significant differences between treatments were recorded for all gases at all times except for the final O_2 reading (Day 275). Oxygen was present in all samples at low levels, with the 2-layer treatment having the higher concentration at four of the sampling times. The initial high concentrations of CO_2, early in ensilage, declined significantly over the bale storage period. N_2 levels showed a substantial increase over the storage period, with substantial treatment effects being evident. It is possible that the increasing N_2 levels recorded may be a better indicator of air entry than O_2 levels as oxygen entering the bale may quickly be respired. Film colour did not have a significant effect on gaseous composition.

Table 10. The effect of film cover (no. of layers) on silage composition and mould growth

No. of layers	DM (g/kg)	DMD (g/kg)	pH	Crude protein (g/kg DM)	Lactic acid (g/kg DM)	NH_3N (g/kg N)	Visible mould (% area)
2	301	763	4.9	140	27	100	21.5
4	310	764	4.7	137	28	86	1.7
6	316	775	4.7	137	27	84	0.7
SEM	*6.45*	*3.51*	*0.04*	*1.75*	*0.92*	*4.35*	*2.1*
Signif.	NS	*	**	NS	NS	*	***

Table 11. The effect of film colour on silage composition and mould growth

Colour	DM (g/kg)	DMD (g/kg)	pH	Crude protein (g/kg DM)	Lactic acid (g/kg DM)	NH_3N (g/kg N)	Visible mould (% area)
Black	304	768	4.7	139	27	85	7.7
Clear	313	763	4.7	136	27	96	8.7
Green	310	762	4.9	138	26	92	9.3
Light green	310	773	4.8	138	28	86	5.2
White	308	772	4.7	139	28	90	9.0
SEM	*8.33*	*4.53*	*0.05*	*2.26*	*1.19*	*5.61*	*2.7*
Signif.	NS	NS	NS	NS	NS	NS	NS

Fig. 4: O_2 levels, 2 vs 4 vs 6 layers

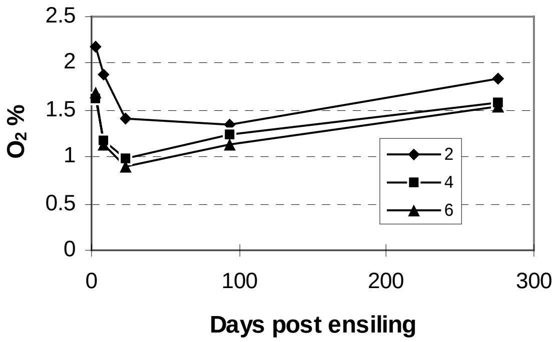


Fig. 5: N_2 levels, 2 vs 4 vs 6 layers

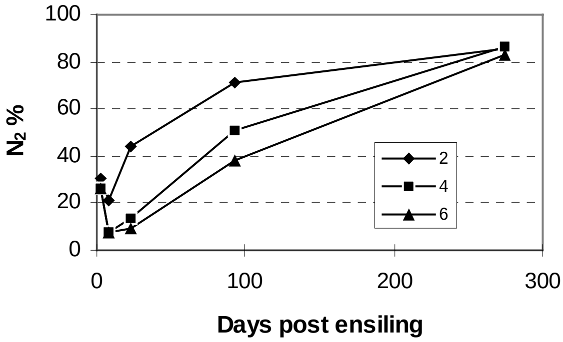
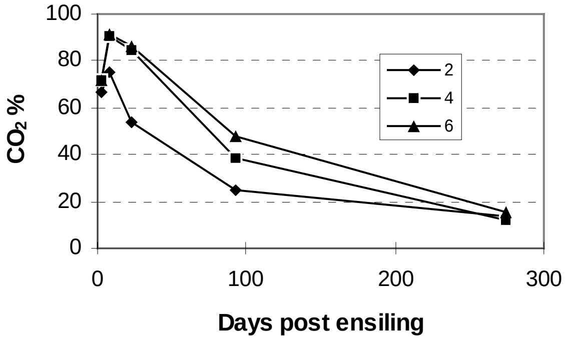


Fig. 6: CO_2 levels, 2 vs 4 vs 6 layers



Conclusions. The level of film cover on bales significantly affected silage preservation, mould development and gaseous composition of wrapped silage bales. The measurement of gaseous composition may prove a useful technique for assessing the permeability of the stretch film cover.

Experiment 5: The influence of the number of layers of film cover and stretch level on silage preservation, gas composition and mould growth on big bale silage

The objective of the trial described here was to determine the effects of using different levels of film cover, and different film stretch levels, on silage preservation, bale gas composition and mould growth.

Materials and Methods. Three different levels of film cover (2, 4 and 6 layers) were applied at three different stretch levels (40%, 70% and 110%) to bales in a 3 x 3 factorial design with 6 replications per treatment. The grass ensiled was a second-harvest, predominantly perennial ryegrass crop cut after a six-week regrowth period. It was wilted to a dry matter of approximately 320 g/kg. The grass was baled with a 1.2 m x 1.2 m chopper baler (Krone KR130). The bales were transported to the storage area where they were wrapped with a McHale 991 bale wrapper with either 2, 4 or 6 layers of 25 µm black stretch film (IP Europe). The gearing of the film pre-stretch unit was altered to produce alternative stretch levels of 40% and 110% in addition to the standard 70%. (At 70% stretch level, the film applied to the bale is 1.7 times longer than the film on the roll.) After wrapping, the bales were placed singly in a net-protected storage area. The bales were fitted with sampling ports which allowed gas samples to be taken at regular intervals. Concentrations of O_2, N_2 and CO_2 were measured at five different times during the storage period using a gas chromatograph fitted with Molecular sieve and Poropak Q columns[2]. Following a 7-month storage period, the bales were cored for silage analysis and the extent of mould development on the bale surface was quantified.

Results and Discussion. Silage composition and mould assessment data for the main effects are given in Tables 12 and 13. The level of film cover did not affect any of the chemical analysis parameters. All silages were well preserved. Mould development was influenced however, with 2-layer cover resulting in extensive mould development. Stretch level did not significantly influence the level of mould development, although the tendency towards less mould development with higher stretch levels may indicate that the increased film tension results in a better seal. The coring procedure used for silage analysis is not optimum for round bales as the area near the surface of the bale is not adequately represented. The gas composition results for the effect of layers are presented in Figs. 7, 8 and 9. Significant differences between treatments were recorded for N_2 and CO_2 at all sampling times. The relationship between CO_2 and N_2 over time is probably a good indicator of air entry. Higher levels of N_2 and lower CO_2 levels indicate air ingress. Any O_2 which enters is probably respired quite quickly. At each sampling time, N_2 levels were highest with 2 layers of cover and lowest with 6 layers. CO_2 levels were highest with 6 layers and lowest with 2 layers of cover. Stretch level had little effect on gaseous composition.

Table 12: The effect of film cover (no. of layers) on silage composition and mould growth

No. of layers	DM (g/kg)	DMD (g/kg)	pH	Crude protein (g/kg DM)	Lactic acid (g/kg DM)	NH_3N (g/kg N)	Visible mould (% area)
2	343	798	4.9	211	42	75	20.4
4	341	803	4.9	209	43	71	0.5
6	349	805	4.9	213	42	70	0.1
SEM	*8.41*	*4.25*	*0.06*	*4.12*	*2.2*	*2.84*	*2.7*
Signif.	NS	NS	NS	NS	NS	NS	***

Table 13: The effect of film colour on silage composition and mould growth

Stretch level (%)	DM (g/kg)	DMD (g/kg)	pH	Crude protein (g/kg DM)	Lactic acid (g/kg DM)	NH_3N (g/kg N)	Visible mould (% area)
40	357	801	5.0	209	41	73	11.1
70	337	804	4.9	199	43	69	6.8
110	339	802	4.9	226	43	75	3.0
SEM	*8.41*	*4.25*	*0.05*	*4.12*	*2.2*	*2.84*	*2.70*
Signif.	NS	NS	NS	***	NS	NS	NS

Fig. 7: O_2 levels, 2 vs 4 vs 6 layers

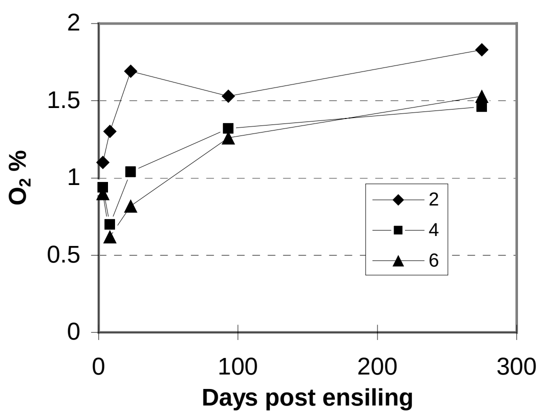


Fig. 8: N_2 levels, 2 vs 4 vs 6 layers

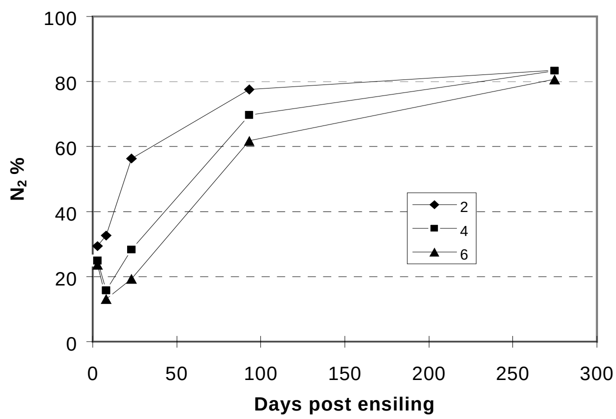
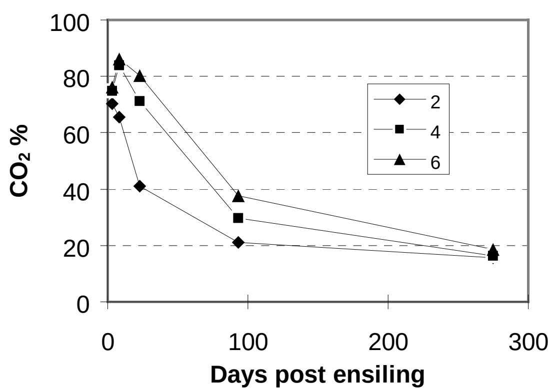


Fig. 9: CO_2 levels, 2 vs 4 vs 6 layers



Conclusions. The level of film cover on bales significantly affected mould development and gaseous composition of wrapped bales. Stretch level had no significant effect but the results warrant further studies in this area.

Experiment 6: The influence of polythene film type and level of cover on ensiling conditions in baled silage

The objective of the work reported here was to compare the performance of conventional and thin polythene films under varied wrapping conditions.

Materials and Methods. Two different film types: conventional 25μm film stretched to 70% (S) and a new 14 μm film stretched to 15% (E) were applied to silage bales in a 2x3x3 factorial experiment. The films were applied at three different covering levels to give two, four and six layers of film cover. Following wrapping, the bales were subjected to three different levels of handling. A third of the bales were handled gently once (A). A third were subjected to three handling operations (B). The final third were subjected to three handling operations, 5 days after wrapping, when some bale shape deformation had taken place (C). There were 6 replications per treatment combination, giving 108 bales in total.

The second-harvest, predominantly ryegrass, sward was wilted for three days, but broken weather resulted in a low dry matter content at harvest (237 g/kg). Bales were made with a fixed-chamber baler (1.2 m x 1.2 m) and moved to the storage area where they were wrapped with each of the two test films at three levels of cover. The handling treatments were applied subsequently and all bales were placed at ground level in a net-protected storage area. Concentrations of O_2, N_2 and CO_2 were measured on gas samples using a gas chromatograph 20 days and 247 days post ensiling. The effectiveness of the seal formed by the polythene was assessed by creating a partial vacuum in the bales (200 Pa) using a hand pump and measuring the time (seconds) for the vacuum to deplete to 150 Pa. After 8 months of storage the proportion of the bale surface showing mould was estimated. All data was analysed using ANOVA except for the non-parametric mould data which is presented as means with standard deviations.

Results and Discussion. The main treatment effects are given in Table 14. The number of layers of film cover influenced most measured parameters. Increased levels of cover gave significantly ($P<0.001$) lower levels of N_2 and higher levels of CO_2, indicating less gas movement and better ensiling conditions. Increasing the number of film layers also improved the level of sealing as measured by the vacuum depletion time, with significant differences between each level of cover. Mould levels were also reduced by increasing the level of film cover. The newer thin film (E) gave reduced CO_2 and increased N_2 levels compared to standard film, indicating some gas movement and slightly poorer ensiling conditions. However, there was a significant interaction ($P<0.001$) between film type and the number of layers, with 2 layers of the thin film resulting in significantly lower CO_2 and higher N_2. Where 4 and 6 layers of cover were used, there was less difference in gas content between film types. Interestingly, the newer thin film gave better levels of sealing, as indicated by the vacuum depletion times. The vacuum depletion test is probably most influenced by the level of sealing achieved between the layers of film. It is likely that tack level and/or film tension of the thin film resulted in good performance. However, the poorer gas profile of the thin film bales indicates that there may have been low levels of gas permeation through the thinner polythene film. The thin-film wrapped bales also had slightly more mould development than those wrapped with standard film. The severity of handling had little effect on the measured parameters. The less severely handled bales (A) had slightly higher CO_2 levels.

Table 14. Main treatment effects on gas levels (Day 20), level of sealing and mould development

	O_2 (ml/l)	N (ml/l)	CO_2 (ml/l)	Seal (s)	Mould *(sd)* (prop.)
Layers					
2	26	349	589	1.9	0.552 *(0.34)*
4	12	69	912	21.2	0.075 *(0.11)*
6	14	52	931	30.4	0.014 *(0.04)*
Sig.	***	***	***	***	
s.e.	*1.3*	*10.6*	*11.7*	*1.1*	
Films					
S	18	126	843	12.3	0.175 *(0.30)*
E	17	188	779	23.4	0.252 *(0.33)*
Sig.	NS	***	***	***	
s.e.	*1.0*	*8.7*	*9.5*	*0.9*	
Handling					
A	18	138	839	18.0	0.174 *(0.31)*
B	19	164	800	18.8	0.234 *(0.32)*
C	15	168	793	16.8	0.233 *(0.32)*
Sig.	NS	NS	*	NS	
s.e.	*1.3*	*10.6*	*11.7*	*1.1*	

Conclusion. The level of film cover on bales, influences silage preservation conditions, as indicated by all measured parametres. The newer thin film performed well in the vacuum depletion test, but resulted in a slightly less favourable gas profile and marginally more mould development.

Experiment 7: The effect of polythene film type and induced film damage on gaseous composition and mould growth on big bale silage

The objective of the work reported here was to determine the effect of film type and induced film damage on gaseous composition within bales, and mould growth on bales.

Materials and Methods. Two different film types: conventional 25μm thickness film stretched at 70% (C) and a prototype 14μm film stretched at 15% (P) were applied to silage bales in a 2x3 factorial design experiment. Following wrapping, the bales were subjected to three different levels of induced damage. One third of the bales were handled minimally, with the bales moved carefully by a loader-mounted handler (M). Another third were subjected to more severe handling, with three handling events by the same handler (S). Six small holes (approx. 5 mm x 2 mm), simulating a low level of bird damage, were made in each bale of the third set of bales (B). There were 6 replications per individual treatment combination giving 36 bales in total. The grass ensiled was a second harvest predominantly ryegrass crop cut after an eight week regrowth period. The grass was wilted for 2 days to approximately 560 g/kg DM and baled with a fixed chamber baler (1.2 m x 1.2 m). The bales were transported to the storage site and wrapped with 4 layers of the test stretch films. After wrapping, the induced damage treatments were applied and all bales were placed in a net-protected storage area. The bales were fitted with sampling ports to allow gas samples to be taken at 5 different times during the storage period. Concentrations of O_2, N_2 and CO_2 were measured using a gas chromatograph on Days 3, 8, 20, 60 and 230 after ensiling. Following a 7-month storage period, the proportion of the bale surface with mould was measured. Analysis of variance was used to analyse the gas data at each sample time and the mould data.

Results and Discussion. There was no significant difference in the level of surface mould between the two film types evaluated. There were significant differences $P<0.001$ in mould development between the damage treatments, with proportions of the surface with mould being 0.002, 0.013 and 0.260 (s.e.=0.018) recorded for the M, S and B treatments, respectively. The gas composition results for the three different damage treatments differed markedly. The simulated bird damage resulted in significantly greater O_2 concentrations immediately after ensiling, with O_2 concentrations of 39, 10 and 10 ml/l (s.e.=2.0) recorded for the B, S and M treatments, respectively. There was no significant difference in O_2 concentrations at the later sampling times. Any O_2 that enters over the storage period is probably respired quite quickly. Treatment B also gave significantly higher N_2 levels and significantly lower CO_2 levels throughout the storage period, indicating continuous air entry into the bales (Figs. 10 and 11). There was no significant difference in gas composition between the C and P films at the first three sampling dates. Differences were evident on Day 60 of storage with CO_2 contents for the C and P films of 380 and 340 ml/l (s.e.=10.4), respectively, with similar differences in N_2 also recorded. The prototype film may not have given the same level of long-term protection from air entry as the conventional film, but further experimentation would be needed to verify this.

Fig. 10: N_2 levels and film damage

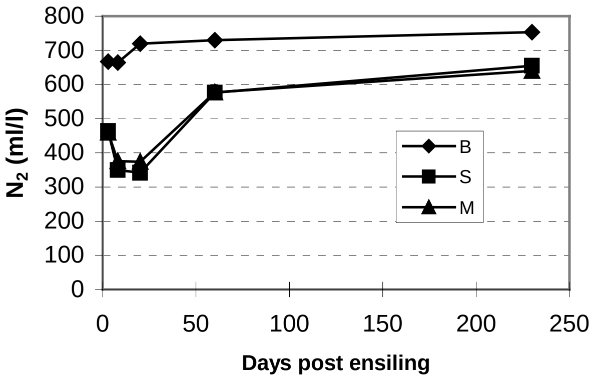
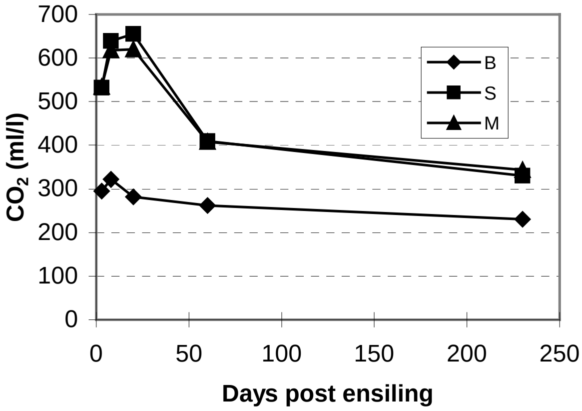


Fig 11 : CO_2 levels and film damage



Conclusion. Minor levels of film damage had a significant effect on silage preservation conditions, as indicated by the change caused in gaseous constituents and the levels of surface mould recorded. The effect of film type on preservation conditions was less clear, but indications were that the prototype thin film may have allowed more air entry over the storage period. More detailed studies of gaseous movement in wrapped bales is needed.

Experiment 8: Silage additives and their effects on the conservation characteristics of first-cut baled silage

Baled silage in Ireland has normally been wilted to facilitate achieving good preservation, eliminate effluent production, reduce the number of bales per ha, reduce bale fresh weight and improve the physical stability of the bales. That the mean national dry matter (DM) concentration for baled silage is about 324 g/kg indicates that successful wilting is generally achieved, and the associated mean pH of 4.8 indicates that fermentation is more restricted than might be expected from a corresponding similarly wilted precision-chop silage. Virtually no additives are currently used in making baled silage in Ireland. Additives might be considered either with wet grass of difficult-to-preserve characteristics or with wilted forage where, if the plastic wrap is not sufficiently impervious to oxygen, the high pH might not be adequately inhibitory to the growth of some undesirable fungi and bacteria (*L. monocytogenes*). The present experiment evaluated the efficacy of a range of additive types under the latter of these conditions.

Materials and Methods. The primary growth of an *Agrostis* and *Poa* dominant sward was cut with a rotary drum mower on 28 May. After 24 h wilting the following treatments were applied in succession to alternate swaths of grass across the field: (1) no additive (NA), (2) Add SafeR (AS; ammonium tetraformate; Trouw Nutrition Ltd.) at 2.5 l/t, (3) Cosil (CS; sulphuric acid plus Cu; Nutribio Ltd.) @ 2.5 l/t, (4) molasses (MO) at 9 l/t, (5) Ecosyl (ES; *Lactobacillus plantarum*; Novokem Ltd.) at 3 l/t, (6) molasses (9 l/t) plus Ecosyl (3 l/t) (M+E), (7) Ecobale (EB; *L. plantarum*, *S. rubidae*, *B. subtilis*; Novokem Ltd.) @ 3 l/t, and (8) Axcool (AC; *L. buchneri;* Biotal Ltd.) @ 4 l/t. Additives were applied across the width of the top of grass swaths through perforated holes in a dribble bar – molasses was applied 2 h pre-baling and the other additives within 15 min. of baling. There was no evidence of loss of additive from the swaths. Eight cylindrical bales (1.2 m nominal diameter) per treatment were transported to the storage area and wrapped in 4 layers of black plastic stretch film. Bales were stored outdoors (on grass beside roadway) for 273 days before being opened, assessed for aerobic stability and surface mould, weighed and sampled.

Results. The mean (s.d.) weight of bales at ensiling was 629 (54.9) kg. The mean (s.d.) chemical composition of the grass at baling was dry matter (DM) 384 (59.2) g/kg, *in vitro* DM digestibility (DMD) 768 (9.8) g/kg, ash 119 (3.5) g/kg DM, crude protein 154 (7.9) g/kg DM and buffering capacity 364 (12.1) mEq./kg DM.

Table 15 presents the treatments effects on silage conservation characteristics. Silage made without additive showed the restricted fermentation characteristics of wilted baled silage. Silage preservation was satisfactory as indicated by the dominance of fermentation products by lactic acid and the non-excessive breakdown of protein-N, volatile fatty acids to ammonia-N. Digestibility and crude protein values indicate a silage of good nutritive value. Treatment with the formic acid-based additive (AS) did not alter (P>0.05) indices of aerobic stability, digestibility, pH or the concentrations of DM, crude protein, volatile fatty acids or ammonia-N. However, AS reduced (P<0.05) the concentration of lactic acid and increased (P<0.05) the concentration of residual WSC. The sulphuric acid based additive (CS) had similar effects to AS, but did not alter (P>0.05) the WSC concentration. The molasses (MO) treatment did not alter (P>0.05) any of the variables measured while the *Lactobacillus plantarum* based inoculant (ES) reduced (P<0.05) the residual concentration of WSC. The combination of M+E stimulated an increased concentration of lactic acid but lower residual concentrations of WSC (P<0.05). It also increased aerobic instability. Both the inoculants based on *L. plantarum*, *S. rubidea* and *B. subtilis* (EB) and *L. buchneri* (AC) reduced the concentration of WSC, and the trend to undergo more extensive aerobic deterioration was significant (P<0.05) for AC.

Considerable variability in conservation characteristics occurred among the 8 bales within each treatment.

The extent of surface mould was small and rarely penetrated to a depth greater than 2.5 cm below the surface. Complete opening of the bale indicated an absence of visible mould through the forage. There was no significant difference (P>0.05) between treatments in the proportion of the visible surface of bales that was covered in mould.

Conclusions. Wilted grass wrapped in four layers of black plastic stretch film preserved satisfactorily in the absence of additive treatment, and the laboratory analyses indicated a good nutritive value. Under the prevailing conditions, additives did not alter the indices of the energy (ie *in vitro* DMD) or protein (ie crude protein and NH_3-N) value of silage. Effects on fermentation were modest although the formic acid based product did restrict fermentation. Baled silage was aerobically relatively stable and had little visible mould development. None of the additives elicited on improvement in aerobic stability or reduced mould development.

Table 15. Silage chemical composition, aerobic stability and assessment of surface mould and waste.

	NA	AS	CS	MO	ES	M+E	EB	AC	SEM	Sign.
Chemical composition[1]										
Dry matter (g/kg)	308	286	291	277	285	284	286	259	12.4	NS
DMD (g/kg)	725	746	731	755	745	739	738	753	7.1	NS
Crude protein (g/kg DM)	148	153	159	153	159	157	167	158	4.2	NS
Lactic acid (g/kg DM)	68	56	56	72	76	78	73	76	3.4	***
Acetic acid (g/kg DM)	23	16	20	26	20	25	34	27	4.4	NS
Propionic acid (g/kg DM)	0.7	0.4	0.5	1.1	0.6	5.4	0.7	1.1	1.6	NS
Butryic acid (g/kg DM)	2.4	2.4	3.4	4.5	4.2	8.6	5.8	3.8	1.7	NS
Lactic acid/fermentation acids (	729	745	712	704	755	713	668	703	32.0	NS
WSC (g/kg DM)	35	44	30	30	24	26	23	21	2.9	***
Ammonia-N (g/kg N)	110	112	95	108	115	105	112	127	7.6	NS
pH	4.33	4.29	4.18	4.26	4.26	4.21	4.33	4.28	0.048	NS
Aerobic stability[2]										
Days to temp. rise	3.8	3.0	3.3	3.5	3.3	2.3	2.5	2.5	0.61	NS
Days to temp. max.	12.3	12.8	11.8	13.0	13.0	11.0	13.0	12.8	0.47	*
Max. temp. rise (^{o}C)	14	21	19	22	16	31	18	27	2.6	**
Accumulated ^{o}C rise to day 5	11	12	16	13	11	23	16	19	2.6	*

Error df: [1]=56 and [2]=24

NA = no additive; AS = Add Safe R; CS = Cosil with Cu; MO = molasses; ES = Ecosyl; M+E = molasses + Ecosyl; EB = Ecobale and AC = Axcool.

4. *SCHIZOPHYLLUM COMMUNE*

While mould colonies of microfungi such as *Penicillium* and *Fusarium* are commonly seen on conventional and on big-bale silage, macrofungi are rarely encountered. However, within recent years a mushroom growth has been appearing with increasing frequency on big bales in Ireland. The mushroom is *Schizophyllum commune*, a gilled bracket fungus (phylum Basidiomycota). The fungus is best known as a white-rot fungus with a worldwide distribution. Its small bracket-like fruit-bodies are commonly seen on fallen branches in deciduous woodland, especially in warmer climates. It also occurs in temperate regions, on wood and a variety of other substrata (Cooke, 1961). While usually considered a saprotroph, it is pathogenic on a variety of plant hosts and is increasingly being reported as a human pathogen (Sigler *et al*., 1997).

The first recorded occurrence of *S. commune* on big-bale silage in Ireland was in October 1990, in Co. Leitrim. In November 1991 the fungus was found on big bales in Co. Tipperary, 150km from the first location. Interestingly, Webster (1991) reported finding *Schizophyllum* on silage in Devon, England in October 1990. The Irish finds were of particular mycological interest because *Schizophyllum* had been recorded only once before in Ireland, 150 years previously on wooden beams at Cork Harbour. By 1995 agricultural interest in *Schizophyllum* intensified as more big bales at various locations were found to be colonised by the fungus. Correspondence with researchers in Britain and other countries does not indicate that *Schizophyllum* is a problem on baled silage in Europe or elsewhere.

Schizophyllum can develop in bales within four to six weeks of wrapping. From August onwards, depending on bale age, *Schizophyllum* is readily visible on the plastic surface of affected bales. Having emerged through the polythene wrap the fungus is first evident as small white growths which eventually expand and develop into gilled bracket mushrooms, often in dense overlapping clusters 10 to 15cm in diameter. More extensive growths to *ca* 50cm wide have been seen. The individual mature fruit-bodies (basidiocarps) are tough and elastic, grey-white to brown in colour, fan-shaped with very short stipes and a tomentose/downy wrinkled upper surface. Cap margins are furrowed, scalloped and incurved. The gills are peach/pink when young and spread out radially from where the fruit-bodies are attached to the bale. With age the gills become brown to grey in colour. A characteristic feature of the gills is the manner in which they appear to split, hence the common name for the fungus - ‘split gill’. By springtime, older *Schizophyllum* specimens are often shrivelled, brittle and are readily dislodged. A green algal growth may be present on the surface of such specimens.

Before emergence through the polythene, the occurrence of *Schizophyllum* in a bale is indicated by the presence of small firm bumps under the polythene surface. The fungus may occur in any position on a bale but most often on the curved sides and shoulders. When the plastic covering is removed from a bale, mats of white to tan-coloured mycelium can be seen on the silage surface, usually accompanied by masses of dense rubbery differentiating tissue. Mechanical pressure exerted by the enlarging fungal mass causes a stretching of the polythene wrap and its eventual penetration or splitting by the fungus. Within bales, *Schizophyllum* colonies ramify widely and deeply. The diffuse white mycelium is not macroscopically distinguishable from other fungi but microscopically can be identified by the presence of clamp connections and numerous minute peg-like projections along the hyphae. The fungus is readily grown in culture on malt extract medium supplemented with chloramphenicol and chlortetracycline (both at 0.15mg ml^{-1}) to inhibit bacterial growth. Most isolates form fruit-bodies within 4 to 8 days. Other species of *Schizophyllum* are known but only *S. commune* has been found on bales.

Within the past decade *Schizophyllum* has established rapidly in its new niche on big-bale silage and is now widespread in Ireland. It has not been found on conventional pit silage and is of rare occurrence in Irish woodlands. Its growth on silage causes loss of feedstuff and also, through air ingress, facilitates growth of aerobic molds and bacteria with consequent health risks to livestock and humans. *Schizophyllum* can be a human pathogen which gives further ground for concern. Farmers are advised not to offer affected bales to livestock.

The following experiments were a collaborative study between the Botany Department at University College Dublin (where most of the laboratory studies were conducted) and Teagasc.

Experiment 9. Schizophyllum on big-bale silage: results of farm survey January 1999

During recent, years mushroom growths protruding through the plastic film of baled silage have been identified as *Schizophyllum commune*. Reports and samples of the mushroom have been received from most counties indicating a widespread distribution of the problem in Ireland. A questionnaire completed through the Teagasc advisory network indicated that mushroom-type growths were seen on *ca* 28% of farms. Personal communications with farmers and visits to particular farms suggested a higher incidence than this and indicated that some bale collections were extensively colonised by *Schizophyllum.* To clarify the situation a survey was conducted to establish the proportion of farms, and the proportion of bales on farms, with visible evidence of *Schizophyllum* protruding through the plastic film.

Survey Methods. Six routes were chosen (Table 16), each 100–150km long, representative of geographical locations and farm enterprises in Ireland and collectively traversing 20 counties. During late January and early February 1999 baled silage was inspected on fifty farms per route. The first ten farms with baled silage were inspected on each of five consecutive sections on each route. For each bale collection the presence/absence of *Schizophyllum* was noted on unopened bales and, if present, its location on bales and incidence on the collection. Bale characteristics and storage details were also noted. Basidiocarp samples were taken to confirm the identity of *Schizophyllum*. Prior to the survey participants met and together visited six farms to ensure standardisation of methods.

Results. *Schizophyllum commune* occurred in all counties and was present on 53% (159/300) of farms surveyed, ranging from 26 to 76% of farms, depending on route (Table 16). Reasons for this variation are not known but may, for example, reflect differences in silage-making practices, meteorological conditions or distribution of the fungus in nature. On 17% of farms 10-50% of the bales were affected; badly affected bale collections, in which more than 50% of bales had *Schizophyllum* present, were recorded on 6 of the 300 farms visited. *Schizophyllum* was recorded most frequently on the curved sides and shoulders of bales, on 141 and 107 of 159 affected farms respectively, in contrast to being recorded on flat bale ends on 60 farms. Results were inconclusive on the preferential emergence of the fungus on sun-facing as opposed to the shaded side of bales and also on whether or not vertical storage of bales was any more beneficial than horizontal storage. A high proportion (>60%) of bale collections inspected showed signs of bird, domestic animal and vermin damage.

Table 16. Occurrence of *Schizophyllum commune* on farms* and incidence on big-bale silage inspected during January-February 1999 along six routes in Ireland

Occurrence and Incidence of *Schizophyllum*	Number (and percentage) of farms on which *Schizophyllum* was observed on bales						
	Route 1 (n=50)	Route 2 (n=50)	Route 3 (n=50)	Route 4 (n=50)	Route 5 (n=50)	Route 6 (n=50)	Overall (n=300)
Schizophyllum present	31 (62%)	38 (76%)	34 (68%)	21 (42%)	22 (44%)	13 (26%)	159 (53%)
<10% of bales affected	15 (30%)	24 (48%)	18 (36%)	17 (34%)	15 (30%)	12 (24%)	101 (34%)
10-50% of bales affected	13 (26%)	13 (26%)	14 (28%)	4 (8%)	7 (14%)	1 (2%)	52 (17%)
>50% of bales affected	3 (6%)	1 (2%)	2 (4%)	0 (0%)	0 (0%)	0 (0%)	6 (2%)

*Fifty farms on each of the following routes: 1. Clonmel – Navan; 2.Kilrush – Roscommon; 3. Killarney – Limerick; 4. Cork – Enniscorthy; 5. Monaghan – Ballina; 6. Bundoran – Carndonagh.

Conclusions. The survey confirmed the widespread occurrence of *Schizophyllum* protruding through the plastic film on big-bale silage in Ireland and recorded its presence on more than half of the 300 farms visited. On a sixth of all farms surveyed 10-50% of bales were affected by the fungus and more than a third of farms had up to 10% of bales affected. As no account was taken of bales in which *Schizophyllum* was growing but had not yet emerged through the wrap the occurrence is probably underestimated. Cumulatively, a sizeable tonnage of baled silage was contaminated by *Schizophyllum* resulting in quantitative and qualitative losses of fodder.

Experiment 10: Inoculation of big bale silage with Schizophyllum commune: influence of bale damage and sward type on extablishment

The purpose of the present investigation was to test a new inoculation method while also investigating the effects of bale wrap damage and sward type on the ability of *Schizophyllum* to establish in baled silage.

Materials and Methods. Two forms of inocula were prepared - (i) a multi-isolate basidiospore suspension and (ii) actively growing mycelia of two *Schizophyllum* isolates. Basidiospores of each of ten *Schizophyllum* isolates were harvested in sterile water. Individual suspensions were pooled to give an inoculum suspension containing 200,000 spores ml^{-1}. Mycelia of Isolates MH15 and OY01 were grown on grass agar medium (25.0g powdered air-dried *Lolium perenne*, 15.0g agar, 1l water) for 7 days at 30°C. The colonised agar 'plate' was then removed to the surface of a 9cm filter paper (Whatman No. 541) and rolled to form a cylinder.

In early June 1998 bales were made using grass from five swards (Table 17). Forage was wilted after cutting and baled at a dry matter of *ca* 30%. Ten inoculum cavities, 10cm deep x 2.5cm diameter, were cut in each bale using an auger; four cavities were made on each side of a bale and one at each end. Bales were inoculated either by spraying 5ml of spore suspension (10^6 spores) into each inoculum cavity or by inserting a mycelial cylinder in each. Following wrapping in four layers of black polythene, bales were turned and dropped in an upright position as when inoculated. Bales were damaged by piercing the plastic wrap, over each inoculum cavity, with a 10cm diameter prod supporting 15 fine needles. Control bales, both damaged and undamaged, but not inoculated with *Schizophyllum* were also included. Bales were then stored unstacked, on their sides, in a N-S orientation. After 5 weeks (mid-July 1998), bales were inspected for the presence of fungal growths on their surface. The wrap was then removed and all inoculum points were assessed visually for growth of *Schizophyllum*; identifications were confirmed microscopically where necessary.

Results. No fungal growths were obvious on bale surfaces prior to wrap removal. Examination of stripped bales showed that *Schizophyllum* did not establish growth at any inoculation point on undamaged bales (Table 17). Furthermore, when culture was attempted *in vitro*, mycelial inoculum retrieved from those bales was shown to have lost viability. *Schizophyllum* did grow at inoculum points on damaged bales, more often from mycelial inoculant than from spores (93/300 and 3/150, respectively). Of the mycelial inoculants, Isolate MH15 established at more inoculation points (65/150) than Isolate OY01 (28/150), but once established there were no obvious differences in the intensity of growth between the two isolates. While the successfulness of inoculant establishment differed depending on sward type, grass from the five swards used was colonised by mycelia of both *Schizophyllum* isolates. *Schizophyllum* was not present on any control bales, damaged or undamaged.

Table 17. Mean number (± sem) of inoculation points on bales (n=3), showing growth of *Schizophyllum* after 5 weeks. For each treatment, ten points were inoculated on each of three replicate bales.

Sward Type	**Undamaged Bales**			**Damaged Bales**		
	Inoculum			Inoculum		
	Mycelium MH15	**Mycelium OY01**	**Spores**	**Mycelium MH15**	**Mycelium OY01**	**Spores**
[1]Oakpark Old	0	0	0	5.0 (±0.6)a	2.7 (±0.3)b	0
[2]Oakpark New	0	0	0	3.7 (±0.7)a	3.0 (±1.0)b	0
[1]Grange Old	0	0	0	2.7 (±1.7)a	0.3 (±0.3)c	0.3 (±0.3)d
[2]Grange New	0	0	0	6.0 (±1.2)a	0.3 (±0.3)c	0.3 (±0.3)d
[3]Grange Poor	0	0	0	4.3 (±1.7)a	3.0 (±1.0)b	0.3 (±0.3)d

[1] 'Old' pasture is defined as a sward not less than 10 years old, [2] 'New' pasture is a sward seeded less than two years prior to the start date, and [3] 'Poor' is an old pasture sward which has not received any fertiliser application in 10 years. Values in each column followed by the same letter are not significantly different.

Conclusions. The inoculation procedure proved successful, however, *Schizophyllum* established more readily from the mycelial inocula than from spores. Damage to the polythene wrap facilitated growth of *Schizophyllum* on big-bale silage while in undamaged bales, mycelium lost viability. Establishment of *Schizophyllum* mycelium in damaged bales was not dependent on sward type.

Experiment 11. Inoculation of big-bale silage with Schizophyllum commune: influence of herbage dry matter, wrap damage and type of inoculum

Previously reported work showed that silage produced from different sward types could be colonised by *Schizophyllum* and that damage to the bale wrap damage facilitates growth of the fungus. The purpose of the present investigation was to further develop inoculation protocols as well as determining the effect on *Schizophyllum* growth of herbage dry matter and timing of bale wrap damage.

Materials & Methods. Bale inocula consisted of (i) colonised 'rolled plate cylinders' and (ii) colonised *Rumex* stalk segments. The latter were prepared by placing sterile 5cm lengths of *Rumex crispus* stalks onto the surface of *Schizophyllum* plate cultures of Isolate MH15 for 14 days at 25°C. In mid-June 1999 bales were made using herbage from a *Lolium perennne*-dominant sward and wilted to *ca* 20, 30 and 45% dry matter (DM). Eight inoculum cavities were cut in each bale – 4 cavities on each of the curved bale surfaces. Bales were inoculated (n=5 per treatment) either by inserting a 'rolled plate cylinder' in each cavity (9 x 2cm) or by placing a colonised *Rumex* segment in each (5 x 1cm cavity). Bales were wrapped in four layers black polythene, turned and dropped in an upright position as when inoculated. Some bales were damaged after wrapping (day 0) while the remainder were not damaged until 7 and 28 days after wrapping. Damage was effected, over each inoculum cavity, using a prod of 15cm diameter supporting 17 fine needles. Control bales for each treatment were inoculated and undamaged. Bales were then stored unstacked, on their sides, in a N-S orientation. After 16 weeks (October 1999) bales were inspected for the presence of fungal growths on their surface. The wrap was then removed and all inoculum points were assessed visually for growth of *Schizophyllum*; identifications were confirmed microscopically where necessary.

Results. Within four months *Schizophyllum* basidiocarps were observed on bale surfaces. The influence of damage to the plastic wrap in favouring the establishment of *Schizophyllum* in bales was confirmed. The effect was seen particularly in high DM bales (Table 18). In undamaged, control bales only 2 of 40 inocula established growth in comparison with 24 of 40 inocula growing in damaged bales. The timing of damage to bales also affected *Schizophyllum* establishment. In high DM bales 60% of the inocula (24/40) grew in bales damaged immediately after wrapping. Fewer inocula established in bales damaged after 7 and 28 days, 3/40 and 1/40 respectively. The dry matter content of bales was also found to influence the ability of *Schizophyllum* to establish in bales. More inocula grew in high DM than in either medium or low DM bales. Table 19 shows the results of an experiment in which two types of *Schizophyllum*-carrier were compared as inocula for bales. *Schizophyllum* established to a greater extent from the *Rumex*-carried inoculum in both medium and high DM bales. Again, inoculum growth was favoured in the high DM bales. A significant difference between the inocula was seen in their abilities to establish in medium DM bales.

Table 18. Effect of herbage dry matter, bale wrap damage and the timing of wrap damage on establishment of *Schizophyllum* in bales. Values followed by the same letter are not significantly different from each other (P<0.05).

Dry matter level of bale	Mean number (± s.e.m) of inoculated points per bale showing growth of *Schizophyllum* and, in brackets, the total number of inoculum points (n=40) and also the number of bales (n=5) per treatment showing growth of *Schizophyllum*			
	Bales not damaged	Bales damaged after 0 days	Bales damaged after 7 days	Bales damaged after 28 days
Low (*ca* 20%)	0 a (0;0)	0.4 ± 0.2 a (2;2)	0.8 ± 0.2 a (4;2)	0.2 ± 0.2 a (1;1)
Medium (*ca* 30%)	0.2 ± 0.2 a (1;1)	0 a (0;0)	0 a (0;0)	0.2 ± 0.2 a (1;1)
High (*ca* 45%)	0.4 ± 0.2 a (2;1)	4.8 ± 0.2 b (24;5)	0.6 ± 0.3 a (3;2)	0.2 ± 0.2 a (1;1)

Table 19. Effect of mycelium carriers on establishment of *Schizophyllum* in bales of different DM levels. Values followed by the same letter are not significantly different from each other (P<0.05).

Schizophyllum carrier	Mean number (± s.e.m) of inoculated points per bale showing growth of *Schizophyllum* and, in brackets, the total number of inoculum points (n=40) and also the number of bales (n=5) per treatment showing growth of *Schizophyllum*		
	Low DM (*ca* 20%)	Medium DM (*ca* 30%)	High DM (*ca* 45%)
Colonised *Rumex* segments	0.2 ± 0.2 a (1;1)	3.4 ± 0.4 b (17;5)	5.8 ± 0.7 c (29;5)
Colonised 'rolled plate cylinder'	0.4 ± 0.2 a (2;2)	0 a (0;0)	4.8 ± 0.2 d (24;5)

Conclusions. *Schizophyllum* growth on big bales is favoured on silage of medium to high dry matter, in bales where the plastic film has been perforated soon after wrapping. In future experiments, which could be completed within four months, *Rumex* segments would be preferred as an inoculum carrier, being easier to prepare, more convenient to use, while successfully supporting the establishment of *Schizophyllum* in silage.

Experiment 12. Growth and survival of Schizophyllum commune mycelium in big-bale silage

In an earlier study, mycelial inoculum which had not established growth in undamaged experimental bales was retrieved and found to have lost viability after five weeks in baled silage. The purpose of the present investigation was to determine if this loss of mycelial viability was caused by the gaseous atmosphere within bales or/and by other chemical/microbial constituents of baled silage.

Materials and Methods. Two types of *Schizophyllum* culture were prepared: (i) 'rolled plate cylinders' which would be in direct contact with the silage and (ii) Petri dish cultures to be exposed to the gaseous environment in bales. 'Rolled plate cylinders' were prepared by growing mycelium of *Schizophyllum* Isolate MH15 on grass agar medium (15.0g powdered air-dried *Lolium perenne*, 15.0g agar, 1l water) for 7 days at 25°C. The colonised agar plate was then transferred from the dish to a 9cm filter paper and rolled to form a cylinder (*ca* 9 x 2cm). Petri dish cultures were prepared by inoculating grass agar medium in 15cm triple-vented plastic dishes with Isolate MH15 and incubating at 25°C for 24 hours. In mid-June 1999 bales were made using herbage from a *Lolium perennne*-dominant sward and wilted to *ca* 20, 30 and 45% dry matter (DM). For bales receiving the 'rolled plate cylinders', eight inoculum cavities (9 x 2cm) were cut in each bale – four cavities on each of the curved bale surfaces, into each of which a mycelial cylinder was placed. For bales receiving the large Petri dishes, eight 'pockets' at the same locations as before were cut in each bale, to *ca* 10cm below the bale surface into which the dishes were inserted and covered over with herbage. Inoculated bales were wrapped in four layers black polythene, turned and positioned in an upright orientation as when inoculated. Bales were then stored unstacked, on their sides, in a N-S orientation.

After 7 and 28 days respective bales were opened and all inoculum cylinders and dishes recovered. Colony diameters of dish cultures were measured and plugs of these, and portions of retrieved mycelial cylinders, were plated onto antibiotic-containing medium (16.0g malt extract agar, 15mg chlortetracycline, 15mg chloramphenicol, 1l water). After incubation at 25°C for 5 days plates were examined for evidence of mycelium re-growth.

Results. No fungal growths were evident on bales either before or after wrap removal. After 7 days in undamaged big bales all 'rolled plate cylinders' and plugs from Petri dish cultures had viable mycelium when tested *in vitro* (Table 19). After 28 days exposure in bales, mycelium from the dish cultures still retained viability but none of the 'rolled plate cylinders' retrieved from bales had living mycelium present. After 7 days exposed to the gas/volatile environment in undamaged bales none of the *Schizophyllum* cultures had grown in the Petri dishes (Table 20) however, the inoculum plugs on the plates were still viable (Table 19). In the same 7-day period control plates at 15°C supported colonies *ca* 20mm in diameter. After 28 days *Schizophyllum* colonies had grown in the Petri dishes in all bales, growth being significantly greater in the higher DM silage.

Table 20. Viability of *Schizophyllum* mycelium retrieved from undamaged big bales.

Silage dry matter level	**Number of viable colonised 'ro cylinders' (n=24)***		Number of viable Petri dish cultures (n=24)*	
	Retrieved after 7 days	Retrieved after 28 days	Retrieved after 7 days	Retrieved after 28 days
Low (*ca* 20%)	24	0	24	24
Medium (*ca* 30%)	24	0	24	24
High (*ca* 45%)	24	0	24	24

* Eight per each of three bales, for each DM level, at each time interval.

Table 21. Effect of gases/volatiles in undamaged big bales on *Schizophyllum* viability and growth in Petri dish culture after 7 and 28 days. Values followed by the same letter are not significantly different from each other ($P<0.05$).

Silage dry matter level	Mean colony diameter ± s.e.m. (mm) (n=24 colonies)*	
	Retrieved after 7 days	Retrieved after 28 days
Low (*ca* 20%)	0 a	51.9 ± 13.5 b
Medium (*ca* 30%)	0 a	64.2 ± 6.6 b
High (*ca* 45%)	0 a	97.7 ± 4.6 c

* Eight Petri dish cultures per each of three bales, for each DM level at each time interval.

Conclusions. The results show that *Schizophyllum* growth in undamaged big bales is influenced by gases/volatiles and also by other components of silage. The gas environment is initially inhibitory to growth but is not lethal to the mycelium. As the silage fermentation proceeds, the gas/volatile composition changes and no longer prevents *Schizophyllum* growth. Likewise, mycelium directly in contact with herbage cannot grow but does retain viability for at least a week however, subsequent changes in the chemical/microbial environment of silage are lethal to the fungus. Elucidation of these effects on *Schizophyllum* could lead to control measures for the fungus.

Experiment 13. Growth of Schizophyllum in various oxygen and carbon dioxide atmospheres

Baled silage is commonly wrapped in four layers black polythene which creates a microaerobic environment favourable to microbial fermentation and silage conservation. Forristal *et al.* (1999) measured gas levels in bales over a 40-week period and showed O_2 levels within the range 1.0–1.65%. Over the same period CO_2 levels fluctuated from 90% after 1 week, to 16% after 40 weeks. The purpose of the present investigation was to determine the ability of *Schizophyllum* to grow under low O_2 levels and low O_2 with high CO_2 levels such as the fungus would be exposed to in baled silage.

Materials and Methods. Growth of the fungus was examined in atmospheres containing 0.01, 0.1, 1.5 & 21% O_2 in a N_2 balance and also in 1.5% O_2 with 60 or 90% CO_2 in a N_2 balance. Additional tests were conducted using oxygen-free nitrogen (OFN), 99.95% CO_2, and compressed air; plates were also incubated in air external to the test chamber. Gas mixtures (certified to be within ± 2% of the stated value) were supplied by BOC Gases and Air Products. Potato dextrose broth plates were inoculated with *Schizophyllum* (n=9 for each of the three isolates G01, MH15 & CN01) and incubated at 23°C in a gas-tight chamber through which gas flow was adjusted to $50 ml.min^{-1}$ after an initial purge of $100 ml.min^{-1}$ for one hour to equilibrate the chamber. After 9 days, mycelial biomass was harvested on pre-weighed filter papers (Whatman No. 541, 9cm) and dried to constant weight at 85°C.

Results. The results of the growth experiments (Figs 12 & 13) are summarised below:

- The three *Schizophyllum* isolates responded similarly to changes in O_2 and CO_2 atmospheres.
- No growth occurred in the absence of O_2. This was shown using oxygen-free nitrogen and confirmed in anaerobic jar tests.
- *Schizophyllum* grew at 0.01% oxygen producing a biomass that was 35% of controls. Biomass production in 1.5% O_2 was 65% of that produced in air.
- Growth occurred in atmospheres containing low O_2 with high CO_2 concentrations. In 1.5% O_2 with 60% CO_2 and 1.5% O_2 with 90% CO_2, growth was 45% and 15% of controls (air), respectively. The inhibitory effect of CO_2 is evident when these results are compared with biomass production at 1.5% O_2. Though CO_2 is inhibitory, some growth did occur at 99.95% CO_2 and the mycelium retained viability after 9 days exposure.
- Optimum growth was recorded in air (compressed, in chamber). Reasons for the consistent biomass differences between cultures grown in air within the chamber and external to it (Fig. 12) are not clear. The additional biomass observed in air-grown *Schizophyllum*, relative to 21% O_2, may be attributable to CO_2 fixation by the fungus.

Figure 12. Biomass production by three *Schizophyllum* isolates in oxygen atmospheres after nine days at 23°C. Each bar represents the mean ± s.e.m. of nine replicates. For each isolate, bars with the same symbol are not significantly different from each other ($P<0.05$). (**A**) OFN; (**B**) 0.01% O_2; (**C**) 0.1% O_2; (**D**) 1.5% O_2; (**E**) 21% O_2; (**F**) compressed air; (**G**) external control.

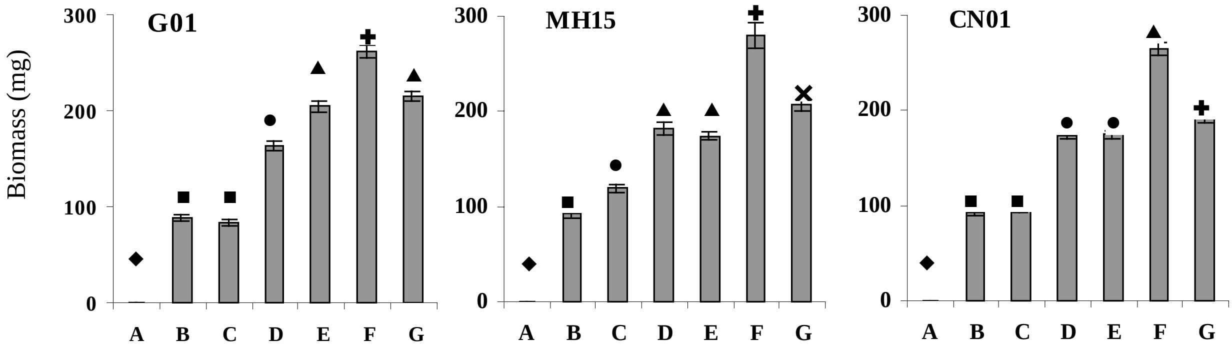
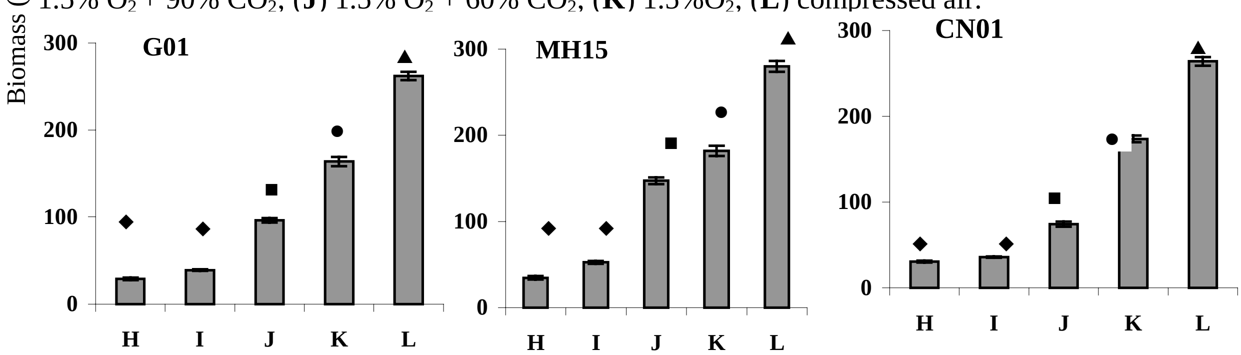


Figure 13. Biomass production in low O_2 with high CO_2 atmospheres by three *Schizophyllum* isolates after nine days at 23°C. Each bar represents the mean ± s.e.m. of nine replicates. For each isolate, bars with the same symbol are not significantly different from each other ($P<0.05$). (**H**) 99.9% CO_2; (**I**) 1.5% O_2 + 90% CO_2; (**J**) 1.5% O_2 + 60% CO_2; (**K**) 1.5%O_2; (**L**) compressed air.



Conclusions. *Schizophyllum commune* isolates from big-bale silage are capable of growing at oxygen levels lower than those recorded in big bales. The fungus is also capable of growth at the high carbon dioxide levels measured during early fermentation in bales. Such attributes contribute to the success of *Schizophyllum* in colonising baled silage under microaerobic conditions.

Experiment 14. Effects of silage organic acids on in vitro growth of Schizophyllum commune

In the present study, the effects of silage acids (acetic, butyric, lactic and propionic) on *Schizophyllum* growth were investigated. The acid concentrations chosen were within, and greater than, the concentration ranges recorded in big-bale grass silage (O'Kiely *et al.,* 1998).

Materials and Methods. *Schizophyllum* was grown in a complete medium (Wessels, 1965) containing glucose (2%) and asparagine (0.15%) as C and N sources, respectively. Appropriate additions (g/L) of the test acids were made to liquid media and pH was adjusted to 4.0 or 5.0, using NaOH or HCl. Media were sterilised by filtration though sterile disposable filter units (0.22 μm pore size; Nalgene). For each test, five replicate Petri dishes (9 cm diameter, each containing 25 ml medium) were centrally inoculated with a single plug (7 mm diameter) of an actively growing *Schizophyllum* culture and incubated at 25 °C for 14 days. Precautions were taken to prevent diffusion of volatiles between cultures. Biomass dry weights were determined by harvesting cultures onto pre-weighed filter papers (Whatman 541), followed by drying at 90 °C for 24 h. Viability of mycelia following exposure to test compounds was determined by transferring hyphae to malt extract agar and incubating at 25 °C. Means and standard errors were calculated using MS Excel 97, and data for each acid was analysed by two-way ANOVA using Statview 5.0.

Results. Figure 14 details the effects of the acids on growth of *Schizophyllum*. For each acid the inhibitory effect was greater at pH 4.0 than at pH 5.0 ($P < 0.01$). Strongest inhibition occurred using butyric acid (Figure 14a), with no growth at 1.0 g/L (pH 4.0) or at 3.5 g/L (pH 5.0). Acetic acid (Figure 14b) had a stimulatory effect on growth to 10.0 g/L at pH 5.0 ($P < 0.01$) but at pH 4.0 was fungistatic at 3.5 g/L. Propionic acid (Figure 14c) prevented growth at 2.0 g/L and 5.0 g/L, at pH 4.0 and pH 5.0, respectively. Lactic acid (Figure 14d) was the least fungitoxic of the compounds tested.

Concentrations of butyric, acetic and propionic acids fungicidal to *Schizophyllum* were, respectively, 5.0 g/L, 20.0 g/L and 20.0 g/L (all at pH 4.0).

Conclusions. Concentrations of lactic acid and acetic acid common in baled silage, *ca.* 30.0 g/L, and 2.5 g/L, respectively, are not inhibitory to growth of *Schizophyllum*, and may have a stimulatory effect. Butyric and propionic acids were inhibitory at all concentrations tested. The propionate concentrations common in baled silage (*ca.* 0.1 g/L) are unlikely to significantly inhibit *Schizophyllum* growth but butyrate concentrations in silage (*ca.* 1.0 g/L) could present a fungitoxic environment.

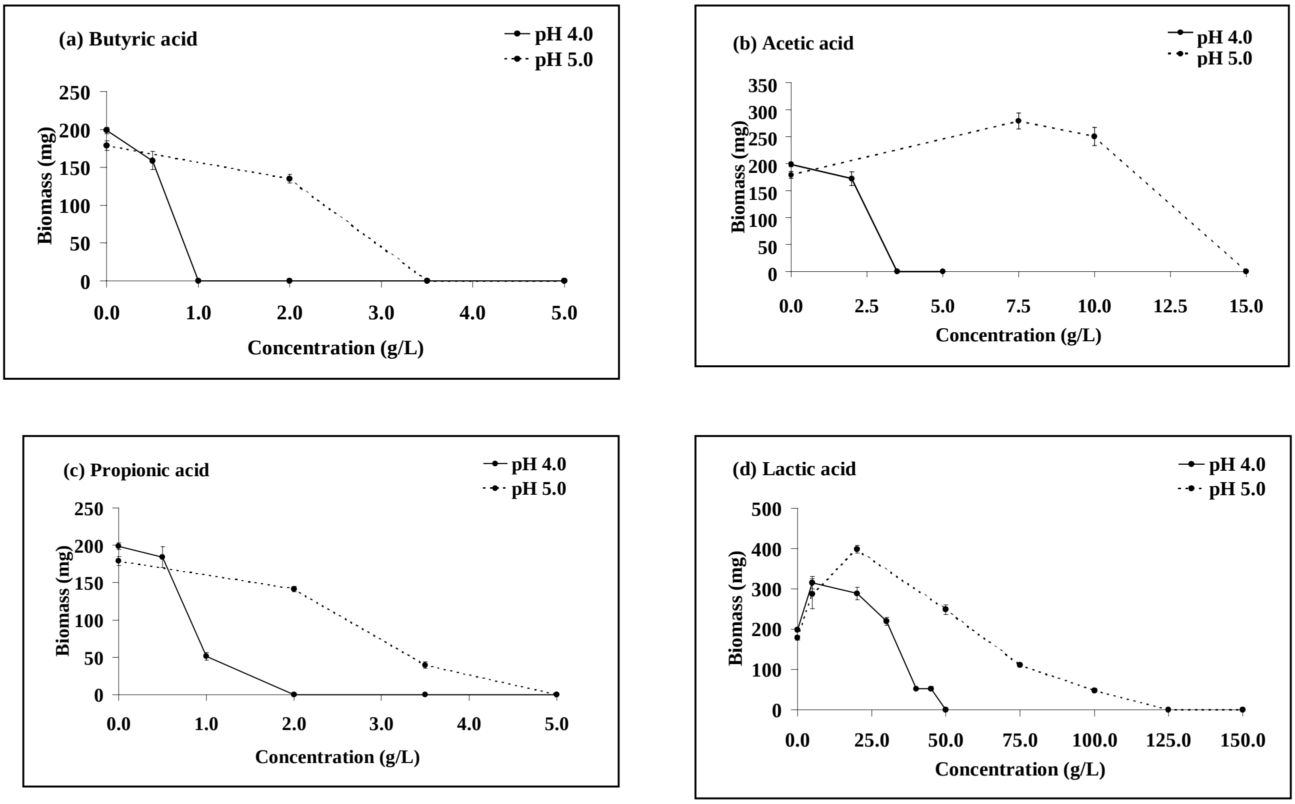


Figure 14. Biomass production (mg dry weight) by *Schizophyllum* after 14 days at 25 °C in media containing different concentrations of (a) butyric, (b) acetic, (c) propionic or (d) lactic acid. Each point is the mean (± s.e) of five replicates.

Experiment 15. Ingestion by beef cattle of baled silage infected with ***Schizophyllum commune***

Schizophyllum commune is commonly found growing on baled silage on Irish farms. As a fungus whose growth and development is facilitated by non-anaerobic conditions within a wrapped (plastic stretch film)bale, its visible presence on conserved forage is likely to be associated with increased quantitative and qualitative losses during ensilage. The aim of the present experiment was to determine the intake of a baled silage with a severe infection of *Schizophyllum commune* relative to other baled or conventional silages. It was conducted at Grange in collaboration with Dr. B. Earley.

Nine Friesian heifers (mean (s.d.) liveweight 377 (42.5)kg when offered Silage 4) were individually tethered and offered a sequence of grass silages *ad libitum* for approximately 12 weeks. Animals did not have access to other feedstuffs, but did have free-access to fresh water. Silages 1 through 5 were offered sequentially for 21, 16, 40, 4 and 3 days, respectively. Silages 1, 3 and 5 were precision-chop, unwilted grass silages stored in bunker silos, while silages 2 and 4 were made from wilted grass and stored as bales wrapped in black stretch-film. Silage 4 was obtained from a commercial farm where the plastic wrap surrounding the bales had been damaged, and where extensive growth of *Schizophyllum commune* had permeated through the bales. Voluntary intakes of silage dry matter were obtained daily for each animal, and blood samples were obtained by jugular veni-puncture on days 14, 15, 35, 36, 72 and 73. Consumption of silage 4 was particularly low, and after four days being offered to the heifers, this treatment was discontinued. Each silage was sampled daily, and composited in chronological sub-groups to produce 4, 3, 6, 2 and 2 samples of Silages 1 through 5, respectively.

Silage composition, *in vitro* digestibility and intake are summarised in Table 22 while Table 23 summarises blood variables. Silages 1, 3 and 5 had high concentrations of crude protein, but were not well preserved – their relatively high contents of butyric acid and ammonia-N were indicative of non-inhibited clostridial activity. [Silages 3 and 5 were the same silage offered before and after the *Schizophyllum commune* infected bales]. In this context, the intake of Silages 1 and 3 were as expected for healthy animals. The intake of Silage 5 was lower than anticipated – it is not clear whether this is a reflection of the relatively short duration for which intake of this silage was measured, or if it was a carryover effect from ingestion of *Schizophyllum commune* infected forage. Silage 2 was successfully wilted, but still showed some evidence of clostridial activity. Consequently, its intake was within the limits expected. Intake of Silage 4 was very low, and it was necessary to discontinue offering it to cattle after four days due to consistently low ingestion by the heifers. The data in Table 23 indicate that both individually and as a group, the animals used had a satisfactory health status which did not give rise to concern, during the period before they were offered Silage 4.

It is concluded that a severe infection of *Schizophyllum commune* in wilted baled silage can result in dramatically low ingestion by cattle offered no other feed source.

Table 22: Silage composition, in vitro digestibility and intake

	Silage 1	Silage 2	Silage 3	Silage 4	Silage 5
	Mean (s.d.)	Mean (s.d.)	Mean (s.d.)	Mean (s.d.)	Mean (s.d.)
Dry matter[1]	202(5.5)	305(50.2)	195(11.5)	740(75.0)	192(1.4)
C.protein[2]	169(11.2)	142(12.0)	189(7.4)	88(1.8)	189(0.7)
Ash[2]	106(9.8)	97(1.0)	120(12.4)	79(11.8)	120(5.7)
DMD[1]	652(65.9)	592(42.9)	700(29.5)	540(57.3)	707(11.3)
OMD[1]	642(70.2)	578(45.6)	695(36.6)	536(70.0)	702(5.6)
pH	4.55(0.493)	4.70(0)	4.35(0.367)	7.90(0.707)	4.20(0.141)
Lactic acid[2]	43(39.0)	40(7.5)	75(30.0)	1(0.9)	66(20.3)
Acetic acid[2]	40(9.6)	10(1.8)	48(14.6)	0.2(0.01)	52(6.9)
Propionic acid[2]	7(2.6)	2(0.6)	5(1.6)	0.02(0.005)	5(1.3)
Butyric acid[2]	18(16.7)	6(3.1)	8(3.3)	0.13(0.071)	8(3.8)
Lactic/Acetic	1.01(0.884)	3.90(0.404)	1.81(1.084)	9.25(6.091)	1.31(0.559)
Lactic/Ferm. acids[1]	352(253.5)	696(39.5)	538(182.4)	790(141.7)	498(121.9)
Ammonia-N[3]	189(115.3)	162(46.1)	154(44.5)	21(4.6)	179(37.4)
DM intake (kgDM/day)	5.1(0.77)	4.8(0.42)	5.0(0.86)	1.7(0.35)	3.4(0.43)

[1](g/kg), [2](g/kg DM), [3](g/kg N)

Table 23: Blood variables for the heifers

	Silage 1	Silage 2	Silage 3
	Mean (s.d.)	Mean (s.d.)	Mean (s.d.)
Protein[1]	58(3.6)	58(3.2)	59(3.7)
Albumin[1]	31(3.2)	32(2.5)	32(2.0)
Globulin[1]	27(2.2)	26(1.9)	27(2.2)
Urea[2]	4.1(0.60)	4.4(0.58)	5.0(0.41)
Glucose[2]	4.2(0.02)	4.0(0.16)	4.6(0.25)
B-hydroxybutyrate[2]	0.38(0.09)	0.30(0.07)	0.40(0.11)
Bilirubin[3]	2.8(1.12)	2.0(0.60)	2.3(0.70)
gGT[4]	10.5(3.3)	11.7(3.5)	14.0(3.9)
Glutamate dehydrogenase[4]	11.3(3.9)	10.4(3.9)	11.9(7.4)
White blood cell count[5]	8.0(1.75)	8.5(1.72)	7.4(1.41)
Lymphocyte%	7.6(7.74)	1.6(1.26)	4.1(4.15)
Monocyte%	1.2(1.04)	2.4(5.32)	3.3(4.82)
Granulocyte%	91.2(8.52)	96.1(5.12)	92.7(5.56)
Lymphocyte no.[5]	0.61(0.706)	0.10(0.067)	0.26(0.283)
Monocyte no.[5]	0.10(0.103)	0.20(0.392)	0.22(0.300)
Granulocyte no.[5]	7.4(1.58)	8.3(1.84)	7.0(1.45)
Red blood cell count[6]	9.9(0.83)	10.2(0.95)	8.9(0.84)
Haemoglobin[7]	11.7(1.04)	12.1(1.05)	10.8(0.88)
Haemocrit%	32.2(2.65)	33.5(2.80)	29.8(2.39)
Mean corpuscular volume[8]	32.6(1.11)	32.8(1.12)	33.6(1.71)
Mean corpuscular haemoglobin[9]	11.8(0.36)	11.9(0.51)	12.2(0.69)
Mean corpuscular haemoglobin[7]	36.2(0.76)	36.3(0.60)	36.2(0.49)
Red blood cell distribution width%	16.7(1.13)	16.9(1.19)	17.5(1.10)
Platelet count[5]	521(69.1)	500(103.2)	531(94.1)
Platelet crit%	0.26(0.038)	0.26(0.043)	0.26(0.025)
Mean platelet volume[8]	5.0(0.70)	5.4(0.84)	5.0(0.67)
Platelet distribution width%	16.4(0.38)	16.1(0.38)	16.1(0.52)
Gamma interferon[10]	0.114(0.0120)	0.114(0.0106)	0.116(0.0101)

[1]g/l, [2]mmol/l, [3]umol/l, [4]u/l, [5]x10^{3}ul, [6] x10^{6}ul, [7]g/dl, [8]fl, [9]pg, [10]O.D.@450nm

5. PREVENTING WILDLIFE DAMAGE

The integrity of the plastic stretch-film surrounding baled silage is vital if anaerobic conditions are to be maintained within bales of forage during ensilage. The main reasons why air accesses wrapped bales include damage to the plastic film due to

(a) mechanical handling of wrapped bales
(b) damage to the plastic film by wildlife, domestic animals (including farm livestock) and humans, and
(c) the amount and quality of plastic film used or the manner in which it is applied to bales.

This study involved collaboration between Teagasc and the Department of Environmental Resource Management at University College Dublin.

Experiment 16: Vertebrate pest damage to wrapped baled silage in Ireland

Agriculture dominates land use in Ireland, and the landscape is characterised by permanent grassland divided into relatively small fields bounded by hedgerows. The latter account for 1.5% of the total land area while forests, which account for about 7% of land area, are usually small in area and are distributed throughout the country. Hedgerows as well as forests, are major habitats for wildlife, and provide vital corridors for their movement (Aalen, 1997). Irish land use thus creates predisposing opportunities for agriculture-wildlife conflicts.

Grass contributes about 97% of total ruminant feed in Ireland (Lee, 1988). Beef and dairy production systems are based on cattle grazing grass in summer and being fed conserved grass-based diets indoors in winter. Currently, about 82% of all farms make silage, utilising 28% of the area of farmland (O'Kiely et al, 1998). Baled silage accounts for one-third of this total, and is made on 80% of all silage making farms. It is the main silage making system on smaller sized farms and the second system on larger sized farms. It is thus widespread throughout the country. On average, the grass in baled silage has been wilted for 1 to 2 days to about 32% dry matter (DM) content. Bales are cylindrical with a nominal width of 1.22m, and are usually mechanically wrapped with four layers of black plastic stretch film in the field immediately after baling and before transporting to the storage site. They are invariably stored outdoors (O'Kiely et al, 1998).

The fundamental principle controlling the preservation of grass as silage is the termination of aerobic biological processes. This is achieved by storing the harvested crop under anaerobic conditions (McDonald et al, 1991). With baled silage this occurs in practise by baling the grass and immediately wrapping each bale with at least four layers of plastic stretch film. If the integrity of this seal is damaged during storage, the subsequent ingress of oxygen will permit the growth of fungi and other micro-organisms, resulting in extensive quantitative and qualitative losses. For example, Wyss (1991) inflicted two holes, 2cm in diameter, in the plastic wrap surrounding bales and three months later recorded higher dry matter losses, mould growth and rotted silage, and a reduced nutritive value, compared to where plastic wrap was not damaged. There was a reduced concentration of CO_2 in bales which had holes in the plastic wrap and an increased O_2 concentration when the holes were on the top of the bales. The latter could also permit rainwater to enter the bales , which could further accentuate losses. There can be health implications due to holes in the plastic wrap. The outer layer of fodder in a damaged bale can become a selective culture medium for Listeria monocytogenes (Fenlon, 1988), and fungal growth can also proliferate. Airborne spores from the latter can lead to respiratory disease and permanent damage to the sensitive mucosal surfaces of the lungs and respiratory passages of livestock and humans. Ingested mycotoxins can interfere with nutrient metabolism and endocrine and exocrine functions, and surpress the immune system (CAST, 1989), resulting in economically deleterious symptoms such as reduced feed consumption, decreased animal performance, poor fertility, and increased incidence and severity of disease (Whitlow and Hagler, 1997).

Damage to the stretch film can be caused by mechanisation difficulties during wrapping, handling, transport or storage, severe weather conditions or vertebrates. The latter includes domesticated farm animals, wildlife and humans. There is a perception that the scale of damage caused by vertebrates to the film surrounding baled silage is often considerable on Irish farms, but this has not been quantified.

Birds such as rooks (Corvus frugilegus), jackdaws (Corvus monedula) and starlings (Sturnus vulgaris) are thought to be the animal species most often responsible for damage to the plastic stretch film. They are all highly gregarious species that are widespread throughout Ireland (Fraissinet et al, 1997; Brenchley and Tahon, 1997; Tiainen and Pakala, 1997), and often come into conflict with man (Feare, 1978; Feare, 1989). Other bird species such as seagulls (Larus spp) and pigeons (Columba palumba L.), as well as rats (Rattus spp), domestic dogs, cats and farm livestock (cattle, sheep and horses) are also thought to be responsible for such damage.

This survey was conducted to determine the scale of visible damage by vertebrates to the stretch film on baled silage in Ireland and relate it to associated silage-making and storage characteristics.

Materials and methods. The survey was conducted in late January 1999 on three-hundred farms selected to give a representative sample of farming systems and geographical locations throughout Ireland. Six routes of 116 (standard deviation (s.d.), 19.3) km mean length were each divided into five equal sections, with the first ten farms making baled silage per section being selected and studied. These routes traversed the range of land use and soil types, geographical locations, weather patterns, farm sizes and farming enterprises found in Ireland. A detailed survey was completed on each farm visited. Records were taken of the number of bales present, the storage characteristics of the bales, the presence or absence of rookeries within 800m of the bales, the presence or absence of visible markings of different animal species on the bales (birds, rats, cats, dogs, farm livestock and humans) and the mechanisms used to prevent or remedy damage to the plastic film on the bales. The scale of damage to the plastic film on the bales was recorded and presented in four categories: 0%, 1 to 10%, 11 to 50% and 51 to 100% of bales damaged. The storage characteristics of the bales that were recorded were (i) orientation - stored on curved side, flat end or both, (ii) storage site - adjacent to farm buildings/yard or in the silage field, (iii) colour of the plastic film, and (iv) height of baled silage storage - one, two, or three tiers high.

Footprints on the plastic film were used to identify the relatively recent presence of birds, cats, dogs or humans on the wrapped bales. In the case of birds, bird droppings were also used in addition to footprints. For rats, the presence of fresh rat runs adjacent to the bales and footprints on the bales were used to identify their proximity to the silage bales.

Bird damage to the plastic stretch film on the bales was identified by holes, mostly on the upper surface of the bales where birds alight. These holes went through all the film layers, and sometimes forage, or the net used to maintain the shape of the bales, had been pulled through the holes by the birds. Dog and cat damage was identified by the presence of paw prints and associated tears and holes in the film. Unlike with bird damage, these were generally present on the sides as well as the top of the bales, and appeared to occur as cats or dogs climbed onto the bales. Damage caused by farm livestock usually appeared as quite large ragged holes in the film on the side of the bales and was associated with other evidence of the presence of livestock around the stored bales. The bales on the periphery of a collection would have been the most vulnerable to this type of attack. The percentage of bales in a collection that had adhesive plastic repair patches (most often applied by the farmer to remedy bird damage occurring in the field between wrapping bales and transporting to storage) on the plastic film was recorded. Any other visible damage to the plastic film was also recorded. Such damage was attributed to mechanical or weather damage, or apparent imperfections in the film. The differentiation of animal damage from imperfections inherent in the film was based on the likelihood that four or more such imperfections would not overlay one another on the bale.

The techniques used to prevent damage to the plastic film on silage bales which were recorded were a) livestock fencing around the bales, b) bird netting over the bales, c) paint on the stretch film, d) tyres on the bales and e) other. Livestock fences constituted any fence type or physical barrier used to prevent the access of livestock to the stored bales. Where paint was applied to the plastic film it was normally applied by brush as white markings or letters. Any other method used to prevent vertebrates gaining access to, or deterring them from damaging, the film on the bales was also recorded.

The data were analysed by chi square analysis, using GENSTAT 5 (Genstat 5 Committee, 1993), to compare the extent of bird or cat damage with bale storage characteristics, and also bird damage with the presence or absence of specified vertebrate markings and damage prevention initiatives.

Results. The results of the survey show that the average farm visited had about 71 (s.d. 60.2) bales remaining at the time of the survey, and that this represented 79(s.d. 60.2)% of the bales that had been available for the winter. Black was the plastic stretch film colour used most frequently (Table 24), with relatively few cases of white or green plastic being found.

On most farms all of the bales were stored in a single tier, although on farms with larger numbers of bales they were likely to be stored two or three tiers high. It was most usual for bales to be stored in or beside the farmyard, although on about one-third of farms they were stored in a grass field (often where the grass for the bales had been grown).

Most farms had at least one rookery within 800m of where the bales were stored (Table 25). The positioning of bales in proximity to such a rookery did not have a significant effect on the levels of bird damage evident on bales (Table 29).

The scale of the interaction between birds and baled silage during storage was also evident in the high proportions of farms where some bales showed evidence of footprints or bird droppings (Table 25). The effects of this are shown in Table 26 where the frequency of different intensities of holes, apparently made by birds, in the plastic wrap on bales can be seen. Almost two-thirds of farms with baled silage had bales with holes through the plastic film similar to the holes made by birds. A chi squared analysis of the results (Table 29) found that bales on farms where the bales were stored on their curved side, or where bales were stored three tiers high, were likely to suffer significantly more bird damage than bales on farms where were stored on their flat end and/or stored one or two tiers high. Bales on farms where the bale wrap had bird footprints or droppings on them, or indeed, bales that had foot markings of cats, dogs, rats and humans, were all more likely to suffer from more bird damage than those that did not. The proportion of bales where the plastic film was damaged by birds was quite variable. On a very small number of farms, over half the bales had holes apparently caused by birds.

After birds, cats appeared to be the next most serious cause of damage by vertebrate animals during storage (Tables 25 and 26). The evidence was that this occurred as the cats were climbing onto the bales, and was seen as small vertically elongated holes on the sides and shoulders of the stored bales. In contrast, no damage to the plastic film was evident in the vicinity of the paw marks left by the cats walking on the bales. Bales stored in the farmyard rather than in a grass field were most vulnerable to this type of damage, while the orientation of the bales during storage had no bearing on the likelihood of such damage (Table 30).

In general, the incidence of observed damage caused to baled silage by rats (4.7% of farms; 0.003% of bales), dogs (3.0% of farms; 0.007% of bales) and farm livestock (9.3% of farms; 0.015% of bales) was less than for birds and cats. Bales on over one-quarter of the farms in the survey had clear visible evidence of damage caused by problems related to mechanisation, weathering or plastic quality (Table 27).

There is a widespread perception of bird damage occurring to the plastic film on bales during the interval between wrapping bales and transporting them from the silage field to the bale storage site. An estimate of the scale of this problem can be obtained from the proportions of farms with different incidences of plastic repair patches on bales (Table 27). Farmers generally protected their stored bales from farm livestock, but the evidence was that protection from other animals was employed much less (Table 28). Chi-squared analysis of protection devices and bird damage indicated no significant difference between those that did and did not use protection devices (Table 29).

Discussion. The baled silage wrap and storage characteristics on the 300 farms surveyed were consistent with those in previous studies of baled silage in Ireland (O'Kiely *et al*, 1998). The strategy of selecting farms on six pre-selected routes can thus be considered to have succeeded in achieving a representative sample of Irish baled silage. A wide range in the incidence of vertebrate pest damage to wrapped baled silage occurred among and within routes. However it was beyond the scope of this survey to attribute geographical or climatic explanations to these ranges.

Birds appear to be a major cause of damage to the plastic wrap on baled silage in Ireland, affecting bales on 63% of farms. Despite the apparent absence of any reference in the literature pertaining to bird damage to the plastic wrap on baled silage, anecdotal evidence suggests that rooks (Corvus frugilegus) are the species most often responsible for this damage. Bird droppings were observed on 85% of bale collections and bird footprints on 56% of collections. Such evidence is indicative of an extensive interaction between birds and stored baled silage which wears off over time due to weathering. They reflect the incidence of farms with damaged plastic wrap, and they indicate the interaction between birds and bales continues over an extended duration of bale storage. Most of the holes in the plastic wrap that were caused by birds were observed on the top surface of the bales. Thus the birds made the holes in the plastic wrap after flying onto the bales, rather than attacking them directly from the ground. The sizes of many of the holes observed suggest that they resulted from birds using their beaks rather than their feet.

Market sources indicate that farmers usually patch holes in the plastic wrap surrounding bales as they are putting them into storage, with relatively little patching occurring thereafter. The presence of such plastic patches thus suggests that considerable damage can be inflicted to the plastic wrap during the relatively short period (i.e. less than 24 hours (O'Kiely *et al,* 1998)) between wrapping and storage, when the wrapped bales were on the stubble on the silage fields. The evidence is that this damage occurred on 53% of farms with bales. It is clear that farmers need to prevent such damage. Consequently, the removal of bales for wrapping at the site of storage, or the immediate removal of the bales after wrapping in the field, is recommended.

No relationship was found between the incidence of bird damage and the presence or absence of rookeries. This is not surprising given the widespread distribution of both baled silage and rookeries throughout Ireland. A characteristic of rookeries in Ireland, which is related to the relatively small sized fields surrounded by hedgerows and trees, is a preponderance of small rookeries throughout the country. A typical rookery in Ireland might contain only a couple of hundred rooks (MacDonald, 1983), whereas populations of thousands would be common in mainland European countries (Hillcoat, 1994). Since rooks will forage within a 1.0 to1.5 km radius of their nests, the implication of this is that virtually all baled silage in Ireland will be made and stored within the home range frequented by rooks. Furthermore, the most abundant feed sources for rooks between May and September are likely to be in the grass stubble immediately after silage or hay are mown (MacDonald, 1983).

In Ireland, silage bales are predominantly wrapped with four layers of black plastic film which has a combined pre-stretch thickness of about 100μm. Because of the nature of the wrapping operation the curved surface of the bale will nominally be wrapped with four layers of plastic film, while the flat ends will have as many as 16 to 20 layers in the centre, decreasing gradually to four layers on the outer edge. Bird damage was predominantly on the top surface of the bale, and bales stored on their curved sides were more prone to such damage than those stored on their flat ends. This is possibly due to there being more layers of film on the flat ends of the cylindrical bales than on the curved sides and to the resultant greater difficulty for a bird to penetrate the greater number of layers of plastic wrap. Although the incidence of bird damage to plastic film on farms where the bales were stored three tiers high was higher than on farms where bales were stored one or two tiers high, the reasons for this effect are not evident.

While most farmers took no precautions to protect the plastic wrap on their bales against wildlife damage during storage, 17% did paint markings onto the bales. This usually involved brush painting white emulsion paint in the shape of an X or an O onto the plastic wrap. This procedure, which seems to be particular to Ireland, is perceived to be a deterrent to bird attack, although the evidence from this survey does not support this. Netting or other devices were rarely used to prevent bird damage. There is clearly considerable need to reduce damage to the plastic wrap in farming practice, and effective approaches to do this need to be identified.

After birds, cats were the species most often responsible for damaging the plastic wrap on baled silage, although published references reporting this could not be found. Most cat damage occurred to bales stored in the farmyard rather than in the field. It appeared to be caused by cats using their unsheathed claws to climb onto the wrapped bales , thereby penetrating the plastic wrap and facilitating aerobic losses as described for bird damage. Cats are territorial domesticated animals that patrol their territories in search of intruders and food. Such patrols by domesticated animals might thus be expected to centre on the farmyard rather than in fields away from human habitation (Hart, 1978), and could lead them to climb onto the bale collections as part of their movement. The latter is supported by the significant relationship observed between cat footprints on bales and damage caused as the cat climbed onto the bales with it's claws unsheathed. The latter was further supported by the observation that cat damage occurred only to the bales on the periphery of collections. The absence of damage when the cat walked on the bales was because their claws were withdrawn and sheathed while walking.

The absence of an interaction between cat damage and bale storage orientation may be explained by the two locations of cat damage on wrapped bales. Damage appears to be caused separately by both the front and rear feet of the cat as it pulls (front feet on the bale shoulder) and pushes (rear feet half-way up the bale) its claws into the film, and by the gripping and penetrating intent of the cat with its claws. While it may be impractical in many situations to prevent cats visiting wrapped baled silage, the holes they make in the plastic may be prevented by placing some material against the bales on the periphery of the collection to facilitate them climbing onto the bales without doing damage to the plastic wrap. After birds and cats, livestock, rats and dogs caused comparatively small amounts of damage to bale collections. Livestock damage should be easily preventable through the correct use and application of livestock fencing.

Rat damage, while a minor incidence, can cause extensive losses to the collections where they are prevalent. The damage occurred generally at ground level and was identifiable by the characteristically serrated plastic edge around the periphery of holes and by the presence of active rat runs and burrows in the vicinity of the bale collection. Such damage could have implications for animal health. Rats (Rattus norvegicus) are the most important host for transmission of leptospirosis (Weil’s disease) to livestock, as well as being a corridor for other diseases (Zieris, 1992; Webster and Macdonald, 1995; and Abd el-Wahed et al, 1999). Damage caused by domestic dogs was of minor incidence and should be substantially preventable.

Conclusions. Vertebrate animal damage to the plastic wrap on baled silage is widespread in Ireland. Of particular importance is the damage caused by birds (63% of farms with bales) and cats (29% of farms) during long term bale storage. Furthermore, birds damaged the plastic wrap during the interval between wrapping the bales and removing them from the silage field to the storage area on 53% of farms. The incidence of damage caused by rats, dogs and livestock is smaller. The proximity of a bale collection to a rookery did not have a significant effect on bird damage levels.

The incidence of damage by birds was greater on farms where bales were stored on their curved side rather than on their flat end, and where bales were stored three tiers high rather than one or two tiers high. Farm where bales had bird footprints or droppings, or indeed, foot markings of cats, dogs, rats and humans, were more likely to have more bird damage than those that did not. Farms where bales were stored in the farmyard rather than in a grass field were most vulnerable to cat damage to the plastic film on bales, while the orientation of the bales during storage had no bearing on the likelihood of damage by cats. Finally, while most farmers erected fencing around their bale collections to prevent access by livestock, few took any precautions to prevent damage by birds or other vertebrate species to the plastic wrap on baled silage.

Table 24: Bale characteristics from 300 farms visited throughout Ireland.

		% of farms
Height of bale storage (%of farms)	- one tier	72
	- two tiers	12
	- three tiers	16
Plastic film colour (%of farms)	- black	96
	- other	4
Storage location (%of farms)	- farmyard	65
	- field	35
Storage orientation (%of farms)	- on end	47

	- on side	49
	- both	4

Table 25. Percentage of farms (all with baled silage) with specified characteristics

	% of farms
Rookeries near the farm	71
Rat runs near the bales	11
Foot-prints on some bales	
~ bird	56
~ cat/dog	39
~ human	11
Bird droppings on some bales	85

Table 26. Percentages of farms with specified incidences of holes in the baled silage plastic film, caused by birds or cats.

% bales per farm	Birds	Cats
None	37	71
1 to 10	50	23
11 to 50	12	6
51 to 100	1	0

Table 27. Percentages of farms with specified incidences of plastic repair patches or damage not caused by vertebrates.

% bales per farm	Plastic repair patches	Non-vertebrate damage
None	47	72
1 to 10	37	26
11 to 50	15	2
51 to 100	1	0

Table 28. Percentages of farms employing various wrapped bale protection initiatives.

Protection system	% of farms
Livestock-proof fencing	86
Anti-bird netting	2
Anti-bird paint	17
Other anti-bird features	9

Table 29: Incidence (%) of damage by birds to baled

							X^2	df	P
Storage height	One tier		Two tiers		Three tiers				
	✗	✔	✗	✔	✗	✔			
	30.7	41.3	3.0	8.7	3.3	13.0	10.60	2	0.005
Bale orientation	Curved		Flat		Both				
	✗	✔	✗	✔	✗	✔			
	14.0	35.0	22.0	25.0	1.0	3.0	11.00	2	0.001
Storage site	Field		Yard						
	✗	✔	✗	✔					
	11.4	23.4	25.7	39.5			1.34	1	0.247
Presence of rookeries									
	Rookery		No rookery						
	✗	✔	✗	✔					
	26.1	45.1	10.7	18.1			0.01	1	0.819
Bird footprints on bales									
	Footprints		No footprints						
	✗	✔	✗	✔					
	12.0	44.0	25.0	19.0			39.70	1	0.001
Bird droppings on bales									
	Droppings		No droppings						
	✗	✔	✗	✔					
	28.3	56.3	8.7	6.7			8.88	1	0.003
Rat runs near bale collections									
	Rat runs		No rat runs						
	✗	✔	✗	✔					
	1.3	10.0	35.7	53.0			10.50	1	0.001
Cat/Dog/Rat paw prints on bales									
	Paw prints		No paw prints						
	✗	✔	✗	✔					
	9.3	30.0	27.7	33			14.70	1	0.001
Human footprints	Footprints		No footprints						
	✗	✔	✗	✔					
	1.3	9.7	35.7	53.3			6.98	1	0.001
Livestock fencing around bales									
	Fencing		No fencing						
	✗	✔	✗	✔					
	32.7	53.0	4.3	10.0			0.99	1	0.321
Bird proof netting over bales									
	Nets		No nets						
	✗	✔	✗	✔					
	1.0	0.7	36.0	62.3			1.15	1	0.283
Paint on bales	Paint		No paint						
	✗	✔	✗	✔					
	34.6	65.4	37.5	62.5			0.05	1	0844
Tyres on bales	Tyres		No tyres						
	✗	✔	✗	✔					
	1.3	1.7	35.7	61.3			0.22	1	0.639
Other protection devices									
	Devices		No devices						
	✗	✔	✗	✔					
	3.0	3.0	34.0	60.0			1.39	1	0.239

✗ = no bird damage , ✔ = bird damage

Table 30: Incidence (%) of damage by cats to baled silage

					X^2	df	P
<u>Storage site</u>	Field		Yard				
	✗	✔	✗	✔			
	29.9	4.7	41.6	23.8	17.20	1	0.001
<u>Bale orientation</u>	Curved		Flat				
	✗	✔	✗	✔			
	37.9	13.2	35.1	13.9	0.22	1	0.639

✗ = no cat damage , ✔ = cat damage

Experiment 17. Bird damage to the plastic stretch-film on baled silage in Ireland

The objectives of the study were to: (a) identify the species of birds that utilise silage fields in the country, (b) identify the species of birds observed on wrapped bales of grass in the field, (c) determine the activity and behaviour of birds in baled silage fields, (d) observe and describe bird damage to the plastic wrap surrounding bales, and (e) identify any seasonal or diurnal changes in bird behaviour and usage of baled silage fields.

Materials and methods. *Survey of bird activity in silage fields throughout Ireland*. In both June and July 2000, an observer drove along a pre-selected route on three consecutive days. The route was c.a. 810km in length, and traversed a representative sample of land use and soil types, geographical locations, local climatic conditions, farm sizes and farming enterprises. A detailed questionnaire was completed for each area of recently harvested grass silage stubble encountered. Records were taken of harvested area, bale characteristics (where applicable), and the numbers and species of specific birds present on the silage stubbles. In the case of baled silage fields, the numbers of birds on the ground and on the bales were recorded. The harvested area was estimated visually. Flock sizes were estimated visually and recorded using a hand-held counter.

The specific bird species whose numbers were recorded each time were: (i) rooks - adults, (ii) rooks - juveniles, (iii) jackdaws, (iv) magpies, (v) hooded crows, (vi) wood pigeons, (vii) starlings (viii) black headed gulls (*L. ridibundus*), (ix) herring gulls (*L. agentatus*), (x) lesser black back gulls (*L. fuscus*), and (xi) others.

*Bird activity in baled silage fields***.** The site for the experiment was at Grange Research Centre, Dunsany, Co.Meath, Ireland (6º 40’ West and 53º 30’ North) at an altitude of approximately 92m above sea level. The landscape is gently undulating and is dominated by intensively managed improved agricultural grasslands (Fossit, 2000). The climate of the area is typically maritime with mild moist winters and cool cloudy summers.

Ten bales of grass were made on 28 occasions between May and October in 1999 and 2000. Swards for baling (0.4ha plots) were mown two days before baling, with wrapping being carried out immediately after baling. All bales were wrapped with four layers of black plastic stretch-film and were placed on their curved side on the ground, 30m apart in rows of three, four and three bales, respectively. Baling plus wrapping took place alternatively in the morning or afternoon.

Each of the sets of ten bales then remained in the field for a period of 24 hours during which observations were made of bird activity within the plot. The birds were observed during three separate two-hour periods in 1999: (i) morning: 0.5 hours after sunrise for two hours, (ii) midday: 1100 to 1300 hours, and (iii) evening: 1700 to 1900 hours. Thus, the midday period was the first observation period for bales wrapped in the morning, and correspondingly the evening period was the first observation period for bales wrapped at midday. In 2000, the bales were observed continuously during the daylight hours over each of the 24-hour periods. Thus, morning was described as sunrise up to 1030 hours, afternoon as 1031 to 1500 hours, and evening as 1501 until sunset. The time periods after baling were recorded. If baling and wrapping took place in the morning, the first period after baling was the afternoon, the second period was the evening, etc.

Two observation techniques were employed. Firstly, scans of the plot of bales were made every 15 minutes, and the numbers and species of birds present were recorded. Secondly, one-minute observations were made of individual birds selected at random in the plots, where the occurrence or non-occurrence of a number of behavioural events were recorded. The location of the bird for the duration of the observation was also recorded (i.e. on the ground or on a bale). The specific bird species recorded were those outlined above. The behavioural events that were identified and recorded during the one-minute observations were: (i) surface feeding, (ii) sub-surface feeding, (iii) walking, (iv) standing and looking,(v) tearing and pulling, (vi) pecking, (vii) vocalising (cawing), (viii) displaying. (ix) preening, and (x) others.

The number of holes caused by birds to the plastic film surrounding each bale was recorded before and after each observation period in 1999 and at the end of the 24 hour period in 2000, and the diameter of all the holes were recorded at the end of the last observation period. The holes in the plastic film were oblong in shape, and the measurement was taken along the long axis of the hole

Data analysis. The data from the scans of the number of birds in the plots was transformed (square root+1) and analysed using general linear modelling. The behavioural data from the experiments on bird activity in baled silage fields was analysed using a general linear model for a binomial response variable with a logit link function.

Results. *Survey of bird activity in silage fields throughout Ireland.* Rooks were the most numerous species encountered during the survey. They were observed in 94% of all the silage stubbles surveyed thereby amounting for 78% of the birds counted. Jackdaws (7%), starlings (6%), black-headed gulls (4%), herring gulls (4%), and lesser black-backed gulls, hooded crows and magpies (1%) accounted for the remainder. No wood pigeons were observed. The largest flock of rooks encountered numbered approximately 400 individuals. The mean (s.d.) number of rooks/ha of silage stubble was 24 (29.7), and the highest density encountered was 124 rooks/ha. Where it could be discerned, the breakdown of adult to juvenile rooks was 0.67:0.33. No birds were seen on wrapped or unwrapped bales of grass during this survey.

Bird activity in baled silage fields.

Bird damage. Overall, the plastic stretch-film on bales was damaged on 16 out of the 28 separate occasions when wrapped bales were placed on silage stubble (12 in 1999, and 4 in 2000). Sixty-seven bales out of a total of 280 were damaged. The number of bales damaged each time varied from zero to ten and the mean (s.d.) number of bales damaged when birds attacked the bales was 4 (3.2). The number of holes in the plastic film surrounding bales varied considerably from zero to 169 holes per bale. The mean (s.d.) number of holes per damaged bale was 34 (33.3) (27 (27.6) in 1999, and 52 (40.2) in 2000). The size of the holes also varied considerably from 1 to over 20mm in diameter, but they were in general small, usually no larger than 6mm in diameter. The mean (s.d.) diameter of a hole was 3.8 (2.23)mm.

Scans. No birds visited the plots on five of the 28 occasions the bales were made. From a total of 1168 scans in both years, no birds were seen in 189/432 scans in 1999, and 583/736 scans in 2000. As in both the survey and the crop utilisation studies, rooks and jackdaws were the predominant species observed. Rooks (0.945) and jackdaws (0.037) accounted for 0.982 of the total number of birds counted. The maximum number of birds seen in a plot was 114 (103 rooks and 11 jackdaws). The ratio of adult to juvenile rooks observed in baled silage fields across both years was 0.78:0.22. However, the ratios of adults to juveniles was quite different in both years (in 1999 it was 0.72:0.28 while in 2000 it was 0.92:0.08), with more juveniles seen in 1999 than in 2000. On average, more rooks visited the baled silage plots in 1999 than in 2000 (P<0.001), in the afternoon rather than in the morning or evening (P<0.001), in the early summer than in the late summer or early autumn (P<0.001), and during dry weather compared to wet weather. Bird activity peaked in the hours immediately after baling and wrapping, and dropped off steadily before another peak 13 to 15 hours after wrapping.

Behavioural observations. Birds observed damaging the plastic film on bales were seen to approach a bale from ground level (no bird was ever seen flying from outside a stubble plot and landing directly onto a bale). The birds were often observed walking around a bale, looking up towards it, and occasionally pecking at the plastic film from ground level, before flying up onto the top of the bale. Once on the bale, the birds would walk around the top surface of the bale, stopping periodically to vigorously peck at concentrated areas of the plastic film. Once the film had been pierced, the birds were sometimes seen to enlarge the holes by tearing and pulling at the plastic film, while occasionally pulling pieces of the underlying netwrap, as well as leaves and stems of grass through the hole. The birds on bales were rarely seen to engage in other activities, unrelated to attacking the film surrounding the bales, although some individuals were observed to perch and rest and/or engage in preening while on the bales. Little damage appeared to be caused to the film by birds using their feet, other than by birds perching onto the smooth surface of the bale at extreme angles near the sides.

Adults were as likely to damage bales as juveniles (P>0.3). Of the total observations of adults, 8% that visited the plots damaged bales, compared to 4% of the juveniles. The time of the day the attacks took place was also significant (P<0.001). Eleven per cent of the observations of rooks were of them damaging bales in the morning, compared to 3% and 1% for the midday and evening, respectively. The time the attacks took place after baling and wrapping was significant (*P*<0.001). The observations of rooks attacking bales in the first, second and third period from baling was 0.01, 0.14 and 0.06, respectively.

Adult rooks spent the greatest proportion of their time engaged in feeding behaviours and related activities on the silage stubble (Figure 15). They spent more time subsurface feeding than surface feeding, and engaged in few other activities while in the fields, although some time was spend standing and preening. Juvenile rooks spent little time feeding, and were mostly engaged in walking and standing. When they did make attempts to feed, they generally engaged in surface feeding. Jackdaws also spent the majority of their time feeding or in feeding related activities. The age of rooks that engaged in feeding was significant (*P*<0.001), with more adults (0.27) engaging in feeding on the stubble than juveniles (0.15). The time of day was a significant factor in feeding, with more birds feeding in the morning (0.14) than in the afternoon (0.04) or evening (0.01). The time from baling was significant (*P*<0.001) with 0.23, 0.11, and 0.15 of the birds observed feeding in the first, second, and third periods from baling, respectively. The year was also a significant factor in feeding (*P*<0.001), with 0.11 and 0.23 of the birds observed engaging in feeding in 1999 and 2000, respectively.

Discussion. *Survey of bird activity in silage fields throughout Ireland.* Rooks were by far the most numerous species observed in silage fields throughout Ireland. This was expected as grass silage stubbles are their main feeding area in June and July (MacDonald, 1983), a finding supported by other studies by the authors. The relatively dry soil surface in summer forces invertebrates to become inactive or disperse to lower soil levels (Feare *et al*., 1974). As meadows are mown, the hitherto unavailable food is exposed to predation, providing temporary food rich areas and thereby resulting in large concentrations of rooks visiting (MacDonald, 1983). The ratio of adult to juvenile rooks of 2:1 was similar to that encountered by MacDonald (1983) who found that young birds made up 30-40% of flock populations at that time of the year, before declining steadily to a minimum of under 10% in early winter. Seagulls are blamed by many farmers as the species primarily responsible for damaging silage bales, especially in coastal areas. The fact that few gulls were encountered relative to the large number of corvids present in silage stubble fields would seem to suggest that they may not be as important a cause of bale damage as anecdotal evidence suggested.

Bird activity in baled silage fieldsBird damage. There was a large amount of variation in the frequency and scale of damage to bales. McNamara *et al*. (2001a) showed that birds damaged bales in the field in 53% of the bale collections surveyed. This was similar to the 57% of occasions bales were damaged in the present study. When damage did occur, the levels of damage were sometimes severe. Studies of the effects of simulated bird damage (McNamara *et al*., 2001b) indicate that holes in the film analogous to those made by rooks can cause considerable losses.

Scans. No birds visited the plots on 18% of the occasions the study was carried out. Once an experiment was set up, there was no guarantee that birds would visit the plots in large numbers, and if they did, would attack the bales. Areas where attacks took place in previous days or weeks would often subsequently have reduced levels of attack, or none, when bales were made nearby. The study was carried out in an area frequented by rooks from a number of rookeries, the latter being within a 1600m radius of the plots. Other factors, such as silage harvesting, slurry spreading, and ploughing and tillage operations on nearby farms proved to be a greater attraction to rooks and jackdaws. These factors would seem to suggest that damage levels to the stretch-film on baled silage could be related to the level of silage harvesting and other operations taking place in the locality.

Rooks and jackdaws were again the most numerous species encountered in the plots. The ratios of adult to juvenile rooks in 1999 (0.72:0.28) was similar to that observed by MacDonald (1983) and reported above. The ratio in 2000 at 0.92:0.08 was much lower than that encountered by MacDonald. Also, more rooks were observed in the plots in 1999 than in 2000. The smaller number of birds visiting the plots in 2000 may be a reflection of greater alternative attractions in the locality. The plots were only 0.4ha in size and birds were often observed to move to nearby larger fields where silage was being harvested, possibly attracted by the larger flocks in these fields with freshly exposed ground.

More rooks were seen in plots in the afternoon than at any other time of the day. This agrees with the studies of Feare *et al*. (1974) and MacDonald (1983) who saw peaks in rook activity in the afternoon. The fact that baling and wrapping took place close to this time is also likely to be a factor. More rooks were seen in the plots in the early-summer than at any other time and numbers in the plots dropped off steadily over the silage making season. Lower numbers of rooks were observed in the plots during wet weather, however these data were too sparsely distributed and could not therefore be logically incorporated into the model for statistical analysis.

Bird activity peaked in the hours immediately after wrapping, followed by another peak 10-18hrs later. The first peak is probably a reflection of the large numbers of birds attracted to the stubble in the hours immediately after baling and wrapping. The second large peak spans a much longer time period than the first one, and most likely represents the increased activity in the plots as birds emerged to feed the following morning or afternoon relative to the time of baling and wrapping. Finally, there were proportionally more birds in the plots at the later stages of the 24hr observation period in the late-summer and early-autumn, than the early-summer. This is probably related to much of the silage in the locality being harvested at that time and rooks staying longer in the plots as they probably had fewer options regarding feeding areas than in the early-summer.

Observations. The observations of bird behaviour in the plots were concentrated on rooks and jackdaws as they were the most numerous species utilising the stubble. Adult rooks and jackdaws tended to spend most of their time feeding while in the plots. Rooks fed more in the morning and in the first hours after baling than at any other time. More adult than juvenile rooks were seen to damage bales. Most of the adult attacks took place on the first occasion bales were made in both years, which would have been the first bales made in the locality, and may have influenced these attacks. After rooks and jackdaws, no other species of bird were observed to damage bales. Rooks and jackdaws are distributed throughout Ireland, which has one of the largest population densities of these birds in Europe (Hagemeijer and Blair, 1997). Rooks tend to roost in fairly small rookeries and roosts, compared to the larger rookery and roost sizes in mainland Europe

(MacDonald, 1983; Hillcoat, 1994). The implications of this are that most of the bales in Ireland will be within the feeding range of rooks and jackdaws.

The motivations for attacks to the plastic film remain unclear. It is possible that a bird may view the bale as a resource. Bales expel a large amount of gas in the hours after wrapping. This gas can sometimes inflate the plastic on parts of the bale and can be heard escaping as it exits the bale between the layers of film under pressure. This noise coupled with the heat and bright lustre of a newly wrapped bale may attract a bird to it and the observations of the birds walking around a bale and displaying a degree of curiosity prior to an attack as described above may add some validity to this theory. Corvids in urban and suburban areas are known to utilise human food waste, especially on refuse collection days, when black plastic bags of waste are often left outside for collection. It is possible that this association with black bags and food could be manifesting itself in the baled silage field. Birds do not appear to obtain any food from wrapped bales. They do not consume grass (Lockie, 1955) and the amount of invertebrates present must be minimal.

No birds were observed bringing food onto a bale to consume. Rooks feeding in silage stubbles feed mostly on leatherjackets (*Tipula* spp.) and small earthworms (*Allolobophoraq* spp.) (MacDonald, 1983) that can be consumed readily on the ground. When food availability is high and energy requirements can be met, as they are in silage stubble, large earthworms will be avoided, especially large ones. The greater time required to consume a large earthworm allows the worm time to produce copious amounts of slime, making themselves unpalatable to all but the most hungry rook (MacDonald, 1983).

Only a small proportion of the total population of rooks and jackdaws utilising the experimental plots were responsible for damaging the bales. Adult rooks were found to be as likely to damage bales as juveniles. During 1999 adults were observed to damage bales on only one occasion, as opposed to the seven times by juveniles. However, although adults damaged bales on fewer occasions, their attacks were more sustained on those occasions. Juveniles were often observed to assemble in groups, while their parents dispersed throughout the plot foraging and intermittently returning to feed them. The juveniles engaged in little feeding during these times, though they did engage in feeding behaviours from time to time. Invariably they moved around the immediate area examining various items, which included nearby silage bales. Sometimes they would probe and/or begin to damage these bales. On other occasions, they would fly onto a bale and, while there inflict damage to the film.

More rooks damaged bales in the morning than at other time of the day, and in the second observational period after baling. This possibly suggests that following the birds initial desire to feed either directly after baling or in the morning after it leaves the roost, it may engage in other activities which might include damaging bales. Thus baling and wrapping large areas of grass in the evening when the bales cannot all be removed until the following day would appear to be quite inadvisable.

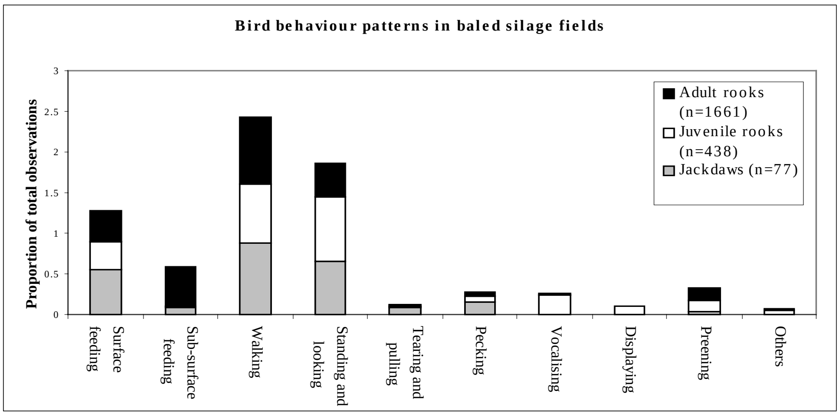


Figure 15. Behavioural observations: the proportion of the total observations during which rooks and jackdaws engaged in the different behaviours

Experiments 18 & 19. Simulated bird damage to the plastic stretch-film surrounding baled silage and its effects on conservation characteristics

Quantitative and qualitative losses in baled silage due to the growth of aerobic fungi resulting from holes in the stretch film can be considerable. O'Kiely *et al*. (1998) found mould growth in bales on proportionally 0.87 of farms, and in proportionally 0.42 of bales surveyed.

Mouldy feeds are well-established health hazards to both humans and livestock (Taar, 1999). The reduced intake of a nutritionally downgraded mouldy feedstuff may lower both the animals performance and its general resistance to health challenges.

The following two experiments aimed to determine the quantitative and qualitative effects of a range of simulated bird damage levels to the plastic stretch film on the conservation characteristics of baled silage.

Materials and Methods. *Experiment 18.* Thirty bales of silage were made (Claas™ Rollant 46 Rotocut baler (with knives)) from grass following a two-day wilt in June 1999 and tied with netting. The bales were then weighed, wrapped (Mc Hale™ 991 BE wrapper) with four layers of black plastic stretch-film (Silawrap™), and assigned at random to five treatments. The treatments consisted of different levels of damage due to the following number of holes made in the surrounding plastic stretch-film: (i) no holes (control), (ii) 1 small hole, (iii) 10 small holes, (iv) 50 small holes, and (v) 1 large hole. Before wrapping, the bales were core sampled (three cores (c. 0.04m in diameter, and 0.5m long) which were combined). The bales were positioned on their curved side, and the core samples were obtained from the top of the bale, and from half-way down both curved sides. The core holes were filled with chopped grass taken from the same grass source as the bales. Forage samples were assayed for dry matter (DM) by drying (98^{o}C for 16 h) in an oven with forced air circulation. Dried (40^{o}C for 40h) samples were milled (1 mm screen) and assayed for *in vitro* dry matter digestibility (DMD) and organic matter digestibility (OMD) (Tilley and Terry, 1963) (with the modification, that the final residue was isolated by filtering rather than centrifuging), buffering capacity (Playne and McDonald, 1966), ash (muffle furnace at 550^{o}C for 5 h) and crude protein (CP) (N x 6.25) using a LECO FP 428 nitrogen analyser (AOAC, 1990). Samples stored at -18^{o}C were finely comminuted and thawed, and had a liquid sample extracted for quantification of the concentration of water-soluble carbohydrates (WSC) (Wilson, 1978).

The average diameter of small holes made in the plastic stretch-film was 3mm, which was the mean diameter of holes measured in the stretch-film on a large number of other bales that had been damaged by rooks. These holes were made using 8mm long nails (diameter 3mm), which were pressed through the plastic film into the top surface of the bales, to a depth of 25mm. A 1.2m long piece of timber with a row of 10 nails at 0.1m intervals and protruding 25mm was used to produce a single row of ten holes. This same implement was used to make the 50 hole treatment. Five parallel rows of 10 holes were made, with rows being 100mm and 200mm left and right of the central row of holes. The large hole was 24mm in diameter and was equivalent to the combined area of the average number of holes caused earlier in the year by rooks or jackdaws to the plastic film on other bales (n=64).

The wrapped bales were stored one tier high on their round sides, outdoors in a farmyard, with netting surrounding them to prevent bird damage (using 15m x 20m green 0.05m gauge bird nets (Silanet™ Volac Feeds Ltd®)). They were checked frequently for actual bird damage and patched where necessary (birds did manage to damage the wrap on the corners of four end bales on two occasions). The plastic film was removed from the bales after 155 days storage, and each bale was weighed and scored for visible mould. Each bale was also core sampled, as previously outlined, for the estimation of DM, CP, DMD, ash, ammonia-N (Space Clinical Analyser, Schiapparelli Biosystems Inc., according to Sigma diagnostics method for plasma ammonia procedure no. 171-uv), lactic acid (using the Boeringer Mannheim method (catologue no. 139084) on a Ciba-Corning Diagnostics 550 Express Clinical Chemistry Analyser), volatile fatty acids (VFA = acetic acid + propionic acid + butyric acid) by gas liquid chromatography (Ranfft, 1973), WSC (Wilson 1978) and acid detergent insoluble nitrogen (ADIN) (Goering *et al*., 1972). The bales were then split using a tractor mounted loader and sheargrab so that visual assessments could be made of the amount of rotted and mouldy material throughout each bale, and overall volume loss.

Experiment 19. Thirty bales were made on 31 May 2000 as before, weighed, and assigned at random to the same treatments as in Experiment 1. Ten bales were assigned to treatment (i), and five bales were assigned to each of the remaining four treatments. Due to poor weather, the grass was wilted for only one day prior to baling. The bales were core sampled for estimation of DMD, OMD, buffering capacity, ash, CP and WSC as in Experiment 18. The core holes were refilled with similar grass and the bales were wrapped with four layers of black plastic stretch-film. The small holes in the plastic film were 3mm in diameter and were inflicted using the same procedures as in Experiment 18. The large hole was 21.2mm in diameter which equaled the combined total area of 50 small holes.

The bales were stored as in Experiment1. They were checked weekly to ensure no further damage was caused. They were opened after 155 days storage, weighed and visually scored for mould, and then dissected to separate visually mouldy or rotten material (collectively termed inedible) and edible silage. These fractions were weighed and separate samples were taken from each bale representative of edible and inedible material. Both sets of samples were analysed for DM, CP, DMD, ash, ammonia-N, lactic acid, volatile fatty acids, WSC and ADIN, as outlined previously.

Baled silage mould assessment. Mould patches were defined as areas of visible mycelial growth on the surface of a bale. The area of mould patches and the depth to which they penetrated the bale were recorded separately for both ends and the visible barrel (i.e. curved side) of the bale, before calculating the proportion of the total visible surface area covered by mould patches. Rotted silage was defined as silage that had extensive aerobic rotting. As above, the surface area and depth of the rotted silage patches were determined for the ends and visible barrel of the bale, before the overall totals were calculated.

Statistical analysis. The null hypothesis was that holes in the plastic-stretch film surrounding the bales would not quantitatively or qualitatively damage the forage in the bales. In Experiment 18, one-way analysis of variance was used to determine if a significant proportion of total variation could be attributed to treatment effects. Similar procedures were used in Experiment 19 to separately analyse the edible and inedible silages. In Experiment 119, for the variables presented in Table 33, paired t-tests were used to assess the significance of apparent differences between edible and inedible silage. For variables where there were large differences in the variances associated with the two means being compared, t-tests were carried out with reduced degrees of freedom (Parker 1979). Missing values were calculated according to Genstat for Windows 5th edition. Finally, the relationship between estimated volume loss (Experiment 18) or calculated DM loss (Experiment 19) and the visual assessment of mould patches and rotted silage on the outer surface of the bales was examined using linear regression.

Results. *Experiment 18.* The mean (standard deviation (s.d.)) weight of the 30 bales at ensiling was 601 (37.1)kg, and the mean (s.d.) composition was DM 317 (31.0)g/kg, DMD 701 (39.0)g/kg, OMD 707 (25.8)g/kg, CP 101 (10.4)g/kg DM, ash 83 (12.9)g/kg DM, WSC 31 (4.5)g/l juice and buffering capacity 340 2(0.7)mEq/kg DM, prior to ensiling. There was no difference in measured variables between the bales assigned to the different treatments (p>0.05).

The mould patches were conical in shape, tapering in diameter as they penetrated deeper into the bale. The bales with one large hole in the plastic film had the deepest mould patches (0.17m), usually manifested as one large conical shaped mould growth penetrating into the bale. Larger (p>0.05) amounts of mouldy and rotten silage were visible on the surface of bales with 50 small holes or one large hole, compared to none, 1 or 10 small holes (Table 31). Correspondingly, the estimated volume loss of bales during ensilage generally increased as the number of small holes increased, and was higher for 1 large hole compared to none, 1 or 10 small holes. The numerically higher volume loss within 1 large hole was not significantly larger (p>0.05) than with 50 small holes. Due to a malfunction in the scales when weighing the bales after ensilage, overall DM loss could not be calculated. Except for CP and fermentation acids, there were no significant treatment effects on forage chemical composition. The visual score for mould appeared to be better than that for rotted silage as an index of the estimated volume loss in a bale (Table 33).

Experiment 19. The mean (s.d.) weight of the 30 bales at ensiling was 809 (40.7)kg, and the mean composition (s.d.) was DM 209 (14.1)g/kg, DMD 734 (13.9)g/kg, OMD 724 (12.8)g/kg, CP 150 (8.7)g/kg DM, ash 83 (9.1)g/kg DM, WSC 23 (3.6)g/l juice and buffering capacity 453 (23.0)mEq/kg DM, prior to ensilage. There was no difference in measured variables between the bales assigned to the different treatments (p>0.05). No effluent was seen emanating from the bales. The bales weighed an average (s.d.) of 773 (36.7)kg after storage. After 155 days storage, large areas of mould growth and rotted silage were observed on bales that had 50 small holes in the plastic film (Table 32). There were no differences between treatments in mould patch depth (p>0.05). The proportion of inedible silage removed from the bales was significantly higher for the bales with 10 or 50 small holes or 1 large hole compared to those with none and 1 small hole. The bales with 50 small holes had the largest proportion of inedible material, and had significantly more (p<0.05) inedible material than the bales with 10 small holes or 1 large hole. The proportion of edible silage DM relative to the DM ensiled did not differ between the treatments (p>0.05). Chemical analysis demonstrated treatment effects on pH, the concentrations of propionic (inedible silage) and butyric (edible silage) acids and the proportion of fermentation acids accounted for by lactic acids (inedible silage). Large differences occurred between the samples of edible and inedible silage (Table 33). Again, the visual score for mould appeared to be better than that for rotted silage as an index of the proportion of inedible silage (Table 34).

Discussion. *Undamaged plastic film.* The control bales (no holes) in both experiments had relatively little visible mould growth or rotted silage on their outer surface. Some of these bales had some mould growth and this was not surprising. The temperature of the plastic stretch-film surrounding the upper parts of the bale, which is subjected to direct solar radiation, fluctuates during the day. High peak temperatures during the day can lead to big increases in permeation rates of O_2 and CO_2 and elevated temperatures on the bale surface (Möller, Klaesson and Lingval, 1999). These factors can permit aerobic microbial activity in the surface forage, further increasing forage temperature. The number of film layers, as well as film colour (black film absorbs more solar radiation and thus is prone to higher peak temperatures than white film), can significantly effect the gaseous composition of bales and subsequent mould growth (Lingval, Pettersson and Wilhelmsson, 1993; Möller *et al,.* 1999; Forristal, O'Kiely and Lenehan, 1999, 2000). Both Lingval *et al.* (1993) and Forristal *et al*. (1999, 2000) found that small amounts of mould growth (0.05, 0.02 and 0.01 of bale surface area, respectively) occurred on bales with four layers of black plastic film, and that increasing the number of layers from four to six reduced or eliminated visible mould growth.

The mean DM losses of 0.19 recorded during ensilage in Experiment 18 occurred during storage and do not include field losses. They are due to a combination of factors including surface waste, other microbial respiration not resulting in surface waste, and extensive fermentation. The DM recoveries recorded were lower than those observed by O'Kiely (1993) in laboratory silos, but similar to those observed with unwilted grass silages in farm-scale bunker silos by O'Kiely and Moloney (1994), and to those recorded by Kennedy (1989) for baled silage.

The overall decrease in mean DM concentration during ensilage (317 to 287g/kg in Experiment 17 and 209 to 181g/kg in Experiment 18 suggests that: either losses of DM during ensilage exceeded losses of water, or that water accumulated either due to the ingress of rainwater through the holes in the plastic or as a byproduct of respiration, or that water migrated within the bale to the upper and outer surfaces of the bale and from where the core samples were obtained. In both experiments, the grass ensiled had a DMD greater than 700g/kg. The reduction in DMD during ensilage of 10 to 17g/kg for the control treatment was similar to that quoted by Dulphy and Demarquilly (1991). The higher protein concentration in Experiment 19 may be partially explained by the earlier harvest date, and reflected the higher forage digestibility in Experiment 19. The more extensive fermentation in Experiment 19 compared to Experiment 18 (higher concentration of fermentation acids and lower concentration of WSC) reflects the absence of effective wilting in Experiment 19. Lactic acid accounted for a lower proportion of fermentation acids in Experiment 19 than in Experiment 18 which reflects both the more difficult ensiling conditions in Experiment 19 (forage of lower WSC concentration and higher buffering capacity) and the inability to aid preservation by achieving a satisfactory, rapid wilt. The high concentration of butyric acid in Experiment 18 indicates extensive activity by saccarolytic clostridia. Such activity would not be expected in forage with a mean DM concentration of 283g/kg, and suggests an uneven distribution of moisture in the silage bale, with some niches of sufficiently high moisture content to permit such microbial activity. This is also evident in the edible silage in Experiment 19, where the activity of clostridia led to higher butyric acid concentrations in some of the treatments. Clostridia, although strict anaerobes, seem to be sometimes indirectly favored by air ingress (Pauly, 1999). The resultant respiration of WSC and fermentation products by aerobic organisms like *Bacillus* results in a rise in pH, the generation of water as a byproduct of respiration, and the return to anaerobic conditions. In turn, saccharolytic clostridial spores can then germinate and multiply in such modified microniches, which are concealed within otherwise acidic surroundings (Jonsson, 1989).

Sample variation. Considerable variation occurred between bales in silage composition, and appeared larger than that frequently reported for conventional silage (Keady and Murphy, 1997; Keady *et al*., 1999). A possible explanation is that the core samples taken represent bales of 600 to 800 kg of forage, whereas with conventional silage, a number of sub-samples are usually composited to produce a sample to represent a quantity of several tonnes of silage. Variation between samples is likely to increase when the quantity of silage represented by each sample decreases. This is suggested by the considerable variation shown in nutrient, water and microorganism levels (Spoelstra, 1981; O'Kiely, 1987; Kelleher, Cafery and Callan, 1989; Kaiser *et al*., 1991) when comparisons were made between samples representative of small quantities of conventional silage. Baled silage like most silages, is heterogenous in chemical and microbial composition (Woolford, 1984), and heterogeneity in bales has been proposed by Jonsson (1989) as an explanation for the growth of clostridia in bales with low mean pH and high mean concentrations of fermentation acids. A further reason for variability between bales is that water condensation which can gather on the outer surface of a bale just under the film, can lead to forage with a higher water content than found further into a bale, thus resulting in two distinct environments within each bale. This wet outer layer, when exposed to air is a selective culture media for *Listeria* (Fenlon, 1988).

In Experiment 18, most of the mouldy or rotted material was on the top surface of the bales where the damage had been inflicted on the plastic film. Thus, cores taken from the sides of the bales and that taken from the top once it passed beyond the horizon with mouldy or rotten silage, represented forage that exhibited relatively little qualitative deterioration. Thus, the mouldy or rotted forage may have been only a minor proportion of the total sample used for chemical analysis. To overcome this, the edible and inedible forage was physically separated in Experiment 19. The standard errors for each variable of the inedible silages were usually higher than those of the edible silages (Table 31), reflecting the variability in the extent of decay for the inedible material.

Damage to the plastic film. The general trend was that with an increase in the number of holes made in the plastic stretch-film, there tended to be a corresponding increase in the amount of mouldy or rotted silage on the bale surface, in the depth to which the mould penetrated the bale, in the volume loss of the bale during ensilage (Experiment 18) and in the proportion of inedible silage present (Experiment 19). This is consistent with an increase in oxygen supply to the forage surface. In Experiment 18, the bales with 1 large hole had similar levels of mouldy and rotted silage on their surface as the bales with 50 small holes. They also had the deepest mould patches and the highest proportion of estimated loss of all the treatments. In Experiment 19, this treatment still had the deepest mould patches, but the proportions of mouldy and rotted silage, and of inedible silage present were closer to those of the bales with 10 small holes. The large hole in Experiment 18 was equivalent to the combined area of the average number of holes caused by birds to the plastic film on other bales. In Experiment 19 however, the large hole was 21.2mm in diameter and reflected the combined total area of 50 small holes. Thus, the smaller hole in Experiment 19 may have had some influence on the reduced amount of mould growth in that experiment. These data suggest that bales with numerous small holes spread accross the plastic film are prone to greater quantitative losses than bales with a single large hole of similar total area.

The proportion of edible silage DM relative to the DM ensiled (Experiment 19) did not differ due to treatment. This was due possibly to the level of waste being relatively low. The amount of waste material in the worst treatment (50 small holes) was proportionally only 0.06 of the DM present. The proportional volume loss in Experiment 18 for bales with 50 small holes (0.21) was much higher than the measured DM losses in Experiment 19. This apparent difference may be due to the different loss assessment methodologies used in the two experiments, as well as to the differences in forage DM concentration between the experiments. The higher DM concentration of the bales in Experiment 18 resulted in lighter, less dense bales. This would have made it easier for O_2 to penetrate into the bale, thereby encouraging the growth of aerobic microorganisms to a greater depth. The mould patch depth data support this explanation. Furthermore, Brady *et al.* (2000), who made micro punctures to the plastic film surrounding wrapped bales, found that the growth of *Schizophyllum commune* increased as forage DM concentration increased.

The concentration of CP in the silage increased in Experiment 18 with increasing damage levels, presumably due to a greater loss of non-nitrogen fractions in the damaged bales. The concentration of fermentation acids decreased with increasing damage levels, probably due to microbial respiration. The ash content in both experiments was normal, indicating the absence of soil contamination in the forage. In Experiment 19, there were large differences in the chemical composition of edible and inedible silage samples. There was a large decrease in the concentration of fermentation acids, and a resultant higher pH, where silage was inedible, probably due to microbial respiration. Corresponding to this loss in the quantity of digestible organic matter, was an increase in the concentration of ash. The higher ADIN for the inedible silage reflects heating experienced as a result of aerobic respiration, which resulted in the production of artifact lignin via the nonenzymatic browning reaction (Malliard reaction) (Goering and van Soest, 1970). The decrease in *in vitro* DMD was likely due to the loss of fermentation acids, the increase in ADIN and possibly also to mycotoxin production by moulds during aerobic deterioration. The higher WSC concentration in the inedible compared to the edible silage was not anticipated, as the respiration which reduced the concentration of fermentation acids was expected to similarly reduce WSC concentrations. The higher concentration in the inedible silage may be directly attributable to the mould rather than to the forage. Most fungal bodies contain large quantities of carbohydrates. Their cell walls consist of polysaccharides (proportionally 0.85), most of which are glucans. They also contain storage carbohydrates in the form of mannitol and trehalose (Deacon, 1997). Some of these were likely to have been recorded as WSC in the assay used.

The linear regressions of visually mouldy and rotted silage assessments to predict volume loss of the bale during ensilage (Experiment 18) or the proportion of inedible silage present (Experiment 19) demonstrate the value of the visual assessments. The proportion of a bale surface area which consisted of rotted silage was usually similar to or slightly less than that which was covered in mould. The material which was deemed to be rotten tended not to penetrate as far into a bale as mould did, and as a result it was a less accurate assessor of the proportion of waste material in a bale than using surface mould assessments.

Conclusions. Overall, from the work reported here, it can be concluded that holes made by rooks and jackdaws to the plastic film surrounding baled silage can result in potentially serious quantitative and qualitative forage losses. If the duration of storage had been longer than 155 days, the extent of damage in some of the treatments could have been greater as a result of continued mould growth and rotting of the silage and possibly rain ingress. From the differences in forage DM between both experiments, it can be suggested that bales with high DM concentrations are likely to experience larger losses as a result of holes in the plastic stretch-film than those with low DM concentrations. Farmers in Ireland will wilt bales for up to two days in an attempt to achieve high DM concentrations and reduce the number and weight of the bales per unit area, thus increasing the risk of losses if the plastic film on these bales is damaged. Further work is warranted with heavily wilted forage to quantify the scale of losses involved.

Table 31. Quantitative and qualitative effects of holes in the plastic stretch-film on the conservation of baled silage, (Experiment 18)

	No holes	1 hole	10 holes	50 holes	1 large hole	*s.e.d*	Sig.
Surface mould (proportion)	0.01	0.04	0.03	0.15	0.12	0.028	***
Surface rotted (proportion)	0.01	0.04	0.04	0.15	0.13	0.040	**
Mould patch depth (m)	0.05	0.07	0.10	0.10	0.17	0.028	**
Bale volume loss (proportion)	0.02	0.08	0.15	0.21	0.32	0.072	**
Dry matter (DM) (g/kg)	283	290	303	281	280	11.3	NS
In-vitro DM digestibility (g/kg)	686	691	669	659	655	20.1	NS
Crude protein (g/kg DM)	97	100	105	108	114	4.5	*
Ammonia-N (g/kg N)	83	72	76	81	70	14.8	NS
PH	4.3	4.5	4.5	4.5	4.6	0.14	NS
Ash (g/kg DM)	93	89	99	95	97	8.8	NS
Lactic acid (g/kg DM)	57	49	45	44	49	6.3	NS
Acetic acid (g/kg DM)	18	15	12	15	15	3.1	NS
Propionic acid (g/kg DM)	1.6	1.6	1.5	1.9	1.6	0.45	NS
Butyric acid (g/kg DM)	14	13	12	17	15	2.7	NS
Fermentation acids[1] (g/kg DM)	91	79	71	78	80	4.5	**
Lactic acid/ fermentation acids[1]	0.64	0.62	0.53	0.56	0.61	0.062	NS
Water-soluble carbohydrates (g/kg DM)	37	35	33	36	33	4.0	NS
Acid detergent insoluble nitrogen (g/kg N)	18	19	18	18	22	2.2	NS

[1]Fermentation acids = lactic acid + volatile fatty acids

Table 32. Quantitative and qualitative effects of holes in the plastic stretch-film on the conservation of baled silage, (Experiment 19)

	No holes	1 hole	10 holes	50 holes	1 large hole	s.e.d. 10x5[1]	s.e.d 5x5[2]	Sig.
Bale weight (kg)	774	785	777	765	762	19.5	22.46	NS
Surface mould (proportion)	0.02	0.02	0.07	0.17	0.06	0.028	0.033	***
Surface rotted (proportion)	0.03	0.04	0.04	0.13	0.06	0.028	0.033	**
Mould patch depth (m)	0.02	0.03	0.07	0.05	0.11	0.044	0.051	NS
Inedible silage (g/kg DM)	4.0	5.0	25.0	60.0	26.0	3.70	5.30	***
Edible silage g DM/kg DM ensiled	830	790	820	810	800	33.0	38.0	NS

[1]s.e.d. when comparing 10 bales (treatment (i)) to 5 bales (treatments (ii) to (iv))
[2]s.e.d. when comparing among treatments (ii) to (v)

Table 33. Quantitative and qualitative effects of holes in the plastic stretch-film on the chemical composition of baled silage, Experiment 19

	Edible silage (E)							Inedible silage (IE)							t test	Sig		
																E	IE	T
	No holes	1 hole	10 holes	50 holes	1 large hole	s.e.d. 10x5[3]	s.e.d. 5x5[4]	No holes	1 hole	10 holes	50 holes	1 large hole	s.e.d. 7x5[5]	s.e.d. 5X5[4]				
Dry matter (g/kg)	183	185	188	176	173	7.4	8.5	179	172	172	160	173	12.5	14.4	2.0[2]	NS	NS	NS
In-vitro DM digestibility (g/kg)	717	737	727	701	735	12.7	14.7	603	611	605	520	589	49.8	57.5	7.6[2]	NS	NS	***
Crude protein (g/kg DM)	162	158	162	162	164	6.3	7.3	180	187	186	191	190	8.0	9.2	7.5	NS	NS	***
Ammonia-N (g/kg N)	95	90	96	108	77	13.3	15.3	78	100	68	79	68	22.5	26.0	1.6	NS	NS	NS
pH	4.2	4.0	4.2	4.4	4.1	0.09	0.10	5.0	6.0	7.0	8.2	7.0	0.64	0.74	9.19[2]	*	*	***
Ash (g/kg DM)	83	84	83	86	85	3.8	4.4	89	99	94	101	100	9.6	11.1	3.7	NS	NS	***
Lactic acid (g/kg DM)	74	113	89	51	89	21.3	24.6	18	13	10	15	17	4.6	5.3	8.9[2]	NS	NS	***
Acetic acid (g/kg DM)	76	58	34	76	71	14.1	16.3	22	44	14	6	11	11.1	12.9	7.8	NS	NS	***
Propionic acid (g/kg DM)	11.1	8.7	8.5	11.5	11.7	4.79	5.53	5.6	9.1	4.6	1.9	2.5	1.99	2.30	3.00	NS	*	**
Butyric acid (g/kg DM)	6.3	3.7	19.0	29.2	12.5	6.36	7.34	0.5	1.1	0.5	0.3	0.5	0.45	0.52	4.83[2]	**	NS	***
Lactic acid/fermentation acids[1]	0.44	0.60	0.48	0.29	0.49	0.10	0.11	0.38	0.32	0.39	0.64	0.61	0.10	0.13	0.13	NS	*	NS
Fermentation acids [1] (g/kg DM)	168	183	180	168	185	16.2	18.7	46	67	29	23	31	13.7	15.8	18.0	NS	NS	***
Water-soluable carbohydrates (g/kg DM)	20	18	16	12	15	3.4	4.0	23	21	33	25	25	3.2	3.7	4.9	NS	NS	***
Acid detergent insoluble nitrogen (g/kg N)	60	58	59	65	55	3.78	4.63	81	81	95	151	110	18.6	21.5	5.3[2]	NS	*	***

[E] edible silage
[IE] inedible silage
[T] edible x inedible silage
[1]Fermentation acids = lactic acid + volatile fatty acids
[2]t value (variances differ by factor >3)
[3] s.e.d. when comparing 10 bales (treatment (i) to 5 bales (treatments (ii) to (iv))
[4] s.e.d. when comparing among treatments (ii) to (v)
[5] s.e.d. when comparing 7 bales (treatment (i) to 5 bales (treatments (ii) to (iv))

Table 34. Regression equations relating visual assessments of bale surface mould and rotted silage to each other and to the proportion of bale loss[1] as a result of holes in the plastic film in Experiments 18 and 19

Regression	Intercept	Slope (*b*)	*s.e.*(*b*)	Correlation coefficient (*r*)	Sig.
Experiment 18					
Surface mould to predict bale volume loss	0.019	0.72	0.066	0.90	***
Surface rotted to predict bale volume loss	0.047	1.44	0.212	0.78	***
Surface mould to predict surface rotted	-0.007	1.12	0.103	0.90	***
Error df = 29					
Experiment 19					
Surface mould to predict proportion inedible silage	0.006	0.26	0.032	0.84	***
Surface rotted to predict proportion inedible silage	0.053	0.25	0.053	0.67	***
Surface mould to predict surface rotted	0.017	0.65	0.096	0.79	***
Error df = 29					

[1] Bale volume loss in Experiment 18 and bale DM loss in Experiment 19

Experiments 20 to 22. Preventing bird damage to wrapped baled silage during short- and long-term storage

Short-term storage. As the birds are primarily attracted to the newly revealed stubble rather than the wrapped bales, gathering the wrapped bales into a small area on the stubble or relocating them away from the stubble offers the opportunity to reduce the incidence of damage to the plastic film in the first days after wrapping. The objective was to quantify the effects of 4 short-term (7-day) storage methods of wrapped bales in the field.

Long-term storage. Although most farmers took no precautions to protect the plastic film on their bales against wildlife damage during storage, 17% did paint markings on the bales. This usually involved brush painting an X or an O on the plastic film. This procedure, which seems to be unique to Ireland, is perceived to be a deterrent to bird attack. Netting (2%) or other devices (9%) were infrequently used strategies to prevent bird damage (McNamara et al. 2001). The efficacy of these repellency devices has not previously been evaluated for preventing this type of damage.

Monofilament lines have been used successfully by Blokpoel and Tessier (1984), Agüero et al. (1991) and Andelt and Burnham (1993) to prevent problems from ring-billed gulls (*Larus delawarensis*), house sparrows (*Passer domesticus*) and rock doves (*Columbia livia*), respectively. Eyespots have been examined as bird aversion devices with mixed success (Scaife 1976, Inglis et al. 1983, Shirota et al. 1983, Avery and Matteson 1995, Belant et al. 1998). The objective was to evaluate the efficacy of painted designs and monofilament line configurations, along with netting, scare-eye balloons and bale orientation, as strategies for preventing bird damage to the plastic film surrounding baled silage in Ireland during long-term storage.

Methods. The experiments were conducted at Grange Research Centre (6º 40’ W 53º 30’ N; altitude approximately 92 m) during the summer and autumn of 1999 and 2000. The landscape is gently undulating and is dominated by intensively managed improved agricultural grasslands (Fossit 2000).

Short-term storage. Two experiments were conducted. For the first experiment (Experiment 20) 4 adjacent replicate blocks of grassland were each subdivided into 3 (each 0.4 ha) adjoining plots. Two of the 3 plots within each block were selected at random and mown on 19 June 1999, between 1100 and 1300 hours, to a sward stubble height of approximately 0.05 m. Baling occurred on the morning of 21 June and bales were wrapped with 4 layers of conventional black plastic stretch-film (Silowrap™). Seventy-two bales were randomly assigned among the 3 treatments within each of the 4 replicate blocks. The 3 treatments were 1) bales spaced 30 m apart on newly mown stubble (i.e., control); 2) bales grouped on newly mown silage stubble; and 3) bales grouped on meadow (unmown plot). The bales were positioned in the center of each appropriate plot. In treatments 2 and 3, the 6 bales within each replicate were stored together on the ground and placed end to end on their curved sides in 2 parallel adjoining rows of 3 bales.

For the second Experiment (Experiment 21), a fourth treatment, bales grouped on a five-week regrowth, was added to the same treatment as above. Grass was harvested for first-cut silage on 1 June 2000. The plots were fertilized following baling. Five weeks later, 4 adjacent replicate blocks were each divided into 4 adjoining plots (each 0.4 ha), with the 4 treatments being allocated at random among the plots within each replicate block. The plots for treatment 4 then mown to a stubble height of 0.05 m and the grass was removed. These plots then received 66 kg N/ha and were allowed to regrow. Five weeks later, the plots allocated to treatments 1 and 2 were mown to a sward stubble height of approximately 0.05 m. Each bale was immediately wrapped with 4 layers of black plastic stretch film after 2 days wilting (348 g DM/kg). Ninety-six bales were randomly allocated to the 16 experimental plots. The bales for treatments 1, 2 and 3 were positioned as already outlined and the bales for treatment 4 were positioned similarly to treatment 3.

Assessment of the botanical composition of the crop on both occasions showed it to consist of mostly rough-stalk meadow-grass (*Poa trivialis*), brown bent (*Agrostis cania*), fine bent (*A. tenuis*) and perennial ryegrass (*Lolium perenne*). All the bales were monitored daily for bird damage to the plastic film for a period of 1 week, with holes in the plastic film typical of those caused by birds being counted and recorded during each visit.

Long-term storage (Experiment 22). One hundred and sixty-two bales were made following cutting and a 2-day-wilt before being randomly allocated among the following 8 treatments: bales on their curved side with 1) no protection (control); 2) a painted eye design; 3) a painted X design; 4) a scare-eye balloon (Bird Barrier, 20975 Chice Street, Carson, CA 96746, USA); 5) monofilament lines 0.5 m above the bales and 2.0 m apart (22.7 kg breakage weight [Omni-Flex®, Extra Sure Strength™ monofilament]); 6) monofilament lines 0.5 m above the bales and 0.5 m apart; 7) netting (15 m x 20 m green 50mm gauge bird nets [Silanet™ Volac Feeds Ltd®] tied 1.0 m above and beside the bales); and 8) bales placed on their flat end with no protection. The eye design was painted on the top of each bale using a 0.45 m external diameter stencil and white emulsion paint. It consisted of an outer circular white band (0.10 m wide), within which was a white “pupil” (0.10 m in diameter) and the surrounding black “iris”. The X design was white, 0.45m in diameter, with a band width of 0.12m. The balloons were 0.50 m in diameter, and were yellow in color, with 6 eye designs (each 0.164 m in diameter) around their circumference. Each eye design consisted of an outer black band (7 mm band width), inside of which was a red band (28 mm band width). The “pupil” of the design (70 mm in diameter) was black in color, and the “iris” (12 mm band width) was yellow. One balloon was positioned on a wooden frame 1.0 m above each appropriate bale collection. The control bales were replicated twice within each of the 3 blocks. The experiment was laid out in 3 replicate blocks, each with 9 collections of 6 bales. Each collection of 6 bales was stored on grass, and placed end to end on their curved side, in 2 adjoining parallel rows of 3 bales. Bale collections within each block averaged (SE) 221(29.7) m apart, with blocks being 132 (47.3) m apart. All bales were monitored weekly for bird damage for 18 weeks, with the number of holes per bale being counted and recorded.

Data analysis. The Friedman test was used to test for treatment effects within the block design. Multiple comparisons following computation of the Friedman test (Conover 1999) were used to identify statistical differences between treatments ($P \leq 0.05$). In the short-term storage experiments data collected for treatments 1, 2 and 3 were compared using the combined data from both experiments. Treatment 4 data were analyzed using the data from the second experiment only. In the long-term storage experiment, the double replication of the controls were analyzed as 2 separate treatments, with their results being combined and presented as a single mean.

Results. *Short-term storage.* Considerable damage was caused by birds to the plastic film when the bales were spaced 30 m apart on the newly mown stubble (Table 35). Damage began occurring on the first day of the experiments. Most of the damage was accomplished in the first 2 to 3 days, with relatively little occurring thereafter. The reduction in bird damage when the bales were grouped on the stubble did not differ from those spaced 30m apart on the newly mown stubble ($P > 0.05$). Relocating bales to an adjacent meadow or grass regrowth immediately after wrapping significantly reduced damage to the plastic wrap surrounding the bales ($P < 0.05$). In fact, the plastic film surrounding the bales in treatments 3 and 4 received no damage on the occasion the second experiment was conducted.

Long-term storage. The only birds noted damaging bales were rooks and jackdaws. The variability in the number of holes among the 3 replicates of some treatments made it difficult to show apparent effects as being statistically significant. For example, within each replicate of 6 bales, the average (SE) number of holes per bale on week 18 was 0.2 (0.17), 3.3 (2.18), and 331.3 (33.30) for the bales protected by 2.0 m lines and 0, 108.3 (7.31), and 165.7 (27.30) for those protected by scare-eye balloons. The control bales (Table 36) incurred an average of 32.4 holes per bale by the end of the experiment. The bales protected by lines at 2.0 m spacings or scare eye balloons were also severely damaged, incurring an average of 105.6 and 91.3 holes per bale, respectively, by the end of the experiment. The bales protected by lines at 0.5 m spacings or raised netting reduced ($P \leq 0.05$) the incidence of damage incurred by the plastic film when compared to the controls. Storing bales in the upright position without protection tended to reduce damage to the plastic film compared to storage on their curved side without protection. When comparing the painted designs, eye designs tended to be better at reducing bird damage than X designs, although the difference was not statistically significant.

Discussion. ***Short-term storage.*** Irish farmers have been advised to remove grass bales from the field immediately after they are made and wrap them at the site of storage to minimize the risk of damage to the plastic film surrounding the bales caused by either mechanical handling or birds (O’Kiely et al. 2000). However, factors such as labor and time constraints on agricultural contractors (who bale and wrap 98% of baled silage), new machines that combine baling and wrapping, and mechanization and time constraints on many farms, result in the wrapping of bales in plastic stretch-film in the silage stubble field on 86% of farms (O’Kiely et al. 1998). Bales are then usually moved to the long-term storage location on the day of wrapping (72% of farms), with transport being on the following day on 22% of farms and at least 2 days post wrapping on a further 5% of farms (O’Kiely et al. 1998). This provides considerable opportunity for birds to damage the wrapped bales in the field (McNamara et al. 2001).

Damage began occurring on the first day after wrapping in both experiments with most of it occurring in the first 2 to 3 days and relatively little thereafter. This is possibly due to birds being attracted in large numbers to the newly revealed stubble to feed on invertebrates, and their numbers subsequently dwindling as food sources on the stubble diminish and more profitable feeding areas became available elsewhere in the locality. Unless they are protected it is important to remove the bales immediately from the stubble. Grouping bales on grass stubble showed a similar pattern of damage to those spread out, but had a tendency towards reduced damage. This effect however was not statistically significant. When the bales were grouped on silage stubble, 60% of the bales used in the two successive experiments were damaged, with the number of holes inflicted by birds to individual bales ranging from 3 to 81. Grouping bales on silage stubble reduced the area of the field within which birds might encounter the bales. Some farmers have adopted this method to reduce bird damage. However, it is not a reliably successful method of preventing damage. Furthermore, the double handling (by machinery) necessary to move the bales into groups, and then from the field to the long-term storage site, increases the risk of mechanical damage occurring. There could also be some risk of damage to the film from repositioning the bales to a second location on the stubble itself.

Relocating bales from the stubble onto an advanced meadow or a younger regrowth succeeded in reducing damage, partly because the bales were being grouped but mainly due to their being removed from the birds feeding site. Although treatments 3 and 4 dramatically reduced bird damage to the plastic stretch-film surrounding baled silage, the strategy of moving bales to an area of long grass was not a fully secure method of preventing such damage, as a small number of the bales on the meadow were damaged.

Long-term storage. In the absence of protection, bales stored on their curved sides suffered damage to the surrounding film due to birds. This agrees with the observations recorded on Irish farms by McNamara et al. (2001). The number of holes inflicted to the film appeared to increase as time progressed, although this was not statistically tested. The rate and pattern of damage was not uniform and individual groups of bales incurred sustained attacks at different intervals over the storage period.

Placing the net 1.0 m above and aside the bales almost totally eliminated damage, and indeed most of the damage occurred in the final weeks of the experiment when storms had temporarily knocked the netting,

compromising the effectiveness of this treatment for a short duration. It would be expected that netting such as used in this experiment, if securely positioned 1.0 m above and aside the bales, would act as a reliable system of preventing damage by birds to the plastic film.

Monofilament lines at the 2.0 m configuration failed to protect plastic film from bird damage but protection was dramatically improved when the spacing between lines was reduced to the 0.5 m configuration. This agrees with work by Blokpoel and Tessier (1984), Agüero et al. (1991), and Andelt and Burnham (1993) who found that monofilament lines at narrow spacings were more effective than larger spacings at repelling birds in different situations. At the narrower spacings, rooks and jackdaws were likely discouraged from flying between the lines, landing on the bales and damaging the plastic film. The range of wing lengths (from the carpal joint to the tip of the longest primary) for rooks and jackdaws are 0.29 - 0.33 m and 0.21 - 0.22 m, respectively (Madge and Burn 1997). The film surrounding the bales protected by scare-eye balloons and lines at the 2.0 m configuration were more severely damaged than the control bales. The apparent negative effects of the latter 2 treatments appeared evident by weeks 10 and 12. Reasons for this scale of failure are not evident.

In contrast, painting an eye design onto the top surface of wrapped bales reduced bird damage to the plastic wrap. When compared to the control bales, the painted eye designs reduced damage by 65%. The reasons for this are unclear, but may be related to a painted eye design on each of the six bales, compared to just 1 balloon with 6 small eye spots over the bales. Several reports have suggested that eyespots may be effective for deterring starlings and other birds (Scaife 1976, Inglis et al. 1983, Shirota et al. 1983, Avery and Matteson 1995), although Belant et al. (1998) found that eyespots were ineffective at deterring starlings from nesting in nest boxes. In contrast to the apparent beneficial effects of the painted eye design, the painted X design, which is commonly employed by Irish farmers, appeared not to confer any benefits.

Storing bales in an upright position (i.e. on their flat end) without any other protection tended to reduce damage to the plastic film when compared to bales stored on their curved side. This trend was possibly due to the potentially greater physical protection given by the considerably greater number of layers of plastic film on the flat ends of a wrapped bale than on the curved side.

Management implications. *Short-term storage.* Ideally, bales should be wrapped at the site of long-term storage rather than at the site of baling. Wrapped bales left spread out at the site of baling are prone to damage by birds. Relocating the bales to an adjacent area of regrowing grass dramatically reduced the extent of bird damage to the plastic film. Grouping bales onto the silage stubble appears to offer some opportunity to reduce damage, but is not an adequately effective protection method.

Long-term storage. Bales stored outdoors suffered considerable and continuing bird damage to the plastic film throughout storage. The use of nets securely positioned 1.0 m above and aside the bales and monofilament lines at 0.5 m spacings were the most effective methods for reducing bird damage. Painting an eye design onto the top surface of bales had potential to reduce damage. However, effective direct physical barriers to access by birds as opposed to scaring devices, appeared to be more reliable. Monofilament lines at spacings greater than 0.5 m, painted X markings and scare-eye balloons, failed to adequately protect the plastic film surrounding bales from bird damage. In an Irish context, the average return on investment (benefit:cost) from optimally using netting and monofilament lines at 0.5 m spacings would be 1.2:1 and 3.0:1 respectively. On farms more susceptible to such bird damage, the rate of return would be larger.

Table 35. Average number of holes (SE) in the plastic stretch-film surrounding baled silage caused by birds in relation to the positioning of bales during short-term storage in Grange, Ireland during 1999 and 2000 with associated Friedman's statistic (T) and *P* value based on the chi-square approximation (2 df)

	Treatment				
	Bales spread out on stubble	Bales grouped on stubble	Bales grouped on meadow	T	*P* value
Day 1	4.5 (1.60)	3.7 (0.55) [a]	0.0	12.54	0.001
Day 2	18.0 (4.34) [a]	11.3 (2.57) [a]	0.1 (0.01)	27.34	$\leq$ 0.001
Day 3	20.9 (4.70) [a]	11.8 (2.58) [a]	0.4 (0.30)	26.55	$\leq$ 0.001
Day 4	21.2 (4.77) [a]	12.0 (2.58) [a]	0.5 (0.34)	23.96	$\leq$ 0.001
Day 5	22.0 (4.95) [a]	12.4 (2.57) [a]	0.5 (0.34)	24.29	$\leq$ 0.001
Day 6	22.1 (5.22) [a]	12.4 (2.57) [a]	0.5 (0.34)	24.29	$\leq$ 0.001
Day 7	22.2 (5.53) [a]	12.6 (2.57) [a]	0.5 (0.34)	25.10	$\leq$ 0.001

[a] Treatment means with the same letter are not different ($P \leq 0.05$) from each other within days

In treatment 4 of the second experiment, (Experiment 21) the number of holes/bale was zero

Table 36. Average weekly (SE) number of holes per bale caused by birds to the plastic stretch-film surrounding baled silage with associated Friedman's statistic (T) and *P* value (df = 8) when bales were protected by netting, monofilament line configurations, painted designs, scare-eye balloons and bale orientation during long-term storage in Grange Ireland, during 2000.

	Week								
Treatment	2	4	6	8	10	12	14	16	18
Control[b]	4.5	4.5	7.0	7.8	10.2	18.2	18.8	23.0	32.4
	(2.48)	(2.48)	(2.98)	(2.95)	(3.61)	(4.45)	(4.46)	(4.53)	(6.96)
2.0 m lines	1.1	2.6	3.0	9.6	23.1	28.3	35.4	105.6	105.6
	(0.78)	(1.39)	(1.41)	(3.54)	(7.90)	(9.50)	(12.78)	(37.13)	(37.13)
Balloons	1.1	1.5	1.5	2.2	7.3	31.3	32.2	49.7	91.3
	(0.65)	(0.65)	(0.65)	(1.19)	(3.79)	(7.86)	(7.94)	(9.14)	(18.87)
Painted "X"	14.7	15.7	16.1	16.1	16.1	16.1	17.9	23.9	23.9
	(5.13)	(5.46)	(5.41)	(5.41)	(5.41)	(5.41)	(5.21)	(7.07)	(7.07)
Upright	1.1	1.2	7.1	8.2	9.2	12.1	12.2	12.3	17.3
	(0.55)	(0.64)	(3.34)	(3.62)	(3.58)	(4.36)	(4.42)	(4.42)	(6.38)
Painted "eye"	1.5	1.6	2.6	2.9	2.9	5.5	5.8	7.9	11.2
	(0.79)	(0.78)	(1.14)	(1.14)	(1.44)	(1.22)	(1.29)	(1.79)	(2.66)
0.5 m lines	0.1	0.1 [a]	0.4	0.6	1.4	1.4 [a]	1.8	5.6 [a]	5.6 [a]
	(0.06)	(0.06)	(0.30)	(0.34)	(0.63)	(0.63)	(0.79)	(2.59)	(2.59)
Netting	0.0[a]	0.0[a]	0.0	0.0[a]	0.0[a]	0.0[a]	0.0[a]	0.9 [a]	1.2 [a]
								(0.73)	(0.78)
T	14.25	16.17	15.84	16.60	16.15	32.85	33.17	32.22	35.89
P-value	0.069	0.035	0.039	0.030	0.035	$\leq$0.001	$\leq$0.001	$\leq$0.001	$\leq$0.001

[a] Values less than ($P \leq 0.05$) the control bales within week

[b] Double replication of the controls were analysed as 2 separate treatments, with their results being combined and presented as a single mean.

Experiments 23 - 25. Efficacy of different colour films and chemical repellents for preventing bird damage to the plastic film on wrapped baled silage in the field

Colour cues have previously been used to enhance the control of crop depredation by birds. Changing the colour of the plastic film used to wrap baled silage offers the opportunity to prevent birds approaching the bales. Consequently a range of colours were compared in terms of the extent to which birds visited and damaged bales wrapped with plastics of different colours.

A number of effective chemical bird repellents have been developed to prevent bird damage to crops. Six bird repellents sprayed onto the plastic-stretch film surrounding baled silage were compared in terms of preventing birds from landing on and damaging the plastic film on baled silage.

Materials and methods. ***Film colour***: In Experiment 23, sixty-four wilted grass bales were randomly allocated among the following eight treatments: bales wrapped with (i) black (control), (ii) white, (iii) dark green, (iv) light green, (v) blue green, (vi) yellow, (vii) red or (viii) transparent, coloured films. The bales were placed on their curved side, each with the same orientation, in a 8x8 grid formation. Each treatment was represented once in each row and column within the grid, and the distance between each bale was 30m. The bales were inspected 24, 48 and 72h. after the treated bales were placed in position The numbers of holes per bale were recorded after each time period. This procedure was carried out on two occasions during July and August, 1999.

In Experiment 24, thirty-six wilted grass bales were randomly allocated to the following three treatments: bales wrapped with (i) black (control), (ii) red or (iii) transparent, coloured films. These bales were placed in a 6x6 grid formation in their appropriate orientation. Each treatment was represented twice in each row and column within the grid. The protocol was as in Experiment 1. This procedure was carried out on two occasions during July and August, 2000.

Bird repellents. In Experiment 25, forty-nine wilted grass bales wrapped with four layers of black plastic film were allocated among the following seven treatments:(i) anthraquinone (1%w/vol), (ii) cinnnamimide (0.5%m/m), (iii) copper oxychloride (1%m/m), (iv) methiocarb (0.1 %m/m), (v) methyl anthranilate (1%w/vol) and (vi) thiram (1% w/vol), each sprayed onto the plastic stretch-film, and (vii) no chemical (control). The protocol was similar to the Experiments 23 and 24. The data for the three experiments, which were non parametric in nature, were analysed using Kruskal Wallis and multiple comparison tests.

Results and discussion. In Experiment 23, the use of different coloured films did not alter ($p>0.05$) the level of damage to the plastic film surrounding the bales when compared to the control (Table 37). In Experiment 24, the use of red and transparent films reduced ($p<0.05$) bird damage (Table 38). There was no difference in damage levels between the red and transparent wrapped bales. In Experiment 25, the use of bird repellent chemicals did not alter ($p>0.05$) the level of damage to the plastic film surrounding the bales when compared to the control (Table 39).

Table 37. Damage (bird holes per bale) to the plastic film in Experiment 23 (Error d.f.=7)

Plastic colour	24h	48h	72h
Dark green	24.1	24.1	45.1
Light green	17.3	23.9	39.9
White	22.1	22.1	32.3
Blue green	21.3	22.2	29.8
Black	19.7	19.7	28.3
Yellow	16.6	19.4	25.5
Red	9.4	9.4	11.9
Transparent	6.9	6.9	7.4
X^2	2.63	4.15	5.00
P value	0.917	0.763	0.660

Table 38. Damage (bird holes per bale) to the plastic film in Experiment 24 (Error d.f.=2)

Plastic colour	24h	48h	72h
Black	15.2	23.0	31.9
Red	3.8	4.7	6.5
Transparent	0.2	3.7	5.5
X^2	11.38	11.50	11.84
P value	0.003	0.003	0.003

Table 39. Damage (bird holes per bale) to the plastic film in Experiment 25 (Error d.f.=6)

Repellent	24h	48h	72h
Methyl anthranilate	2.1	2.9	11.0
Thiram	1.9	7.1	8.8
Control	4.0	4.9	6.7
Methiocarb	3.9	4.3	6.1
Cinnamamide	1.6	2.3	4.9
Copper oxychloride	0.9	1.2	2.8
Anthraquinone	0.0	0.4	1.3
X^2	6.85	4.63	3.99
P value	0.335	0.592	0.678

Conclusions. Plastic film colour has the potential to reduce the extent of bird damage to the plastic film surrounding silage bales. Red and transparent had the most significant beneficial effect. Bird repellent chemicals examined did not prevent damage to the plastic film.

6. PERFORMANCE OF BEEF CATTLE OFFERED THREE BALED SILAGES

One experiment was conducted, and is reported here.

Experiment 26 : Productivity of finishing beef heifers offered three baled silages and three levels of supplementary concentrates

In many experiments evaluating the effects of silage additives on subsequent animal production, beef cattle are offered untreated or treated silages without any supplementary concentrates. However, as shown by the data of O'Kiely and Moloney (1994), occasions occur where the relative rankings of additive treatment effects on animal productivity can change depending on whether or not supplementary concentrates were offered. Similarly, the response to supplementary concentrates can vary depending on the silage additive treatment involved. Thus, the opportunity exists for different conclusions to be made in the absence of recognising the potential existence of interaction effects. Baled silage is now made on 73% of all farms and accounts for about 35% of the area harvested for ensilage. Baled silage is typified by a mean dry matter (DM) concentration of about 320 g/kg and a restricted fermentation as evidenced by a relatively high pH. If additives were to lead to a major reduction in baled silage pH and a change in fermentation characteristics, interactions with supplementary concentrates in terms of animal productivity responses could occur. This experiment determined if interactions occurred between the effects of silage additive and supplementary concentrates on the productivity of beef cattle offered wilted baled silage.

Materials and Methods. The primary growth of a permanent grassland sward was baled (Claas Rollant 46 Roto Cut), transported to the storage area (mean bale weight 604 kg) and wrapped in four layers of black plastic stretch film on 18 to 21 May, after approximately 31 h wilting. Alternate groups of 10 bales received no additive, bacterial inoculant (Ecosyl; Zeneca Bioproducts Ltd.) at 3 l/t or ammonium tetraformate at 4.2l/t (additives applied to the swath 6 m in front of the baler pick-up reel). Bales were stored two tiers high, outdoors and under netting for 214 days before feeding commenced. Twelve continental-cross heifers were allocated to each of nine dietary treatments arranged in a 3 (silage additive treatments) x 3 (supplementary concentrate levels; 0, 2.5 and 5.0 kg/head daily) factorial complete block (starting liveweight and breed) design. Silages were individually offered *ad libitum* for 138 days. Blood samples were obtained by venipuncture at 0800 and 1400 h on day 70, relative to concentrates and silage being offered at 0830 h and 1000 h, respectively. Carcass data were obtained post-slaughter. Data were considered as a 3 x 3 factorial arrangement of treatments within a complete block design and were subjected to two-way analysis of variance.

Results and Discussion. The mean (s.d.) composition of the grass at ensiling was dry matter (DM) 351 (56.5) g/kg, crude protein 147 (18.7) g/kg DM, *in vitro* DM digestibility (DMD) 789 (12.9) g/kg, ash 85 (6.2) g/kg DM, buffering capacity 553 (46.1) mEq/kg DM, water soluble carbohydrates (WSC) 42 (17.3) g/l and nitrates 271 (164.4) mg/l. For silages made using no additive, inoculant or formate, the mean (s.d.) pH was 4.68 (0.331), 4.36 (0.246) and 4.74 (0.297), respectively, with corresponding values for lactic acid concentration of 52 (21.4), 75 (19.8) and 42 (16.6) g/kg DM, acetic acid concentration of 7 (6.1), 6 (5.0) and 5 (3.5) g/kg DM, NH_3-N of 98 (5.9), 89 (11.9) and 108 (11.7) g/kg N and WSC of 74 (16.1), 62 (12.0) and 74 (13.9) g/kg DM. Mean concentrations of propionic acid were < 1g/kg DM and butyric acid < 4 g/kg DM. Evidence of mould growth or aerobic degradation of forage on the bale surface was minor, and no treatment effects were evident. The three silages exhibited similar aerobic stability and deterioration characteristics, with mean (s.d.) values of 2.2 (0.94), 2.1 (0.90) and 1.9 (0.79) days and 4.6 (2.23), 5.0 (2.49) and 4.8 (2.38) days for the intervals until temperature rise commenced or temperature maxima were reached for the silages made with no additive, inoculant or formate, respectively, and with corresponding values for the accumulated temperature rise during 5 days aerobiosis of 15(3.4), 15(1.7) and 14(2.1)^{o}C. The formate additive increased ($P < 0.001$) silage DM intake and both additives reduced ($P < 0.001$) blood non-esterified fatty acid (NEFA) concentrations. Otherwise, silage additive treatment did not affect intake, performance or blood variables (Table 40). Supplementary concentrates increased ($P < 0.05$) animal growth and kill-out rates and blood β -hydroxybutyrate concentration, and reduced ($P < 0.001$) silage DM intake and blood NEFA. No interactions between additive and supplementary concentrates were detected.

Conclusion. The response to supplementary concentrates was similar for beef heifers offered wilted baled silage made using three different additive treatments.

Table 40. Silage intake, animal performance and blood variables.

Silage additive (A)	None			Inoculant			Acid				Significance		
Concentrates (C; kg/day)	0	2.5	5.0	0	2.5	5.0	0	2.5	5.0	s.e.[1]	A	C	A x C
Silage DM intake (kg/day)	8.4	6.9	5.4	7.9	7.0	5.2	8.7	7.5	6.3	0.19	***	***	NS
Start liveweight (kg)	410	411	413	410	413	411	418	415	407	3.0	NS	NS	NS
Liveweight gain (g/day)	642	899	925	615	903	925	638	800	986	43.2	NS	***	NS
Carcass gain (g/day)	488	724	772	530	726	770	506	676	762	27.5	NS	***	NS
Kill-out rate (g/kg)	530	556	564	546	555	564	535	557	554	4.8	NS	***	NS
KCF[2] weight (kg)	9.3	11.3	10.6	8.1	11.0	12.9	9.7	11.4	13.2	0.87	NS	***	NS
Blood BHB[3] (mmol/l)	0.19	0.30	0.33	0.22	0.32	0.40	0.19	0.30	0.38	0.024	NS	***	NS
Blood glucose (mmol/l)	3.7	4.0	4.1	3.8	3.7	3.7	3.8	3.9	3.9	0.12	NS	NS	NS
Blood NEFA[4] (mmol/l)	0.23	0.13	0.15	0.13	0.12	0.13	0.14	0.09	0.11	0.018	***	***	NS
Blood urea (mmol/l)	3.4	3.8	4.2	3.9	4.7	4.1	3.5	4.2	4.1	0.31	NS	*	NS

Error df = 88; [1]interaction s.e.; [2]kidney and channel fat; [3]β hydroxybutyrate; [4]non-esterified fatty acids

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