End of project report

RMIS No. 5137

Beef production from feedstuffs conserved using new technologies to reduce negative environmental impacts

Authors

Padraig O'Kiely, Teagasc, Grange Beef Research Centre, Dunsany, Co. Meath

Paul Crosson, Teagasc, Grange Beef Research Centre, Dunsany, Co. Meath

William J. Hamilton, Teagasc, Grange Beef Research Centre, Dunsany, Co. Meath; Teagasc, Crops Research Centre, Oak Park, Carlow; UCD School of Geography, Planning and Environmental Policy, Belfield, Dublin 4

Enda Little, Teagasc, Grange Beef Research Centre, Dunsany, Co. Meath; Teagasc, Crops Research Centre, Oak Park, Carlow; UCD School of Agriculture, Food Science and Veterinary Medicine, Belfield, Dublin 4

Pamela Stacey, Teagasc, Grange Beef Research Centre, Dunsany, Co. Meath; UCD School of Agriculture, Food Science and Veterinary Medicine, Belfield, Dublin 4

Karl Walsh, Teagasc, Grange Beef Research Centre, Dunsany, Co. Meath; UCD School of Agriculture, Food Science and Veterinary Medicine, Belfield, Dublin 4

Alistair D. Black, Teagasc, Grange Beef Research Centre, Dunsany, Co. Meath

James C. Crowley, Teagasc, Crops Research Centre, Oak Park, Carlow

Michael J. Drennan, Teagasc, Grange Beef Research Centre, Dunsany, Co. Meath

Dermot P. Forristal, Teagasc, Crops Research Centre, Oak Park, Carlow

Richard Hackett, Teagasc, Crops Research Centre, Oak Park, Carlow

Mark McGee, Teagasc, Grange Beef Research Centre, Dunsany, Co. Meath

Aidan P. Moloney, Teagasc, Grange Beef Research Centre, Dunsany, Co. Meath

Martin O'Brien, Teagasc, Grange Beef Research Centre, Dunsany, Co. Meath

Edward G. O'Riordan, Teagasc, Grange Beef Research Centre, Dunsany, Co. Meath

Bernard Rice, Teagasc, Crops Research Centre, Oak Park, Carlow

and

Rogier Schulte, Teagasc, Environment Research Centre, Johnstown Castle, Wexford

in collaboration with

Frank P. O'Mara, UCD School of Agriculture, Food Science and Veterinary Medicine, Belfield, Dublin 4

Michael Wallace, UCD School of Agriculture, Food Science and Veterinary Medicine, Belfield, Dublin 4

William Nolan, UCD School of Geography, Planning and Environmental Policy, Belfield, Dublin 4

Anne Buttimer, UCD School of Geography, Planning and Environmental Policy, Belfield, Dublin 4

George P. Keane, UCD School of Agriculture, Food Science and Veterinary Medicine, Belfield, Dublin 4

Tommy Boland, UCD School of Agriculture, Food Science and Veterinary Medicine, Belfield, Dublin 4

C. Alan Rotz, Dept. of Agricultural and Biological Engineering, Pennsylvania State University, USA

Beef Production Series No. 82

Teagasc

Grange Beef Research Centre

Dunsany

Co. Meath

Ireland

December 2007

ISBN 1 84170 493 8

Contents **Page no.**

1. Introduction

Most (*ca*. 86%) Irish farms make some silage. Besides directly providing feed for livestock, the provision of grass silage within integrated grassland systems makes an important positive contribution to effective grazing management and improved forage utilisation by grazing animals, and to effective feed budgeting by farmers. It can also contribute to maintaining the content of desirable species in pastures, and to livestock not succumbing to parasites at sensitive times of the year. Furthermore, the optimal recycling of nutrients collected from housed livestock can often be best achieved by spreading the manures on the land used for producing the conserved feed.

On most Irish farms, grass silage will remain the main conserved forage for feeding to livestock during winter for the foreseeable future. However, on some farms high yields of whole-crop (i.e. grain + straw) cereals such as wheat, barley and triticale, and of forage maize, will be an alternative option provided that losses during harvesting, storage and feedout are minimised and that input costs are restrained. These alternative forages have the potential to reliably support high levels of animal performance while avoiding the production of effluent. Their production and use however will need to advantageously integrate into ruminant production systems. A range of technologies can be employed for crop production and conservation, and for beef production, and the optimal options need to be identified.

Beef cattle being finished indoors are offered concentrate feedstuffs at rates that range from modest inputs through to *ad libitum* access. Such concentrates frequently contain high levels of cereals such as barley or wheat. These cereals are generally between 14% to 18% moisture content and tend to be rolled shortly before being included in coarse rations or are more finely processed prior to pelleting. Farmers thinking of using 'high-moisture grain' techniques for preserving and processing cereal grains destined for feeding to beef cattle need to know how the yield, conservation efficiency and feeding value of such grains compares with grains conserved using more conventional techniques.

European Union policy strongly encourages a sustainable and multifunctional agriculture. Therefore, in addition to providing European consumers with quality food produced within approved systems, agriculture must also contribute positively to the conservation of natural resources and the upkeep of the rural landscape. Plastics are widely used in agriculture and their post-use fate on farms must not harm the environment - they must be managed to support the enduring sustainability of farming systems. There is an absence of information on the efficacy of some new options for covering and sealing silage with plastic sheeting and tyres, and an absence of an inventory of the use, re-use and post-use fate of plastic film on farms.

Irish cattle farmers operate a large number of beef production systems, half of which use dairy bred calves. In the current, continuously changing production and market conditions, new beef systems must be considered. A computer package is required that will allow the rapid, repeatable simulation and assessment of alternate beef production systems using appropriate, standardised procedures. There is thus a need to construct, evaluate and utilise computer models of components of beef production systems and to develop mathematical relationships to link system components into a network that would support their integration into an optimal system model. This will provide a framework to integrate physical and financial on-farm conditions with models for estimating feed supply and animal growth patterns. Cash flow and profit/loss results will be developed. This will help identify optimal systems, indicate the cause of failure of imperfect systems and identify areas where applied research data are currently lacking, or more basic research is required.

The three separate components with parallel objectives to this programme were to:

1. Develop technologies for conserving and optimally feeding alternative/complimentary feedstuffs to grass silage.
2. Quantify the use and re-use of plastic sheeting or film used to seal ensiled feedstuffs or mulch maize, and evaluate some new options.
3. Develop computer programs that will facilitate investigating prototype models of forage-based beef production systems.

2. Technologies for conserving alternative feedstuffs to grass silage

The objectives of this section were to:

1. Define the balance between yield and composition as cereals (including maize) grow through to maturity
2. Develop optimal methods for processing and preserving moist grain
3. Quantify the nutritive value of moist grain relative to conventional grain
4. Quantify the nutritive value of whole-crop cereal harvested at a high dry matter concentration, and of forage maize, using new technologies

Experiment 2.1: Yield and composition of maize: interaction of harvest date, plastic mulch and cultivar

[E.M. Little, P. O'Kiely, J.C. Crowley, G.P. Keane]

Forage maize is established as a crop with the potential to consistently supply high yields of quality forage on some Irish farms. Despite its success, considerable variability in crop yield, quality and maturity at harvest can exist from year to year. These reflect differing prevailing weather conditions, particularly temperature during May to September. The use of plastic mulch has increased the likelihood of achieving higher yields of high quality maize crops and has permitted it extend into areas once considered unsuitable for the crop. Two cultivars of differing maturity were grown with or without plastic mulch to examine how yield and composition altered during the harvest window of early September to early November.

Materials and Methods Two forage maize cultivars of differing maturity under Irish conditions (Tassilo: FAO 210 (early) and Benicia: FAO 270 (late)) were grown at Oak Park in 2002 and 2003. In 2002, each plot consisted of 4 rows (70cm spacing) of 5m length sown in duplicate blocks either uncovered (NP) or under complete-cover clear polythene mulch (P; 6 micron; IP Europe Ltd) on 24 April using a Samco precision seed drill at a seed rate of 100,000 seeds/ha. Standard fertiliser (150kg N, 50kg P, 200kg K/ha) and weed control (4.5l atrazine/ha) were both applied pre-sowing. Crop samples (2x1m per plot) were taken every 10 days from 10 September to 09 November. In 2003, each plot consisted of 4 rows (70 cm spacing) of 10 m length. Plots were sown in triplicate on 23 April using a Samco precision seed drill, with similar seeding rate, weed control and fertiliser input as in 2002. Samples of 1 m length per plot were taken on the same dates as in 2002. Whole crop, stover and cob weights were measured and chemical composition determined.

Results: In 2002, plastic mulch increased ($P<0.001$) crop DM yield, the proportion of cob in crop DM, crop starch content and cob DM content for both cultivars (Table 2.1.1). The late cultivar Benicia demonstrated the greater increase ($P<0.05$) in cob proportion and starch content when sown under plastic cover. As harvest date was delayed an increase ($P<0.001$) in cob DM content, cob proportion in DM and starch content was recorded. Yields of DM increased initially but remained constant once peak yield was achieved which tended to be before mid October. Cultivar type did not influence ($P>0.05$) overall DM yield but the early cultivar Tassilo did have increased ($P<0.001$) cob DM, cob proportion and to a lesser extent increased ($P<0.05$) starch content compared to Benicia under both sowing regimes.

In 2002, as harvest date was delayed cob starch content increased ($P<0.001$) and cob DMD and ADF generally decreased ($P<0.001$) (Table 2.1.2). However cob ADF did increase initially in uncovered plants before decreasing. Plastic mulch increased ($P<0.001$) cob starch content, this effect being most evident with Benicia ($P<0.01$) particularly in early September. It also reduced ADF ($P<0.01$) and DMD ($P<0.05$). Tassilo generally had a higher starch and lower DMD and a similar ADF to Benicia.

In 2002, delaying harvest date from early September until November resulted in a decrease ($P<0.001$) in the proportion of stover in the crop DM and a reduction ($P<0.001$) in stover DMD (Table 2.1.2). Stover NDF correspondingly increased ($P<0.001$) over time. Stover DM increased in early November after air frost damage intensified leaf senescence. The use of plastic mulch did not influence ($P>0.05$) stover DM content but it did reduce ($P<0.001$) the proportion of stover in the DM. Plastic mulch use also affected quality, producing a higher ($P<0.001$) NDF and a lower ($P<0.01$) DMD than uncovered plants. Cultivar had no affect ($P>0.05$) on stover DM or NDF concentration but the earlier cultivar Tassilo generally had a higher ($P<0.01$) DMD and a lower ($P<0.001$) stover proportion in the DM. The response of stover proportion, DMD and NDF to plastic mulch was not consistent over all harvest dates and in the case of NDF and DMD varied with cultivar.

In 2003, in general, delaying harvesting from early Sept. to Nov. increased ($P<0.001$) the proportion of cob in the crop and cob DM and starch contents but reduced ($P<0.001$) NDF (neutral detergent fibre), ADF (acid detergent), ash and crude protein contents (Table 2.1.3). Tassilo, the earlier cultivar, contained a higher proportion of cob than Benicia at each harvest, but over time this variable increased more with Benicia. Tassilo also had a higher DM content that increased less over time than for Benicia. The increase in starch and decline in NDF, ADF and ash with later harvesting was significantly less with Tassilo than Benicia. Plastic mulch increased ($P<0.001$) the proportion of cob in the crop and cob DM and starch contents, and reduced ($P<0.001$) NDF, ADF, ash and crude protein contents, with the effects becoming significantly smaller as harvest date was delayed. The increase in the proportion of cob in the crop and of cob DM and starch contents in response to mulching was significantly smaller with Tassilo than Benicia, while the significant decline in ash content with Benicia due to plastic mulch was absent with Tassilo. *In vitro* DM digestibility (DMD) was higher ($P<0.001$) at the three later harvests compared to the first three harvests. However, the temporal

changes in DMD, although significant (P<0.001), were not steadily incremental. Tassilo cobs had a lower (P<0.001) mean DMD than those of Benicia (797 *vs.* 844 g/kg) while mulching did not (P>0.05) affect DMD.

In 2003, in general, delaying harvest date from early Sept. to Nov. reduced the proportion of stover in the crop (P<0.001) and its DMD (P<0.05) but increased (P<0.001) DM and NDF contents (Table 2.1.3). Stover DM content increased sharply in early Nov. after air frost damage increased senescence. Tassilo, the earlier cultivar, contained a lower proportion of stover than Benicia at each harvest, but over time this variable declined more (P<0.05) with Benicia. Plastic mulch consistently reduced (P<0.001) the contribution of stover to the whole crop, although the decline over time was greater (P<0.001) without mulch. Tassilo had a higher (P<0.05) DM concentration than Benicia at the three middle harvest dates. Whereas mulch generally increased (P<0.001) stover DM concentration, the scale of this effect was larger (P<0.05) with Tassilo than Benicia, and was more evident (P<0.01) at the final four compared to the first three harvest dates. Plastic mulch generally increased (P<0.001) NDF concentration, although the effect (P<0.05) was reversed with Tassilo harvested on 20 Oct.

Conclusions In 2002, plastic mulch increased crop DM yield, cob proportion and starch content and advanced cob ripeness (increased cob DM content) in both cultivars. Little yield benefit was obtained from prolonging harvest after 20 October, however cob maturity (i.e. starch content) of the plants not grown under plastic (NP) continued to increase. Tassilo (early) was about three weeks more advanced in terms of cob ripeness than Benicia (late) when grown under plastic. Benicia grown without plastic mulch did not mature adequately and was unsuitable for growing without plastic mulch.

A progressive rise in cob starch content was observed over time and was most evident in uncovered plants reflecting the greater maturity of covered plants. A corresponding decrease in cob ADF was observed as starch rose. The initial rise in cob ADF of uncovered plants could indicate the later, final stages of rachis development when compared to those under plastic cover. The temporal decline in cob *in vitro* DMD was quite large and may reflect decreasing degradability of starch and/or increasing indigestibility of the rachis as the cob matures.

Delaying harvest date reduced the contribution of the stover to crop DM yield and considerably reduced its DMD and increased its NDF over the same period. Plastic mulch advanced the plant growth stage and level of cob development thus reducing the contribution of the stover to crop DM yield and reducing stover DMD on any given date. Stover in the later cultivar, Benicia, accounted for a greater proportion of crop DM yield, in particular when grown without plastic mulch, but its DMD was lower when compared to the earlier cultivar Tassilo.

In 2003, in general, forage maize cobs continued to mature from early Sept. through to early Nov., with the rate of change declining as time progressed. By early Sept. both the earlier cultivar and the use of plastic mulch had additively progressed crop maturity. However, between early Sept. and Nov. both the late cultivar and maize grown with no plastic mulch underwent the most extensive physiological development. Nevertheless, the earlier cultivar and the use of plastic mulch still resulted in cobs of more advanced maturity in early Nov.

Delaying harvest date reduced the proportion of stover in crop DM yield. The corresponding decline in DMD was considerably less than in 2002, with the difference being mediated by the growing degree day (>10^0C; 1 May to 31 Oct.) values of 448 and 592 for 2002 and 2003, respectively. The plastic mulch advanced the physiological development of the maize stover, particularly at earlier harvests, but without reducing its DMD. Similarly, the earlier cultivar (Tassilo) reached various stages of stover development sooner than the later cultivar, but with no cultivar effect on DMD.

Table 2.1.1. Yield and physical composition of forage maize grown in 2002 and 2003

Harvest date (H)	Cultivar (C)	Plastic mulch (M)	2002					2003				
			Crop DM yield t/ha	DM (g/kg) Plant	Cob	Stover	Cob in crop (g/kg)	Crop DM yield t/ha	DM (g/kg) Plant	Cob	Stover	Cob in crop (g/kg)
10-Sep	Tassilo	NP	6.17	176	158	183	235	13.71	224	349	171	460
	Tassilo	P	13.85	242	348	187	490	20.12	299	491	198	569
	Benicia	NP	8.01	172	94	180	47	16.37	188	185	189	225
	Benicia	P	12.70	213	254	197	335	19.07	239	372	184	456
20-Sep	Tassilo	NP	7.92	200	192	202	217	15.90	278	426	197	541
	Tassilo	P	16.90	276	434	190	554	19.91	366	557	219	661
	Benicia	NP	9.26	182	116	196	104	17.92	224	257	212	305
	Benicia	P	14.76	226	304	192	413	19.54	286	449	202	534
30-Sep	Tassilo	NP	9.43	204	246	185	380	16.68	298	522	183	596
	Tassilo	P	17.57	319	511	186	657	19.54	353	571	209	645
	Benicia	NP	11.24	183	144	195	186	18.45	243	393	185	443
	Benicia	P	14.14	248	365	186	511	23.64	298	516	186	587
10-Oct	Tassilo	NP	9.50	209	296	168	458	16.67	372	556	245	611
	Tassilo	P	17.19	331	568	179	671	17.48	447	617	291	659
	Benicia	NP	11.31	189	184	191	246	20.55	279	408	226	415
	Benicia	P	15.67	259	429	172	561	23.17	370	558	243	609
20-Oct	Tassilo	NP	8.82	250	350	198	474	15.50	387	570	260	603
	Tassilo	P	16.36	380	566	226	677	19.50	486	650	334	642
	Benicia	NP	11.37	214	224	210	280	19.33	305	478	224	495
	Benicia	P	16.12	293	483	188	590	23.80	398	590	277	574
30-Oct	Tassilo	NP	9.71	256	341	196	554	18.37	382	578	245	623
	Tassilo	P	15.30	334	537	197	648	17.22	481	653	313	670
	Benicia	NP	11.28	205	226	196	343	18.51	314	480	236	491
	Benicia	P	16.25	312	486	202	607	18.82	407	597	284	572
09-Nov	Tassilo	NP	10.00	284	340	240	540	15.38	449	590	300	674
	Tassilo	P	16.06	434	578	292	661	15.65	557	697	384	694
	Benicia	NP	10.52	225	224	227	370	18.53	409	494	344	523
	Benicia	P	16.38	364	466	269	616	19.19	475	631	341	610
Sig	H		**	***	***	***	***	***	***	***	***	***
	C		NS	***	***	NS	***	***	***	***	*	***
	M		***	***	***	NS	***	***	***	***	***	***
	HxC		NS	NS	NS	NS	NS	***	NS	**	*	*
	HxM		NS	**	NS	NS	*	***	*	**	**	***
	CxM		**	*	NS	NS	**	NS	NS	*	*	**
	HxCxM		NS	NS	NS	NS	NS	***	NS	NS	NS	NS
s.e.m	HxCxM		0.583	8.3	13.1	7.5	19.4	0.272	10.3	12.9	10.8	20.8

[1]gDM/kgDM; [2]g/kg; [3]g/kgDM

Table 2.1.2: Chemical composition in 2002

Harvest date (H)	Cultivar (C)	Plastic mulch (M)	Cob						Stover			
			Starch g/kgDM	DMD g/kg	NDF g/kgDM	ADF g/kgDM	Ash g/kgDM	CP g/kgDM	DMD g/kg	NDF g/kgDM	ADF g/kgDM	Ash g/kgDM
10-Sep	Tassilo	NP	36	883	466	192	42	131	703	559	348	61
	Tassilo	P	361	857	321	152	24	98	698	572	337	66
	Benicia	NP	37	936	240	92	60	166	677	599	301	58
	Benicia	P	373	888	301	139	29	105	687	581	309	54
20-Sep	Tassilo	NP	141	824	397	228	35	122	734	514	324	59
	Tassilo	P	489	849	311	113	19	79	683	589	336	66
	Benicia	NP	39	928	276	122	48	146	691	566	274	49
	Benicia	P	461	866	360	120	23	89	679	591	323	56
30-Sep	Tassilo	NP	277	837	326	163	30	119	707	554	319	56
	Tassilo	P	462	813	285	114	21	71	634	676	358	72
	Benicia	NP	89	875	367	175	35	99	665	562	290	51
	Benicia	P	512	862	326	107	21	81	625	637	368	61
10-Oct	Tassilo	NP	377	837	324	135	25	108	650	614	362	66
	Tassilo	P	520	804	359	95	20	76	611	712	408	78
	Benicia	NP	147	855	326	174	38	127	629	628	337	50
	Benicia	P	571	798	285	81	20	72	569	710	394	61
20-Oct	Tassilo	NP	409	839	296	105	25	92	629	651	367	78
	Tassilo	P	504	762	257	100	20	71	624	713	423	83
	Benicia	NP	372	854	297	120	30	102	592	645	352	60
	Benicia	P	567	811	204	73	20	67	589	738	378	67
30-Oct	Tassilo	NP	439	802	326	113	24	89	588	741	421	62
	Tassilo	P	513	776	258	96	20	70	536	769	464	75
	Benicia	NP	377	862	287	106	33	106	548	688	432	65
	Benicia	P	614	790	202	76	19	67	531	772	445	72
09-Nov	Tassilo	NP	471	776	303	97	21	91	583	773	442	64
	Tassilo	P	589	733	235	85	18	69	534	781	505	58
	Benicia	NP	438	850	259	114	29	101	574	729	466	54
	Benicia	P	576	799	212	78	18	69	483	787	458	61
Sig	H		***	***	**	***	***	***	***	***	*	*
	C		*	*	NS	*	***	*	**	NS	NS	*
	M		***	*	*	**	***	***	**	***	NS	*
	HxC		NS	NS	**	*	NS	NS	NS	NS	NS	NS
	HxM		***	NS	*	*	**	NS	*	**	NS	NS
	CxM		**	NS	NS	NS	***	NS	NS	NS	NS	NS
	HxCxM		*	NS	*	**	NS	NS	**	*	NS	NS
s.e.m	HxCxM		23.1	13.2	23.7	9.6	1.6	5.7	9.8	9.3	27.5	4.3

Table 2.1.3: Chemical composition in 2003

Harvest date (H)	Cultivar (C)	Plastic mulch (M)	Cob						Stover			
			Starch g/kgDM	DMD g/kg	NDF g/kgDM	ADF g/kgDM	Ash g/kgDM	CP g/kgDM	DMD g/kg	NDF g/kgDM	ADF g/kgDM	Ash g/kgDM
10-Sep	Tassilo	NP	343	753	435	164	20	96	577	686	413	74
	Tassilo	P	459	780	291	112	16	78	591	699	396	70
	Benicia	NP	187	858	430	179	30	111	578	680	414	65
	Benicia	P	451	817	290	132	17	75	596	713	420	72
20-Sep	Tassilo	NP	402	775	358	154	17	87	569	678	403	73
	Tassilo	P	457	785	254	101	16	72	564	751	442	71
	Benicia	NP	338	802	416	162	26	110	534	722	456	56
	Benicia	P	513	819	288	113	16	66	577	723	442	75
30-Sep	Tassilo	NP	468	774	303	118	20	80	589	714	413	79
	Tassilo	P	545	798	257	109	18	68	566	772	454	80
	Benicia	NP	453	823	317	132	22	85	570	724	448	79
	Benicia	P	566	831	221	92	19	64	621	735	411	82
10-Oct	Tassilo	NP	474	796	288	122	16	82	570	717	427	75
	Tassilo	P	515	794	243	108	15	73	593	743	443	72
	Benicia	NP	474	859	283	117	18	82	582	693	424	60
	Benicia	P	550	858	206	93	15	63	572	729	439	76
20-Oct	Tassilo	NP	496	821	270	104	13	84	558	755	461	78
	Tassilo	P	535	812	253	103	13	71	562	703	414	70
	Benicia	NP	510	865	255	85	18	81	573	745	457	68
	Benicia	P	577	852	203	75	14	65	573	760	450	74
30-Oct	Tassilo	NP	511	821	268	103	15	82	547	732	432	76
	Tassilo	P	526	812	251	115	17	70	565	745	443	63
	Benicia	NP	538	851	217	93	16	68	574	721	430	64
	Benicia	P	573	854	217	89	16	70	546	752	448	73
09-Nov	Tassilo	NP	511	810	256	111	14	79	579	745	462	61
	Tassilo	P	520	825	239	109	14	71	560	788	471	58
	Benicia	NP	523	871	228	89	17	80	512	788	498	52
	Benicia	P	589	850	192	72	15	68	559	777	478	65
Sig	H		***	***	***	***	***	**	*	***	***	***
	C		NS	***	*	*	***	NS	NS	NS	*	NS
	M		***	NS	***	***	***	***	NS	**	NS	NS
	HxC		*	NS	*	**	*	NS	NS	NS	NS	NS
	HxM		***	NS	***	***	**	*	NS	NS	NS	NS
	CxM		***	**	NS	NS	***	NS	NS	NS	NS	*
	HxCxM		NS	NS	NS	NS	NS	NS	NS	*	NS	NS
s.e.m	HxCxM		19.1	8.8	14.9	7.3	1.1	4.7	15.1	13.2	11.9	4.8

Experiment 2.2: Intake, performance and carcass characteristics of beef cattle offered diets based on whole-crop wheat or forage maize relative to grass silage or *ad libitum* concentrates

[K. Walsh, P. O'Kiely, A.P. Moloney, T.M. Boland]

The objectives were, within a single experiment, to quantify the relative intake, digestibility, performance and carcass characteristics for beef cattle offered grass silage, forage maize silage or WCW silage (each supplemented with concentrates) as the sole dietary source of forage, to rank these relative to an *ad libitum* concentrates based-diet, and to compare the system of urea+urease additive treated, processed WCW (also known as 'alkalage') with fermented WCW silage.

Materials and methods: *Forage production:* A commercial crop of winter wheat (*Triticum aestivum* L., cv. Soissons) was sown in a loam soil on 8 October 2002 at a target seeding rate of 250 seeds/m^2 and managed as for commercial grain production, using pesticide, herbicide, fungicide and fertiliser inputs appropriate for high yielding crops. Representative plots within the crop were direct-cut, precision-chop harvested (Class Jaguar 900 series, Claas, Bury St Edmonds, UK) on 7 August 2003 for fermented WCW (410 g DM/kg) and on 3 September 2003 for urea-treated, processed WCW (666 g DM/kg). The harvester was fitted with a grain processor when harvesting the latter forage – otherwise settings were as when harvesting the fermented WCW. The stubble heights after fermented WCW and urea-treated, processed WCW were harvested were 14.1 cm and 13.5 cm, respectively. In producing urea-treated, processed WCW, a urea+urease additive ('Home 'n' Dry', Volac, Royston, UK) was mechanically mixed with layers of the later harvested WCW as it was being ensiled, at a rate of 48.5 kg / tonne of forage DM. At each time of harvest, wheat plants were selected randomly and cut at the same stubble height as the remainder of the crop for quantification of the proportion of the plant composed of grain, straw and chaff.

The maize (*Zea mais.* L., cv. Benecia) was sown under complete cover plastic mulch into a loam soil on 16 April 2003 at a seed rate of 99,000 seeds per ha. The crop was sprayed with atrazine (Barclay Chemicals Ltd., Tyrellstown way, Damastown Industrial Estate, Mulhuddart, Dublin 15, Ireland) at a rate of 5 l per ha at sowing. It was direct-cut, precision chop-harvested on 6 October 2003 to a stubble height of 28.0 cm and at 304 g DM/kg using a Class Jaguar 860 series harvester (Claas, Bury St Edmonds, UK) fitted with a 4.5 m Kemper maize header (RU450) and corn cracker. At the time of harvest, maize plants were selected randomly and cut at the same stubble height as the remainder of the crop for quantification of the proportion of the plant composed of grain, cob (grain + rachis) and stover.

The grass silage was made from a predominantly ryegrass (*Lolium perenne* L., cv. Millenium) sward. It was mown on 6 June 2003 with a rotary mower (Pottinger conditioner mower, Pottinger, Grieskirchen, Austria) and harvested at 151 g DM/kg with a precision-chop harvester (Pottinger Mex VI, Pottinger, Grieskirchen, Austria). A formic acid based additive (850 g/kg) (Add-SafeR, Interchem Ltd., Cherry Orchard Ind. Est., Dublin 10) was applied at a rate of 1.0 l per tonne of fresh grass. All forages were ensiled in horizontal, walled, roofed, concrete silos. They were mechanically compacted and sealed beneath two layers of black 0.125mm polythene which were then fully covered with tyres.

To allow for the quantification of conservation efficiency, all forages were weighed at ensiling and feed out.

Growth study animals, and treatments: Based on the mean of two consecutive daily live-weights at the start of the experiment and on breed, seventy continental crossbred finishing steers were grouped into blocks, and from within blocks were allocated at random to one of 5 dietary treatments (n=14):

1. Grass silage plus 3 kg concentrates/head/day (GS)
2. Maize silage plus 3 kg concentrates/head/day (MS)
3. Fermented whole-crop wheat plus 3 kg concentrates/head/day (FWCW)
4. Urea-treated, processed whole-crop wheat plus 3 kg concentrates/head/day (UPWCW)
5. *Ad libitum* concentrates plus 5 kg grass silage/head/day (ALC)

Animals were housed in groups of 4 or 5 in slatted floor pens (i.e. one treatment per pen). Replicate pens within a treatment were positioned in different parts of the building. Forages in treatments 1-4 and concentrates in treatment 5 were offered *ad libitum* (at 1.15 times each animals daily intake) through individual electronically controlled Calan gates (American Calan Inc., Northwood, NH, USA) for 160 days. The same concentrate, fed at 3 kg/head/day, was used to supplement the four forage-based treatments in order to maximise the proportion of the forage in the total diet and to be able to compare the forages without the supplementary concentrates having a confounding effect. It was formulated to a target crude protein (CP) content of 190 g/kg DM in order to meet the animals requirements on the lowest protein forage, maize silage. The supplementary concentrate contained 650 g rolled barley, 280 g soya bean meal, 50 g molasses and 20 g minerals and vitamins/kg (839 g DM/kg) and was fed each morning before animals were offered their daily allocation of forage. The concentrate used in the ALC treatment contained 830 g rolled barley, 100 g soya bean meal, 50 g molasses and 20 g minerals and vitamins/kg (838 g DM/kg). All animals had continuous access to clean, fresh water. Feed refusals were weighed daily and discarded twice per week.

Experimental procedure: Live-weight was recorded every 3 weeks, with start and final live-weights being calculated as the means of weights recorded on 2 consecutive days. Mid-way through the experiment blood samples were collected via jugular venipuncture from all animals before feeding and 2 and 6 hours after feeding, into tubes containing lithium heparin as anticoagulant. Plasma was decanted after centrifugation at 2000 *g* for 10 min and stored at -20 ^{0}C for subsequent analysis. Animal behaviour, recorded as either eating, ruminating, drinking or idle, was visually assessed every 10 min for 24 h mid-way through the experiment. Metabolisable energy intakes (MEI) were calculated as the DM intake (DMI) of the forages and concentrates multiplied by their respective estimated ME concentrations. A secondary calculation, surplus MEI (SMEI), was made by subtracting the ME required for maintenance from total MEI.

Cold carcass weight (hot carcass x 0.98), perirenal plus retroperitoneal fat weight and carcass grades for conformation and fatness were recorded after slaughter. Kill out rate (KO) was calculated as the proportion of live-weight accounted

for by cold carcass weight and is expressed as g carcass weight / kg live-weight. Carcass gains were estimated assuming that initial carcass weights were 500 g/kg initial live-weight. Carcasses were chilled at 4 ^{0}C for 24 h after which a muscle sample was taken from between the 5th and 7th ribs of the *M. longissimus dorsi*. This was over-wrapped with cling film and left to bloom for 2 h before measuring redness ('a') (+ = red, - = green), yellowness ('b') (+ = yellow, - = blue) and brightness ('L') (0 = black, 100 = white). Subcutaneous fat colour was measured at the 10th rib on each carcass. These colour measurements were taken using a Minolta ChromaMeter CR100 (Minolta Camera Co., Ltd., Osaka, Japan).

The digestibility of the four forages alone and supplemented with concentrates was determined simultaneous to one another and to the growth study with eight continental crossbred steers (mean initial liveweight 353 kg) assigned to two 4 x 4 latin squares. Each period consisted of 14 days for adaption, during which time animals were offered their forage *ad libitum* and those offered forages plus concentrates were offered their concentrates at the same rate per kg metabolic liveweight as for the corresponding steers on the growth study. This was followed by 8 days during which faeces were collected and forages offered at 0.85 of *ad libitum* intake. For the steers offered forages and supplementary concentrates during this 8 day period, the amount of concentrates offered was calculated so that these animals would have a similar forage:concentrate ratio as the animals on the growth study had during the previous week.

Aerobic stability of the forages was assessed in triplicate on 5 occasions for 8 days at 20 ^{0}C using an automated temperature recording system. The silage was placed into polythene-lined polystyrene (2.5 cm thick) containers (59 cm x 39 cm x 22 cm) with a polystyrene lid fitted loosely on top. Thermocouples were placed in the middle of the silage in each box and the temperature of the silage was recorded every hour by a data logger (SG ELTEK 80T, Eurolec Instumentation Ltd., Dundalk, Co.Louth, Ireland). Containers of water stored beside the silage acted as reference temperatures to which all silage temperatures were compared. Indices of aerobic stability were duration (h) to temperature rise by > 2^0 C and > 5^0 C, the maximum temperature rise (^{0}C) and the duration (h) to maximum temperature rise. Indices of aerobic deterioration were the accumulated temperature rise to 120 and 192 h (^{0}C).

Results: The experimental treatments of grass silage, maize silage, fermented WCW and urea-treated, processed WCW, each supplemented with 3 kg concentrates/head/day, are abbreviated GS, MS, FWCW and UPWCW, respectively. The experimental treatment of *ad libitum* concentrates supplemented with 5 kg grass silage/head/day is abbreviated ALC.

Plant, silage and concentrate composition and forage aerobic stability: The proportions of the wheat and maize plants made up of grain and straw+chaff or stover at harvest time are shown in Table 2.2.1. The wheat plant at both harvest times contained approximately 0.5 grain and 0.5 straw+chaff. The maize had a lower proportion of stover (compared to straw+chaff) but a similar amount of grain as the wheat, with the difference being made up of the rachis of the cob.

The particle length and proportion of physically damaged grain in the forages at feed-out are shown in Table 2.2.2. Grass silage had a lower proportion of particles in the 0-25 mm length and consequently higher amounts in the other length categories compared to the other forages. The particle length of the maize silage was slightly shorter than for the fermented WCW. Virtually all the grain was physically damaged in the maize silage and the amount visually damaged in the fermented WCW and urea-treated, processed WCW was 0.68 and 0.88, respectively.

The chemical composition of the forages and concentrates and the conservation efficiency of the forages are shown in Tables 2.2.2 and 2.2.3. The grass silage was of moderate quality, having a relatively low DM content and DMD and high NDF and ADF contents. Its preservation was not good, as evidenced by the relatively high pH, propionic acid and NH_3-N values, and the relatively low ratio of lactic to acetic acid (1.3:1.0). The maize silage and fermented WCW had satisfactory fermentations, as indicated by their low pH values, high lactic to acetic acid ratios (3.1:1.0 and 2.7:1.0, respectively) and negligible propionic and butyric acid contents. The maize silage had a high *in vitro* DMD but was characteristically low in crude protein. The fermented WCW had a lower DMD than maize silage but a higher crude protein concentration. The urea-treated, processed WCW underwent an alkaline preservation with a very restricted fermentation. It had a numerically higher *in vitro* DMD than the fermented WCW and similar concentrations of NDF and ADF. The ammonia analysis of aqueous extracts from both undried and oven dried (40^{0}C) samples of urea-treated, processed WCW (to account for the loss of volatile nitrogen during oven drying) allowed for the correction of its crude protein from 145 to 168 g/kg DM.

The conservation efficiency of the grass silage was numerically lower than the other three forages with no difference between the fermented WCW and the urea-treated, processed WCW, while the maize silage was numerically slightly lower than the two WCW's.

Forage aerobic stability and deterioration indices are presented in Table 2.2.2. The maize silage was the most unstable on exposure to air, having a higher maximum temperature rise and shorter duration to reach maximum temperature or to rise by 2 ^{0}C or 5 ^{0}C. It also deteriorated more than the other treatments, this being reflected in the higher accumulated temperature rise to 120 h and 192 h.

DM intake: Intakes are shown in Table 2.2.4. Intake of UPWCW was higher than GS, MS (P<0.01) and FWCW (P<0.05) while intake of GS was lower (P<0.001) than the other three forage treatments. There was no difference in forage intake between MS and FWCW. No difference was found in total DM intake (TDMI) between FWCW and UPWCW or between MS and FWCW but intake of UPWCW was higher (P<0.01) than for MS. Cattle offered GS had a lower (P<0.001) TDMI than all other treatments. ME intake was higher (P<0.001) for animals offered the ALC treatment than all other treatments. No difference in ME intake was observed between MS and FWCW or UPWCW but it was found to be lower (P<0.05) for animals offered the FWCW treatment than the UPWCW treatment. Animals offered GS had a lower (P<0.001) ME intake than all other groups.

Animal performance: Animal behaviour results when offered the five diets are presented in Table 2.2.4. The percentage of time animals were observed eating was in the order GS>FWCW>UPWCW=MS>ALC. Animals offered GS spent the greatest percentage of time ruminating while those offered ALC spent the least. Of all the forage-based treatments, animals offered UPWCW had the lowest percentage occasions observed ruminating, with no difference between those offered MS and FWCW or GS and FWCW.

Animal performance results are presented in Table 2.2.4. No difference was observed in live-weight, carcass gain or carcass weight between FWCW and UPWCW but animals on MS had a higher (P<0.05) carcass gain than those on UPWCW. Animals on ALC had a higher carcass gain and carcass weight compared to GS, UPWCW (P<0.001) and FWCW (P<0.01) but no difference was found compared to MS. No difference was observed in KO rate between FWCW and UPWCW. The KO rate was highest for ALC, lowest for GS and UPWCW, and intermediate for MS and FWCW. Animals on MS and ALC were found to be most efficient at converting feed into carcass gain. There was no difference (P>0.05) in FCE between UPWCW and FWCW or between UPWCW and GS. Animals on MS and FWCW had a higher (P<0.05) efficiency of carcass gain per unit of MEI than those on GS or UPWCW, with no difference (P>0.05) being observed between ALC and UPWCW. However, when carcass gain per unit of surplus MEI available to the animal for growth is examined, the GS treatment is more efficient (P<0.001) than all other treatments but is similar to the MS treatment, with no difference between MS and FWCW or between UPWCW and ALC (P>0.05). Plasma urea levels were highest and lowest (P<0.001) in animals offered UPWCW and MS, respectively.

Carcass traits: Carcass data are presented in Table 2.2. 4. Treatment had no effect on carcass conformation. Animals on GS had a lower (P<0.05) carcass fat score compared to all other treatments. Perirenal and retroperitoneal fat weight was higher (P<0.05) for cattle on MS and ALC compared to all other treatments. The proportion of the carcass made up of this fat was higher (P<0.05) for cattle on MS than all other treatments except ALC where it was similar (P>0.05). No difference (P>0.05) was observed between FWCW and UPWCW. Treatment was found to have no effect (P>0.05) on muscle 'L', 'a' or 'b' values, or on fat 'L' or 'a' values. Subcutaneous fat from animals on GS was more yellow than that from animals on ALC, MS, UPWCW (P<0.001) and FWCW (P<0.05) while fat from animals on UPWCW was less yellow than fat from GS, FWCW, ALC (P<0.001) and MS (P<0.01).

Diet digestibility: Apparent digestibilities and faecal grain content of the forage diets alone and with concentrates are presented in Table 2.2.5. The DM and OM digestibility for grass silage and maize silage alone was higher compared to fermented WCW (P<0.01), and similar (P>0.05) to urea-treated, processed WCW. The DOMD was higher (P<0.05) for the maize silage than the grass silage or fermented WCW, but similar (P>0.05) to the urea-treated, processed WCW. The digestibility of the CP was lower for maize silage compared to each of the other three forages (P<0.05). The NDF digestibility was highest for grass silage, lowest for fermented WCW and urea-treated, processed WCW, with maize silage being intermediate, but similar (P>0.05) to urea-treated, processed WCW. No difference (P>0.05) was found between treatments for digestibility of the starch component. Supplementation of the forages with concentrates numerically increased the digestibility of most components. The DMD and OMD were higher for the diets based on maize silage (P<0.05) compared to fermented WCW and urea-treated, processed WCW, with no difference between the grass silage-based diet and these latter two treatments. The DOMD was higher (P<0.05) for the maize silage treatment than the other three treatments. The NDF digestibility was lower for the fermented WCW and urea-treated, processed WCW treatments compared to grass silage (P<0.01) and maize silage (P<0.05) treatments. No difference (P>0.05) was observed in CP digestibility between any of the treatments.

Conclusions: Where GS, MS and FWCW were compared within a single experiment with finishing beef cattle, feed intake and animal performance were lower for those offered GS, with no difference between the MS and FWCW treatments. Animals offered the GS treatment also had a more yellow carcass fat than those offered the MS or FWCW treatments. Estimated carcass output/ha was highest for MS. Compared to the ALC treatment, animals offered the GS, MS and FWCW treatments had a lower estimated ME intake. However, the MS treatment supported a similar carcass gain and FCE to that of the ALC treatment. No intake or animal productivity advantage was evident from the UPWCW compared to FWCW. However, carcass gain per unit of MEI and SMEI were higher for the FWCW treatment. The carcass fat of animals offered the UPWCW treatment was whiter than those offered the FWCW treatment.

Table 2.2.1: Physical composition [a] of plants at harvest (g DM[b]/kg DM)

	Plant		
	Maize	Wheat – FWCW[c]	Wheat – UPWCW[d]
Grain in plant	487 (41.4)	502 (19.3)	494 (25.1)
Cob in plant (maize only)	579 (39.3)	-	-
Straw+chaff or stover in plant	421 (39.3)	498 (19.3)	506 (25.1)

[a] Mean, standard deviation in brackets; [b] Dry matter; [c] As used in the fermented whole-crop wheat treatment; [d] As used in the urea-treated, processed whole-crop wheat treatment.

Table 2.2.2: Physical and chemical composition , conservation efficiency and aerobic stability and deterioration indices of the forages at feed out [a]

	Grass silage	Maize silage	Fermented WCW [b]	Urea-treated, processed WCW
Physical composition				
Particle length (g dry matter (DM) / kg DM)				
0 – 25 mm	486 (86.0)	946 (23.5)	818 (40.8)	881 (27.7)
26 – 50 mm	240 (42.5)	33 (9.3)	85 (11.5)	59 (20.4)
51 – 75 mm	110 (30.5)	7 (6.3)	36 (8.1)	27 (4.8)
76 – 100 mm	69 (24.8)	4 (5.9)	25 (13.4)	13 (5.5)
> 100 mm	95 (50.2)	9 (16.7)	35 (17.7)	20 (12.1)
Proportion of grain broken	-	1.00 (0.012)	0.68 (0.053)	0.88 (0.041)
Chemical composition and conservation efficiency				
Dry matter [c] (g/kg)	174 (10.3)	315 (3.9)	404 (4.3)	716 (7.5)
DM composition, g/kg, unless otherwise stated				
Dry matter digestibility	674 (26.0)	765 (8.6)	689 (14.6)	712 (23.0)
ME (MJ/kg DM) [d]	9.2 (0.41)	11.5 (0.18)	10.1 (0.24)	10.8 (0.36)
Crude protein	116 (4.0)	80 (1.6)	117 (2.7)	168 [e] (11.0)
Ash	107 (10.9)	40 (2.3)	56 (2.4)	41 (2.3)
Neutral detergent fibre	674 (14.4)	426 (36.5)	442 (21.1)	443 (43.7)
Acid detergent fibre	421 (9.9)	224 (11.7)	264 (10.5)	229 (22.4)
Starch	nd [f]	302 (17.3)	229 (22.2)	312 (64.7)
WSC [g]	10 (0.7)	11 (0.9)	16 (1.7)	13 (1.0)
Fermentation characteristics, g/kg volatile-corrected DM				
pH	4.30 (0.226)	3.95 (0.065)	4.02 (0.080)	7.13 (0.421)
Ethanol	25 (2.6)	9 (2.3)	5 (1.2)	1 (0.2)
Lactic acid	57 (25.2)	62 (6.1)	49 (4.6)	5 (1.4)
Acetic acid	44 (9.1)	20 (2.2)	18 (1.7)	10 (1.3)
Propionic acid	6 (2.2)	1 (0.3)	1 (0.4)	1 (0.2)
Butyric acid	1 (0.7)	1 (0.5)	2 (0.8)	1 (0.3)
NH_3-N [h, i] (g/kg N)	155 (23.8)	86 (16.8)	113 (16.0)	241 (35.5)
Conservation efficiency [j]	0.75	0.91	0.96	0.96
Aerobic stability and deterioration indices				
h to TR [k] >2^{0}C	131 (45.1)	39 (13.4)	180 (18.0)	149 (58.2)
h to TR >5^{0}C	149 (46.1)	49 (17.3)	188 (9.2)	170 (47.0)
Max. temperature rise (^{0}C)	8.8 (7.77)	20.3 (4.02)	3.7 (4.74)	4.5 (6.10)
h to max. TR	165 (33.5)	78 (22.2)	192 (0.0)	178 (29.5)
ATR [l] to 120h (^{0}C)	7 (7.0)	53 (26.1)	2 (1.0)	8 (8.2)
ATR to 192h (^{0}C)	31 (30.8)	87 (108.6)	4 (7.1)	16 (18.5)

[a] Mean, standard deviation in brackets; [b] Whole-crop wheat; [c] Corrected for loss of volatiles when oven drying; [d] Metabolisable energy, estimated based on *in vivo* DOMD (AFRC, 1993); [e] Corrected for loss of NH_3-N during oven drying; [f] Not determined; [g] Water soluble carbohydrates; [h] Assay on aqueous extract from undried sample; [i] From assay on aqueous extract from undried and oven dried (40^{0}C) sample, UPWCW contained 5.5 (s.d. 0.71) and 1.4 (s.d. 0.20) g NH_3-N/kg DM, respectively; [j] t DM out of silo / t DM into silo; [k] Temperature rise; [l] Accumulated temperature rise.

Table 2.2.3: Chemical composition [a] of the concentrates

Concentrate type	*Ad libitum*	Forage supplement
DM[b] (g/kg)	838 (18.7)	839 (18.5)
Composition of DM (g/kg DM, unless otherwise stated)		
DMD[c] (g/kg)	863 (4.9)	866 (7.5)
DOMD[d]	818 (9.5)	814 (3.8)
Crude protein	145 (12.4)	199 (21.8)
Ash	45 (5.7)	49 (4.5)
Starch	424 (29.2)	334 (26.1)
ME[e] (MJ/kg DM)	13.0	13.0

[a] Mean, standard deviation in brackets;[b] Dry matter; [c] Dry matter digestibility, measured *in vitro;* [d] Digestible organic matter in the dry matter, measured *in vitro*; [e] Metabolisable Energy, estimated based on *Energy and Protein Requirements of Ruminants* (AFRC, 1993).

Table 2.2.4: Feed intake, animal behaviour, performance, plasma urea, feed conversion efficiency and carcass characteristics for cattle offered the five diets

	Diets					s.e.m.	Sig.[1]
	GS[2]	MS[3]	FWCW[4]	UPWCW[5]	ALC[6]		
Feed intake							
Concentrate intake (kg DM[7]/d)	2.52	2.52	2.52	2.52	8.91 (1.081)[8]	-	-
Forage intake (kg DM/d)	4.92^{c}	7.02^{b}	7.31^{ab}	7.68^{a}	1.03^{d}	0.165	***
Total DM intake (kg/d)	7.41^{c}	9.54^{b}	9.82^{ab}	10.19^{a}	9.92^{ab}	0.198	***
ME[9] intake (MJ/d)	81.6^{d}	108.6^{bc}	102.8^{c}	110.1^{b}	125.9^{a}	2.26	***
Animal behaviour[10]							
Eating	13.8^{a}	8.0^{c}	11.1^{b}	8.8^{c}	4.9^{d}	0.28	***
Ruminating	37.0^{a}	30.1^{b}	33.5^{ab}	25.6^{c}	19.9^{d}	0.66	***
Drinking	0.7^{b}	0.8^{b}	1.6^{a}	1.1^{bc}	1.5^{ac}	0.07	*
Idle	48.8^{d}	61.6^{b}	54.4^{c}	64.5^{b}	73.9^{a}	0.79	***
Performance, feed conversion efficiency and blood metabolite							
Live-weight gain (g/d)	802^{c}	1200^{ab}	1149^{b}	1132^{b}	1302^{a}	48.3	***
Carcass gain (g/d)	479^{d}	776^{ab}	723^{bc}	686^{c}	851^{a}	30.9	***
Carcass weight (kg)	290^{c}	335^{ab}	329^{b}	321^{b}	348^{a}	5.2	***
Kill out rate (g/kg)	523^{d}	547^{ab}	539^{bc}	532^{cd}	551^{a}	4.2	***
FCE[11]	16.0^{a}	12.4^{c}	13.8^{b}	15.0^{ab}	12.0^{c}	0.5	***
Carcass gain/MEI[12] (g/MJ)	5.9^{c}	7.2^{a}	7.0^{a}	6.2^{bc}	6.8^{ab}	0.24	***
Carcass gain/SMEI[13] (g/MJ)	15.7^{a}	13.9^{ab}	13.5^{bc}	11.2^{d}	11.7^{cd}	0.71	***
Plasma urea (mmol/l)	4.6^{b}	2.7^{c}	5.0^{b}	6.8^{a}	4.9^{b}	0.21	***
Carcass characteristics							
Conformation[14]	2.66	3.00	2.93	2.93	3.07	0.10	NS
Fat score[15]	3.15^{b}	3.45^{a}	3.60^{a}	3.49^{a}	3.59^{a}	0.09	**
PRF[16] (kg)	6.4^{c}	10.6^{a}	8.5^{b}	7.2^{bc}	10.1^{a}	0.52	***
PRF (g/kg carcass)	22.4^{c}	31.4^{a}	26.0^{bc}	22.4^{c}	29.1^{ab}	1.66	***
Muscle "L" (brightness)	35.7	36.4	35.4	37.2	36.7	0.92	NS
Muscle "a" (redness)	18.4	19.3	17.3	18.4	20.9	0.91	NS
Muscle "b" (yellowness)	6.6	7.2	6.4	6.8	7.4	0.36	NS
Fat "L" (brightness)	64.8	63.2	65.0	64.8	63.2	1.04	NS
Fat "a" (redness)	5.3	7.4	6.5	5.9	6.4	0.53	NS
Fat "b" (yellowness)	12.7^{a}	9.4^{c}	11.3^{b}	7.6^{d}	9.9^{c}	0.47	***

[1] Significance: within row, means with the same superscripts are not significantly different (P>0.05); NS, not significant, *P<0.05, **P<0.01, ***P<0.001; [2] Grass silage plus 3 kg concentrates; [3] Maize silage plus 3 kg concentrates; [4] Fermented whole-crop wheat plus 3 kg concentrates [5] Urea-treated, processed whole-crop wheat plus 3 kg concentrates; [6] *Ad libitum concentrates* plus 5 kg grass silage; [7] Dry matter; [8] Standard deviation in brackets; [9] Metabolisable energy; [10] Percentage of occasions observed; [11] Feed conversion efficiency, kg DM intake / kg carcass gain; [12] Metabolisable energy intake; [13] Surplus metabolisable energy intake; [14] EU Beef Carcass Classification Scheme: scale 1 (poorest = P) to 5 (best = E); [15] EU Beef Carcass Classification Scheme: scale 1 (leanest) to 5 (fattest); [16] Perirenal + retroperitoneal fat.

Table 2.2.5: *In vivo* digestibility of components of forage diets (proportions)

Component	*Forages alone*				s.e.m.	Sig.[1]
	Grass silage	Maize silage	Fermented WCW [2]	Urea-treated, processed WCW		
Dry matter	0.694^{a}	0.695^{a}	0.628^{b}	0.648^{ab}	0.0079	**
Organic matter	0.706^{a}	0.712^{a}	0.648^{b}	0.671^{ab}	0.0075	**
DOMD[3]	0.634^{b}	0.685^{a}	0.613^{b}	0.641^{ab}	0.0086	**
Crude protein	0.640^{a}	0.503^{b}	0.598^{a}	0.594^{a}	0.0140	**
Neutral detergent fibre	0.736^{a}	0.559^{b}	0.410^{c}	0.488^{bc}	0.0229	***
Starch	-	0.994	0.984	0.984	0.0017	NS
Faecal grain content (g/kg DM)	0^{c}	2^{bc}	9^{a}	7^{ab}	1.0	**
	Forages with supplementary concentrates				s.e.m.	Sig. [1]
	Grass silage	Maize silage	Fermented WCW	Urea-treated, processed WCW		
Dry matter	0.732^{ab}	0.762^{a}	0.691^{b}	0.688^{b}	0.0104	**
Organic matter	0.748^{ab}	0.776^{a}	0.710^{b}	0.708^{b}	0.0099	**
DOMD	0.685^{b}	0.744^{a}	0.672^{b}	0.674^{b}	0.0096	**
Crude protein	0.698	0.648	0.666	0.658	0.0208	NS
Neutral detergent fibre	0.714^{a}	0.629^{a}	0.475^{b}	0.503^{b}	0.0219	***
Starch	0.965^{b}	0.990^{a}	0.984^{a}	0.984^{a}	0.0018	***
Faecal grain content (g/kg DM)	10	8	13	15	2.7	NS

[1] Significance: within row, means with the same superscript are not significantly different ($P>0.05$); NS, not significant; **$P<0.01$; ***$P<0.001$; [2] Whole-crop wheat; [3] Digestible organic matter in the dry matter.

Experiment 2.3: Intake, digestibility, rumen fermentation and performance of beef cattle fed diets based on whole-crop wheat or barley harvested at two cutting heights relative to maize silage or *ad libitum* concentrates

[K. Walsh, P. O'Kiely, A.P. Moloney, T.M. Boland]

The objectives were to quantify the relative intake, digestibility, rumen fermentation, performance and carcass characteristics of beef steers fed diets based on good quality whole-crop wheat and barley silages, each harvested at two cutting heights, and to rank these relative to diets based on good quality maize silage and *ad libitum* concentrates.

Materials and methods: *Forage production:* Winter wheat (*Triticum aestivum* L., cv. Concord) and spring barley (*Hordeum vulgare* L., cv. Tavern) were sown in October 2003 and March 2004, respectively, and each was managed as for commercial grain production, using pesticide, herbicide, fungicide and fertiliser inputs appropriate for high yielding crops. To ensure that both cereals available to harvest were similar for both cutting heights, cutting height treatments were randomly allocated to duplicate plots within each of four replicate blocks within crop, which were direct-cut, precision-chop harvested (Class Jaguar 900 series, Claas, Bury St Edmonds, UK) on 5 August 2004 for whole-crop wheat (508 g DM/kg), head-cut wheat (533 g DM/kg), whole-crop barley (498 g DM/kg) and head-cut barley (509 g DM/kg). Prior to harvest, entire plant heights (i.e., above ground level) were 67.3 cm and 70.8 cm for the wheat and barley, respectively. The stubble heights after each of the four crops were harvested were 12.4 cm, 29.3 cm, 12.5 cm and 30.3 cm, respectively. At the time of harvest, 400 wheat and 400 barley plants were randomly selected and cut at the same stubble height as the remainder of the crop for quantification of the proportion of the plant composed of grain, straw and chaff.

Maize (*Zea mais***.** L., cv. Justina) was sown under complete-cover clear polythene mulch (6 micron; IP Europe Ltd, Wexford, Ireland) on 16 April 2004 at a seed rate of 99,000 seeds per ha. The crop was sprayed with atrazine (Barclay Chemicals Ltd., Tyrellstown way, Damastown Industrial Estate, Mulhuddart, Dublin, Ireland) at a rate of 5 l per ha at sowing. It was direct-cut, precision chop-harvested on 11 October 2004 to a stubble height of 27.9 cm and at 293 g DM/kg using a Class Jaguar 860 series harvester fitted with a 4.5 m Kemper maize header (RU450) and corn cracker. At the time of harvest, 60 maize plants were randomly selected and cut, at the same stubble height as the remainder of the crop, for quantification of the proportion of the plant composed of grain, cob (i.e., grain + rachis) and stover.

All forages were ensiled in horizontal, walled, roofed, concrete silos and mechanically compacted and sealed beneath two layers of black 0.125mm polythene which were then fully covered with tyres.

Animals and treatments: There were three component animal studies in the current experiment, corresponding to groups of steers used to study the growth, digestibility and rumen fermentation characteristics of the experimental diets.

In the case of the growth study, based on the mean of two consecutive daily live weights (LW's) at the start of the experiment, on previous treatment (plus or minus concentrates) and on breed (Limousin, Charolais, Simmental and Belgian Blue cross), 90 continental crossbred steers (mean 438 ± 31.2 kg; mean 22 months of age) were allocated to 15 replicate blocks and from within blocks, were randomly assigned to one of 6 dietary treatments (*n*=15/treatment) being:

1. Maize silage plus 3 kg concentrates/head/day (MS)
2. Whole-crop wheat silage plus 3 kg concentrates/head/day (WCW)
3. Head-cut wheat silage plus 3 kg concentrates/head/day (HCW)
4. Whole-crop barley silage plus 3 kg concentrates/head/day (WCB)
5. Head-cut barley silage plus 3 kg concentrates/head/day (HCB)
6. *Ad libitum* concentrates plus 5 kg grass silage/head/day (ALC)

Steers were housed in groups of 5 in slatted floor pens (i.e. one treatment per pen). Replicate pens within a treatment were positioned in different parts of the building. Forages in Treatments 1-5 and concentrates in Treatment 6 were offered *ad libitum* (at 1.15 times each steers daily intake) through individual electronically controlled Calan gates (American Calan Inc., Northwood, NH, USA) for 160 days. The rate of 3 kg/head/day permitted forages to be the major component of the diet. The same concentrate was used with the five forages to allow the latter be compared without the ingredient composition of the supplementary concentrate potentially having a confounding effect. It was formulated to a target crude protein (CP) content of 200 g/kg DM to meet the estimated CP requirement of the steers offered the maize silage, the lowest CP forage. The supplementary concentrate contained 120 g rolled barley grain, 120 g rolled wheat grain, 120 g maize grain, 230 g soya-bean meal, 340 g molassed beet pulp, 50 g molasses and 20 g minerals & vitamins/kg (866 gDM/kg) and was fed each morning before the steers were fed their daily allocation of forage. The concentrate used in the ALC treatment contained 830 g rolled barley grain, 100 g soya bean meal, 50 g molasses and 20 g minerals and vitamins/kg (858 g DM/kg). All steers had continuous access to clean, fresh water. Feed refusals were weighed daily and discarded twice per week.

The apparent digestibility of the five forages alone and supplemented with concentrates, the same as used in the growth study, was determined simultaneously with ten continental crossbred steers (mean initial LW 356 kg) assigned to two 5 (treatment) x 4 (period) incomplete Latin Squares.

Rumen fermentation parameters were measured using five Holstein-Friesian steers (mean 450 kg) fitted with rumen cannulae of 10 cm internal diameter (Bar Diamond, Inc., Parma, ID, USA).

Experimental procedure: In the growth study, LW was recorded every 3 weeks during the experiment, and start and final LW's were calculated as means of LW recorded on 2 consecutive days. On one day mid-way through the experiment, blood was sampled from each steer via jugular venipuncture before feeding and 2 and 6 hours after feeding, into tubes containing lithium heparin or sodium fluoride as anticoagulants. Plasma was decanted after centrifugation at 2000 *g* for 10 min at 4 ^{0}C and stored at -18 ^{0}C for subsequent analysis. Steer behaviour, recorded as either eating, ruminating, drinking or idle, was visually assessed every 10 min for 24 h on one day mid-way through the experiment.

Metabolisable energy (ME) values were calculated as in Experiment 2.2. At the end of the 160 day study period, steers were slaughtered and cold carcass weight (hot carcass x 0.98), perirenal plus retroperitoneal fat weight and carcass grades for conformation and fatness were recorded. Kill-out, carcass and meat data were determined as for Experiment 2.2.

Each period in the digestibility study consisted of 14 days for adaptation, during which time steers were fed the appropriate forages *ad libitum.* Steers offered forage plus concentrate were fed concentrates at the same rate per kg metabolic LW as the steers on the growth study. This was followed by 8 days during which forages were offered at 0.85 of *ad libitum* intake, and faeces was collected. For steers offered forages and supplementary concentrates during this 8 day period, the amount of concentrate offered was calculated so that these steers would have a similar forage:concentrate ratio as the steers on the growth study had during the previous week.

A Latin Square design was employed for the rumen fermentation study, consisting of five periods, each of 15 days duration, with 14 days for dietary adaptation followed by a 1 day sampling period. Steers were housed in individual stalls and had access to water at all times. They were offered the appropriate forages *ad libitum* and supplemented with 3 kg concentrates (i.e., the same concentrate as used in the growth study) for the duration of the 14 day adaptation period. On day 15, forages were fed at 0.85 of *ad libitum* intake and supplemented with concentrates, calculated so that these steers would have a similar forage:concentrate ratio as the steers on the growth study had during the previous week. Rumen fluid samples of approximately 200 ml were collected through the rumen cannulae at 0830 (before feeding), 1030, 1230, 1430, 1630, 2030, 0030 and 0830 on day 15 of each period to assess rumen fermentation characteristics. Rumen fluid pH was measured immediately after collection using an Orion digital pH meter and glass electrode. A 20 ml sub-sample was acidified with 0.5 ml of 9M sulphuric acid and stored at -18 ^{o}C for subsequent analysis.

Aerobic stability of the forages was assessed as for Experiment 2.2.

Results: The harvested yield for the maize silage, whole-crop wheat, head-cut wheat, whole-crop barley and head-cut barley were 18.0, 13.0, 11.5, 10.5 and 8.4 t DM per ha, respectively.

Plant, silage and concentrate composition and forage aerobic stability: Wheat, barley and maize plants had similar straw+chaff and stover proportions (Table 2.3.1). The lower grain but similar cob proportion in maize relative to the grain content of wheat and barley reflect the rachis contributing 0.118 of the harvested maize plant.

The *in vitro* DMD of the grain and straw or stover components were numerically highest with maize and lowest with barley (Table 2.3.2). Conversely, barley grain had a higher CP than wheat grain, which in turn was higher than maize grain. Starch content was highest in wheat grain and lowest in maize grain.

Maize silage had a higher proportion of its grain visibly broken than the other forages and both forms of wheat had more of their grain broken than the corresponding forms of barley (Table 2.3.3). All silages had excellent preservation as evidenced by low pH (3.9-4.2), high lactic:acetic acid ratio (2.2-4.7:1), low NH_3-N (16.7-28.5 g/kg N) and negligible propionic and butyric acid contents (0.1-0.7 g/kg DM). The maize silage had a characteristically low CP concentration. Increasing the cutting height increased the DM concentration of wheat from 488 g/kg to 520 g/kg. It also caused a numerical increase in DMD, CP, starch, WSC and estimated ME, and a decrease in ash, aNDFom and ADFom. The same trends were found for the whole-crop and head-cut barley due to the rise in cutting height.

The maize was the most unstable silage on exposure to air, having a higher maximum temperature rise and shorter duration to reach maximum temperature or to rise by 2 ^{0}C or 5 ^{0}C (Table 2.3.3). It also deteriorated more than the other treatments, reflected in the higher accumulated temperature rises to 120 and 192 h. Table 2.3.4 summarises concentrate chemical composition.

Dry matter intake: Intake of ME was lower (P<0.05) for steers fed the MS treatment than those fed any other treatment (Table 5). Intake of N was higher (P<0.05) for steers on the ALC treatment than all other treatments. Those offered WCB or HCB had higher (P<0.05) N intakes than those offered WCW or HCW, which in-turn had higher (P<0.001) N intakes than those offered MS.

Animal behaviour, performance, feed efficiency and blood metabolites: Steers fed ALC had a lower proportion of occasions observed eating (P<0.01) and ruminating (P<0.05) (Table 2.3.5).

Steers fed the ALC treatment had higher LW and carcass gains (P<0.001) and carcass weight (P<0.01) than those on the forage-based treatments. When the data for treatments WCW, HCW, WCB and HCB were analysed as a 2 x 2 factorial arrangement, an effect was found for crop type, with steers fed either of the barley treatments having a higher (P<0.05) KO than those offered either of the wheat treatments (s.e. 3.30). Steers fed the MS treatment had a better (P<0.05) FCE than those on the WCW or WCB treatments. Steers fed the ALC treatment had a better (P<0.05) FCE than all other treatments. Carcass gain per unit of ME intake or per unit of surplus ME intake was higher (P<0.05) for steers fed the ALC and MS treatments compared to all other treatments, except HCB, which had a similar carcass gain/ME intake to that of MS. Steers fed the ALC treatment had a higher (P<0.05) plasma urea concentration than all other treatments. Plasma urea was also higher (P<0.05) in steers fed HCB compared to the other forage-based treatments, while those on the MS treatment had a lower value (P<0.01) compared to all other treatments. When the data for treatments WCW, HCW, WCB and HCB were analysed as a 2 x 2 factorial arrangement, an effect was found for crop type and the interaction between cutting height and crop type, with steers offered either of the barley treatments having a higher (P<0.001) plasma urea than those offered either of the wheat treatments (s.e. 0.083). The interaction between cutting height and crop type (P<0.01) was such that steers fed the HCB treatment had a higher plasma urea than those fed the HCW treatment (s.e. 0.117).

Carcass quality traits: Fat from steers fed the ALC treatment was more red (fat "a") ($P<0.05$) than that from steers fed the MS, WCB or HCB treatments. Steers fed ALC had a more yellow ($P<0.01$) fat than those on any of the other treatments.

Diet apparent digestibility: When the forages were fed alone, digestibility of the aNDFom was higher ($P<0.05$) in steers fed the head-cut barley compared to those offered the whole-crop wheat (Table 2.3.6). When data for both forms of wheat and barley were analysed as a 2 x 2 factorial arrangement, an effect was found for crop type on aNDFom digestibility, with steers fed either of the barley treatments having a higher ($P<0.05$) value than those offered either of the wheat treatments (s.e. 0.0260). Starch digestibility was higher ($P<0.01$) for steers offered maize silage compared to whole-crop barley or head-cut barley. When the data for the whole-crop and head-cut wheat and barley were analysed as a factorial, an effect was found for crop type on starch digestibility such that steers fed either form of barley had a lower starch digestibility ($P<0.05$) than those fed either form of wheat (s.e. 0.0083). Faecal grain content was higher ($P<0.05$) for steers fed either whole-crop barley or head-cut barley compared to maize silage or whole-crop wheat. When the data were analysed as a 2 x 2 factorial arrangement for both forms of wheat and barley, faecal grain content was higher ($P<0.01$) for steers fed either form of barley compared to those fed either form of wheat (s.e. 9.2).

For the data was pertaining to whole-crop and head-cut wheat and barley supplemented with concentrates, steers fed either form of barley had a higher CP digestibility ($P<0.05$; s.e. 0.0183) and faecal grain content ($P<0.01$; s.e. 13.3) than those offered either form of wheat. However, steers offered maize silage and concentrates had a higher ($P<0.01$) starch digestibility than all other treatments, while those fed whole-crop wheat or head-cut wheat had a higher ($P<0.01$) starch digestibility than those on whole-crop barley or head-cut barley.

Rumen fermentation: Rumen ammonia was lower ($P<0.05$) for the HCW treatment than WCB or HCB and lower for the MS than WCB (Table 2.3.7). Steers fed either of the barley treatments had a higher ($P<0.01$) rumen ammonia value than those offered either of the wheat treatments (s.e. 5.18).

Conclusions: Feeding whole-crop wheat or barley containing a high proportion of grain (>0.50 g DM/kg) can support a similar level of animal performance to that achieved with good quality maize silage, but with a poorer FCE. Raising the cutting height of wheat or barley as done here may not confer an intake, performance or FCE advantage in steers fed the head-cut forage, over and above that achievable from the whole-crop form, and may infact result in a lower carcass output per hectare. Feeding an *ad libitum* concentrate-based diet to finishing steers offers a superior level of animal performance and FCE compared to that achieved from the forage-based diets examined in this study.

Table 2.3.1. Physical composition[a] of plants at harvest (g DM/kg DM)

	Plant		
	Maize[b]	Wheat[c]	Barley[a]
Grain in plant	466 (33.0)	578 (11.6)	576 (12.1)
Cob in plant (maize only)	584 (26.0)	-	-
Straw + chaff or stover in plant	416 (26.0)	422 (11.6)	424 (12.1)

[a]Mean, standard deviation in brackets; [b]Cut at 27.9cm stubble height; [c]Cut at 12.4cm stubble height; [d]Cut at 12.5cm stubble height

Table 2.3.2: Chemical composition[a] of plants at harvest (g/kg DM, unless otherwise stated)

	Component			
	DMD (g/kg)[b]	Ash	CP[c]	Starch
Maize				
Stover	683 (18.3)	60 (3.7)	81 (7.0)	nd[d]
Cob core (rachis)	655 (20.0)	20 (1.3)	31 (3.1)	nd
Cob grain (kernels)	935 (11.1)	17 (0.3)	95 (3.1)	555 (18.7)
Wheat				
Bottom $^2/_3$ straw	627 (30.5)	69 (3.8)	60 (6.1)	nd
Top $^1/_3$ straw	625 (37.7)	59 (6.6)	74 (9.4)	nd
Chaff	577 (17.2)	55 (4.2)	70 (2.7)	nd
Grain	911 (10.0)	16 (0.6)	108 (1.9)	619 (8.2)
Barley				
Bottom $^2/_3$ straw	471 (40.2)	48 (4.9)	54 (6.1)	nd
Top $^1/_3$ straw	571 (17.8)	64 (6.5)	79 (3.7)	nd
Chaff	586 (23.5)	80 (0.6)	74 (2.3)	nd
Grain	895 (11.0)	17 (0.6)	120 (6.0)	588 (6.0)

[a] Mean, standard deviation in brackets; [b] *In vitro* dry matter digestibility; [c] Crude protein; [d] Not determined.

Table 2.3.3: Physical and chemical composition and aerobic stability and deterioration indices of the forages at feed out [a]

	Maize silage	Whole-crop wheat	Head-cut wheat	Whole-crop barley	Head-cut barley
Physical composition					
Particle length (g dry matter (DM) / kg DM)					
0 – 25 mm	901 (57.9)	876 (42.2)	827 (93.6)	896 (24.7)	913 (44.3)
26 – 50 mm	57 (21.7)	68 (19.4)	69 (26.9)	54 (13.4)	33 (21.1)
51 – 75 mm	18 (17.5)	25 (9.7)	38 (25.2)	20 (7.0)	23 (13.3)
76 – 100 mm	10 (8.0)	16 (7.4)	27 (21.1)	16 (4.2)	10 (5.3)
> 100 mm	13 (18.9)	14 (17.7)	39 (29.9)	15 (9.4)	21 (13.9)
Proportion of grain broken	0.97 (0.037)	0.34 (0.112)	0.30 (0.093)	0.26 (0.087)	0.24 (0.054)
Chemical composition					
Dry matter [b] (g/kg)	301 (8.6)	488 (20.9)	520 (17.2)	491 (13.8)	499 (10.8)
DM composition, g/kg, unless otherwise stated					
Dry matter digestibility	721 (17.6)	745 (11.0)	760 (21.7)	722 (32.0)	750 (52.1)
DOMD [c]	693 (18.7)	717 (11.4)	744 (20.9)	712 (21.0)	755 (16.1)
ME (MJ/kg DM) [d]	10.9 (0.29)	11.3 (0.18)	11.7 (0.33)	11.2 (0.33)	11.9 (0.25)
Crude protein	87 (3.1)	104 (3.3)	110 (2.6)	117 (4.5)	121 (3.1)
Ash	37 (2.0)	44 (4.5)	33 (2.2)	48 (7.9)	39 (3.5)
Neutral detergent fibre	450 (23.7)	400 (21.3)	342 (28.3)	465 (48.8)	437 (45.1)
Acid detergent fibre	242 (4.7)	217 (11.3)	183 (18.7)	230 (18.6)	194 (21.0)
Starch	279 (20.4)	343 (26.6)	402 (42.9)	289 (49.5)	324 (54.0)
WSC [e]	11 (2.4)	12 (2.0)	18 (3.7)	14 (2.4)	15 (3.0)
Fermentation characteristics, g/kg volatile-corrected DM, unless otherwise stated					
pH	3.9 (0.15)	4.1 (0.05)	4.1 (0.12)	4.2 (0.08)	4.1 (0.05)
Ethanol	6 (0.7)	4 (2.2)	1 (0.3)	1 (0.1)	2 (1.5)
D-Lactate	24 (5.8)	9 (1.5)	8 (1.9)	8 (1.3)	8 (0.7)
L-Lactate	19 (4.3)	8 (1.0)	7 (1.1)	7 (1.1)	8 (0.6)
Acetic acid	20 (4.9)	6 (2.3)	3 (0.7)	4 (0.8)	7 (3.3)
Propionic acid	0.7 (0.22)	0.1 (0.06)	0.1 (0.05)	0.1 (0.02)	0.1 (0.03)
Butyric acid	0.3 (0.18)	0.2 (0.08)	0.4 (0.13)	0.2 (0.08)	0.4 (0.23)
NH_3-N (g/kg N) [f]	28.4 (5.60)	28.5 (5.07)	25.7 (5.01)	17.3 (4.18)	16.7 (3.14)
Aerobic stability and deterioration indices					
h to TR [g] $>2^0$C	38 (14.1)	85 (61.5)	114 (39.5)	117 (38.7)	105 (57.6)
h to TR $>5^0$C	43 (15.8)	97 (55.6)	136 (38.8)	139 (33.6)	122 (58.7)
Max. temperature rise (^{0}C)	24.9 (3.39)	13.0 (7.14)	9.1 (4.73)	8.3 (4.46)	9.0 (6.43)
h to max. TR	65 (18.3)	115 (48.5)	154 (28.7)	166 (28.7)	133 (50.8)
ATR [h] to 120h (^{0}C)	70 (13.2)	23 (16.8)	7 (7.3)	5 (4.1)	13 (13.9)
ATR to 192h (^{0}C)	140 (17.5)	51 (32.2)	23 (15.6)	25 (14.7)	33 (28.3)

[a] Mean, standard deviation in brackets; [b] Corrected for loss of volatiles when oven drying; [c] Digestible organic matter in the dry matter; [d] Metabolisable energy, estimated based on *in vivo* DOMD (AFRC, 1993); [e] Water soluble carbohydrates; [f] Ammonia nitrogen. Assay on aqueous extract from undried sample; [g] Temperature rise; [h] Accumulated temperature rise; The grass silage (perennial ryegrass-dominant, permanent pasture sward) used in the ALC treatment had a DM concentration of 235 g DM/kg, an *in vitro* DMD of 730 g/kg, crude protein of 136 g/kg DM, aNDFom of 563 g/kg DM, WSC of 10 g/kg DM, pH of 3.8, ethanol of 15.2 g/kg DM, lactic acid of 99 g/kg DM, acetic acid of 26 g/kg DM, propionic acid of 1.7 g/kg DM, butyric acid of 1.9 g/kg DM and NH_3-N of 35 g/kg N.

Table 2.3.4: Chemical composition [a] of the concentrates

Concentrate type	*Ad libitum*	Forage supplement
DM [b] (g/kg)	858 (7.4)	866 (6.2)
Composition of DM (g/kg, unless otherwise stated)		
DMD [c] (g/kg)	832 (18.5)	873 (6.9)
DOMD [d]	779 (21.6)	797 (8.9)
Crude protein	149 (7.5)	190 (6.2)
Ash	55 (2.7)	81 (2.5)
Starch	409 (27.0)	206 (22.1)
ME [e] (MJ/kg DM)	13.0	13.0

[a] Mean, standard deviation in brackets; [b] Dry matter; [c] Dry matter digestibility, measured *in vitro;* [d] Digestible organic matter in the dry matter; [e] Metabolisable Energy, estimated based on *Energy and Protein Requirements of Ruminants* (AFRC, 1993).

Table 2.3.5: Intake of concentrate and forage, growth rate, carcass weight, kill out rate, feed conversion efficiency (FCE), plasma metabolites and carcass quality characteristics for cattle offered the six diets

	Diets						s.e.m.	P [1]
	MS [2]	WCW [3]	HCW [4]	WCB [5]	HCB [6]	ALC [7]		
Feed intake								
Concentrate intake (kg DM [8] /d)	2.60	2.60	2.60	2.60	2.60	8.22 (0.501)[9]	-	-
Forage intake (kg DM/d)	6.80	7.27	7.11	7.26	7.10	1.40 (0.047)[10]	0.176	NS
Total DM intake (kg/d)	9.43	9.90	9.74	9.89	9.74	9.62	0.182	NS
ME [11] intake (MJ/d)	108.3^{b}	116.4^{a}	117.4^{a}	115.5^{a}	118.8^{a}	121.2^{a}	2.05	***
Nitrogen intake (kg /d)	0.174^{d}	0.200^{c}	0.204^{c}	0.215^{b}	0.217^{b}	0.227^{a}	0.0033	***
Animal behaviour [12]								
Eating	8.6^{a}	9.2^{a}	7.5^{a}	9.1^{a}	8.0^{a}	4.3^{b}	0.69	***
Ruminating	32.3^{a}	30.2^{ab}	25.7^{c}	29.6^{abc}	27.0^{bc}	20.2^{d}	1.59	***
Drinking	1.0	2.1	1.6	1.5	1.5	1.8	0.30	NS
Idle	58.5^{d}	58.8^{cd}	65.3^{b}	60.2^{bcd}	63.9^{bc}	74.1^{a}	1.90	***
Performance, feed conversion efficiency and blood metabolite concentrations								
Live-weight gain (g/d)	1235^{b}	1254^{b}	1237^{b}	1151^{b}	1240^{b}	1473^{a}	44.9	***
Carcass gain (g/d)	781^{b}	741^{b}	758^{b}	736^{b}	785^{b}	939^{a}	31.2	***
Carcass weight (kg)	344^{b}	338^{b}	341^{b}	337^{b}	345^{b}	366^{a}	5.4	**
Kill out rate (g/kg)	541	529	535	541	541	549	5.6	NS
FCE [13]	12.0^{b}	13.5^{a}	13.1^{ab}	13.6^{a}	12.6^{ab}	10.3^{c}	0.51	***
Carcass gain/MEI [14] (g/MJ)	7.2^{ab}	6.4^{c}	6.4^{c}	6.4^{c}	6.7^{bc}	7.8^{a}	0.26	***
Carcass gain/SMEI [15] (g/MJ)	14.4^{a}	11.9^{b}	11.9^{b}	11.9^{b}	12.3^{b}	14.1^{a}	0.58	**
Plasma urea (mmol/l)	3.5^{d}	4.2^{c}	4.0^{c}	4.4^{c}	4.8^{b}	5.3^{a}	0.14	***
Plasma glucose (mmol/l)	4.2	4.2	4.4	4.3	4.2	4.4	0.13	NS
Carcass characteristics								
Conformation [16]	3.27^{ab}	2.80^{c}	3.00^{ac}	3.00^{ac}	2.92^{bc}	3.30^{a}	0.129	*
Fat score [17]	3.14	3.31	3.19	3.11	3.49	3.55	0.145	NS
PRF [18] (kg)	9.0	9.5	10.2	8.5	9.3	9.3	0.56	NS
PRF (g/kg carcass)	26.7	28.3	30.2	25.5	27.4	25.6	1.82	NS
Muscle “L” (brightness)	33.8	32.3	32.2	33.5	33.1	33.6	0.55	NS
Muscle “a” (redness)	15.0	14.4	14.0	14.3	14.3	14.6	0.47	NS
Muscle “b” (yellowness)	5.2	4.7	4.5	4.7	4.9	4.9	0.24	NS
Fat “L” (brightness)	65.6	63.8	64.3	64.4	65.9	64.3	1.01	NS
Fat “a” (redness)	5.8	6.2	6.1	5.6	5.7	7.2	0.44	NS
Fat “b” (yellowness)	7.8^{b}	8.3^{b}	8.0^{b}	7.8^{b}	8.5^{b}	9.7^{a}	0.30	***

[1] Significance: within row, means with the same superscripts are not significantly different ($P>0.05$); NS, not significant, *$P<0.05$, **$P<0.01$, ***$P<0.001$; [2] Maize silage plus 3 kg concentrates; [3] Whole-crop wheat plus 3 kg concentrates; [4] Head-cut wheat plus 3 kg concentrates; [5] Whole-crop barley plus 3 kg concentrates; [6] Head-cut barley plus 3 kg concentrates; [7] *Ad libitum concentrates* plus 5 kg grass silage; [8] Dry matter; [9] Standard deviation in parentheses; [10] Not included in the analysis of variance for this variable; standard deviation in parentheses; [11] Metabolisable energy; [12] Percentage of occasions observed; [13] Feed conversion efficiency, kg DM intake / kg carcass gain; [14] Metabolisable energy intake; [15] Surplus metabolisable energy intake; [16] EU Beef Carcass Classification Scheme: scale 1 (poorest = P) to 5 (best = E); [17] EU Beef Carcass Classification Scheme: scale 1 (leanest) to 5 (fattest); [18] Perirenal + retroperitoneal fat.

Table 2.3.6: Total DM intake and i*n vivo* apparent digestibility (g/g) of components of forage diets

	Maize silage	Whole-crop wheat	Head-cut wheat	Whole-crop barley	Head-cut barley	s.e.m.	P [1]
Forages only							
Total DM intake (kg/d)	6.90	6.99	7.25	7.72	8.27	0.549	NS
In vivo apparent digestibility							
Dry matter	0.664	0.654	0.692	0.661	0.678	0.0170	NS
Organic matter	0.679	0.682	0.709	0.678	0.695	0.0169	NS
Crude protein	0.484	0.512	0.567	0.583	0.598	0.0276	NS
Neutral detergent fibre[2]	0.504^{ab}	0.460^{b}	0.512^{ab}	0.558^{ab}	0.591^{a}	0.0299	*
Starch	0.996^{a}	0.964^{ab}	0.967^{ab}	0.936^{b}	0.935^{b}	0.0090	**
Faecal grain content (g/kg DM)	1^{b}	21^{b}	41^{ab}	90^{a}	91^{a}	11.7	**
Forages with supplementary concentrates							
Total DM intake (kg/d)	7.17^{b}	8.63^{ab}	9.67^{a}	9.74^{a}	9.96^{a}	0.723	*
In vivo apparent digestibility							
Dry matter	0.720	0.699	0.725	0.704	0.705	0.0119	NS
Organic matter	0.739	0.725	0.743	0.722	0.723	0.0116	NS
Crude protein	0.600	0.593	0.607	0.638	0.634	0.0198	NS
Neutral detergent fibre[2]	0.563	0.509	0.547	0.593	0.588	0.0284	NS
Starch	0.997^{a}	0.956^{b}	0.954^{b}	0.915^{c}	0.897^{c}	0.0066	***
Faecal grain content (g/kg DM)	1^{b}	40^{b}	58^{b}	137^{a}	140^{a}	15.3	***

[1] Significance: within row, means with the same superscript are not significantly different ($P>0.05$); NS, not significant, * $P<0.05$, ** $P<0.01$, *** $P<0.001$;
[2] aNDFom.

Table 2.3.7: pH, concentrations of ammonia, lactic acid and total volatile fatty acids (VFAs) and molar proportions of individual VFAs in the rumen of steers fed the five forage-based treatments

	Diets					s.e.m.	P [1]
	MS [2]	WCW [3]	HCW [4]	WCB [5]	HCB [6]		
pH	6.54	6.39	6.41	6.43	6.44	0.050	NS
D-Lactate (mg/l)	191	64	84	47	147	52.1	NS
L-Lactate (mg/l)	186	54	61	39	117	45.7	NS
Ammonia (mg/l)	25^{bc}	33^{abc}	19^{c}	59^{a}	55^{ab}	7.4	*
Total VFA (mmol/l)	82.3	95.1	112.5	105.9	95.9	8.24	NS
Molar proportions (mmol/mmol)							
Acetic acid	62.7	62.0	61.1	64.1	63.5	1.54	NS
Propionic acid	17.5	17.2	18.6	16.3	16.4	0.96	NS
Butyric acid	15.1	16.6	15.5	15.1	15.7	0.73	NS
Valeric acid	4.6	4.2	4.8	4.6	4.3	0.46	NS
Acetate:Propionate ratio	3.7	3.8	3.6	4.1	3.9	0.24	NS

[1] Significance: within row, means with the same superscripts are not significantly different ($P>0.05$); NS, not significant, $*P<0.05$, $**P<0.01$, $***P<0.001$; [2] Maize silage plus concentrates; [3] Whole-crop wheat plus concentrates; [4] Head-cut wheat plus concentrates; [5] Whole-crop barley plus concentrates; [6] Head-cut barley plus concentrates.

Experiment 2.4: Intake, digestibility and rumen characteristics in cattle offered whole-crop wheat or barley silages of contrasting grain to straw ratios

[K. Walsh, P. O'Kiely, H.Z. Taweel, M. McGee, A.P. Moloney, T.M. Boland]

Therefore, the objectives of this study were to quantify the intake, digestibility and rumen characteristics in cattle offered varying G:S ratios of whole-crop wheat or barley silages.

Materials and methods: *Forage production:* The feedstuffs used were derived from the whole-crop cereals (whole-crop wheat (488 g DM/kg), high-cut wheat (520 g DM/kg), whole-crop barley (491 g DM/kg) and high-cut barley (499 g DM/kg)) used by Walsh et al. (2007). The whole-crop wheat and high-cut wheat together were used to produce wheat grain and wheat straw for the current experiment, while the whole-crop barley and head-cut barley together were used to produce barley grain and barley straw. In each case the chaff was included with the straw. The silages were removed from the silos and loaded into an Abbey Super-mix 100 forage wagon (Abbey Farm Machinery, Nenagh, Co. Tipperary, Ireland) and mixed. This allowed the compressed silage to be loosened before it was conveyed from the forage wagon to a Deutz Fahr Top Liner 4060 HTS combine harvester (IAM Agricultural Machinery, Hebron Industrial Estate, Kilkenny, Ireland) via a Climax 1200 rubber conveyor (Zijlstra & Bolhuis BV, Beneden Dwarsdiep 25, 9640 AA Veendam, The Netherlands). The conveyor acted to further loosen the silage and to provide a continuous flow of material into the combine harvester. The harvester then separated the silage into grain and straw (plus chaff). The wheat grain (523 g DM/kg), wheat straw (463 g DM/kg) and barley straw (447 g DM/kg) were formed into round, compacted bales and sealed within 8-10 layers of polythene stretch-film using an Orkel MP 2000 Maize Baler/Wrapper (B&H Imports, Balbriggan, Co. Dublin, Ireland). As bales would not form properly, the barley grain (552 g DM/kg) was ensiled in a low (*ca.* 1 m) narrow (*ca.* 1.5 m) concrete bunker silo, compacted and sealed within two layers of black 0.125mm polythene, and fully covered with tyres. All feeds were stored under roof.

Intake and digestibility study: Based on the mean of two consecutive daily liveweights at the start of the experiment, eight Aberdeen Angus cross-bred steers (mean bodyweight 407 (s.d. 24.2) kg) were ranked by liveweight and alternative animals were allocated to wheat or barley dietary treatments. The experimental design consisted of two balanced Latin Squares, one for each cereal, with each having four periods of 34 d duration. The treatments were four ratios of grain to straw for both wheat and barley: 0:100, 30:70, 60:40 and 90:10. A period was composed of 14 d for dietary adaption and 10 d for measurement of *ad libitum* feed intake, followed by 2 d of restricted feeding acclimatisation and 8 d of digestibility measurement. Each treatment was supplemented with prilled feed grade urea and ammonium sulphate (Trouw Nutrition UK Ltd., Belfast, Northern Ireland). The urea was added to equalise crude protein (CP) across treatments and the ammonium sulphate was included to achieve a nitrogen:sulphur ratio (N:S) of 10:1 in the diet (Dwivedi et al., 1994; Zinn et al., 1997). The daily feed of each animal was further supplemented with 80 g of a mineral plus vitamin mixture (vitamin A (0.50 million i.u./kg), vitamin D_3 (0.13 million i.u./kg), vitamin E (1.5 g/kg), Ca (28.5%), Na (5.6%), P (1.6%), Co (42 mg/kg), Cu (0.5 g/kg), I (10 mg/kg), Fe (1000 mg/kg), Mn (5800 mg/kg), Se (2.25 mg/kg) and Zn (7500 mg/kg) (David Taylor Animal Nutrition Ltd., Collinstown, Co.Westmeath, Ireland)). The minerals used were in the oxide form where possible to facilitate controlling the amount of sulphur in the mix. Animals were accomodated in individual stalls and had access to fresh water at all times.

Following dietary adaptions, animals were weighed at the start and end of each 10 d *ad libitum* intake interval. For the duration of the 10 d, the amount of feed offered was adjusted daily so that refusals were small (*ca.* 0.05 of feed offered), therefore limiting the opportunity for selection and ensuring that animals consumed the desired ratio of G:S on their respective treatment. Feed refusals were weighed and discarded daily. Feed (wheat grain, wheat straw, barley grain and barley straw) was sampled on alternate days, stored at -18°C until the end of the experiment and then composited within a period for d 1 to 5 and 6 to 10 for subsequent analysis. At the end of the *ad libitum*

interval, feed offered was restricted to 0.95 of *ad libitum* intake for the remaining 10 d and apparent diet digestibility was determined in the final 8 d.

Rumen study: Four Holstein-Friesian steers (mean 659 (s.d. 56.9) kg) fitted with rumen cannulae of 10 cm internal diameter (Bar Diamond, Inc., Parma, ID, USA) were used. The experiment was a balanced Latin Square design, consisting of four periods, each of 18 d duration, with 14 d for dietary adaptation followed by 4 d of sampling. Animals were housed in individual stalls and had access to water at all times. The four experimental treatments offered were four ratios of G:S for barley only: (1) 0:100, (2) 30:70, (3) 60:40 and (4) 90:10. Each treatment was supplemented with feed grade urea, ammonium sulphate and a mineral+vitamin mix as described previously. Feed was offered *ad libitum* at 0900 until d 14. From d 14 until the end of each period, feed was offered at 0.95 of the mean DMI of each individual animal on d 11, 12 and 13. Animals were offered their daily allocation of feed in four meals at 0900, 1100, 1400 and 1700 from d 15 to 18 to reduce the opportunity for dietary selection.

Feed (barley grain and barley straw) was sampled daily from days 15 to 18, stored at -18°C until the end of the experiment and then composited to give one sample per animal per period for subsequent analysis.

Rumen fluid samples of approximately 200 ml were collected through the rumen cannulae at 0900 (before feeding), 1000, 1100, 1300, 1500, 1700, 1900, 2100 on d 14 and 0100 and 0900 on d 15 of each period to assess fermentation characteristics. Rumen fluid pH was measured immediately after collection using an Orion digital pH meter (SA720) and glass electrode. A 20 ml sub-sample was acidified with 0.5 ml of 9M sulphuric acid and stored at -18^{o}C for subsequent analysis.

The marker used to estimate the flow of the rumen fluid phase was Co-EDTA. Following removal of the 0900 rumen fluid sample on d 15, 8 g of Co-EDTA dissolved in 800 ml of distilled water was dispersed throughout the rumen of each animal via the cannula using a plastic tube (500 mm long with an internal diameter of 5 mm) attached to a large stainless steel funnel.

Degradability of feed DM, OM, starch, fibre and nitrogen fractions were determined by *in sacco* rumen incubation according to Woods et al. (2003). Samples (1.5 g) of dried and milled (2 mm screen) barley grain and straw were weighed into previously weighed 50 x 100 mm N free polyester monofilament bags (Ankom, Macedon, NY, USA), of 53 micron (± 10) pore size, according to the G:S ratio for each treatment. Samples of the dried and milled grain and straw were taken for analysis of ash, N, aNDFom and starch. Seventy bags were placed in two large (295 x 350 mm) nylon mesh bags (2.5 mm pore size) (i.e. 35 nylon bags in each large mesh bag) which was closed at one end by means of a 90 cm length of nylon string. A stainless steel weight (500g) was attached to one end of the string approximately 45 cm from the bag to ensure the bags did not float to the top of the rumen mat. The other end of the string was also 45 cm from the bag and attached to a washer of 40 mm external diameter, which remained outside the cannula to facilitate easy removal of the bags. The bags were inserted in the rumen of the animal on the corresponding treatment following removal of the 0900 rumen fluid sample on day 15. Six bags were removed following 2 h incubation, 8 bags following 4 and 8 h, 10 bags following 12, 24, and 48 h and 12 bags following 72 h. An additional 6 bags were not incubated and were used for zero time incubation. They were subsequently treated the same as the other bags. Upon removal from the rumen, all bags were stored at -18^{0}C. Separately, 40 bags were incubated for 336 h in four separate (because of the long incubation time) cannulated steers to calculate the totally undegradable fraction and, upon removal, these too were stored at -18^{0}C until the end of the study. At the end of the study, all bags including zero time incubations were defrosted and received a mild blending using a stomacher. They were subsequently washed together in cold water using an automatic domestic washing machine to determine the washable fraction. The wash procedure was 40 min wash, 25 min rinse and spin and 10 min spin. The bags were dried at 40^{0}C for 48 h and subsequently removed to a desiccator and weighed when cool. The contents of the bags at each time point were then emptied for subsequent analysis.

On d 17, two blood samples were obtained by jugular venipuncture from each animal immediately before, and 3 and 6 h after the morning feeding. Seperate vacutainers containing lithium heparin and potassium oxalate/sodium fluoride as anticoagulants were used. Plasma was decanted after centrifugation at 2000 *g* for 10 min at 4^{0}C and stored at -18^{0}C for subsequent analysis.

On d 18, two rumen evacuations were carried out to quantify rumen pool size (calculated from the first evacuation) and fractional clearance rate (Kcl). The animals did not receive any feed between the two evacuations, but water was freely available. At 1100 total rumen contents were removed, weighed and sampled, and returned to the rumen. At 1900, rumen contents were again removed, weighed and sampled and returned to the rumen. Samples were stored at -18°C for subsequent analysis.

Results: *Intake and digestibility study*: The physical and chemical composition of the individual dietary ingredients and the experimental treatments produced from them are shown in Tables 2.4.1 and 2.4.2. The proportion of wheat straw in the wheat grain was higher than that of the barley straw in the barley grain. The barley grain and wheat grain contained a similarly low proportion of straw.

All four dietary ingredients were well preserved, having low pH (3.76 – 3.95), high lactic:acetic acid ratios (1 : 0.3-0.6), low ammonia N values (26-41 g/kg N) and low propionic and butyric acid concentrations (0.6-1.4 g/kg DM). For both the wheat and barley, the DM, *in vitro* DMD, ash and starch values were higher, and aNDFom and ADFom concentrations lower, for grain than straw. The concentration of CP was similar between barley grain and straw and numerically higher for wheat straw than wheat grain. The barley straw had a higher aNDFom (556 v 444 g/kg DM) but lower starch (198 v 309 g/kg DM) than the wheat straw. The barley grain had a higher CP (130 v 105 g/kg DM) than the wheat grain.

Ad libitum intakes for the four ratios of G:S for both barley and wheat are shown in Table 2.4.3. Intake of grain linearly increased ($P<0.001$) while that of straw decreased ($P<0.001$) as the ratio of G:S increased for both barley and wheat. However, no treatment effect was observed ($P>0.05$) in total DMI or in DMI expressed relative to liveweight for barley or wheat.

Barley: Apparent digestibilities and faecal grain contents of the diets are presented in Table 2.4.3. There was a positive linear ($P<0.001$) and quadratic ($P<0.01$) effect on the digestibility of the DM and OM as the G:S ratio increased. There was a negative linear effect of increasing G:S ratio on aNDFom digestibility ($P<0.01$). Both a linear ($P<0.05$) and quadratic ($P<0.01$) effect were observed for G:S ratio on N digestibility. A negative linear effect was found for digestibility of starch ($P<0.01$) and a positive linear effect for faecal grain content ($P<0.001$) with increasing G:S ratio.

Wheat: Apparent digestibilities and faecal grain contents of the diets are presented in Table 2.4.3. Increasing the G:S ratio had a positive linear effect on the digestibility of the DM and OM ($P<0.001$), N ($P<0.01$) and on faecal grain content ($P<0.01$). It had a corresponding negative linear effect on the digestibility of the aNDFom ($P<0.001$) and starch ($P<0.01$).

Rumen study: The chemical composition of the dietary ingredients used in this study (barley straw and grain), and of the resulting experimental treatments produced, are presented in Tables 2.4.4 and 2.4.5. Both the straw and grain had a good preservation, as indicated by their low pH (3.84 – 3.93), low ammonia N values (21-22 g/kg N) and low propionic and butyric acid contents (0.8-2.4 g/kg DM). The DM concentration of the grain (570 g DM/kg) was higher than the straw (489 g DM/kg). The grain had a higher *in vitro* DMD (851 v 690 g/kg) and starch concentration (616 v 219 g/kg DM) and a lower aNDFom concentration (140 v 497 g/kg DM) than the straw. Both had a similar CP concentration.

Restricted feed intakes are presented in Table 2.4.6. A positive linear effect ($P<0.001$) was found for grain intake and total DMI, and a negative linear effect ($P<0.001$) for straw intake as the G:S ratio increased.

Results for rumen fermentation variables are given in Table 2.4.6. A negative linear effect of G:S ratio was found on rumen pH ($P<0.001$), the molar proportion of acetic acid ($P<0.01$) and the acetate:propionate ratio ($P<0.01$). It was found to also have a negative linear and quadratic effect ($P<0.05$) on the non-glucogenic ratio (NGR). Increasing the G:S ratio had a positive linear effect on rumen ammonia ($P<0.001$), total VFA concentration ($P<0.01$), the molar proportions of *iso-* and *n-* butyric acid and total butyric acid ($P<0.01$), molar proportion of *Iso-* ($P<0.01$) and *N-* ($P<0.05$) valeric acid and total valeric acid ($P<0.01$), while the effect on propionic acid was both linear and quadratic ($P<0.01$). There was no difference ($P>0.05$) between treatments in the concentration of D- or L-lactic acid.

Concentrations of plasma metabolites measured are shown in Table 2.4.6. No effect was observed for any of the variables ($P>0.05$).

Rumen pool sizes are shown in Table 2.4.7. No effect was found on rumen liquid, DM, OM or aNDFom pool sizes. A positive linear effect ($P<0.01$) was evident for G:S ratio on the rumen starch pool size.

A positive linear effect of G:S ratio was found on the 'a' fraction , and a negative effect on the 'b' fraction in the DM, OM and N ($P<0.001$). No effect ($P>0.05$) was found on these two fractions in the starch. A negative linear effect was observed for the 'c' fraction in the DM ($P<0.01$) and OM ($P<0.001$), no effect ($P>0.05$) in the N, and a positive linear effect ($P<0.05$) in the starch fraction. A negative linear effect were found for G:S ratio on the 'U' fraction in the DM ($P<0.001$), OM ($P<0.001$), N ($P<0.01$) and starch ($P<0.05$). A positive linear effect ($P<0.01$) was also found on the effective degradability (ED) in the DM, OM and N. The G:S ratio was observed to have a positive linear effect ($P<0.05$) on the 'U' fraction in the aNDFom. A negative linear effect was found on the 'd' fraction ($P<0.05$ and 0.01) and the Kd ($P<0.01$ and 0.001) in the NDF. The G:S ratio had a negative linear effect ($P<0.05$) on the ED in the aNDFom.

No effect ($P>0.05$) was found on the fractional clearance rates of DM, OM, aNDFom or starch ($Kcl_{DM,}$ $Kcl_{OM,}$ $Kcl_{aNDFom,}$ Kcl_{STARCH}) or on liquid passage rate.

In all cases, the parameter estimates in the linear or quadratic relationships of percentage grain in the diet on the dependent variable, where significant, are given in Table 2.4.8.

Conclusions: The results show that increasing the proportion of grain in whole-crop wheat or barley silage based diets from 0 to 0.9 increased the intake of digestible nutrients. These increases were found to be linear and held for both wheat and barley. Rumen fermentation variables were successfully quantified in cattle consuming varying G:S ratios of whole-crop barley silage.

Table 2.4.1 Physical and chemical composition of the dietary ingredients used for the intake and digestibility studies [a]

Dietary ingredient	Barley straw	Barley grain	Wheat straw	Wheat grain
Physical composition				
Proportion grain	0.08 (0.031)	0.96 (0.010)	0.07 (0.016)	0.85 (0.004)
Proportion straw+chaff	0.92 (0.031)	0.04 (0.010)	0.93 (0.016)	0.15 (0.004)
Proportion of grain broken	0.39 (0.053)	0.60 (0.105)	0.81 (0.125)	0.79 (0.048)
Chemical composition				
DM [b] (g/kg)	466 (13.0)	573 (3.5)	495 (9.5)	551 (3.9)
Composition of DM (g/kg, unless otherwise stated)				
DMD [c] (g/g)	0.660 (0.0261)	0.869 (0.0181)	0.709 (0.0196)	0.852 (0.0840)
Crude protein	129 (3.3)	130 (3.1)	119 (4.6)	105 (9.4)
Ash	59 (4.6)	32 (7.0)	53 (4.7)	34 (4.2)
aNDFom[d]	556 (20.5)	141 (14.5)	444 (18.4)	168 (13.4)
ADFom[e]	310 (21.9)	62 (3.5)	250 (8.4)	88 (5.7)
Starch	198 (25.9)	638 (15.0)	309 (16.4)	638 (15.0)
Fermentation characteristics, g/kg volatile-corrected DM, unless otherwise stated				
pH	3.95 (0.055)	3.84 (0.108)	3.79 (0.029)	3.76 (0.027)
Ethanol	3 (1.8)	2 (0.9)	3 (1.2)	3 (1.2)
D-lactic acid	10 (2.8)	10 (0.8)	13 (2.3)	11 (1.1)
L-lactic acid	8 (1.4)	8 (0.9)	10 (2.3)	9 (1.6)
Acetic acid	11 (6.7)	8 (3.6)	7 (3.2)	6 (2.3)
Propionic acid	1.4 (0.7)	0.8 (0.56)	0.6 (0.32)	0.6 (0.34)
Butyric acid	1.1 (0.75)	1.0 (0.59)	1.0 (0.66)	1.0 (0.55)
NH_3-N (g/kg N)	26 (3.3)	25 (4.9)	39 (12.0)	41 (9.8)

[a] Mean, standard deviation in parentheses; [b] Dry matter; [c] Dry matter digestibility, measured *in vitro;* [d] Neutral detergent fibre; [e] Acid detergent fibre.

Table 2.4.2 Calculated chemical composition of the dietary treatments in the intake and digestibility studies [a]

Cereal	Barley				Wheat			
Grain : straw	0 : 100	30 : 70	60 : 40	90 : 10	0 : 100	30 : 70	60 : 40	90 : 10
DM [b] (g/kg)	466	498	530	562	495	512	529	545
Composition of DM (g/kg, unless otherwise stated)								
DMD [c] (g/g)	0.660	0.723	0.786	0.848	0.709	0.752	0.795	0.837
CP[d]	166	167	168	170	160	160	160	161
Ash	59	51	43	35	53	47	41	36
aNDFom[e]	556	431	307	183	444	361	279	196
ADFom[f]	310	236	161	87	250	202	153	104
Starch	198	330	462	595	309	408	506	605

[a] Means; [b] Dry matter; [c] Dry matter digestibility, measured *in vitro;* [d] Crude protein, calculated based on CP of dietary ingredients and inclusion of urea and ammonium sulphate; [e] Neutral detergent fibre; [f] Acid detergent fibre.

Table 2.4.3 Dry matter (DM) intake, i*n vivo* apparent digestibility of components of diets and faecal grain content

Cereal	Barley				s.e.m.	Significance[1]	
Grain : straw	0 : 100	30 : 70	60 : 40	90 : 10		L	Q
Ad libitum intake (kg/d)							
Grain	0.00	2.58	5.24	7.28	0.260	***	
Straw	8.44	6.04	3.57	0.90	0.400	***	
Total DM intake	8.44	8.62	8.81	8.17	0.572		
DM intake/kg LW^2 (g/kg)	17	18	18	17	1.1		
In vivo apparent digestibility (g/g)							
Dry matter	0.653	0.658	0.698	0.753	0.0050	***	**
Organic matter	0.675	0.682	0.718	0.771	0.0043	***	**
Neutral detergent fibre	0.592	0.541	0.487	0.401	0.0240	**	
Nitrogen	0.700	0.671	0.685	0.733	0.0075	*	**
Starch	0.979	0.932	0.921	0.924	0.0104	**	
Faecal grain content (g/kg DM)	9	55	77	158	9.8	***	

Cereal	Wheat				s.e.m.	Significance	
Grain : straw	0 : 100	30 : 70	60 : 40	90 : 10		L	Q
Ad libitum intake (kg/d)							
Grain	0.00	2.31	4.47	7.30	0.257	***	
Straw	7.41	5.30	2.94	0.81	0.360	***	
Total DM intake	7.41	7.61	7.41	8.11	0.555		
DM intake/kg LW (g/kg)	16	16	16	17	1.2		
In vivo apparent digestibility (g/g)							
Dry matter	0.685	0.699	0.736	0.771	0.0065	***	
Organic matter	0.713	0.727	0.759	0.791	0.0066	***	
Neutral detergent fibre	0.578	0.497	0.453	0.355	0.0243	***	
Nitrogen	0.690	0.690	0.713	0.735	0.0093	**	
Starch	0.992	0.990	0.986	0.978	0.0023	**	
Faecal grain content (g/kg DM)	1	3	5	17	2.3	**	

[1] L, Q = Significance level of linear (L) and quadratic (Q) effects. Within row, means with the same superscript are not significantly different (P>0.05); * P<0.05, ** P<0.01, *** P<0.001; [2] Liveweight.

Table 2.4.4 Chemical composition of the dietary ingredients used in the rumen fermentation study [a]

Dietary ingredient	Barley straw	Barley grain
DM [b] (g/kg)	489 (12.4)	570 (9.6)
Composition of DM (g/kg, unless otherwise stated)		
DMD [c] (g/g)	0.690 (0.0114)	0.851 (0.0820)
Crude protein	126 (3.1)	119 (4.3)
Ash	58 (3.5)	28 (0.6)
aNDFom[d]	497 (18.4)	140 (4.3)
ADFom[e]	275 (5.8)	62 (2.4)
Starch	219 (12.9)	616 (17.2)
Fermentation characteristics, g/kg volatile-corrected DM, unless otherwise stated		
pH	3.93 (0.071)	3.84 (0.105)
Ethanol	4 (0.4)	3 (0.6)
D-lactic acid	8 (0.9)	6 (1.0)
L-lactic acid	6 (0.7)	5 (1.1)
Acetic acid	26 (4.4)	15 (1.4)
Propionic acid	2.4 (0.58)	0.8 (0.09)
Butyric acid	1.8 (0.48)	1.2 (0.08)
NH_3-N (g/kg N)	21 (0.9)	22 (1.3)

[a] Mean, standard deviation in parentheses; [b] Dry matter; [c] Dry matter digestibility, measured *in vitro;* [d] Neutral detergent fibre; [e] Acid detergent fibre.

Table 2.4.5 Calculated chemical composition of the dietary treatments used in the rumen fermentation study [a]

Cereal	Barley			
Grain : straw	0 : 100	30 : 70	60 : 40	90 : 10
DM [b] (g/kg)	489	513	538	562
Composition of DM (g/kg, unless otherwise stated)				
DMD [c] (g/g)	0.690	0.738	0.786	0.835
Crude protein [d]	163	162	161	159
Ash	58	49	40	31
aNDFom[e]	497	390	283	175
ADFom[f]	275	211	147	83
Starch	219	338	457	576

[a] Mean, standard deviation in parentheses; [b] Dry matter; [c] Dry matter digestibility, measured *in vitro;* [d] Calculated based on crude protein of dietary ingredients and inclusion of urea and ammonium sulphate; [e] Neutral detergent fibre; [f] Acid detergent fibre.

Table 2.4.6 Feed intake, rumen pH and concentrations of ammonia, lactic acid and total volatile fatty acids (VFA) and molar proportions of individual VFA, and plasma metabolites in steers

Cereal	Barley				s.e.m.	Significance[1]	
Grain : straw	0 : 100	30 : 70	60 : 40	90 : 10		L	Q
Restricted feed intake (kg dry matter (DM)/d)							
Grain	0.00	3.19	7.35	11.60	0.298	***	
Straw	9.19	7.00	4.58	1.24	0.309	***	
Total DM intake	9.19	10.19	11.93	12.84	0.201	***	
Rumen fermentation variables							
pH	6.80	6.70	6.59	6.38	0.046	***	
D-lactic acid (mg/l)	55	103	60	65	15.1		
L-lactic acid (mg/l)	41	80	34	46	14.0		
Ammonia (mg/l)	134	173	155	208	6.9	***	
Total VFA (mmol/l)	96	116	145	180	14.5	**	
Molar proportions (mmol/mol)							
Acetic acid	673	651	572	486	27.0	**	
Propionic acid	171	162	172	193	3.4	**	**
iso-butyric acid	22	26	33	37	3.0	**	
n-butyric acid	86	103	139	161	10.9	**	
Total butyric acid	109	129	172	198	12.7	**	
iso-valeric acid	31	39	58	75	7.4	**	
n-valeric acid	16	19	27	49	8.4	*	
Total valeric acid	48	58	85	125	15.3	**	
Acetate:Propionate	4.0	4.1	3.4	2.6	0.19	**	
NGR[2]	5.3	5.7	5.4	4.7	0.17	*	*
Plasma metabolites (mmol/l)							
Glucose	3.64	3.55	3.50	3.65	0.079		
Urea	4.11	4.20	4.32	4.30	0.269		
βHB[3]	0.33	0.40	0.39	0.35	0.047		

[1] L, Q = Significance level of linear (L) and quadratic (Q) effects. Within row, means with the same superscript are not significantly different ($P>0.05$); * $P<0.05$, ** $P<0.01$, *** $P<0.001$; [2] Non-glucogenic ratio ((acetic acid + (2*butyric acid))/propionic acid); [3] βeta hydroxy butyrate.

Table 2.4.7 Mean rumen pool sizes, *in sacco* degradability, fractional clearance (Kcl) rates, and liquid passage rate

Cereal	Barley				s.e.m.	Significance[1]	
Grain : straw	0 : 100	30 : 70	60 : 40	90 : 10		L	Q
Rumen pool size (kg)							
Liquid (fresh)	61.8	54.2	58.5	47.9	4.07		
DM[2]	8.4	8.2	9.7	9.4	0.77		
OM[3]	7.4	7.2	8.6	8.5	0.68		
aNDFom[4]	5.7	5.3	5.8	5.3	0.37		
Starch	0.15	0.20	0.65	1.05	0.173	**	
In sacco degradability							
Dry matter							
a[5]	0.46	0.57	0.68	0.82	0.005	***	
b[6]	0.41	0.32	0.23	0.13	0.007	***	
c[7]	0.03	0.03	0.02	0.02	0.002	**	
U[8]	0.14	0.11	0.08	0.05	0.006	***	
ED[9]	0.60	0.67	0.76	0.85	0.004	***	
Organic matter							
a	0.44	0.56	0.68	0.82	0.005	***	
b	0.42	0.33	0.23	0.13	0.006	***	
c	0.03	0.02	0.02	0.02	<0.001	***	
U	0.14	0.11	0.08	0.05	0.006	***	
ED	0.59	0.67	0.76	0.85	0.004	***	
Nitrogen							
a	0.73	0.79	0.84	0.90	0.004	***	
b	0.14	0.11	0.09	0.05	0.008	***	
c	0.04	0.03	0.06	0.04	0.010		
U	0.13	0.10	0.08	0.04	0.008	**	
ED	0.79	0.83	0.87	0.93	0.003	***	
Starch							
a	0.91	0.92	0.92	0.93	0.009		
b	0.09	0.08	0.08	0.07	0.009		
c	0.29	0.35	0.61	0.67	0.094	*	
U	0.003	0.003	0.003	0.002	<0.001	**	
ED	0.98	0.99	0.99	0.99	0.001	**	
aNDFom							
U	0.21	0.22	0.23	0.27	0.010	*	
d[6]	0.74	0.73	0.68	0.61	0.017	**	
Kd[7]	0.03	0.02	0.02	0.02	0.001	***	
ED	0.62	0.59	0.56	0.53	0.018	*	
Fractional clearance (Kcl) rates and liquid passage rate (%/h)							
Kcl_{DM}	4.9	5.4	6.7	5.7	0.96		
Kcl_{OM}	5.0	5.8	6.8	5.7	0.97		
Kcl_{aNDFom}	4.3	4.8	4.7	3.6	0.60		
Kcl_{Starch}	14.0	16.0	18.7	17.9	3.49		
Liquid passage rate	9.3	10.3	9.9	9.9	0.74		

[1] L, Q = Significance level of linear (L) and quadratic (Q) effects. Within row, means with the same superscript are not significantly different (P>0.05); * P<0.05, ** P<0.01, *** P<0.001; [2] Dry matter; [3] Organic matter; [4] Neutral detergent fibre; [5] Rapidly degradable (soluble) fraction; [6] Potentially degradable fraction; [7] Fractional rate of degradation (h^{-1}); [8] Totally undegradable fraction; [9] Effective degradability.

Table 2.4.8 Relationships between percentage of grain in the diet and variables measured (where a significant effect was observed)[a]

	Parameter estimates (s.e.)				
Dependent variable	Intercept (s.e.)	Linear (s.e.)	Quadratic (s.e.)	R^2	Sig.
Table 3:					
In vivo DMD	0.639 (0.0104)	0.001 (0.0002)		0.73	***
In vivo OMD	0.663 (0.0097)	0.001 (0.0002)		0.74	***
aNDFom digestibility	0.599 (0.0281)	-0.002 (0.0005)		0.55	**
N digestibility	0.700 (0.0111)	-0.002 (0.0006)	0.00002 (0.000006)	0.56	**
Starch digestibility	0.965 (0.0111)	-0.001 (0.0002)		0.39	**
Faecal grain	4.7 (11.25)	1.561 (0.2004)		0.81	***
In vivo DMD	0.679 (0.0082)	0.001 (0.0001)		0.76	***
In vivo OMD	0.708 (0.0080)	0.001 (0.0001)		0.74	***
aNDFom digestibility	0.577 (0.0217)	-0.002 (0.0004)		0.73	***
N digestibility	0.683 (0.0094)	0.001 (0.0001)		0.42	**
Starch digestibility	0.994 (0.0019)	-0.0002 (0.00003)		0.61	**
Faecal grain	-1.5 (2.50)	0.171 (0.0445)		0.51	**
Table 6:					
Intake – Total	9.134 (0.5377)	0.042 (0.0096)		0.58	***
pH	6.8205 (0.0820)	-0.005 (0.0015)		0.41	***
Ammonia	136.8 (10.09)	0.681 (0.1798)		0.51	***
Total VFA	91.875 (13.0172)	0.942 (0.2319)		0.54	**
Acetic acid	69.15 (2.334)	-0.214 (0.0416)		0.65	**
Propionic acid	17.044 (0.7304)	-0.049 (0.0391)	0.001 (0.0004)	0.41	**
n-butyric acid	8.333 (0.7916)	0.087 (0.0141)		0.73	**
Butyric acid	10.568 (0.9311)	0.103 (0.0166)		0.73	**
iso-valeric acid	2.808 (0.6421)	0.050 (0.0114)		0.58	**
Valeric acid	3.988 (1.4368)	0.086 (0.0256)		0.45	**
Acetate:Propionate ratio	4.24 (0.213)	-0.016 (0.0038)		0.56	**
Non-glucogenic ratio	5.31 (0.270)	0.020 (0.0145)	-0.0003 (0.00015)	0.34	*
Table 7:					
Rumen starch pool	0.04 (0.135)	0.011 (0.0024)		0.58	**
DM - a	0.451 (0.0063)	0.004 (0.0001)		0.99	***
DM - b	0.410 (0.0070)	-0.003 (0.0001)		0.98	***
DM - c	0.029 (0.0018)	-0.0001 (0.00003)		0.54	**
DM - U	0.140 (0.0075)	-0.001 (0.0001)		0.78	***
DM - ED	0.597 (0.0060)	0.003 (0.0001)		0.98	***
OM - a	0.438 (0.0061)	0.004 (0.0001)		0.99	***
OM - b	0.425 (0.0062)	-0.003 (0.0001)		0.98	***
OM - c	0.028 (0.0014)	-0.0001 (0.00003)		0.50	***
OM - U	0.137 (0.0068)	0.001 (0.0001)		0.81	***
OM - ED	0.588 (0.0054)	0.003 (0.0001)		0.98	***
N - a	0.730 (0.0076)	0.002 (0.0001)		0.93	***
N - b	0.138 (0.0049)	-0.001 (0.0001)		0.88	***
N - U	0.132 (0.0094)	-0.001 (0.0002)		0.72	**
N - ED	0.782 (0.0044)	0.002 (0.0008)		0.97	***
Starch - c	0.274 (0.0656)	0.004 (0.0012)		0.49	*
Starch - U	0.003 (0.0004)	-0.00002 (0.000007)		0.31	**
Starch - ED	0.983 (0.0013)	0.0001 (0.00002)		0.63	**
aNDFom - u	0.205 (0.0132)	0.0004 (0.00025)		0.20	*
aNDFom - d	0.751 (0.0156)	-0.001 (0.0003)		0.62	**
aNDFom - Kd	0.026 (0.0012)	-0.0001 (0.00002)		0.64	***
aNDFom -ED	0.624 (0.0197)	-0.001 (0.0004)		0.43	*

[a] See footnotes to tables 3, 6 and 7 for explanations of abbreviations.

Experiment 2.5: A note on the on-farm moist grain storage and feeding practices in Ireland

[P.Stacey, P.O'Kiely, B.Rice and F.P.O'Mara]

The aim of this study was to identify the characteristics of farms where high moisture grain (HMG) was conserved using new technologies, the grain conservation and feeding practices employed and the chemical composition of the grain at feed-out.

Materials and Methods: The survey was conducted in January and February 2001 on the complete population (identified from trade and Teagasc advisory sources) of farms where > 10t HMG was conserved the previous summer and autumn using new technologies. The latter excluded propionic acid or sodium hydroxide treatments followed by aerobic storage. A questionnaire was completed for each of the farms visited. Section 1 established the farm characteristics and crop management practices involved in the production of the HMG crops, Section 2 sought answers to harvesting related issues, Section 3 dealt with the storage of the grain and associated factors (e.g. dimensions of the silo, plastic use and methods of pest control, etc.), Section 4 related to the management of the stored feed and the level of feeding and type of livestock involved and, finally, Section 5 dealt with some general questions, for example the number of years the farmer was involved in harvesting HMG, where farmers sourced their information for the use of new grain technologies, and the advantages and disadvantages they perceived in HMG systems.

For each moist grain feedstuff, a grab sample was taken from across the feed face and a core sample was taken from the centre of each silo.

Results: The 51 farms surveyed conserved 55 crops, and were located mainly in Leinster and Donegal. There were 32 crops of wheat, 22 of barley and 1 of oats (Table 2.5.1). Fifty-three crops were managed as for conventional commercial grain production, while two were under-sown with grass. The vegetation from the latter was subsequently cut with a mower and conserved as silage.

The mean areas conserved as HMG were 8.2 ha for wheat, 9.5 ha for barley and 16.1 ha for the single crop of oats (Table 2.5.1). The mean harvest date was 11 August, with a latest date of 4 September and an earliest date of 15 July, respectively. The mean yield (t/ha) corrected to 850g DM/ kg was 7.7, with a maximum and minimum of 11.4 and 4.7, respectively. The average DM at harvesting (g/kg) was 664, with a maximum (max.) and minimum (min.) value of 560 and 780, respectively. Contractors were hired for combine harvesting 33 of the crops, with farmers themselves harvesting their own crops in 22 cases. Combine harvesting was judged by contractors and/or farmers to be slower than for ripe grain for 40 of the 55 crops. Harvesting difficulties were attributed to crop intake at the combine header (1 crop), choking of the threshing drum (5 crops), clogging of the unloading auger (4 crops) and grain loss over the shakers at the rear of the combine (4 crops).

Proportionately 0.8 of farmers did not perceive straw wetness at harvesting as a problem. Straw was tedded before baling for 0.67 of crops. The average (s.d.) number of days for straw to be left on the ground before baling was 6.0 (4.53). Straw was conserved in large round or square bales, small-square bales or as silage, from 38, 3, 6 and 3 crops, respectively. It was burned or chopped in-situ from 1 and 2 crops, respectively. Two farmers bought-in HMG but not the straw. Straw was fed (25 crops) to livestock or used as bedding (24 crops).

Forty-three crops (26 wheat, 16 barley and 1 oats) were treated with an acid-cocktail additive and simultaneously rolled (i.e. crimped) (AR) using a specialised machine located in the farmyard. The mean (s.d.) DM of AR at harvesting was 662 (45.8) g/kg and the corresponding values for the speed of grain treatment were 9.9 (3.45) t /h. The two acid-cocktail additives used were Crimpstore (Kemira Chemicals (UK) Ltd., N. Yorkshire) that had a stated composition of formic acid, ammonium formate, propionic acid, benzoic acid and ethylbenzoate, and Cornsile (FSL Bells Ltd., Wiltshire) that was stated to consist of lignosulphate, formic acid and acetic acid. Estimates were that Crimpstore and Cornsile were applied at mean (s.d.) rates of 4.1 (1.81) and 7.9 (1.96) l/t, respectively. Thirty-three of the AR treated crops also had additional water applied prior to sealing (not quantified). All of the AR HMG was mechanically compacted in the silo prior to sealing, with compaction being accomplished in 0.74 of cases using a four-wheel drive tractor or industrial loader. Alternatively, a two-wheel drive tractor (0.02), pick-up truck (0.02) or quad-bikes (0.14) were used for compacting. In 0.07 cases farmers did not specify how they compacted the grain in the silo.

The 12 crops (6 wheat and 6 barley) that were urea-treated but not rolled (UN) had a mean (s.d.) DM at harvesting of 674 (43.9) g/kg. Urea solution was mixed with the grain using a conventional feeder wagon for 11 crops, and was mixed using an auger applicator for one crop. The mean (s.d.) speed of grain treatment was 8.5 (3.95) t /h, with the corresponding value of 53 (11.8) l urea solution applied/ t grain. The urea solution applied to 9 crops was Nugrain (Hydro-Nutrition, Hydro Agri (UK) Ltd., Lincolnshire) while a locally manufactured mixture (unspecified) was used in 3 crops. The UN treated HMG was not mechanically compacted in the silo prior to sealing.

All grain was stored in horizontal silos with a concrete base. Thirty-seven of the silos were roofed, with the grain in 54 silos being sealed beneath black polythene sheeting; in one case the UN grain was sealed beneath a tarpaulin. The black polythene sheeting used was either the conventional (0.125 mm thick) material used for sealing ensiled forages, or was 0.25 mm thick. The mean (s.d.) quantity ensiled was 90 (66.4) tonnes, and the height, width and length of the stored grain (m), was 1.7 (0.55), 5.9 (2.56) and 10.3 (5.08), respectively. The entire process of HMG treatment, which included combine-harvesting the grain, chemical and/or mechanical processing of the grain, clamp filling and sealing took on average (s.d.) 2 (0.9) days. For the AR HMG, rodent presence was noted in 13 grain silos and bird presence in 7 grain silos. Similarly, for the UN HMG, there were rodents and birds present in 4 and 2 grain silos, respectively.

The mean (s.d.) rate of removing a complete feed-face from the silo during feed-out was 5.4 (4.57) and 9.0 (6.60) days for the AR and UN systems, respectively. Moist grain was removed from silos using a grain bucket, mechanical grab or manually for 42, 5 and 8 of the crops, respectively. The HMG was mechanically mixed with other dietary ingredients immediately prior to feeding to livestock for 45 crops, and was fed separately in 10 cases. Conserved moist grain was offered to a range of livestock types, and was offered to more than one livestock category on some farms (Table 2.5.2). Livestock were introduced and adjusted to the target level of supplementation with HMG over a period of 0, 1-4, 5-7, 14, 21 and >21 days for 22, 4, 10, 8, 6 and 5 of the crops, respectively.

On average (s.d.), AR and UN HMG were offered at 4.5 (1.94) and 4.5 (1.81) kg/head per day, respectively. Animals offered conserved HMG were accommodated on straw-bedded floors, slatted floors or peat for 22, 31 and 2 of the crops, respectively.

Farmers identified encountering digestive upsets with animals fed HMG for 8 of the 55 crops. They noted what they described as none, low or high levels of grain in the faeces with 35, 13 and 7 crops, respectively, the frequency of observing grain in the faeces being higher with the UN system. Thus, 4 of the 12 UN crops were rolled immediately prior to feeding. Waste was noted at feed-out on proportionately only 0.47 of HMG crops, and 0.92 of the crops experiencing such visible deterioration due to mould were categorised by farmers as having < 0.10 of original quantity ensiled lost to aerobic deterioration. The composition of the core and feed face samples were similar for all of the variables except in the case of UN HMG for NH_3-N, pH and CP (Table 2.5.3). For the latter variable, a lower NH_3-N was noted for the samples taken from the feed-face compared to the core samples, presumably due to losses via volatilisation from the feed-face. The CP, DMD and ash values of AR HMG are comparable to those published by Givens (1990) for cereal grains, with the exception of CP concentration that was considerably higher for the UN HMG.

The forage diets contained grass silage when 44 of the 55 HMG crops were fed to livestock. Combinations of maize silage (14), whole-crop cereal silage (5), straw (10) and fodder beet (5) were used with the grass silage in the various diet mixes. A high proportion of the crops conserved as HMG were home-mixed (0.82) with dry concentrate feedstuffs rather than purchased compound concentrates, and were balanced for vitamins and minerals in 19 cases. Protein supplementation of AR HMG diets took place using a range of single ingredients (e.g. soyabean meal, distillers' grains, corn gluten, brewers' grains, cottonseed, copra, and rapeseed). Soyabean meal was the most frequently used supplementary protein source, being used in 26 out of 43 cases.

For proportionately 0.59, 0.39 and 0.02 of the farms in this survey, this was the first, second or sixth season for them to employ these HMG technologies. Technical information on HMG systems was obtained from contractors or the suppliers of HMG machinery or additives in 0.82 of cases, as well as from farming publications (0.13) and other farmers (0.07). Farmers' perceptions of the advantages and disadvantages of the HMG systems are outlined in Table 2.5.4. Proportionately 0.86 of farmers would consider using these new technologies again.

Conclusions: Moist grain systems operated satisfactorily on most farms. The feeding of HMG could provide an alternative to dry grain when managed properly.

Table 2.5.1. Number of crops by type and harvesting details

	Winter barley	Winter wheat	Spring barley	Spring wheat	Spring oats
Total crops	4	25	18	7	1
AR†	2	21	14	5	1
UN‡	2	4	4	2	0
Hectares treated					
Average	9.9	8.9	9.0	7.3	16.1
s.d.	4.30	5.94	4.28	7.72	
Maximum	15.0	24.3	16.2	20.2	
Minimum	4.5	3.6	2.8	2.0	
Harvest date					
Average	29/07/00	09/08/00	15/08/00	22/08/00	NA
s.d. (days)	14.7	10.8	8.8	10.5	
Latest	15/08/00	03/09/00	28/08/00	04/09/00	
Earliest	15/07/00	20/07/00	04/08/00	12/08/00	
Dry matter content (g/kg)					
Average	672	667	651	676	700
s.d.	33.0	46.5	50.6	33.6	
Maximum	650	600	560	650	
Minimum	720	780	760	730	
Yield (t/ha) corrected to 150 g moisture /kg					
Average	7.3	8.8	6.1	8.3	5.1
s.d.	0.79	1.79	1.12	1.52	
Maximum	8.4	11.3	8.5	11.4	
Minimum	6.6	5.2	4.7	6.6	

†AR = Acid-treated, rolled high moisture grain (HMG); ‡UN = Urea-treated, not rolled HMG

Table 2.5.2. The number of cases where different types of livestock were offered high moisture grain (offered to >1 animal category on some farms)

	AR[1] treated grains	UN[2] treated grains
Bulls	17	6
Finishing steers	24	9
Finishing heifers	16	5
Dairy cows	20	3
Beef cows	2	3
Sheep	5	5
Other[3]	12	3

[1]AR = Acid-treated, rolled high moisture grain (HMG); [2]UN = Urea-treated, not rolled HMG
[3]replacement heifers, weanlings, calves

Table 2.5.3. Comparison of core and feed-face samples of high moisture grain

	Mean	s.d.	Maximum	Minimum
[1]*AR: Core samples*				
Moisture content (g/kg)	383	57.3	500	248
pH	4.3	0.52	6.5	3.7
Crude protein (g/kg dry matter (DM))	115	15.4	153	87
DM digestibility (g/kg)	888	32.5	926	758
Ash (g/kg DM)	18	4.2	29	11
Sugars (g/kg DM)	58	16.9	104	29
Starch (g/kg DM)	615	43.6	713	510
Lactic acid (g/kg DM)	16	8.5	38	3
Ammonia-N (g/kg N)	35	13.5	60	14
AR: Feed-face				
Moisture content (g/kg)	384	54.3	492	234
pH	4.4	0.54	6.0	3.8
Crude protein (g/kg dry matter (DM))	116	17.3	157	78
DM digestibility (g/kg)	886	32.9	922	769
Ash (g/kg DM)	21	10.6	73	10
Sugars (g/kg DM)	54	18.2	87	12
Starch (g/kg DM)	616	50.8	739	540
Lactic acid (g/kg DM)	15	7.7	41	2
Ammonia-N (g/kg N)	39	15.4	87	17
[2]*UN: Core samples*				
Moisture content (g/kg)	307	69.5	415	242
pH	8.6	0.8	9	7
Crude protein (g/kg dry matter (DM))	175	30.3	225	132
DM digestibility (g/kg)	920	13.9	937	902
Ash (g/kg DM)	22	4.9	32	19
Sugars (g/kg DM)	49	13.0	65	25
Starch (g/kg DM)	625	47.4	684	565
Lactic acid (g/kg DM)	2	1.3	5	1
Ammonia-N (g/kg N)	169	65.4	292	98
UN: Feed-face				
Moisture content (g/kg)	281	60.7	407	205
pH	8.6	1.09	10	6
Crude protein (g/kg dry matter (DM))	179	25.4	234	139
DM digestibility (g/kg)	921	15.7	943	893
Ash (g/kg DM)	21	3.9	27	16
Starch (g/kg DM)	629	41.4	685	563
Sugars (g/kg DM)	52	11.1	66	26
Lactic acid (g/kg DM)	2	1.4	6	1
Ammonia-N (g/kg N)	126	47.1	218	61

[1]AR = Acid-treated, rolled high moisture grain (HMG); [2]UN = Urea-treated, not rolled HMG

Table 2.5.4. Perceived advantages and disadvantages of the high moisture grain systems

Advantages	Proportion of farmers	Disadvantages	Proportion of farmers
Store their grain	0.91	Hard to harvest r	0.15
Traceability of feed for own livestock	0.87	Grain losses in tl	0.07
Can offer *ad libitum*	0.35	Stress on combir	0.24
Earlier harvest	0.96	Mould on grain a	0.25
Labour saving during feed-out	0.87	Pit management	0.04
Higher yield	0.25	Vermin nuisance	0.15
Lower cost	0.56	Hard to feed	0.05
Pleasant to work with	0.76	Reliance on spec	0.25

Experiment 2.6: Changes in yield and composition of barley, wheat and triticale grains harvested during advancing stages of ripening

[P. Stacey, P. O'Kiely, R. Hackett, B. Rice and F.P. O'Mara]

This experiment was designed to quantify the patterns of change in grain yield, estimated nutritive value, ensilability and grain loss during harvesting for winter wheat, barley and triticale managed as on Irish commercial cereal farms, and harvested at a succession of stages of ripeness.

Materials and Methods: *Experimental design:* Field plots were located at Teagasc Oak Park, Carlow (52° 50'N latitude, 6°55'W longitude, 61 m above sea level) on Mortarstown Series Grey-Brown podzolic and Athy-Complex Grey-Brown complex soil type (Conry and Ryan, 1967).

In 2001, plots (20 m × 3 m) of barley *(Hordeum vulgare* L., cv. Regina; sown 18 October 2000; 181 kg/ha inorganic fertiliser N) and wheat *(Triticum aestivum* L., cv. Madrigal; sown 12 January 2001; 136 kg/ha inorganic fertiliser N) were man-aged as for commercial grain production, using pesticide, herbicide, fungicide and fertiliser inputs appropriate for high yielding crops. Twenty plots for each cereal were arranged in a randomised complete block design with five harvest times (H1 to H5) and four replicate blocks. As the crop approached maturity, grain DM concentration was measured frequently; harvest times were based on target concentrations of 600, 660, 720, 780 and >800 g/kg. Plots were harvested to a stubble height of 6 cm using a plot combine harvester (Deutz Fahr Farmliner 3370, with a 2.4 m cutting width) equipped with a built-in grain collection and weighing system to allow individual plot yield to be determined. Harvested grains from each plot were sub-sampled and stored at -18 °C until subsequent qualitative analysis.

In 2002, plots of barley (32 m × 3 m; cv. Regina; sown 9 October 2001; 150 kg/ha inorganic fertiliser N), wheat (24 m × 3 m; cv. Falstaff; sown 30 October 2001; 224/ha kg inorganic fertiliser N) and a semi-dwarf variety of triticale (40 m × 3 m; X *Triticosecale* Wittmack, cv. Fidelio; sown 26 October 2001; 180 kg/ha inorganic fertiliser N/) were grown. The plots were arranged in a similar design to 2001, with comparable crop husbandry, harvesting and sampling procedures. The one exception was that only four harvest times were feasible for barley due to prevailing weather conditions.

Two estimates of harvest losses were made in each plot. The standing crop was flattened at two random positions. Steel frames (2.4 m × 0.6 m) covered with heavy-duty polyvinyl were placed on top of the flattened crop to allow unrestricted passage for the harvester. Once the combine harvester had passed clear of the frames the chaff and straw on the trays were manually separated and removed, and any grains that had passed through the harvester and onto the frames were collected, weighed and dried. The weight of the recovered grains was used to estimate losses of grain across the entire area of the plot and this added to the weight of grain recorded in the combine hopper to obtain harvestable yield per plot.

Data were obtained daily from a meteorological station located within 200 m of the field plots for the period 1 July to 10 September in both seasons.

Results: Meteorological results data, based on summaries over consecutive 10 or 11 day intervals, are presented in Table 2.6.1.

In 2001, the grain DM concentration of barely changed over a 19-day interval from 546 g/kg to 835 g/kg and fresh yield values on successive harvest dates decreased progressively (Table 2.6.2). Grain DM yields were higher ($P < 0.01$) at H3 and H4 than at the other harvests. Starch tended to be highest at H2 and H3, while the values for crude protein, ash, WSC and OMD did not change ($P > 0.05$) throughout the harvest period. Buffering capacity decreased ($P < 0.01$) during the 19 day interval. ForH1 through to H5, neutral detergent fibre (NDF) concentrations in DM were 223, 218, 225, 226 and 226 (s.e. 3.7; $P = 0.47$) g/kg, respectively, with corresponding values for acid detergent fibre (ADF) of 62, 61, 61, 63 and 61 (s.e. 1.2; $P = 0.56$) g/kg.

In 2002, the grain DM concentration of barley increased ($P < 0.001$) over a 13 day interval from 538 g/kg to 855 g/kg while fresh yields decreased ($P < 0.001$) correspondingly (Table 2.6.2). Grain DM yield was lower at H4 than at the first three harvests whereas crude protein concentration was higher ($P < 0.05$) at H2 than H1, with H3 and H4 being intermediate. Grain WSC concentrations were higher ($P < 0.05$) at H2 and H3 compared to H1 and H4. None of the other yield or composition variables in Table 2.6.2 were significantly affected ($P > 0.05$) by harvest date.

In 2001, the grain DM concentration of wheat increased from 626 g/kg to 822 g/kg over a 22-day period while the fresh yield simultaneously decreased ($P < 0.001$). Neither DM yield, crude protein, starch nor ash concentrations differed across the five harvests. Grain WSC values were higher ($P < 0.001$) at H3 and H4 than at other harvests. The OMD was lower at H4 than at adjacent harvests, while grain buffering capacity was higher ($P < 0.01$) at H1 than at subsequent harvests. For H1 through to H5, respectively, the NDF concentrations were in the DM were 160, 154, 156, 153 and 150 (s.e. 2.0; $P < 0.05$) g/kg, and the corresponding ADF concentrations were 40, 38, 37, 37 and 37 (s.e. 0.3; $P < 0.001$) g/kg.

The grain DM concentration for wheat in 2002 increased during the 15-day interval from 580 g/kg to 818 g/kg (Table 2.6.2) and the fresh yield decreased simultaneously ($P < 0.001$) (Table 2.6.2). The grain DM yield achieved at H2 was higher ($P < 0.001$) than at H1, H3 or H5, while crude protein concentration was lower ($P < 0.05$) at H1 than at H4. The OMD was lower at H1 ($P < 0.01$) and the ash concentration was higher ($P < 0.05$) at H2 than at the other harvests. Grain WSC values were lower ($P < 0.05$) at H4 than at H1, H2 or H5. Starch concentration was higher ($P < 0.01$) at H4 and H5 than at earlier harvests whereas the lowest ($P < 0.001$) buffering capacity was at H5.

The grain DM concentration of triticale increased at successive harvests during the 21 day interval (Table 2.6.2). The fresh yields of triticale grain decreased ($P < 0.001$) from H1 to H4 and H5. There was no change ($P > 0.05$) over time in DM yield, crude protein, starch or OMD. Grain WSC values were lower ($P < 0.05$) at H1 than at the final three harvests. Ash concentration was highest ($P < 0.05$) at H1 while buffering capacity was lowest ($P < 0.001$) at H1 and highest at H2.

Harvesting losses of grain DM (kg) per ha were influenced by harvest date for barley in 2001 and 2002, and for wheat in 2001. Values for barley decreased from the highest loss at H1 to the lowest at H5 in 2001. Losses for wheat in 2001 increased ($P < 0.001$) from H1 to H4 but all were at or under 10 kg/ha, and there was no detectable loss for H5. In 2002 barley losses were higher ($P < 0.01$) at H3 than at other harvests.

Correlations coefficients between grain DM concentration and fresh yield across the times of harvest were barley -0.98 (2001) and -0.98 (2002), wheat -0.84 (2001) and -0.94 (2002) and triticale -0.96. The regression relationships between the yield, composition and harvesting loss variables and the time of harvest are presented in Table 2.6.3.

Grain DM concentration increased linearly ($P < 0.001$) with advancing harvest date in 2002 for barley and wheat, while the increase was quadratic ($P < 0.001$) for barley and wheat in 2001 and for triticale in 2002. Fresh yield decreased linearly ($P <0.001$) with advancing harvest date for barley in 2002, while the decline was quadratic ($P < 0.001$) for the remaining four crops. For wheat in both 2001 and 2002 and triticale, grain DM yield was not directly related to the date of harvest, whereas for barley there was a quadratic relationship in both years reflecting yield decline for ripe grain.

Grain starch concentration was not significantly related to harvest time ($P > 0.05$), except for wheat in 2002 where the relationship was quadratic ($P < 0.01$) and reflected an initial decline followed by a larger increase in value as harvest date advanced. In the case of crude protein, there was no relationship with harvest time for barley in 2001 or triticale while, there were contrasting quadratic relationships for barley in 2002 ($P < 0.05$) and wheat in 2001 ($P < 0.01$), and a linear increase ($P < 0.05$) for wheat in 2002. Digestibility of the grain was linearly related to date of harvest for barley in 2002 (negative, $P < 0.01$) while the relationship for wheat in 2002 was quadratic ($P < 0.01$). In the latter case, after an initial increase, digestibility declined towards the final harvest. There was no relationship between NDF or ADF and the time of harvest for barley in 2001. The NDF concentration of wheat declined linearly ($P < 0.01$) in 2001 with advancing maturity whereas the quadratic relationship ($P < 0.01$) for ADF indicated a decreasing rate of decline with later harvesting. The decline in ash concentration was quadratic for barley in 2001 ($P < 0.05$) and for triticale ($P < 0.01$). Grain buffering capacity was significantly related to harvest date for three of the five cereal crops. A linear decline was recorded for barley in 2001 ($P < 0.001$) while a quadratic relationship occurred with wheat in 2001 reflecting a large decline between H1 and H3 but with little change thereafter. For wheat in 2002, a quadratic relation-ship reflected a rise in buffering capacity between H1 and H2, followed by a much larger decline through to H5. Grain WSC content increased ($P < 0.05$) linearly for barley in 2001 and quadratically for triticale, the latter indicating a declining rate of increase as the crop ripened. Quadratic relationships ($P < 0.01$) for barley in 2002 and wheat in 2001 reflected higher values at the intermediate harvests.

Harvest loss was linearly and negatively related ($P < 0.001$) to harvest date for barley in 2001, whereas the relationship for wheat in 2001 was quadratic ($P < 0.01$) with the rate of increase declining as harvest date advanced. Relationships were not significant for the other crops.

Conclusions: The relatively constant grain DM yield, nutritive value and harvesting losses, together with the favourable indices of ensilability, as grain DM concentration of winter barley, wheat and triticale advanced from approximately 550 to over 800 g/kg, indicate that farmers harvesting grain produced using high input practices under Irish conditions can employ a range of conservation technologies without compromising the yield or quality of the harvested grain. In some cases, crops (e.g., barley) allowed to ripen beyond 813 g/kg may suffer grain loss via shattering prior to harvesting, but the qualities of the grain from these ripe crops are similar to the more moist grains.

Because grain DM concentration increased by an average of 16 to 29 g/kg per day the interval for which grain is at a target DM concentration to harvest can be quite short and grain needs to be monitored at least daily if a target DM concentration is to be achieved at harvest.

Table 2.6.1: Meteorological data at the experimental site during the time of sampling, together with long term (29 years) means

Date	Temperature (ºC)			Rainfall (mm)		
	Mean	*Max.*	*Min.*		*Max.*	*Min.*
2001				**Mean**		
July[1]						
1-10	14.9	18.3	12.8	0.5	3.3	0.0
11-20	11.8	13.1	10.1	2.0	8.0	0.0
21-31	16.2	18.9	14.5	0.1	0.5	0.0
August[1]						
1-10	13.7	15.9	12.3	3.7	21.2	0.0
11-20	15.7	19.2	13.7	3.5	14.0	0.0
21-31	13.8	15.3	12.3	1.0	3.9	0.0
September[1]						
1-10	13.9	16.0	10.9	0.4	2.2	0.0
2002						
July[1]						
1-10	12.1	13.4	11.3	2.5	6.9	0.0
11-20	14.2	17.3	12.3	0.4	2.1	0.0
21-31	15.6	17.3	13.3	0.9	4.4	0.0
August[1]						
1-10	15.1	18.3	11.3	4.3	18.5	0.0
11-20	15.4	17.4	14.4	1.1	5.2	0.0
21-31	15.2	17.5	12.3	0.4	1.7	0.0
September[1]						
1-10	12.5	14.2	11.2	0.7	2.1	0.0

	Temperature (ºC)			Rainfall (mm)
	Mean	*Mean max.*	*Mean min.*	*Mea*
1968 to 1996				
July[2]	15.7	20.2	11.2	1.6
August[2]	15.3	19.9	10.7	2.1
September[2]	13.0	17.3	8.7	2.2

[1] mean daily value; maximum and minimum daily average; [2] mean monthly temperature; maximum and minimum monthly average temperature; mean daily rainfall; Note: mean no. days with ≥0.2mm rainfall was 13.0, 13.9 and 14.5 in July, August and September respectively between 1968-1996

Table 2.6.2: Grain yield, chemical composition and harvesting losses of five cereals over sequential harvests

Crop and harvest no.	Harvest date[1]	*Harvestable yield*		**Composition[2]**							**Harvesting loss**
		Fresh t/ha	DM t/ha	DM g/kg	CP g/kgDM	Starch g/kgDM	OMD g/kg	Ash g/kgDM	BC mEq/kgDM	WSC g/kgDM	kg grain DM/ha
Barley 2001											
H1	6 July	12.5	6.80	546	101	585	844	25.6	107	43	577
H2	9 July	10.8	6.73	631	100	636	843	24.9	102	44	438
H3	12 July	9.8	7.06	724	103	652	839	26.2	102	46	361
H4	18 July	8.7	7.04	818	102	589	846	25.1	92	46	321
H5	25 July	8.0	6.68	835	104	613	846	23.9	88	47	95
s.e.		0.16	0.050	8.7	1.9	14.9	4.7	0.49	3.0	1.0	47.1
Signif.		***	***	***	NS	*	NS	NS	**	NS	***
Barley 2002											
H1	5 July	11.5	6.26	538	98	573	876	25.8	70	39	248
H2	12 July	8.7	6.19	711	106	554	867	27.8	64	43	256
H3	15July	7.7	6.32	825	105	558	867	25.1	64	42	557
H4	18 July	6.4	5.48	855	102	566	861	24.4	65	38	162
s.e.		0.17	0.109	3.2	1.6	7.3	3.3	0.99	1.8	0.8	56.9
Signif.		***	***	***	*	NS	NS	NS	NS	*	**
Wheat 2001											
H1	16 Aug	12.6	7.80	626	112	667	862	18.7	95	50	2
H2	22 Aug	10.6	7.63	726	109	699	870	18.7	82	50	5
H3	23 Aug	9.9	7.76	794	107	689	869	17.1	81	53	6
H4	27 Aug	9.6	7.67	803	105	668	854	18.2	82	54	10
H5	7 Sept	9.3	7.63	822	117	679	879	17.4	82	49	0
s.e.		0.20	0.087	7.0	2.6	9.7	4.6	0.42	2.4	0.6	0.6
Signif.		***	NS	***	NS	NS	*	NS	**	***	***
Wheat 2002											
H1	6 Aug	16.5	9.53	580	110	638	866	18.7	61	53	48
H2	12 Aug	15.5	10.39	672	112	620	901	29.0	68	54	114
H3	14 Aug	14.7	9.77	664	113	650	889	18.2	63	50	156
H4	19 Aug	12.7	9.95	783	116	711	900	16.2	63	48	199
H5	21 Aug	11.9	9.73	818	113	707	887	15.6	50	54	181
s.e.		0.29	0.164	9.5	1.1	15.0	4.9	2.46	1.9	1.1	43.7
Signif.		***	*	***	*	**	**	*	***	*	NS
Triticale 2002											
H1	12 Aug	15.0	8.39	561	98	675	894	20.4	55	64	44
H2	19 Aug	11.9	8.07	681	98	671	891	19.3	76	66	42
H3	21 Aug	10.7	8.07	751	103	665	889	19.4	61	67	37
H4	27 Aug	9.9	8.07	811	100	664	886	19.0	63	68	54
H5	2 Sept	10.0	8.29	826	96	662	881	19.1	65	68	42
s.e.		0.23	0.159	3.6	1.7	5.7	4.7	0.27	1.5	0.8	13.1
Signif.		***	NS	***	NS	NS	NS	*	***	*	NS

[1] H1-H5 denotes the first time of grain harvest through to the final harvest

[2] Dry matter (DM); crude protein (CP); organic matter digestibility (OMD); buffering capacity (BC); water-soluble carbohydrate (WSC)

Table 2.6.3. Relationship ($y= a+bx+cx^2$) between grain yield, nutritive value, ensilability variables (y) with date of harvest and time of harvest (x; days from first harvest date)

	a[1]	s.e.	b[1]	s.e.	c[1]	s.e.	R^2	Signif.
Barley 2001								
Fresh yield (t/ha)	12.4	0.28	-0.50	0.080	0.015	0.0040	0.88	***
DM yield (t/ha)	6.7	0.09	0.07	0.024	-0.004	0.0012	0.34	*
DM (g/kg)	542	12.2	35.9	3.43	-1.08	0.171	0.95	***
Crude protein (g/kgDM)	101	1.3	0.16	0.127			0.08	
Starch (g/kgDM)	606	17.8	4.7	4.97	-0.258	0.2485	0.06	
NDF (g/kgDM)	221	2.7	0.32	0.259			0.08	
ADF (g/kgDM)	62	0.9	-0.01	0.085			<0.01	
OMD (g/kg)	842	3.2	0.18	0.303			0.02	
Ash (g/kgDM)	25.4	0.43	0.09	0.120	-0.009	0.0060	0.33	*
Buffering capacity (mEq/kgDM)	106	1.9	-1.02	0.177			0.65	***
WSC (g/kgDM)	44	0.7	0.15	0.063			0.24	*
Harvest loss (kg grain DM/ha)	539	31.5	-22.6	3.00			0.76	***
Barley 2002								
Fresh yield (t/ha)	11.5	0.14	-0.39	0.016			0.98	***
DM yield (t/ha)	6.2	0.13	0.10	0.046	-0.012	0.0036	0.62	**
DM (g/kg)	541	9.3	25.5	1.05			0.98	***
Crude protein (g/kgDM)	98	1.8	2.0	0.66	-0.136	0.0506	0.43	*
Starch (g/kgDM)	573	7.6	-5.2	2.72	0.36	0.209	0.23	
OMD (g/kg)	876	2.9	-1.10	0.325			0.45	**
Ash (g/kgDM)	25.9	1.23	0.54	0.439	-0.053	0.0338	0.20	
Buffering capacity (mEq/kgDM)	70	1.9	-1.26	0.677	0.071	0.0521	0.30	
WSC (g/kgDM)	39	0.8	1.20	0.293	-0.097	0.0226	0.58	**
Harvest loss (kg grain DM/ha)	228	90.3	52.1	32.17	-3.94	2.477	0.17	
Wheat 2001								
Fresh yield (t/ha)	12.6	0.51	-0.43	0.110	0.013	0.0045	0.59	***
DM yield (t/ha)	7.8	0.23	-0.01	0.019			0.01	
DM (g/kg)	626	11.5	24.8	2.46	-0.72	0.101	0.91	***
Crude protein (g/kgDM)	113	2.3	-1.35	0.488	0.068	0.0201	0.46	**
Starch (g/kgDM)	674	10.3	2.0	2.21	-0.087	0.0909	0.05	
NDF (g/kgDM)	159	1.6	-0.41	0.132			0.35	**
ADF (g/kgDM)	40	0.6	-0.36	0.124	0.010	0.0051	0.49	**
OMD (g/kg)	861	4.2	0.57	0.360			0.35	
Ash (g/kgDM)	18.5	0.33	-0.05	0.028			0.16	
Buffering capacity (mEq/kgDM)	94	2.4	-2.24	0.509	0.08	0.021	0.56	***
WSC (g/kgDM)	49	0.9	0.66	0.199	-0.031	0.0082	0.46	**
Harvest loss (kg grain DM/ha)	1.0	0.87	1.24	0.187	-0.058	0.0077	0.78	***
Wheat 2002								
Fresh yield (t/ha)	16.5	0.37	-0.10	0.110	-0.014	0.0069	0.86	***
DM yield (t/ha)	9.6	0.21	0.13	0.062	-0.008	0.0039	0.20	
DM (g/kg)	569	11.3	16.0	1.13			0.92	***
Crude protein (g/kgDM)	111	1.03	0.29	0.103			0.31	*
Starch (g/kgDM)	634	15.3	-3.6	4.47	0.62	0.281	0.60	***
OMD (g/kg)	867	5.4	6.5	1.59	-0.338	0.0997	0.55	**
Ash (g/kgDM)	19.6	2.87	1.29	0.839	-0.111	0.0527	0.29	
Buffering capacity (mEq/kgDM)	61	2.3	1.95	0.668	-0.169	0.0420	0.61	***
WSC (g/kgDM)	54	1.7	-0.55	0.499	0.031	0.0313	0.07	
Harvest loss (kg grain DM/ha)	58	36.9	9.7	3.71			0.28	
Triticale 2002								
Fresh yield (t/ha)	15.0	0.26	-0.60	0.056	0.017	0.0025	0.93	***
DM yield (t/ha)	8.4	0.17	-0.06	0.035	0.003	0.0016	0.15	
DM (g/kg)	556	7.8	25.2	1.65	-0.58	0.074	0.98	***
Crude protein (g/kgDM)	97	2.3	0.70	0.474	-0.037	0.0212	0.16	
Starch (g/kgDM)	675	5.4	-1.03	1.135	0.020	0.0508	0.16	
OMD (g/kg)	894	4.3	-0.50	0.903	-0.006	0.0404	0.23	
Ash (g/kgDM)	20.4	0.24	-0.17	0.052	0.005	0.0023	0.54	**
Buffering capacity (mEq/kgDM)	58	3.3	1.6	0.70	-0.065	0.0311	0.24	
WSC (g/kgDM)	64	1.0	0.32	0.206	-0.006	0.0092	0.35	*
Harvest loss (kg grain DM/ha)	42	10.4	0.2	0.82			<0.01	

[a]DM= dry matter, NDF= neutral detergent fibre, ADF= acid detergent fibres, OMD = organic matter digestibility, WSC=water soluble carbohydrate; [b]Error df = 18 and 17 for linear and quadratic relationships, respectively (corresponding df = 14 and 13 for barley 2002); [c]Where quadratic was not significant the equation was reduced and is in a linear form; [d]Loss of grain at harvesting (DM basis); Values within brackets are standard errors.

Experiment 2.7: Comparisons of alternative conservation strategies for high moisture cereal grains

[P. Stacey, P. O'Kiely, R. Hackett, B. Rice and F.P. O'Mara]

The aims of this research were to quantify the conservation characteristics of barley, wheat and triticale grains harvested at different stages of ripeness and stored anaerobically following contrasting processing and additive treatments.

Materials and methods: Field plots were located at Teagasc Oak Park, Carlow (52º 50'N latitude, 6º55'W longitude, 61m above sea level) on a Mortarstown Series Grey-Brown podzolic and Athy–Complex Grey-Brown complex soil type (Conry and Ryan, 1967). Plots of barley (*Hordeum vulgare* L.) and wheat (*Triticum aestivum* L.) in 2001 and barley, wheat and triticale (X *Triticosecale* Wittmack) in 2002 were grown and harvested as in current, good commercial farm practice.

Harvest times were based on target grain DM concentrations of 600, 660, 720, 780 and above 800 g/kg. Plots were harvested to a stubble height of 6 cm using a plot combine harvester (Deutz Fahr Farmliner 3370, with a 2.4m cutting width) equipped with a built-in grain collection and weighing system to allow individual plot yields to be determined. At each harvest, a 200kg sample of grain was produced. Such samples were obtained for each of the five harvests of Barley 2001, Wheat 2001 and Wheat 2002, and for a single harvest of Barley 2002 and Triticale 2002 – the latter pair were from a harvest with an intermediate DM value. Furthermore, at the fourth harvest of Wheat 2002, additional samples were reconstituted to a target DM of 660 g/kg by carefully and evenly applying fresh water. The harvest dates (designated H1 to H5 in the tables) for Barley 2001 were 6, 9, 12, 18 and 25 July, and for Wheat 2001 they were 16, 22, 23 and 27 August and 9 September. Similarly, for Barley 2002 and Triticale 2002 the harvest dates were 12 July and 19 August, respectively, while for Wheat 2002 the harvest dates were 6, 12, 14, 19 and 21 August.

At each harvest (excluding the dry grain at the final harvest of Barley 2001, Wheat 2001 and Wheat 2002), 100kg grain was passed through a crimper-roller (Murska 350S, SAS Kelvin Cave Ltd., UK) operating at a tractor power take-off speed of 540 rpm and an inter-roller spacing of 0.46-0.48mm (i.e. at roller setting 4), while the remainder of the grain was unprocessed (left whole) prior to additive treatment.

The additive treatments applied to Barley 2001 and Wheat 2001 were: (1) no additive (NA), (2) Crimpstore 2000 (Kemira Chemicals (UK) Ltd.; formic acid, ammonium formate, propionic acid, benzoic acid and ethylbenzoate mixture) at 6 l/t (Acid 1), (3) Graintona (FSL Bells Ltd., UK; acetic acid, isobutyric acid mixture) at 8 l/t (Acid 2), (4) NuGrain (Hydro Nutrition, Hydro Agri (UK) Ltd.; urea solution) at 50 l/t (Urea) and (5) Biograin (Biotal Ltd., Wales; *Lactobacillus buchneri*) at 10 l/t (Biol. 1). For the Biograin treatment the DM concentration of grain was quickly assessed by microwave drying. The whole or rolled grain was then placed in a water-tight mixer with a quantity of water sufficient to reduce grain DM concentration to 550 g/kg, and continuously mixed for up to 15 minutes. After removing unabsorbed water, the additive was applied as described above. Approximately 4 kg grain DM were ensiled in each of triplicate laboratory silos per treatment. The additive treatments applied to Barley 2002, Wheat 2002 and Triticale 2002 were: (1) NA, (2) Acid 2, (3) Urea, (4) Biol. 1 and (5) Siloking (Agri-King, Inc., USA; *Lactobacillus plantarum, Pediococcus pentosaceus*) at 400 g/t (Biol. 2). Biol 1 was applied as described previously, while Biol 2 was applied as a dry formulation. All additives were intimately mixed with the grains prior to ensiling. The silos were stored at 15°C for >100 days.

Additional samples of Barley 2001, Wheat 2001 and Wheat 2002 that were harvested at the final target DM of >800 g/kg were dried in a forced-air circulation oven at 70°C for 16h. Triplicate samples of approximately 5 kg grain DM were subsequently stored aerobically in open polystyrene boxes (59 x 39 x 22 cm) for the same duration and at the same temperature as the laboratory silos.

After >100 days of ensilage the silos were opened, and all of the contents weighed. Any mouldy material was separated from the clean grains and weighed.

Results: Grain DM concentration generally increased as the harvest date (Table 2.7.1) of a crop got later. Patterns of change in other chemical composition variables were usually not clearly and chronologically related to harvest date or DM concentration. However, grain WSC tended to be higher and buffering capacity lower where a crop was harvested late rather than early. Overall, triticale composition tended to be intermediate between barley and wheat for *in-vitro* OMD, ash and starch, but crude protein levels were lower than either barley or wheat (Table 2.7.1). The earlier harvests of wheat in 2002 had lower starch concentrations than the later harvests, but this was not evident for wheat in 2001 or for barley in 2001.

Grain post-ensiling: The main effect of delaying the harvest date of barley, wheat or triticale was an increase in DM concentration. The effects on CP concentration were not linearly progressive over time while ash and residual WSC concentrations tended to decrease with progressively later harvesting. Generally, *in-vitro* OMD was lowest at the earliest harvest. The main effects of rolling were reduced DM and starch concentration, generally a lower *in-vitro* OMD and generally a higher CP and residual WSC concentration. The main effects of additive use were that DM was decreased when Urea, and in particular Biol.1, were used and acidification generally increased DM concentration. Urea addition increased CP concentration and frequently *in-vitro* OMD. Biol 1 significantly reduced grain DM concentration, although with some of the grains harvested at

later dates the grains were unable to absorb the full complement of water with which they were mixed prior to application of the additive.

For Barley 2001 (Table 2.7.2) the effects on *in-vitro* OMD and starch were not linearly progressive over time. Rolling increased ($P<0.001$) ash concentration and reduced ($P<0.001$) starch, these effects being largest at the earliest harvest. Acid-based additives generally increased residual WSC ($P<0.001$). Urea and Biol.1 generally decreased ($P<0.001$) WSC concentration and Biol.1 decreased *in-vitro* OMD, particularly with rolled grains. Starch concentration was reduced ($P<0.05$) where an additive was applied, compared to NA.

For Barley 2002 (Table 2.7.3), among additive effects, Biol.2 had the highest DM after ensiling ($P>0.05$). *In-vitro* OMD was improved by additive addition ($P<0.001$), while starch concentration was reduced ($P<0.001$) by both urea and the biological additives used. There were no significant interactions between processing and additive treatments for nutritive value variables.

Later harvesting of Wheat 2001 (Table 2.7.4) resulted in higher starch ($P<0.001$) compared to H1. Rolling increased ash ($P<0.001$) concentration over time. Rolling generally increased ($P<0.001$) CP concentration, an effect that was most evident with the Urea treatment at the earlier times of harvesting. Overall, i*n-vitro* OMD was improved ($P<0.05$) by additive addition with the exception of Biol.1 treatment of rolled grain in H2 to H4. Starch concentration tended to be altered by Acid1, but was reduced ($P<0.05$) by Acid2, Urea and Biol.1 in comparison to NA. The relativity of these effects was not consistent over time. Acid additives increased ($P<0.05$) WSC for whole and rolled grain at H1, and for rolled grain at H2. Urea increased WSC more with rolled than whole grain, after H1. Biol.1 reduced WSC at earlier harvests, while at later harvests it increased WSC in whole grain.

For Wheat 2002 (Table 2.7.5), rolling increased ash ($P<0.05$) concentration. Acid2 application reduced ($P<0.05$) starch concentration irrespective of processing method. The effects of Urea treatment on CP concentration were not consistent over time – it increased crude protein at each harvest, particularly in the rolled grain. Biol.2 increased ensiled grain DM concentration above NA particularly for whole grain.

At H4, rewetting Wheat 2002 grains resulted in a lower ($P<0.05$) DM and ash concentration post-ensiling, and a higher ($P<0.001$) *in-vitro* OMD. Rolling rewetted grain decreased ($P<0.01$) DM and starch ($P<0.05$) further than rolling non-wetted grains at H4. Acid1 reduced ($P<0.05$) the starch concentration of whole rewetted grains. Urea treatment of rewetted whole or rolled grain resulted in a CP concentration equivalent to that of non-wetted whole wheat. However, these were lower than the CP concentrations achieved by non-wetted rolled wheat at H4 ($P<0.001$). Biological additive application reduced ($P<0.05$) the starch concentration of whole or rolled grain.

Rolling of Triticale 2002 grains increased ($P<0.001$) ash values (Table 2.7.6). The reduction ($P<0.05$) in starch concentration with Acid2 occurred only with rolled grain while the increase when Urea was applied was evident ($P<0.05$) only with whole grain. Urea and both biological additives increased ($P<0.001$) ash concentration.

Grain standards (Table 7) that were dried and stored aerobically maintained a relatively stable nutritive composition. The major change in composition during storage was a decline in starch concentration.

Later harvesting was usually associated with conserved grain of a higher pH and with lower amounts of fermentation products (lactic acid (LA), acetic acid (AcA) and ethanol) and ammonia-N. Generally, rolled grains had a lower final pH value and higher levels of fermentation products and ammonia-N than their whole grain equivalents. Among additive treatments, NA produced relatively high levels of ethanol, with rolled grains having slightly lower levels than the whole grain treatments. Acid1 tended to reduce pH and ethanol and increase ammonia-N. In contrast, Acid2 generally increased pH and reduced LA, ethanol and ammonia-N values. Urea addition increased pH and ammonia-N. Biol.1 addition generally decreased pH and increased AcA. Biol.2 also reduced pH. In most cases less than 2g of PA or BA per kg DM were detected, and therefore the results are not presented.

For Barley 2001, Acid1 increased ammonia-N concentration more with rolled than with whole grain, and the magnitude of this effect increased at later harvests. Urea increased the concentration of LA more in rolled than whole grain, especially at earlier harvests. Biol.1 increased LA concentration mainly with whole grain, and particularly at the two later harvests.

When Barley 2002 was treated with Acid2 or Urea the concentration of ethanol was reduced. Urea treatment increased ($P<0.05$) AcA and ammonia-N with rolled grain moreso than with whole grain. Biol.1 and Biol.2 reduced pH and increased LA more with rolled than whole grain, and Biol.1 increased AcA considerably in rolled grain. In rolled grain, Biol.2 supported an increased ($P<0.001$) LA concentration moreso than did Biol.1.

When Wheat 2001 was treated with Acid1 or Acid2, there was a reduction ($P<0.001$) in the level of LA produced compared to NA. Acid1 addition reduced ($P<0.001$) AcA compared to the NA treatment. Urea treatment increased ($P<0.01$) LA at earlier harvests especially when rolled. Biol.1 had higher ($P<0.01$) LA and AcA concentrations across harvests, and these levels were elevated by rolling. At H3 and H4, Biol.1 had higher ($P<0.05$) ethanol values than NA, regardless of processing treatment.

For Wheat 2002, Acid2 produced low levels of LA after H1. Urea treatment produced LA levels above ($P<0.001$) that of the NA treatment only at H1. Biol.1 increased ($P<0.01$) AcA above that of the NA

treatment over time. This effect was most marked with whole grain at H1 and H2, and with rolled grain at H4. Across harvest dates, rolling the NA treatment produced lower ($P>0.05$) ethanol levels with the exception of H4. Rolling Biol.1 reduced ($P<0.001$) ethanol production with the exception of H1.

Rewetted Wheat 2002 H4 grains had a lower ($P<0.05$) pH at silo opening compared to the non-wetted H4 grains, and were similar to the wetter H3 grains. Rewetting grains resulted in a general increase in LA and decrease in ethanol concentration. The increase in ammonia-N associated with rewetting was manifest mainly by the Urea treatment.

Rolling Triticale 2002 generally reduced the ethanol concentration of grain at silo opening, although this effect was not evident with Acid2 or Urea. Urea increased LA with rolled grain and reduced AcA with both whole and rolled grain. Biol.1 increased ammonia-N and reduced ethanol.

The dried and aerobically stored standards contained low concentrations of fermentation products.

Later harvesting (H3 and H4) led to a small but significant ($P<0.05$) increase in DM recovery (DMr) for Barley 2001, but had no effect ($P>0.05$) with Wheat 2001 or Wheat 2002 (Table 2.7.8). Whereas rolling did not influence ($P>0.05$) DMr, there was a main effect of additive for all of the cereals except Wheat 2002. For Barley 2001, both acid additives and Urea increased ($P<0.05$) DMr while Biol.1 resulted in a lower ($P<0.05$) recovery rate. For Barley 2002, Acid 2 increased ($P<0.05$) DMr with rolled grain while Urea increased ($P<0.05$) DMr with both whole and rolled grain. For Wheat 2001, higher ($P<0.05$) DMr rates were obtained with both acid additives and Urea compared to Biol.1. For Triticale 2002, Acid2 and Urea increased ($P<0.05$) DMr with whole grain, but not with rolled grain ($P>0.05$).

Although harvest date had a significant effect ($P<0.001$) on aerobic stability (days to temperature rise; T-Rise) and aerobic deterioration (accumulated temperature rise to day 5; ATR) for Barley 2001 and Wheat 2001 and 2002, there was not a consistent chronological effect of harvest date on these variables for any of the five crops studied (Table 2.7.9). The effects of rolling on aerobic stability was significant only with Wheat 2002, and on aerobic deterioration for Barley 2002 and Wheat 2001 and 2002 – the overall trend was for rolling to increase aerobic deterioration slightly. Among additives, Acid1, Biol.1 and Urea generally improved aerobic stability and decreased deterioration, while Acid2 and Biol.2 were less consistent in their effects.

Later harvesting of Barley 2001 increased ($P<0.001$) the duration to T-Rise and decreased ATR ($P<0.001$). T-Rise was deferred by Acid1, Biol.1 and Urea, while ATR was reduced byAcid1 and Biol.1. Acid 2 was frequently unable to prevent temperature rise, showing highest ATR ($P<0.001$) across harvests (most notably with rolled grain). Rolling Barley 2002 resulted in poorer aerobic stability variables including a higher ATR ($P<0.01$). Rolled NA had a higher ($P<0.05$) ATR than the rest of the treatments. Acid2, Biol.1 and in particular Urea deferred aerobic instability and restricted ATR.

Early harvesting of Wheat 2001 increased ($P<0.001$) ATR. Rolling reduced stability and increased deterioration. NA had a higher ($P<0.001$) ATR but a shorter duration to T-Rise than when additives were used. The largest effects occurred with Biol.1. Rolling Wheat 2002 generally resulted in a lower ($P<0.001$) amount of time to T-rise and higher ATR ($P<0.001$). Among additives, Acid2 resulted in the highest ($P<0.001$) ATR. Urea achieved the lowest ATR. Biol.1 had a lower ATR than Biol.2. Rolled Acid2 had the highest ATR at H3. Rewetting the Wheat 2002 grains gave rise to the shortest duration to T-Rise and highest ATR. Acid2 addition to the rewetted whole grains increased ATR ($P<0.01$).

Rolling Triticale 2002 grains did not affect aerobic stability or deterioration ($P>0.05$). Biol.1 reduced deterioration for both processing treatments ($P<0.05$), while rolled Urea was able to also lessen deterioration.

Conclusions: It has been demonstrated that HMG (barley, wheat or triticale) stored anaerobically for durations in excess of 100 days can undergo efficient conservation with relatively small quantitative or qualitative losses. Such conservation can be conducted over a wide range of stages of ripeness (above a grain DM concentration of 550 g/kg) and with whole or rolled (i.e. crimped) grain. The additives evaluated differed in mode of action and thus in the types of effects expressed. Even in the absence of additive application, no grain could be described as having preserved badly. Acid 1 generally lead to HMG of lower pH and better aerobic stability than Acid 2. Urea had differential effects on whole and rolled grain, but improved aerobic stability. It was not feasible to determine if it would obviate the requirement for rolling grain prior to feeding to ruminants. Biol 1 was effective at improving aerobic stability subsequent to silo opening, while such benefits were not evident with Biol 2. It was also demonstrated that rewetting grain, as might happen during heavy rain, did not prevent applying these technologies to effective and efficient conservation of grain. Finally, some caution may be required when extrapolating the results presented here to efficiently conserving HMG at a farm scale.

Table 2.7.1. Mean (s.d.) chemical composition of cereals prior to ensiling

Crop	HD[1]	Dry matter (g/kg)	Crude protein (g/kgDM)	Ash (g/kgDM)	OMD (g/kg)	Starch (g/kg DM)	WSC[2] (g/kg DM)	Buffering capacity (mEq/kgDM)
Barley 2001								
	H1	557 (2.2)	97 (1.2)	24 (0.4)	839 (5.2)	586 (25.4)	25 (0.9)	91 (4.3)
	H2	643 (5.4)	102 (1.8)	27 (3.3)	799 (4.8)	637 (10.6)	26 (0.9)	95 (3.6)
	H3	726 (2.6)	104 (0.8)	49 (0.4)	783 (10.0)	653 (55.5)	30 (1.6)	77 (3.8)
	H4	821 (1.7)	99 (1.3)	24 (0.4)	823 (5.3)	590 (35.4)	33 (2.3)	69 (2.6)
	H5	847 (5.6)	99 (1.4)	25 (2.2)	838 (8.5)	613 (17.0)	33 (1.0)	72 (1.8)
Barley 2002								
	H1	725 (4.2)	104 (0.7)	27 (0.6)	851 (4.2)	554 (12.2)	N/A[3]	64 (4.1)
Wheat 2001								
	H1	616 (1.2)	108 (0.8)	19 (0.4)	866 (2.5)	668 (12.0)	28 (1.2)	93 (11.0)
	H2	714 (0.1)	111 (1.3)	20 (0.7)	866 (2.3)	679 (6.4)	31 (0.8)	58 (6.7)
	H3	784 (0.6)	111 (2.0)	18 (0.1)	864 (2.5)	690 (33.2)	35 (2.0)	62 (8.7)
	H4	802 (1.0)	109 (2.0)	19 (0.2)	868 (6.0)	669 (11.1)	34 (1.4)	87 (11.2)
	H5	866 (1.2)	108 (0.8)	20 (0.5)	868 (6.1)	680 (18.3)	35 (1.1)	82 (4.6)
Wheat 2002								
	H1	575 (4.5)	113 (2.5)	19 (0.5)	885 (8.6)	638 (27.4)	N/A[3]	69 (6.0)
	H2	657 (3.8)	112 (3.3)	18 (0.5)	874 (12.3)	620 (51.7)	N/A[3]	65 (4.6)
	H3	660 (2.7)	116 (0.9)	17 (0.4)	889 (4.3)	651 (27.9)	N/A[3]	61 (1.2)
	H4	775 (3.6)	118 (1.3)	17 (0.6)	895 (7.3)	711 (11.0)	N/A[3]	59 (4.0)
	H5	807 (2.3)	114 (3.0)	17 (0.4)	889 (5.4)	707 (5.3)	N/A[3]	56 (2.0)
Triticale 2002								
	H1	690 (1.3)	94 (1.6)	20 (0.5)	875 (2.3)	662 (12.5)	N/A[3]	68 (7.9)

[1]harvest date (defined in text); [2]WSC measured in 2001 only; [3]not available

Table 2.7.2. Interaction of harvest date, processing and additive treatment effects on nutritive value and fermentation variables for Barley 2001

	DM[3] (g/kg)	CP[4] (g/kg DM)	Ash (g/kg DM)	OMD[5] (g/kg)	Starch (g/kg DM)	WSC[6] (g/kg DM)	pH	Lactic (g/kg DM)	Acetic (g/kg DM)	Ethanol (g/kg DM)	NH_3-N[7] (g/kg DM)
H1; whole											
NA[1]	561	100	25.5	854	615	49.5	4.7	6.6	1.1	14.8	0.3
Acid 1	574	100	24.1	815	615	54.6	5.2	4.1	0.4	6.7	0.2
Acid 2	574	96	22.3	831	624	50.3	5.4	3.0	1.0	5.1	0.1
Urea	562	154	24.0	852	613	16.8	9.0	4.2	5.9	5.2	5.7
Biol. 1[2]	528	102	25.0	810	606	24.2	4.2	8.0	12.1	15.1	0.4
H1; rolled											
NA[1]	539	104	28.8	799	537	100.0	4.1	17.5	3.7	9.6	0.7
Acid 1	542	107	27.0	810	532	83.6	3.8	30.8	6.0	6.1	0.9
Acid 2	551	98	25.3	818	580	94.1	5.1	5.4	2.9	5.9	0.2
Urea	527	221	27.5	810	560	22.1	5.0	34.0	21.7	15.4	5.6
Biol. 1[2]	499	110	27.4	771	575	16.1	4.0	11.7	33.6	13.1	1.0
H2; whole											
NA[1]	662	100	24.4	815	628	30.1	5.2	4.0	1.1	17.3	0.1
Acid 1	676	101	23.8	833	629	47.1	4.8	1.8	0.3	2.0	0.1
Acid 2	671	97	22.9	825	598	36.7	5.7	2.2	0.7	6.2	0.0
Urea	667	125	23.0	853	623	17.5	7.3	7.4	2.5	5.1	1.5
Biol. 1[2]	580	103	24.5	822	621	32.1	4.3	5.7	7.0	11.7	0.2
H2; rolled											
NA[1]	639	102	25.7	820	633	27.8	4.1	19.0	9.0	9.7	0.4
Acid 1	652	103	25.9	812	595	67.9	4.1	8.9	3.7	3.3	0.6
Acid 2	645	99	25.4	829	602	51.6	5.1	3.5	3.3	6.9	0.1
Urea	633	136	24.4	841	601	23.5	5.2	36.7	10.9	20.8	5.5
Biol. 1[2]	520	110	26.9	777	588	15.0	4.2	13.9	30.4	8.9	1.0
H3; whole											
NA[1]	744	102	25.9	829	650	21.4	5.9	1.8	1.0	19.4	0.0
Acid 1	756	101	23.7	840	621	28.5	4.0	1.6	0.1	0.5	0.2
Acid 2	746	98	24.6	826	606	29.5	6.0	2.9	0.8	7.3	0.0
Urea	737	132	22.4	818	588	32.0	9.1	3.4	2.4	0.5	3.7
Biol. 1[2]	578	104	25.0	820	587	31.5	4.3	16.9	6.1	10.2	0.3
H3; rolled											
NA[1]	724	103	24.7	835	618	24.9	4.7	11.3	4.8	15.4	0.1
Acid 1	727	102	23.6	835	612	37.5	4.3	3.9	6.4	3.6	0.6
Acid 2	725	102	25.2	826	608	29.1	5.5	4.4	3.7	10.0	0.1
Urea	699	134	22.6	782	585	32.1	9.2	4.9	9.0	6.3	2.0
Biol. 1[2]	538	107	28.5	802	545	15.8	4.2	14.9	27.1	7.5	0.9
H4; whole											
NA[1]	852	102	24.7	835	588	29.8	6.9	1.7	0.6	3.2	0.0
Acid 1	857	104	21.9	819	597	27.5	3.6	1.7	0.5	0.4	0.3
Acid 2	856	100	22.1	828	576	29.1	5.4	1.1	0.7	3.3	0.2
Urea	848	140	21.9	842	575	12.4	8.7	3.4	3.5	0.5	4.0
Biol. 1[2]	754	105	23.6	818	571	18.2	4.0	8.7	8.3	4.1	0.6
H4; rolled											
NA[1]	838	104	25.5	838	566	28.6	5.9	3.4	2.7	8.4	0.0
Acid 1	837	110	23.3	806	564	28.8	3.8	4.0	1.1	1.0	1.0
Acid 2	840	103	23.8	828	575	30.4	5.9	7.0	0.3	4.4	0.1
Urea	820	167	23.4	815	560	2.0	7.2	13.8	10.2	10.9	4.6
Biol. 1[2]	719	112	26.1	787	547	12.3	4.8	2.1	26.7	6.6	0.4
Significance											
Harvest date (H)	***	***	***	***	***	***	***	***	***	***	***
Processing (P)	***	***	***	***	***	***	***	***	***	***	***
Additive (A)	***	***	***	***	***	***	***	***	***	***	***
HxP	***	***	*	**	***	***	***	***	***	NS	**
HxA	***	***	***	***	***	***	***	***	***	***	***
PxA	***	***	***	***	NS	***	***	***	***	***	NS
HxPxA	***	***	*	***	NS	***	***	***	**	***	***
S.E.M. (HxPxA)	1.6	1.5	0.21	4.4	11.1	2.47	0.14	2.16	11.08	0.71	0.36

H1-H4=harvest number; [1]no additive; [2] biological additive; [3]dry matter; [4]crude protein; [5]*in-vitro* organic matter digestibility; [6]water soluble carbohydrate; [7]ammonia-N

Table 2.7.3. Interactions of processing and harvest date on nutritive value and fermentation variables for Barley 2002

	DM[3] (g/kg)	CP[4] (g/kg DM)	Ash (g/kg DM)	OMD[5] (g/kg)	Starch (g/kg DM)	pH	Lactic (g/kg DM)	Acetic (g/kg DM)	Ethanol (g/kg DM)	NH_3-N[7] (g/kg DM)
Whole grain										
NA[1]	751	104	26.0	788	573	6.2	1.7	0.5	16.8	0.0
Acid2	749	103	24.9	846	564	5.7	1.1	1.2	7.7	0.0
Urea	730	128	25.5	871	553	9.0	1.8	3.0	4.0	4.6
Biol.[2] 1	718	104	24.5	843	559	4.9	2.1	2.3	11.6	0.1
Biol. 2	753	96	24.9	842	559	5.0	2.7	0.6	13.4	0.0
Rolled grain										
NA	736	108	27.0	811	534	5.7	2.4	4.7	16.4	0.2
Acid2	728	106	26.7	832	545	5.6	1.6	4.9	5.9	0.7
Urea	711	132	24.9	859	532	9.1	2.5	9.7	3.4	9.1
Biol. 1	691	106	26.1	830	536	4.3	7.4	30.7	15.3	0.5
Biol. 2	738	104	25.2	833	537	4.2	14.0	3.0	13.8	0.3
Processing (P)	***	***	NS	NS	NS	***	***	***	NS	***
Additive (A)	***	***	NS	***	***	***	***	***	***	***
PxA	NS	NS	NS	NS	NS	***	***	***	NS	***
S.E.M. (PxA)	2.4	1.4	0.66	7.3	6.3	0.72	0.40	1.50	0.95	0.80

[1]no additive; [2] biological additive; [3]dry matter; [4]crude protein; [5]*in-vitro* organic matter digestibility; [6] ammonia-N

Table 2.7.4 Interactions of harvest date, processing and additive treatment effects on nutritive value and fermentation variables for Wheat 2001

	DM[3] (g/kg)	CP[4] (g/kg DM)	Ash (g/kg DM)	OMD[5] (g/kg)	Starch (g/kg DM)	WSC[6] (g/kg DM)	pH	Lactic (g/kg DM)	Acetic (g/kg DM)	Ethanol (g/kg DM)	NH_3-N[7] (g/kg DM)
H1; whole											
NA[1]	638	110	18.4	819	659	22.2	3.9	11.4	3.1	16.8	0.3
Acid 1	649	109	19.8	816	656	35.9	4.2	5.7	0.8	2.6	0.4
Acid 2	645	104	18.2	864	638	41.2	5.4	2.7	1.3	5.2	0.1
Urea	623	154	18.1	861	633	26.0	9.0	11.1	7.6	3.1	8.9
Biol. 1[2]	577	110	18.6	851	640	16.4	4.2	10.8	15.0	10.7	0.6
H1; rolled											
NA[1]	632	112	19.8	816	644	25.4	3.9	22.8	6.2	7.2	1.0
Acid 1	637	112	19.2	809	625	35.8	4.2	12.2	2.8	3.3	1.1
Acid 2	633	108	18.8	835	589	54.7	4.7	6.9	5.4	6.6	0.5
Urea	618	233	18.2	857	589	23.3	6.3	36.9	7.8	5.8	7.3
Biol. 1[2]	560	119	20.8	841	648	9.8	4.1	24.3	22.4	9.2	1.6
H2; whole											
NA[1]	742	113	19.8	871	701	13.3	5.1	3.5	2.3	31.1	0.1
Acid 1	757	111	17.1	866	719	13.5	4.3	2.7	0.6	1.1	0.2
Acid 2	750	107	18.8	887	687	15.8	5.5	2.8	1.4	9.1	0.0
Urea	740	137	16.4	899	691	15.5	9.2	2.8	2.0	1.7	5.1
Biol. 1[2]	593	118	18.5	856	692	15.3	4.1	6.5	20.2	14.0	0.5
H2; rolled											
NA[1]	734	112	18.3	871	706	11.2	4.5	11.4	6.2	21.3	0.3
Acid 1	743	112	16.9	854	692	16.5	4.6	3.0	1.1	2.5	0.6
Acid 2	738	112	18.4	889	673	18.2	5.7	3.2	3.0	13.1	0.1
Urea	718	146	15.6	895	693	17.4	9.4	6.4	5.6	3.5	9.1
Biol. 1[2]	547	125	20.2	821	654	8.5	4.2	22.0	23.7	29.9	1.8
H3; whole											
NA[1]	808	111	17.7	855	699	7.9	5.9	2.4	0.6	2.2	0.0
Acid 1	818	114	15.2	876	712	5.9	3.5	1.8	0.0	0.1	0.3
Acid 2	807	109	16.9	885	715	7.9	6.4	2.2	0.2	2.9	0.0
Urea	807	164	16.5	863	691	8.3	9.4	1.9	1.8	0.4	2.9
Biol. 1[2]	576	118	16.5	846	724	14.4	4.1	6.7	19.6	11.8	0.5
H3; rolled											
NA[1]	795	113	18.3	861	697	8.7	6.0	2.2	2.9	9.3	0.0
Acid 1	795	115	15.7	873	728	7.7	4.0	2.4	0.3	0.2	0.9
Acid 2	792	112	17.1	884	714	9.2	6.0	2.1	2.9	4.6	0.0
Urea	778	147	15.9	877	714	12.9	9.3	2.2	7.3	1.1	6.9
Biol. 1[2]	559	123	18.4	810	680	7.9	4.1	20.3	23.4	18.2	1.4
H4; whole											
NA[1]	828	113	18.3	837	706	7.3	6.6	2.1	0.2	0.4	0.0
Acid 1	835	115	15.2	893	703	5.6	3.4	2.2	0.0	0.7	0.3
Acid 2	831	111	17.3	878	698	7.4	5.4	1.9	1.0	1.8	0.0
Urea	825	178	16.9	889	672	6.2	9.3	1.3	1.4	0.5	1.4
Biol. 1[2]	562	118	17.2	873	686	20.2	4.1	5.9	20.9	11.7	0.5
H4; rolled											
NA[1]	819	113	18.3	873	687	7.6	6.3	2.0	2.3	4.4	0.0
Acid 1	818	118	16.0	883	680	6.6	3.9	1.5	0.2	0.5	1.2
Acid 2	816	112	18.0	881	698	7.4	6.2	1.4	1.0	1.7	0.0
Urea	800	158	17.0	887	680	11.0	9.4	1.2	8.9	0.5	5.7
Biol. 1[2]	541	124	18.4	842	670	8.5	4.2	19.7	21.6	23.7	1.7
Significance											
Harvest date (H)	***	***	***	***	***	***	***	***	***	***	***
Processing (P)	***	***	***	***	***	NS	*	***	***	***	***
Additive (A)	***	***	***	***	***	***	***	***	***	NS	**
HxP	*	***	*	NS	*	***	***	***	NS	***	***
HxA	***	***	***	***	***	***	***	***	***	***	***
PxA	***	***	***	***	NS	***	***	***	***	***	***
HxPxA	**	***	NS	NS	***	***	***	***	***	***	***
S.E.M. (HxPxA)	3.2	2.4	0.3	7.3	8.5	0.70	0.10	0.78	0.62	0.73	0.28

H1-H4=harvest number; [1]no additive; [2]biological additive; [3]dry matter; [4]crude protein; [5]*in-vitro* organic matter digestibility; [6]water soluble carbohydrate; [7]ammonia-N

Table 2.7.5. Interactions of harvest date, processing and additive treatment effects on nutritive value and fermentation variables for Wheat 2002

	DM[3] (g/kg)	CP[4] (g/kg DM)	Ash (g/kg)	OMD[5] (g/kg)	Starch (g/kg DM)	pH	Lactic (g/kg DM)	Acetic (g/kg DM)	Ethanol (g/kg DM)	NH_3-N[6] (g/kg DM)
H1; whole										
NA[1]	573	118	19.8	896	587	4.1	14.3	12.5	12.0	1.1
Acid2	595	110	18.2	896	559	5.1	2.1	13.7	7.3	0.3
Urea	566	190	20.2	906	584	8.4	32.3	7.1	9.3	12.4
Biol. 1[2]	546	118	21.3	882	611	4.4	7.1	25.8	10.3	1.6
Biol. 2	591	115	19.0	887	574	4.1	16.6	7.1	7.8	0.9
H1; rolled										
NA[1]	571	115	20.5	877	566	3.9	38.9	10.5	9.3	1.7
Acid2	569	116	21.4	888	430	3.8	29.0	16.4	9.4	1.5
Urea	558	228	21.4	889	514	4.7	79.6	11.7	9.9	11.8
Biol. 1[2]	546	132	20.4	893	594	3.8	43.7	12.1	11.8	1.9
Biol.2	574	115	20.9	883	563	3.9	40.8	10.3	9.6	1.8
H2; whole										
NA[1]	672	118	24.5	897	606	4.4	5.8	4.3	12.0	0.3
Acid 2	684	113	18.4	892	595	5.4	0.5	2.6	4.5	0.2
Urea	654	143	16.4	913	635	9.0	1.0	3.0	2.3	7.5
Biol. 1[2]	638	119	16.6	891	638	4.3	3.8	20.8	14.1	0.4
Biol.2	680	117	17.7	882	636	4.2	8.8	3.5	12.3	0.3
H2; rolled										
NA[1]	661	117	18.5	888	600	3.9	29.6	10.7	9.7	1.1
Acid 2	661	114	20.1	887	552	4.8	6.0	5.2	5.0	0.5
Urea	633	169	19.6	898	619	8.7	4.6	7.6	6.3	9.7
Biol. 1	631	118	18.7	878	622	3.9	30.1	11.6	8.5	0.8
Biol.2	661	116	20.2	868	606	4.0	24.6	7.9	13.6	0.9
H3; whole										
NA[1]	665	118	18.7	906	609	4.4	5.8	5.2	15.4	0.3
Acid 2	677	112	18.4	912	583	5.3	1.9	0.6	4.0	0.1
Urea	664	138	17.9	929	633	8.9	1.8	2.0	1.7	6.8
Biol. 1[2]	636	118	18.7	845	626	4.2	2.2	16.7	15.3	0.3
Biol.2	673	118	18.5	916	640	4.2	6.8	2.8	12.6	0.2
H3; rolled										
NA[1]	673	117	18.2	901	614	4.2	17.8	2.7	2.6	0.7
Acid 2	678	115	17.6	907	565	5.3	3.4	5.6	4.1	0.3
Urea	654	149	18.1	929	610	8.7	6.5	5.5	4.3	9.8
Biol. 1[2]	635	120	17.9	904	613	4.0	24.7	20.5	7.5	1.0
Biol.2	678	118	18.2	905	622	4.1	18.4	7.2	8.7	0.7
H4; whole										
NA[1]	806	118	17.9	909	624	5.7	1.9	1.0	13.8	0.1
Acid 2	804	114	17.2	922	611	5.6	0.4	1.3	7.4	0.0
Urea	770	141	17.0	933	629	9.3	0.6	2.2	0.6	3.5
Biol. 1[2]	768	120	18.0	909	603	4.4	0.9	9.1	19.0	0.1
Biol.2	795	118	17.8	905	618	5.8	2.6	1.6	8.1	0.1
H4; rolled										
NA[1]	788	120	18.6	911	637	5.4	14.7	10.7	19.8	0.4
Acid 2	786	119	18.0	909	619	5.8	2.5	10.3	5.8	0.3
Urea	750	173	21.2	924	624	9.2	2.0	5.9	1.3	5.1
Biol. 1[2]	734	122	18.8	890	626	4.4	12.4	39.9	10.0	0.7
Biol.2	785	121	19.0	894	607	4.5	13.5	9.2	15.6	0.4
H4RW[7]; whole										
NA[1]	669	118	16.7	926	631	4.2	2.4	6.2	12.2	0.0
Acid 2	695	118	16.7	920	573	5.3	2.2	0.0	4.2	0.0
Urea	679	148	17.5	943	637	8.9	2.6	1.3	1.4	8.1
Biol. 1[2]	652	119	17.3	931	607	4.1	3.9	21.0	10.1	0.1
Biol.2	703	121	17.8	934	606	4.2	3.0	3.5	8.1	0.2
H4RW[7]; rolled										
NA[1]	645	118	17.4	914	614	3.8	9.9	10.8	9.8	0.1
Acid 2	647	118	16.7	929	626	4.8	4.4	2.6	13.1	0.2
Urea	632	144	18.1	941	606	8.5	5.5	4.4	4.4	14.0
Biol. 1[2]	605	121	17.5	929	570	4.0	13.7	23.2	10.5	1.4
Biol.2	649	118	17.3	917	589	3.8	25.0	11.0	11.8	0.4
Significance										
Harvest date (H)	***	***	***	***	***	***	***	***	***	***
Processing (P)	***	***	***	***	**	NS	NS	***	***	***
Additive (A)	***	***	*	***	***	***	***	***	***	***
HxP	***	***	***	NS	NS	***	***	***	***	***
HxA	***	***	***	NS	NS	***	***	***	***	***
PxA	***	***	***	NS	NS	***	***	NS	***	***
HxPxA	***	***	***	NS	NS	***	***	***	***	***
S.E.M. (HxPxA)	1.9	2.6	0.6	10.0	60.5	0.08	1.37	1.85	1.31	0.29

H1-H4=harvest number; [1]no additive; [2] biological additive; [3]dry matter; [4]crude protein; [5]*in-vitro* organic matter digestibility; [6]ammonia-N; [7]reconstituted grain

Table 2.7.6. Interactions of processing and additive treatments on nutritive value and fermentation variables for Triticale 2002

	DM[3] (g/kg)	CP[4] (g/kg DM)	Ash (g/kg DM)	OMD[5] (g/kg)	Starch (g/kg DM)	pH	Lactic (g/kg DM)	Acetic (g/kg DM)	Ethanol (g/kg DM)	NH_3-N[6] (g/kg DM)
Whole grain										
None	710	96	19.7	911	556	4.7	5.9	7.6	24.8	0.4
Acid 2	721	94	19.0	919	572	5.5	1.2	5.6	8.6	0.1
Urea	685	129	19.2	941	615	9.0	2.8	4.1	3.9	9.0
Biol. 1[2]	671	99	20.4	923	580	4.1	10.0	33.9	19.6	0.8
Biol. 2	714	97	20.2	632	575	4.3	10.0	5.7	19.2	0.4
Rolled grain										
NA[1]	700	98	20.1	912	563	4.1	23.4	15.8	15.3	0.9
Acid 2	705	95	19.7	907	524	5.2	5.8	15.2	11.0	0.6
Urea	678	169	22.7	939	548	8.1	35.2	10.9	10.0	10.4
Biol. 1[2]	667	101	20.5	921	562	4.0	26.6	28.9	10.7	1.4
Biol. 2	703	99	20.8	917	579	4.1	23.1	13.4	19.0	1.3
Processing (P)	***	***	***	NS	***	**	***	***	*	***
Additive (A)	***	***	***	**	**	***	**	***	***	***
PxA	NS	***	***	NS	***	NS	*	***	***	NS
S.E.M (PxA)	2.3	2.2	0.23	6.3	8.9	0.24	3.68	0.77	1.34	0.21

[1]no additive; [2] biological additive; [3]dry matter; [4]crude protein; [5]*in-vitro* organic matter digestibility; [6]ammonia-N

Table 2.7.7. Nutritive value and fermentation variables measured on barley and wheat standards post aerobic storage

	DM[1] (g/kg)	Crude protein (g/kg DM)	Ash (g/kg DM)	WSC[2] (g/kg DM)	OMD[3] (g/kg)	Starch (g/kg DM)	pH	Lactic (g/kg DM)	Acetic (g/kg DM)	Ethanol (g/kg DM)
Barley 2001										
Mean	852	99	23.3	35.4	806	541	7.3	18.9	0.4	1.7
s.d.	3.7	0.8	0.5	0.99	6.9	4	0.1	0.66	0.6	0.6
Wheat 2001										
Mean	893	107	17.9	34.6	860	620	6.6	6.5	0	0
s.d.	2.9	1.3	0.41	0.99	9.1	3.9	0.0	3.17	0	0
Wheat 2002										
Mean	891	110	16.8	N/A	924	604	6.4	14.5	0	7.2
s.d.	3.5	0.7	0.21	N/A	23.3	30.6	0.0	1.87	0	0.34

[1] dry matter; [2]water-soluble carbohydrate; [3] *in-vitro* organic matter digestibility

Table 2.7.8. Dry matter recovery rates (g DM recovered/ g DM ensiled) of high moisture ensiled barley, wheat and triticale grains

Harvest no.	Additives 2001	Additives 2002	Barley 2001		Barley 2002		Wheat 2001		Wheat 2002		Triticale 2002	
			Whole	Rolled	Whole	Rolled	Whole	Rolled	Whole	Rolled	Whole	Rolled
H1	NA[1]	NA[1]	983	983			978	993	987	991		
H1	Acid 1	Acid 2	993	985			998	995	997	990		
H1	Acid 2	Urea	993	989			995	995	987	977		
H1	Urea	Biol. 1	986	978			993	965	985	987		
H1	Biol. 1	Biol. 2	981	960			967	987	994	988		
H2	NA[1]	NA[1]	987	986	993	989	987	990	984	996	985	991
H2	Acid 1	Acid 2	973	993	993	998	995	996	998	995	997	993
H2	Acid 2	Urea	992	992	1002	1000	994	990	999	998	1000	985
H2	Urea	Biol. 1	990	979	991	984	1002	1000	986	995	980	989
H2	Biol. 1	Biol. 2	979	981	994	994	983	992	879	994	989	991
H3	NA[1]	NA[1]	988	990			993	992	985	994		
H3	Acid 1	Acid 2	999	992			999	998	998	998		
H3	Acid 2	Urea	993	993			996	995	1002	1000		
H3	Urea	Biol. 1	1001	999			999	1001	986	993		
H3	Biol. 1	Biol. 2	987	983			983	983	996	998		
H4	NA[1]	NA[1]	992	993			996	994	992	991		
H4	Acid 1	Acid 2	997	999			999	999	990	993		
H4	Acid 2	Urea	997	997			999	999	1001	1002		
H4	Urea	Biol. 1	997	997			998	975	988	980		
H4	Biol. 1	Biol. 2	980	978			983	979	984	988		
H4 RW[1]		NA[1]							989	989		
H4 RW[1]		Acid 2							999	991		
H4 RW[1]		Urea							1002	995		
H4 RW[1]		Biol. 1							980	982		
H4 RW[1]		Biol. 2							986	1003		
Significance												
Harvest date (H)			***				NS		NS			
Processing (P)			NS		NS		NS		NS		NS	
Additive (A)			***		***		***		NS		***	
HxP			*				NS		NS			
HxA			NS				NS		NS			
PxA			NS		**		NS		NS		***	
HxPxA			NS				NS		NS			
S.E.M. (HxPxA)			4.6		1.4		7.1		15.5		1.6	

H1-H4=harvest number; [1] no additive; [2]H4RW= harvest 4 grains reconstituted

Table 2.7.9. Aerobic stability variables of high moisture ensiled barley, wheat and triticale grains

Additives		Days to temperature rise					ATR[6]				
		2001		2002			2001		2002		
2001	2002	Bar[3]	Wh[4]	Bar[3]	Wh[4]	Trit[5]	Bar[3]	Wh[3]	Bar[3]	Wh[3]	Trit[5]
H1; whole											
NA[1]	NA[1]	5	1	-	9	-	4	20	-	0	-
Acid 1	Acid 2	3	5	-	6	-	22	10	-	9	-
Acid 2	Urea	4	3	-	9	-	10	11	-	0	-
Urea	Biol. 1	4	5	-	9	-	11	7	-	0	-
Biol. 1	Biol. 2	9	9	-	6	-	0	1	-	6	-
H1; rolled											
NA[1]	NA[1]	5	4	-	5	-	2	34	-	10	-
Acid 1	Acid 2	7	5	-	9	-	1	5	-	1	-
Acid 2	Urea	3	4	-	8	-	45	28	-	0	-
Urea	Biol. 1	9	5	-	6	-	0	7	-	5	-
Biol. 1	Biol. 2	9	9	-	6	-	0	1	-	6	-
H2; whole											
NA[1]	NA[1]	2	4	4	8	4	28	8	5	0	7
Acid 1	Acid 2	6	3	5	5	5	8	5	5	4	3
Acid 2	Urea	3	7	9	5	6	8	2	2	2	11
Urea	Biol. 1	4	7	7	8	5	11	3	2	0	5
Biol. 1	Biol. 2	8	8	4	5	9	3	2	7	2	1
H2; rolled											
NA[1]	NA[1]	4	3	2	5	4	6	8	13	4	10
Acid 1	Acid 2	6	9	6	3	5	4	2	6	9	8
Acid 2	Urea	3	5	9	7	9	40	6	2	1	1
Urea	Biol. 1	5	8	5	5	9	3	2	4	2	1
Biol. 1	Biol. 2	5	8	3	5	5	3	2	8	4	10
H3; whole											
NA[1]	NA[1]	5	2	-	6	-	4	8	-	1	-
Acid 1	Acid 2	8	2	-	5	-	3	7	-	2	-
Acid 2	Urea	5	2	-	7	-	5	5	-	1	-
Urea	Biol. 1	6	2	-	7	-	30	8	-	0	-
Biol. 1	Biol. 2	9	2	-	4	-	0	3	-	4	-
H3; rolled											
NA[1]	NA[1]	5	2	-	4	-	6	10	-	3	-
Acid 1	Acid 2	5	2	-	3	-	3	6	-	21	-
Acid 2	Urea	4	2	-	8	-	11	5	-	0	-
Urea	Biol. 1	9	2	-	6	-	1	9	-	2	-
Biol. 1	Biol. 2	9	4	-	4	-	0	2	-	8	-
H4; whole											
NA[1]	NA[1]	4	2	-	9	-	6	10	-	0	-
Acid 1	Acid 2	6	2	-	9	-	5	6	-	0	-
Acid 2	Urea	9	9	-	9	-	3	1	-	0	-
Urea	Biol. 1	8	4	-	9	-	3	4	-	0	-
Biol. 1	Biol. 2	7	7	-	9	-	3	1	-	0	-
H4; rolled											
NA[1]	NA[1]	3	2	-	7	-	6	8	-	2	-
Acid 1	Acid 2	6	6	-	5	-	3	2	-	3	-
Acid 2	Urea	9	5	-	9	-	2	5	-	0	-
Urea	Biol. 1	9	4	-	9	-	3	4	-	0	-
Biol. 1	Biol. 2	7	8	-	8	-	4	3	-	0	-
H4RW[2]; whole											
NA[1]	NA[1]	-	-	-	1	-	-	-	-	5	-
Acid 1	Acid 2	-	-	-	1	-	-	-	-	11	-
Acid 2	Urea	-	-	-	4	-	-	-	-	3	-
Urea	Biol. 1	-	-	-	1	-	-	-	-	5	-
Biol. 1	Biol. 2	-	-	-	4	-	-	-	-	6	-
H4RW[2]; rolled											
NA[1]	NA[1]	-	-	-	1	-	-	-	-	5	-
Acid 1	Acid 2	-	-	-	1	-	-	-	-	4	-
Acid 2	Urea	-	-	-	1	-	-	-	-	7	-
Urea	Biol. 1	-	-	-	1	-	-	-	-	8	-
Biol. 1	Biol. 2	-	-	-	1	-	-	-	-	7	-
Significance											
Harvest date (H)		***	***	-	***	-	***	***	-	***	-
Processing (P)		NS	NS	NS	***	NS	NS	*	**	***	NS
Additive (A)		***	***	***	***	NS	***	***	***	***	NS
HxP		NS	NS	-	NS	-	NS	***	-	*	-
HxA		***	*	-	NS	-	***	***	-	***	-
PxA		*	*	NS	NS	NS	***	***	*	***	*
HxPxA		NS	NS	-	*		***	**	-	***	-
S.E.M. (HxPxA)		1.1	1.1	1.1	0.9	1.6	2.2	1.7	1.2	1.2	3.0

H1-H4=harvest number; [1]no additive; [2]reconstituted grain; [3]barley; [4]wheat; [5]triticale; [6] accumulated temperature rise to day 5

Experiment 2.8: Feeding value for finishing beef steers of wheat grain conserved by different techniques

[P. Stacey, P. O'Kiely, A.P. Moloney and F.P. O'Mara]

The aims of this experiment were to quantify the conservation characteristics and feeding value for beef cattle of conventional wheat grain (propionic acid-treated and rolled) compared with high-moisture grain (HMG) stored anaerobically and either crimped and ensiled with an additive or urea-treated as whole grain, and to determine the response to increasing the proportion of the diet provided by wheat grain conserved by these three approaches.

Materials and Methods: A crop of winter wheat (cv. Claire) sown in October 2000 received a total nitrogen input of 220 kg N per ha and was managed as for commercial grain production. Grain samples prior to harvesting were initially obtained daily and, closer to harvesting, on a few occasions within days, and had their DM concentration rapidly estimated using microwave drying.

Wheat grain treatments: Acid-treated, rolled/ crimped and ensiled (ER) Representative plots from within the wheat crop were combine-harvested (Case International Harvester 2188; axial flow; 9.1 m header) on 20 August 2001. The harvester was operated at a reduced forward speed of 4.0 km /h (engine speed 2030 revolutions per minute (rpm)) and little visible loss of grain occurred. The grain was weighed (57.2 t), sampled, passed through a crimper-roller (Murska 350S, SAS Kelvin Cave Ltd., Somerset, UK) (tractor power take-off speed of 540 rpm; rollers set 0.46 – 0.48 mm apart) and had an acid-based additive (Crimpstore 2000, Kemira Chemicals (UK) Ltd.) applied at the base of the unloading auger, i.e. before it exited the crimper-roller. This additive was applied at 8 l/t and its stated ingredients were formic acid, ammonium formate, propionic acid, benzoic acid and ethyl benzoate. The speed of grain treatment was 4.32 t/h. The ER grain was placed in a horizontal, walled, roofed concrete silo (23.0 m long x 4.3 m wide x 2.3 m high), compacted with an industrial loader (Volvo 412s) and an all-terrain vehicle (Honda TRX 350se, Four Trax, 350 4x4 ES), and sealed beneath two layers of black 0.125mm polythene sheeting (IS 246 1989) and a complete layer of tyres. A layer of silt was used to seal the edges of the polythene sheet next to the walls and at ground level. Polythene sheeting placed between the grain and supporting walls was folded onto the top surface of the grain before the main polythene sheets were put into place. The dimensions of the mass of stored grain were 16.0 m long, 4.3 m wide and 0.9 m high. Netting (green 0.05m gauge: Silanet^{TM}, Volac Feeds Ltd.) was then positioned 1.4 m above the grain to protect it from birds.

Urea-treated but not rolled (UN) Comparable plots as for ER were similarly harvested on 21 August. The grain was weighed (67.3 tonnes) and sampled. Units of approximately 5.0 t were placed into a diet mixer wagon (Abbey Super Mix 100, Abbey Farm Equipment Ltd., Ireland) and mixed with urea solution (NuGrain, Hydro-Nutrition, Hydro Agri (UK) Ltd.; 430 g urea/l) applied at 47.0 l/t (20 kg urea/ t). The combination of grain and urea solution was mixed for 5 min. and the speed of grain treatment was 10.0 t/h. The treated grain was stored as for ER, except that whole grains were not compacted in the silo, and the stored material was 13.7 m long x 4.3 m wide x 1.5 m high. This treatment was sealed beneath polythene sheeting as described above and had protective netting erected 0.8 m above the grain.

Dry, propionic acid-treated, rolled (PR) The remaining representative plots were harvested and weighed on 28 August, as for ER and UN. Propionic acid (Propcorn, Interchem Ltd., Ireland; 99.5% propionic acid) was applied at 9.0 l/t through an acid applicator with a flow meter and the whole grain was stored aerobically in a similar silo to those described above. The PR grain (42.8 t) was not compacted in the silo and was stored 9.1 m long x 4.3 m wide x 1.2 m high. It was covered with a single sheet of hessian fabric (660g/m; Synthetic Packaging Ltd., Clara, Co. Offaly), and protected from birds using netting at a height of 1.1 m above the stored grain.

Grass silage: Grass from a permanent sward of mixed botanical composition was cut to a stubble height of 5 to 6 cm on 24 July 2001 with a rotary drum mower (Pottinger Type PSM 353, Model CAT NOVA 310T). It was precision-chop harvested (Pottinger Mex VI) within 3 h of mowing. Formic acid (850g/kg) (Add-Safer, Trouw (UK) Ltd.) was applied through the harvester at 1.9 l/t. The grass was weighed (419 t) into three horizontal, walled, roofed silos (each 24.0 m long x 3.5 m wide x 3.0 m high). It was compacted using an industrial loader and covered and sealed as for the ER treatment above.

Animals and treatments: Friesian steers (n=120; 12 steers per treatment; mean starting age = 19.2 months) were treated for internal and external parasites (Ivomec Super injection, Merial Animal Health Ltd., UK) and offered unwilted grass silage *ad libitum* for 3 weeks pre-trial. The level of supplementary rolled wheat was gradually increased to 6 kg per head daily where appropriate. Based on the mean of two consecutive daily weighings at the end of this acclimatisation period, steers were allocated on a live-weight basis to 12 replicate blocks and then randomly assigned from within blocks to the ten treatments. All animals were offered grass silage *ad libitum* together with (i) no wheat; (ii) - (iv) dry wheat (propionic acid treated and rolled) (PR) at 3 kg (low) or 6 kg/head daily (medium), or *ad libitum* (high); (v) – (vii) urea treated whole wheat grain (UN) at equivalent DM allowances to (ii) and (iii) above, or *ad libitum;* (viii) – (x) acid treated and crimped/ rolled, ensiled wheat (ER) at equivalent DM allowances to (ii) and (iii) above, or *ad libitum*.

Animal management and measurements: Steers were group-penned (six per pen; two pens per treatment) by treatment in a slatted floor shed and individual intakes were recorded daily through electronically controlled Calan doors for 144 days. Cattle allocated to the *ad libitum* grain treatments were gradually adapted to these levels of grain over a period of 28 days. Pens within treatments were located in different parts of the shed. Animals offered wheat grain were additionally supplemented with 100 g soyabean meal and 30 g mineral plus vitamin mixture/kg wheat (adjusted for DM) offered. The mineral plus vitamin mixture contained vitamin A (0.50 million i.u./kg), vitamin D_3 (0.13 million i.u./kg), vitamin E (1.5 g/kg), Se (2.00 mg/kg), Cu (0.5 g/kg), Ca (31%), Na (5.49%) and P (1.48%). Animals on the grass silage only diet were supplemented with 45 g mineral plus vitamin mixture per head daily.
The PR grain was passed through the crimper twice weekly during feed out (sufficient for 3-4 days feeding) using the same settings as for the ER grain treatment. At feed out, each wheat treatment was mixed with the vitamin and mineral mixture and soyabean meal in an Adelphi mixer (W.L. Holland, Preston, England; machine no. 3775) for 5 minutes. Grass silage was offered to each animal at 1.1 times the previous days' intake and fresh water was available *ad libitum.* The nominal 3 kg and 6 kg daily grain allocations for ER and UN were at the equivalent DM input as for PR, based on fortnightly estimates of DM obtained by oven drying. The 3 kg allocation of each form of wheat was offered in a single feed at 08:15 h daily whereas the 6 kg allocation was offered in equal amounts at 08:15 h and 16:00 h.
Steers (4 steers per treatment), in units of three replicate blocks, were individually tethered for 48 h between days 102 and 109, and had their faeces collected between 25 – 48 h. Faecal sub-samples from each animal were dried at 70 °C for 72 h, milled (Christy and Norris) through a sieve with 1 mm pores and assessed for starch. Additional faecal sub-samples were washed through a sieve (3 mm), the residue was dried at 98 °C for 16 h and visually apparent whole grains were manually removed and weighed. The latter were expressed as a proportion of faecal DM.
Simultaneous to the individual faecal collections, blood samples were taken through in-dwelling jugular catheters at 08:00 h, 10:00 h and 18:00 h for determination of beta-hydroxybutyrate (BHBA), non-esterified fatty acids (NEFA), urea, glucose and ammonia. Fresh feed was offered at 08:15 h, with the cattle consuming a nominal 6 kg wheat daily being offered the second half of their daily allocation at 16:00 h.
Final live-weight was the mean of two consecutive daily live-weights immediately before slaughter. Cold carcass weight (hot carcass x 0.98) and kidney plus channel fat (KCF) weight were recorded after slaughter. Carcass weight gain was estimated as the difference between final carcass weight and 0.48 of initial live weight. Samples of *M. longissimus dorsi* (LD) were taken 24 h post-mortem from between ribs 5 to 7 and stored at 3 ˚C for a further 24 h. Colour measurements (lightness (l), redness (a) and yellowness (b) of the muscle and subcutaneous fat was measured using a Minolta ChromaMeter CR 100 (Minolta Camera Co., Ltd., Osaka, Japan) and the chroma (C) and hue (H) angle were calculated.

Results: The mean (s.d.) chemical composition of the different feedstuffs at various stages of conservation are shown in Table 2.8.1. Grass silage, ER, UN and PR were aerobically stable and the differences between the feedstuffs were relatively minor (Table 2.8.2).

Mean (s.d.) modulus of fineness for ER, UN and PR at removal from the silo were 5.34 (0.418), 4.99 (0.016) and 4.87 (0.124) with corresponding values of 4.23 (0.086), 4.78 (0.062) and 4.36 (0.249) after inclusion of soyabean meal, vitamins and minerals. The mean (s.d.) proportions of silage DM in the particle length categories of <25 mm, 26-50 mm, 51-75 mm, 76-100 mm and >100 mm were 334 (0.1), 321 (0.1), 164 (0), 87 (0) and 93 (0) g/kg DM, respectively.

Yeast and mould counts in grass silage, UN and PR were less than ten colony forming units (cfu)/ g whereas the values in ER were 1460 cfu/g and 70 cfu/ g, respectively.
Grass silage DM intake was highest and total diet DM intake was lowest ($P<0.01$) for the animals offered unsupplemented grass silage (Table 2.8.3). The steers fed PR and ER had lower silage DM intake than the UN fed steers ($P<0.01$). Increasing the level of wheat in the diet reduced ($P<0.001$) silage DM intake and increased total DM intake (data not shown). Wheat DM intakes differed at *ad libitum* level of feeding, with cattle consuming less ($P<0.05$) ER than UN or PR.

Grass silage only steers had similar levels of faecal starch to low ER and PR treatments. Increasing the level of wheat offered generally increased ($P<0.001$) faecal DM and starch contents and the proportion of whole grain in the faeces (Table 2.8.3). Cattle offered PR had a lower ($P<0.01$) faecal DM content than those offered UN or ER. In contrast, animals offered UN had high ($P<0.001$) faecal whole grain and starch contents. The largest increase in starch ($P<0.05$) and in whole grain content ($P<0.001$) in the faeces with increasing levels of wheat fed occurred in the animals offered UN.
Steers offered GS only had the lowest ($P<0.001$) mean plasma glucose and urea concentrations (Table 2.8.3). Mean plasma glucose was lower ($P<0.05$) for UN than ER or PR. Animals offered UN had higher ($P<0.001$) mean plasma urea concentrations than those offered ER or PR. Higher levels of wheat supplementation generally increased plasma ammonia, urea and glucose levels. There was an interaction ($P<0.05$) between diet

type and level of supplementation for plasma urea with increasing levels of UN resulting in larger increases in blood urea concentration than with ER or PR.
Animals offered grass silage only had the lowest ($P<0.001$) final live-weight, carcass weight, daily carcass weight gain and KCF weight at slaughter (Table 2.8.3) but they had a kill out proportion equal to the low UN and low PR diets. On average, steers offered UN had a lower ($P<0.05$) live-weight and carcass weight gain than those offered ER or PR. The KCF weight was not affected ($P>0.05$) by form of wheat. Increasing rates of wheat consumption increased ($P<0.001$) live and carcass weight gain. In general the low level of wheat supplementation resulted in lower ($P<0.001$) KCF weights than the medium or high rates of supplementation.
The total DM intake (kg) per kg estimated carcass weight gain was 19.4, 18.0 and 16.2 for steers offered low, medium and high ER, with corresponding values of 24.6, 23.3 and 22.3 for UN and 23.6, 17.4 and 15.6 for PR. In the same order, total DM intake (kg) per kg live-weight gain was 11.9, 10.5, 10.4, 14.1, 13.9, 13.0, 13.1, 10.9 and 10.1.
Grass silage fed steers had similar ($P>0.05$) muscle 'a' values to the steers supplemented with wheat, but had somewhat lower ($P<0.001$) fat 'a values' (redness). Form of wheat did not alter muscle 'a' values ($P>0.05$) but resulted in higher fat 'a' ($P<0.05$) and 'b' ($P<0.01$) values, with higher values achieved for the UN and PR diets compared to ER. Increasing the level of supplementation from low to medium resulted in an increase ($P<0.05$) in muscle 'a' value (redness) but increasing from medium to high levels of wheat reduced ($P<0.001$) the fat 'b' value (yellowness). There was no significant interaction between level and form of wheat for muscle 'a' or fat 'a' or 'b' values. Muscle hue was not affected by level or form of wheat offered. Muscle chroma was affected by the level of wheat offered, the chroma value increasing when wheat was fed at medium to high levels compared to the low level ($P<0.05$), but this was not evident across wheat form offered ($P>0.05$). Fat hue value was greater for the GS diet ($P<0.01$) than the diets where wheat was included. Fat hue value was lower ($P<0.001$) for ER diets compared to either UN or PR. Fat hue value was lower ($P<0.001$) for high levels of wheat inclusion compared to low and medium levels. Fat chroma value was similar for low and high levels of supplementation but less than the fat chroma value for the medium level of supplementation ($P<0.01$). There were no significant interactions between level and form of wheat for muscle and fat hue and chroma.

Table 2.8.4 presents the linear regression relationships between the level of each of ER, UN, PR consumed and intake, faecal, blood plasma, performance and meat colour measurements. Silage DM intake decreased linearly ($P<0.001$) as proportion of wheat increased in the diet. There was a linear increase ($P<0.001$) in daily live and carcass weight gain, kill out proportion ($P<0.05$ for UN) and KCF weight with increasing levels of wheat in the diet. The relationships for blood variables were not significant ($P>0.05$) with ER. With UN, increasing the level consumed increased mean plasma concentrations of BHBA, glucose and urea while with PR increasing the level consumed increased glucose and urea. Increasing levels of wheat consumed increased faecal DM, starch and the proportion of whole grain in the faeces, with sizeable rates of increase for starch and whole grain in cattle offered UN. For cattle offered ER, increasing the level consumed increased muscle 'a value', reduced fat 'b value' and did not alter muscle 'L value'. For cattle offered PR, increasing the level of wheat consumed reduced fat 'b value'. Increasing the levels of wheat for any of the three wheat treatments, decreased the hue value of fat ($P<0.001$). Increasing wheat in the diet of ER fed steers increased ($P<0.001$) the chroma value for muscle and decreased the hue value for fat.

Conclusion: The ER treatment of wheat can be an acceptable alternative to the more traditional PR treatment in conventional finishing beef production systems in Ireland. Good flexibility in time of harvest is required in order to harvest at the desired DM concentration, and excellent silo management is needed to minimize qualitative and quantitative conservation losses or the production of mycotoxins. Since HMG can be successfully conserved and fed to cattle at higher moisture contents than in the present experiment, there is the flexibility to harvest such crops between circa 600 and above 700 g DM /kg and obtain comparable animal performance as with conventional ripe grain. Thus, beef farmers have the option to vary their system of cereal grain conservation without major changes to animal performance or product quality. In contrast, the UN treatment as used in this experiment was not satisfactory due to the high loss of apparently undigested whole wheat grains through the animals. In farming practice such grain would have to undergo a processing such as rolling or crimping. Finally, the environmental implications of treatments such as UN need careful assessment.

Table 2.8.1. Chemical composition of forage and grains at different stages of conservation *(g/kg DM* unless otherwise stated, and not for pH*)*

Material		*DM*[d] *(g/kg)*	*pH*	*Crude protein*	*In vitro OMD*[e] *(g/kg)*	*Ash*	*BC*[f] *(mEq/kg DM)*	*Starch*	*NDF*[g]	*actic aci*	*NH_3-N*	*Ethanol*	*Aceticacid*	*Prop.acid*	*Butyric acid*
	Mean	226	3.9	152	679	96	649		543	119	3.1	12	31	2	6
Grass silage															
	s.d.	9.7	0.11	4.6	14.1	5.0	27.0		12.3	16.7	0.40	1.3	5.6	1.0	5.2
	Mean	872		492	913	79		10							
Soyabean meal															
	s.d.	3.3		2.3	2.4	0.8		1.0							
Grains at harvest															
	Mean	705	6.0	127	887	17	78	683							
ER[a]															
	s.d.	1.1	0.04	1.8	4.8	0.2	2.6	8.0							
	Mean	746	6.1	129	890	18	78	680							
UN[b]															
	s.d.	4.0	0.0	1.1	8.8	0.4	2.6	13.2							
	Mean	849	6.1	125	895	17	72	683							
PR[c]															
	s.d.	4.3	0.04	1.6	16.1	0.4	1.7	8.9							
Grains after additive treatment															
ER[a]	Mean	692	4.3	134	897	17	137	668							
	s.d.	4.6	0.04	1.3	4.4	0.2	2.8	12.7							
UN[b]	Mean	734	6.3	218	845	18	85	661							
	s.d.	3.7	0.04	1.9	5.3	0.5	5.6	10.3							
PR[c]	Mean	852	4.6	124	891	17	171	666							
	s.d.	3.0	0.05	1.0	9.7	0.2	1.1	26.8							
Grain at feedface															
	Mean	693	4.3	116	925	17	143	671	91	2	1.4	2	1	1	0
ER[a]															
	s.d.	10.1	0.15	2.4	7.4	1.7	8.1	18.5	6.1	0.6	0.45	0.5	0.3	0.1	0
	Mean	738	9.3	145	934	17	127	664	99	1	3.2	1	1	0	0
UN[b]															
	s.d.	9.1	0.07	3.9	9.7	0.9	8.5	39.0	5.3	0.4	1.06	0.5	0.2	0	0
	Mean	827	4.8	111	933	18	148	655	143	3	0.1	2	1	11	0
PR[c]															
	s.d.	8.1	0.26	4.8	9.4	1.9	16.8	23.4	8.1	1.2	0.03	0.6	0.2	1.2	0

[a] acid treated , rolled/crimped and ensiled high moisture grain (HMG) stored anaerobically; [b] urea treated whole (not rolled) HMG stored anaerobically; [c] propionic acid treated whole grain stored aerobically, rolled at feedout; [d] dry matter; [e] organic matter digestibility; [f] buffering capacity; [g] neutral detergent fibre

Table 2.8.2. Mean (s.d.) aerobic stability indices of grass silage and conserved grains

	Grass silage	ER[a]	UN[b]	PR[c]
Days to temperature rise	7.0 (2.82)	6.3 (0.47)	7.0 (1.63)	8.3 (0.94)
Maximum temperature rise (ºC)	3.3 (1.89)	3.0 (0.82)	2.3 (0.47)	2.0 (0.0)
ATR[d] to day 5	3.3 (2.94)	2.6 (2.25)	2.4 (2.12)	2.4 (1.48)

[a] acid treated, rolled/crimped and ensiled high moisture grain (HMG) stored anaerobically; [b] urea treated whole (not rolled) HMG stored anaerobically; [c] propionic acid treated whole grain stored aerobically, rolled at feedout; [d]accumulated temperature rise (ºC)

Table 2.8.3. Feed intake, faecal, blood, performance and colour variables of Friesian cattle

Wheat form (WF)	GS[a]	ER[b]			UN[c]			PR[d]					Significance[g]			
Wheat level (WL)	None	Low	edium	High	Low	edium	High	Low	edium	High	S.E[e].	S.E[f].	GS[g]	WF	WL	WF x WL
Feed intake																
Silage dry matter (DM) intake (kg/ day)	7.4	5.3	3.7	1.3	5.9	4.6	1.5	5.8	3.9	1.2	0.15	0.16	***	***	***	NS
Wheat DM intake (kg/day)	0	2.5	4.9	7.8	2.4	4.8	8.3	2.4	4.9	8.2	0.10	0.10	***	NS	***	*
Faeces																
Starch (g/kg DM)	8	9	15	31	51	99	118	9	14	20	10.4	9.7	***	***	***	*
Proportion whole grain (g DM/kg DM)	0	9	34	42	168	310	401	4	10	19	24.4	23.1	***	***	***	***
DM (g/kg)	143	158	160	184	155	162	204	147	152	175	6.0	6.0	***	**	***	NS
Plasma metabolites (mmol/ L)																
Ammonia	0.75	0.51	0.62	0.67	0.59	0.74	0.73	0.53	0.59	0.62	0.058	0.059	*	NS	*	NS
Beta hydroxybutyrate	0.31	0.42	0.48	0.41	0.38	0.45	0.48	0.37	0.42	0.38	0.046	0.044	NS	NS	NS	NS
Glucose	4.13	4.40	4.54	4.53	4.31	4.35	4.44	4.27	4.40	4.56	0.060	0.060	***	*	**	NS
Non-esterified fatty acids	0.17	0.13	0.17	0.16	0.12	0.12	0.15	0.17	0.12	0.16	0.021	0.021	NS	NS	NS	NS
Urea	4.42	5.03	4.88	5.08	5.16	5.79	6.88	4.58	4.68	5.34	0.243	0.237	***	***	***	*
Performance																
Starting live weight (kg)	517	519	520	518	518	516	517	522	518	520	1.6	1.6	NS	NS	NS	NS
Final live weight (kg)	532	616	645	657	604	618	635	613	640	667	9.4	9.2	***	**	***	NS
Daily live weight gain (g)	101	684	887	983	612	724	843	650	868	1043	65.5	64.9	***	*	***	NS
Kill-out proportion (g/kg)	484	503	502	516	495	502	501	493	511	520	4.4	4.3	***	*	***	NS
Carcass weight (kg)	256	310	324	339	299	310	319	303	327	347	5.3	5.2	***	***	***	NS
Estimated daily carcass gain (g)	64	421	517	629	351	433	491	362	545	676	35.6	35.0	***	***	***	NS
Kidney and channel fat weight (kg)	6.5	11.3	12.4	12.6	10.2	12.2	14.3	9.8	14.9	14.0	1.06	1.02	***	NS	***	NS
Meat colour [h]																
Muscle 'L' value	35.3	34.4	34.9	34.9	35.0	35.0	35.1	35.0	35.1	35.3	0.46	0.45	NS	NS	NS	NS
Muscle 'a' value	13.0	13.2	13.4	14.3	13.1	14.0	13.5	13.0	14.2	13.3	0.38	0.38	NS	NS	*	NS
Fat 'a' value	3.8	7.9	6.8	7.8	5.0	7.2	7.1	5.8	6.0	6.7	0.63	0.63	***	*	NS	NS
Fat 'b' value	13.7	12.8	13.2	11.4	13.6	14.5	12.4	13.4	14.3	11.5	0.39	0.41	***	**	***	NS
Muscle hue[i]	17.2	17.7	17.7	17.6	18.4	17.9	17.5	17.9	18.1	18.2	0.59	0.21	NS	NS	NS	NS
Muscle chroma[j]	13.6	13.8	13.5	13.8	15.1	13.9	14.2	14.1	15.0	14.7	0.26	0.26	NS	NS	*	NS
Fat hue[i]	75.0	59.7	67.1	70.2	55.6	60.0	60.4	62.8	68.0	63.9	1.19	1.19	***	***	***	NS
Fat chroma[j]	14.3	15.2	14.7	14.5	13.9	13.3	14.4	14.9	15.6	16.3	0.31	0.32	NS	NS	**	NS

[a] grass silage only; [b] acid treated, rolled/crimped and ensiled high moisture grain (HMG) stored anaerobically; [c] urea treated whole (not rolled) HMG stored anaerobically;
[d] propionic acid treated whole grain stored aerobically, rolled at feedout; [e] S.E. (standard error) for the interaction between WF (ER, UN, PR) and WL (low, medium, high)
[f] S.E. (standard error) for the 10 treatment one-way ANOVA; [g] NS = not significant; * = P<0.05; ** = P<0.01; *** = P<0.001; [h] 'L value' is defined as lightness, 'a value' as redness and 'b value' as yellowness;
[i] Hue is defined by Dunne *et al.* (2004); [j] Chroma is defined by Dunne *et al*. (2004); [g] grass silage treatment for the 10 treatment one-way ANOVA

Table 2.8.4. Relationships between level of ER, UN and PR consumed and intake, faecal, blood metabolite, performance and meat colour variables

	ER[a]				UN[b]				PR[c]			
Feed intake	Intercept (s.e.)	Slope (s.e.)	Sig.	R^2	Intercept (s.e.)	Slope (s.e.)	Sig.	R^2	Intercept (s.e.)	Slope (s.e.)	Sig.	R^2
Silage dry matter (DM) intake (kg/ day)	7.4 (0.14)	-0.7 (0.03)	***	0.94	7.7 (0.16)	-0.63 (0.028)	***	0.91	7.6 (0.16)	-0.68 (0.028)	***	0.93
Faeces												
Starch (g/kg DM)	6.2 (7.25)	2.96 (1.280)	*	0.09	12.4 (12.2)	12.6 (2.17)	***	0.41	6.5 (1.99)	1.36 (0.355)	***	0.23
Proportion whole grain (g DM/kg DM)	1 (4.5)	4.8 (0.80)	***	0.43	18 (29.0)	45 (5.2)	***	0.61	-0.6 (2.38)	2.1 (0.43)	***	0.33
DM (g/kg)	137 (6.7)	4.6 (1.20)	***	0.23	137 (5.7)	6.4 (1.02)	***	0.45	134 (7.6)	3.87 (1.354)	*	0.14
Blood metabolites (mmol/L plasma)												
Ammonia	0.64 (0.064)	-0.002 (0.0114)	NS	0.00	0.69 (0.052)	0.003 (0.0093)	NS	0.00	0.65 (0.052)	-0.009 (0.0092)	NS	0.01
Beta hydroxybutyrate	0.33 (0.045)	0.014 (0.0080)	NS	0.04	0.32 (0.025)	0.020 (0.0045)	***	0.28	0.31 (0.036)	0.010 (0.0064)	NS	0.02
Glucose	4.05 (0.164)	0.058 (0.0290)	NS	0.06	4.16 (0.052)	0.032 (0.0093)	***	0.19	3.99 (0.160)	0.058 (0.0286)	*	0.06
Non-esterified fatty acids	0.15 (0.021)	0.001 (0.0037)	NS	0.00	0.15 (0.018)	-0.002 (0.0032)	NS	0.00	0.16 (0.023)	-0.002 (0.0041)	NS	0.00
Urea	4.40 (0.249)	0.076 (0.044)	NS	0.06	4.36 (0.226)	0.266 (0.0402)	***	0.48	4.19 (0.232)	0.106 (0.0415)	*	0.11
Performance												
Final live weight (kg)	552 (11.9)	13.5 (2.13)	***	0.45	549 (12.7)	10.8 (2.26)	***	0.32	548 (12.1)	14.4 (2.16)	***	0.48
Daily live weight gain (g)	235 (66.9)	95.4 (11.9)	***	0.57	220 (58.0)	77.8 (10.40)	***	0.54	208 (57.1)	101.1 (10.00)	***	0.68
Kill-out proportion (g/kg)	487 (4.0)	3.2 (0.72)	***	0.28	487 (4.52)	1.9 (0.81)	*	0.09	483 (3.4)	4.2 (0.61)	***	0.51
Carcass weight (kg)	269 (7.3)	8.7 (1.30)	***	0.48	267 (7.6)	6.5 (1.35)	***	0.32	262 (13.0)	8.9 (2.32)	***	0.61
Estimated daily carcass gain (g)	139 (32.7)	59.7 (5.83)	***	0.69	130 (33.3)	45.4 (5.94)	***	0.55	109 (25.8)	67.2 (4.60)	***	0.82
Kidney and channel fat weight (kg)	7.8 (0.90)	0.64 (0.161)	***	0.24	7.0 (1.05)	0.84 (0.188)	***	0.29	7.2 (0.85)	0.91 (0.170)	***	0.37
Meat colour[d]												
Muscle 'L' value	35.0 (0.34)	-0.02 (0.059)	NS	0.05	35.2 (0.35)	-0.02 (0.062)	NS	0.00	34.8 (1.30)	-0.1 (0.23)	NS	0.00
Muscle 'a' value	12.8 (0.32)	0.14 (0.056)	*	0.11	13.0 (0.35)	0.09 (0.062)	NS	0.02	13.0 (0.39)	0.07 (0.069)	NS	0.00
Fat 'a' value	4.9 (0.63)	0.36 (0.113)	**	0.17	3.9 (0.49)	0.41 (0.087)	***	0.31	4.2 (0.53)	0.30 (0.096)	**	0.16
Fat 'b' value	13.7 (0.41)	-0.21 (0.073)	**	0.14	13.9 (0.38)	-0.09 (0.067)	NS	0.02	14.0 (0.41)	-0.19 (0.073)	*	0.11
Muscle hue[e]	17.2 (0.26)	0.12 (0.052)	**	0.11	17.4 (0.31)	0.05 (0.055)	NS	0.00	17.4 (0.31)	0.08 (0.055)	NS	0.02
Muscle chroma[f]	13.4 (0.34)	0.16 (0.062)	**	0.11	13.7 (0.38)	0.09 (0.068)	NS	0.02	13.6 (0.42)	0.08 (0.075)	NS	0.01
Fat hue[e]	71.5 (1.97)	-1.84 (0.355)	***	0.36	74.9 (1.61)	-1.67 (0.286)	***	0.41	74.1 (1.80)	-1.47 (0.320)	***	0.30
Fat chroma[f]	14.8 (0.54)	-0.05 (0.096)	NS	0.00	14.6 (0.45)	0.07 (0.081)	NS	0.00	14.8 (0.47)	-0.06 (0.084)	NS	0.00

[a] acid treated, rolled/crimped and ensiled high moisture grain (HMG) stored anaerobically; [b] urea treated whole (not rolled) HMG stored anaerobically; [c] propionic acid treated whole grain stored aerobically, rolled at feedout;
[d] 'L value' is defined as lightness, 'a value' as redness and 'b value' as yellowness; [e] Hue is defined as by Dunne et al. (2004)
[f] Chroma is defined by Dunne et al. (2004)

Experiment 2.9: Red clover for silage: management impacts on yield and composition during the season after sowing

[O'Kiely P., O'Riordan E. G. and Black A. D.]

This experiment quantified the impacts of red clover cultivar, companion grass, harvest schedule and nitrogen fertiliser on crop yield and composition in its first year after reseeding. The effects of these factors will be assessed in subsequent years to fully monitor their impacts on persistence.

Materials and methods: Within a randomised complete block (n=4) design, field plots (24 per block, each 10m x 2m) were used to evaluate a 2 (cultivars) x 2 (alone or with companion grass) x 2 (harvest schedule) x 2 (application of N fertiliser in spring) combination of factors relating to red clover, and a 2 (harvest schedule) x 4 (application of N fertiliser in spring) combination of factors relating to a monoculture of perennial ryegrass. Two cultivars of red clover (Merviot and Ruttinova) were each sown in monoculture or with perennial ryegrass (*cv*. Greengold) in August, 2001. They received 0 or 50 kg inorganic N fertiliser ha^{-1} in mid-March 2002 and had a first-cut harvest date of 2 June or 19 June. Sequential harvests following 2 June were taken after 50, 44 and 97 days, with the corresponding durations after 19 June being 44, 42 and 88 days. Monoculture plots of perennial ryegrass (*cv*. Greengold) received 0, 50, 100 or 150 kg inorganic N ha^{-1} in mid-March and immediately after the first three harvests, and had similar harvest dates to the red clover. All plots were harvested to a 5 cm stubble height and received 22 kg P and 95 kg K ha^{-1} after the first, second and third harvests, and double those rates after the fourth harvest. Immediately before the final harvest, a visual assessment was made of the proportion of ground cover contributed by red clover. Dry matter (DM) content was determined by drying in a forced-air oven at 98^{o}C for 16h. Samples dried at 40^{o}C for 48h were milled through a 1mm screen before chemical analyses. Clover data were analysed using a General Linear Model that accounted for each of the four factors and all two-, three- and four-way interactions. Linear and quadratic equations were fitted to the data from the ryegrass treated with different rates of N fertiliser.

Results: Inclusion of ryegrass with red clover influenced herbage yield and quality. Binary mixtures had a higher ($p<0.01$) annual yield (13,506 *vs.*12,510 kg ha^{-1}; s.e.m. 259.9) and average DMD (730 *vs.* 702 g kg^{-1}; s.e.m. 2.5) than red clover monocultures. Red clover cultivar influenced herbage yield. Swards with Merviot had a lower ($p<0.05$) annual DM yield than those with Ruttinova (12,542 *vs.*13,474 kg ha^{-1}), but did not differ ($p>0.05$) in weighted annual DMD (716 *vs.* 715 g kg^{-1}). The yield advantage to Ruttinova was clearcut at the first and particularly the second harvest. Schedules with earlier first-cut harvesting of swards containing red clover had improved annual digestibility (733 *vs.* 699 g kg^{-1}; $p<0.001$), although annual yield did not change ($p>0.05$). Application of inorganic N to red clover-based swards in spring influenced neither annual yield nor DMD ($p>0.05$). The only interaction related to annual output was a larger ($p<0.05$) increase in DM yield in response to the inclusion of ryegrass with red clover for the early compared to the late first-cut harvest schedule. Treatment effects within individual harvests are summarised in Table 2.9.1, and most of the possible interactions (84/88) were not significant ($p>0.05$). Monocultures of ryegrass receiving no inorganic N had a mean annual DM yield of 9,311 and 9,594 kg ha^{-1} for the early and late first-cut harvest schedules, respectively, with corresponding average weighted DMD's of 788 and 720 g kg^{-1}. First and fourth cuts of red clover monocultures (Table 2.9.1) yielded less than ryegrass (Table 2.9.2), whereas the binary mixture had a similar yield to ryegrass that had up to 40 kg N ha^{-1} applied. In contrast, the yield of red clover at the second harvest was similar or better than ryegrass plus 80 – 150 kg N ha^{-1}, and was similar to ryegrass plus 40 – 80 kg N ha^{-1} at the third harvest. Red clover generally had a lower DMD than ryegrass, although for the first and fourth harvests the binary mixture had a comparable DMD to a pure sward of ryegrass. There were some early indications of persistency towards the end of the first full season. The proportion of ground cover accounted for by red clover was higher ($p<0.001$) with monocultures of red clover than with binary mixtures (0.79 *vs.* 0.57; s.e.m.0.031). The early first-cut system had a larger ($p<0.01$) red clover ground cover than the late system (0.75 *vs.* 0.61). In contrast, neither spring application of N fertiliser (0.71 *vs.* 0.65 for 0 and 50 kg N ha^{-1}, respectively) nor red clover cultivar (0.68 *vs.* 0.69 for Merviot and Ruttinova, respectively) altered ($p>0.05$) the proportion of red clover. There were no interactions ($p>0.05$) between these factors.

Herbage WSC contents (Table 2.9.3) were generally low, although the values were higher for swards containing Merviot than Ruttinova in Harvests 2 ($P<0.01$) and 3 ($P=0.054$). Red clover cultivar did not influence ($P>0.05$) herbage buffering capacity. Inclusion of ryegrass with red clover increased ($P<0.001$) WSC values in Harvests 1, 2 and 4, and reduced ($P<0.001$) buffering capacity at each harvest. Application of inorganic N to red clover-based swards in spring influenced ($P>0.05$) neither WSC nor buffering capacity. Schedules with earlier first-cut harvesting of swards containing red clover resulted in higher ($P<0.001$) WSC values in Harvests 1, 2 and 3, but a lower ($P<0.001$) value in H4.

They also had a lower ($P<0.001$) buffering capacity at Harvests 1 and 3. With the exception of harvest schedule, treatments generally had little ($P>0.05$) effect on herbage DM content.

The late harvest schedule in Harvests 1 ($P<0.01$) and 2 ($P<0.05$) reduced WSC content more when red clover was in a binary mixture with ryegrass rather than in monoculture. It also lead to a larger increase ($P<0.05$) in buffering capacity with Ruttinova than Merviot in Harvest 1. In Harvest 4, the late harvest schedule resulted in a larger ($P<0.05$) increase in WSC content with Merviot than Ruttinova. Spring application of N fertiliser increased ($P<0.05$) WSC content more at Harvest 2 when red clover was in a binary mixture with grass than when in monoculture.

Merviot had a lower crude protein content than Ruttinova in Harvests 1 (159 vs. 172 (sem 2.9) g $kgDM^{-1}$; $P<0.01$) and 2 (197 vs. 207 (3.0) $kgDM^{-1}$; $P<0.05$), and a lower ($P<0.05$) ash in Harvest 4 (102 vs. 105 (1.2) $kgDM^{-1}$). Red clover monocultures had a higher ($P<0.001$) crude protein content compared to binary mixtures with ryegrass in Harvests 1 (184 vs. 147 (2.9) $kgDM^{-1}$), 2 (216 vs. 188 (3.0) $kgDM^{-1}$), 3 (246 vs. 210 (4.6) $kgDM^{-1}$) and 4 (274 vs. 224 (2.4) $kgDM^{-1}$), but had a lower ash content in Harvests 2 (112 vs. 119 (1.3) $kgDM^{-1}$; $P<0.001$), 3 (119 vs. 127 (1.9) $kgDM^{-1}$; $P<0.01$) and 4 (100 vs. 107 (1.2) $kgDM^{-1}$; $P<0.001$). Applying N fertiliser in spring had no effect ($P>0.05$) on crude protein or ash contents at any harvest. Herbage from the early harvest regime had a lower ($P<0.001$) crude protein content for Harvests 1 (159 vs. 172 (2.9) $kgDM^{-1}$), 2 (190 vs. 214 (3.0) $kgDM^{-1}$) and 3 (216 vs. 240 (4.6) $kgDM^{-1}$), and a higher ($P<0.001$) ash at Harvest 1 (109 vs. 100 (1.5) $kgDM^{-1}$) and a lower ($P<0.01$) value at Harvest 4 (101 vs. 106 (1.2) $kgDM^{-1}$). The late harvest schedule increased ($P<0.05$) crude protein content more for Ruttinova than Merviot in Harvest 3, and it increased ash less ($P<0.05$) for Ruttinova than Merviot in Harvest 4.

There were no significant ($P>0.05$) three- or four-way interactions for DM, WSC, crude protein or ash contents, or for buffering capacity.

Conclusions: The inclusion of grass with red clover gave a clear improvement in herbage yield and digestibility during the first season after reseeding. Comparable improvements in yield and digestibility were mediated by red clover cultivar and harvest schedule, respectively. In contrast, the application of inorganic N in spring resulted in no benefit.

Swards with Merviot tended to have a higher WSC but a lower crude protein than those with Ruttinova. Red clover in binary mixture with ryegrass generally resulted in higher WSC and ash contents but a lower buffering capacity and crude protein content than when in monoculture. Spring application of inorganic N had little impact on herbage chemical composition, while the early harvest schedule usually resulted in a higher WSC content and a lower buffering capacity and crude protein content compared to the late harvest schedule.

Table 2.9.1. Herbage yield (kg DM ha^{-1}) and digestibility (DMD) (g kg^{-1}) for red clover treatments at each harvest in the year after sowing.

Cult.[1]	Grass[2]	N[3]	Date[4]	Cut 1		Cut 2		Cut 3		Cut 4	
				Yield	DMD	Yield	DMD	Yield	DMD	Yield	DMD
Merv.[5]	No	No	Early	4,196	719	3,564	707	3,442	735	255	700
	No	No	Late	5,734	662	3,503	715	2,730	709	400	744
	No	Yes	Early	5,063	717	3,737	709	3,437	719	260	700
	No	Yes	Late	6,083	643	2,833	721	2,383	741	477	731
	Yes	No	Early	6,027	754	3,415	741	3,498	743	1,090	718
	Yes	No	Late	6,743	682	2,166	698	2,687	755	1,045	779
	Yes	Yes	Early	6,545	764	2,807	754	3,449	744	1,129	727
	Yes	Yes	Late	7,466	701	1,139	737	2,009	762	1,026	777
Rutt.[6]	No	No	Early	4,890	721	3,998	711	3,387	735	470	723
	No	No	Late	6,166	656	4,023	707	2,520	732	231	737
	No	Yes	Early	5,184	731	3,972	699	3,015	723	361	718
	No	Yes	Late	6,774	662	3,937	688	2,754	714	302	731
	Yes	No	Early	6,624	756	3,050	739	3,434	731	1,293	725
	Yes	No	Late	7,009	692	2,845	729	2,106	750	910	775
	Yes	Yes	Early	6,481	762	3,004	746	3,084	738	1,374	750
	Yes	Yes	Late	8,103	675	3,018	756	2,434	736	1,043	774
s.e.m.											
1[7]				175.1	3.4	166.0	4.9	90.1	3.7	52.1	3.3
2[8]				247.6	4.9	234.8	6.9	127.4	5.2	73.7	4.7
3[9]				350.2	6.9	332.1	9.7	180.2	7.4	104.2	6.6
4[10]				495.2	9.7	469.6	13.8	254.8	10.5	147.4	9.4

[1]Clover cultivar; [2]Presence of companion grass; [3]Application of inorganic N in spring; [4]Early or late first-cut harvest schedule; [5]Merviot; [6]Ruttinova; [7]Single factor; [8]2 factors; [9]3 factors; [10]4 factors.

Table 2.9.2. Linear and quadratic relationships between input of inorganic N fertiliser (kg ha^{-1}) and ryegrass dry matter yield (DMY)(kg ha^{-1}) or DM digestibility (DMD)(g kg^{-1}).

Cut	Date[*]	y[#]	a[#]	S.E.	b[#]	S.E.	Sig.	c[#]	S.E.	Sig.	R^2
1	Early	DMY	5,893	414.2	21.2	13.30	0.135	-0.13	0.085	0.162	0.17
1	Early	DMD	772	10.1	-0.1	0.11	0.310				0.07
1	Late	DMY	6,511	383.6	30.0	12.32	0.030	-0.17	0.079	0.048	0.32
1	Late	DMD	690	15.4	-0.1	0.50	0.823	0.00	0.003	0.705	0.03
2	Early	DMY	1,514	428.3	15.8	4.58	0.004				
2	Early	DMD	806	8.1	-0.2	0.09	0.054				
2	Late	DMY	1,028	265.7	28.1	8.53	0.006	-0.15	0.055	0.018	0.50
2	Late	DMD	788	11.5	-0.5	0.37	0.226	0.00	0.002	0.316	0.13
3	Early	DMY	1,243	136.1	46.5	4.37	0.000	-0.22	0.028	0.000	0.93
3	Early	DMD	818	9.9	-0.6	0.32	0.103	0.00	0.002	0.257	0.32
3	Late	DMY	1,102	224.7	27.6	7.22	0.002	-0.08	0.046	0.095	0.81
3	Late	DMD	789	7.4	0.2	0.24	0.310	0.00	0.002	0.152	0.25
4	Early	DMY	1,038	209.8	27.8	6.74	0.001	-0.15	0.043	0.004	0.60
4	Early	DMD	796	13.2	-1.4	0.42	0.007	0.01	0.003	0.030	0.54
4	Late	DMY	886	170.3	25.2	5.47	0.000	-0.12	0.035	0.005	0.73
4	Late	DMD	785	10.7	0.1	0.34	0.743	0.00	0.002	0.334	0.31

[*]Early or late first-cut harvest schedule; [#]$y=a+bx+cx^2$.

Table 2.9.3. Herbage water-soluble carbohydrate and dry matter contents and buffering capacity for red clover treatments for each harvest in the first year after sowing.

Cultivar	Grass[1]	N[2]	Date[3]	Harv.[4] 1			Harv. 2			Harv. 3			Harv. 4		
				WSC[5]	BC[6]	DM[7]	WSC	BC	DM	WSC	BC	DM	WSC	BC	DM
Merviot	No	No	Early	58	482	153	71	552	168	55	507	134	62	463	224
	No	No	Late	33	479	182	43	556	122	34	591	128	78	461	238
	No	Yes	Early	62	472	147	63	552	174	54	515	139	56	453	243
	No	Yes	Late	45	465	190	44	525	129	43	618	136	75	469	254
	Yes	No	Early	121	407	157	87	513	165	57	477	135	62	419	270
	Yes	No	Late	67	476	171	46	490	126	48	512	138	91	369	248
	Yes	Yes	Early	116	418	148	103	469	160	64	452	145	61	388	266
	Yes	Yes	Late	79	451	179	62	473	133	55	505	137	89	378	250
Ruttinova	No	No	Early	68	471	150	60	567	160	54	531	131	62	498	237
	No	No	Late	39	544	168	35	558	123	46	616	128	63	488	248
	No	Yes	Early	60	473	140	56	555	169	52	515	139	57	467	221
	No	Yes	Late	36	538	176	34	542	122	27	601	133	67	468	247
	Yes	No	Early	121	423	154	69	530	168	49	467	139	68	413	282
	Yes	No	Late	55	491	170	38	489	125	35	524	142	83	377	244
	Yes	Yes	Early	106	396	153	94	473	179	58	396	140	75	382	251
	Yes	Yes	Late	46	465	175	40	521	121	36	545	138	91	383	246
s.e.m.[8]				10.0	20.1	7.6	8.6	19.6	6.7	6.8	29.0	5.6	6.0	14.5	12.4

[1]With companion grass; [2]Application of inorganic N in spring; [3]Early or late first-cut harvest schedule; [4]Harvest; [5]Water-soluble carbohydrates (g kgDM^{-1}); [6]Buffering capacity (mEq kgDM^{-1}); [7]Dry matter (g kg^{-1}); [8]For 4-way interaction.

Experiment 2.10: Red clover for silage: management impacts on yield during the third year after sowing

[P. O'Kiely, E.G. O'Riordan and A.D. Black]

This experiment quantified the impacts of red cloever cultivar, companion grass, harvest schedule and nitrogen fertiliser on crop yield in the third year after reseeding, and compared these to grass receiving inorganic N fertiliser.

Materials and Methods: This involved the same plots, etc. as described in Experiment 2.9. Sequential harvests following 26 May were taken after 47, 49 and 93 days, with the corresponding durations after 10 June being 54, 45 and 75 days.

Results: Comparing main effects, annual yield did not differ between Merviot and Ruttinova (15347 and 15642 kg DM ha^{-1}; P>0.05), while the inclusion of ryegrass with red clover increased annual yield (15141 and 15849 kg DM ha^{-1}; P<0.01) (Table 2.10.1). Application of inorganic N fertiliser to red clover-based swards in spring reduced annual yield (15813 and 15177 kg DM ha^{-1}; P<0.01), while earlier first-cut harvesting of swards containing red clover produced a higher yield than the later first-cut schedule (16033 and 14957 kg DM ha^{-1}; P<0.001). Neither two- nor three-way interactions were significant (P>0.05), while four-way interactions although significant (P<0.05) were of minor importance. The proportion of herbage accounted for by red clover in May or November was higher (P<0.05) for the mono-culture, zero N fertiliser and early-harvest schedule compared to the binary mixture, 50 kg N ha^{-1} and the late harvest schedule, respectively.

Conclusions: Herbage yield was increased in swards with red clover by including ryegrass in the seed mix, by not applying inorganic N fertiliser in mid-March and by adopting the early harvest schedule. Red clover cultivar did not affect annual yield. The optimum red clover treatment combinations gave herbage yields equivalent to ryegrass mono-culture plus fertiliser N (Table 2.10.2) as follows: Cut 1 - grass plus 47 kg N, Cuts 2 and 3 - > grass plus any rate of N fertiliser, and Cut 4 - < grass plus 0 kg N.

Table 2.10.1. Herbage yield (kgDM ha^{-1}) for red clover treatments per harvest

Cult.[1]	Grass[2]	N[3]	Date[4]	Cut 1	Cut 2	Cut 3	Cut 4	Total
Merv.[5]	No	No	Early	6420	5431	4089	389	16329
Merv.	No	No	Late	6327	5153	3026	143	14649
Merv.	No	Yes	Early	5939	5091	3655	390	15075
Merv.	No	Yes	Late	5998	4653	2924	198	13774
Merv.	Yes	No	Early	6394	5341	3829	428	15992
Merv.	Yes	No	Late	6825	5470	3466	357	16119
Merv.	Yes	Yes	Early	6375	5162	3695	584	15816
Merv.	Yes	Yes	Late	7312	4395	2767	552	15026
Rutt.[6]	No	No	Early	6102	5216	4015	513	15846
Rutt.	No	No	Late	6611	5398	2871	113	14994
Rutt.	No	Yes	Early	6690	4977	3944	523	16134
Rutt.	No	Yes	Late	6351	5026	2715	234	14326
Rutt.	Yes	No	Early	7219	5425	4107	619	17369
Rutt.	Yes	No	Late	7191	4986	2808	219	15203
Rutt.	Yes	Yes	Early	6719	4314	3719	953	15706
Rutt.	Yes	Yes	Late	7185	4848	3038	490	15561
s.e.m.[7]				330.7	277.2	150.3	105.6	438.6

[1]Clover cultivar; [2]Presence of companion grass; [3]Application of inorganic N in spring; [4]Early or late first-cut harvest schedule; [5]Merviot; [6]Ruttinova; [7]four factor interaction

Table 2.10.2. Relationships between inorganic N fertiliser input (x; kg ha^{-1}) and ryegrass dry matter yield (y; kg ha^{-1})

Cut	Date[*]	a[#]	s.e.	b[#]	s.e.	Sig.	c[#]	s.e.	Sig.	R^2
1	Early	4369	348.6	68.1	11.19	<0.001	-0.34	0.072	<0.001	0.80
1	Late	5930	439.1	55.0	14.10	0.002	-0.32	0.090	0.003	0.54
2	Early	2357	269.1	45.0	8.64	<0.001	-0.26	0.055	<0.001	0.68
2	Late	2045	154.2	36.7	4.95	<0.001	-0.18	0.032	<0.001	0.86
3	Early	2072	170.7	26.7	5.48	<0.001	-0.12	0.035	0.005	0.77
3	Late	1942	333.5	26.8	10.71	0.026	-0.11	0.068	0.136	0.52
4	Early	1023	132.8	24.5	4.27	<0.001	-0.15	0.027	<0.001	0.72
4	Late	595	144.3	15.6	4.64	0.005	-0.07	0.030	0.026	0.58

[*]Early or late first-cut harvest schedule; [#]$y=a+bx+cx^2$

3. The use of plastic sheeting or film to seal ensiled feedstuffs and mulch maize

The objectives in this section were to:

1. Evaluate alternatives to the current polythene film system for sealing grass from air during ensilage
2. Review the literature on silage, maize, plastic and policy relating to the production, primary use and secondary re-use of plastic (see Hamilton, 2003).
3. Survey plastic use on Irish farms, and its subsequent fate.
4. Propose alternate strategies for use/re-use of plastic

Experiment 3.1: Genatex® as a protective sheeting for silage

[P. O'Kiely and M.J. Drennan]

Forage ensiled in bunker or clamp silos is conventionally sealed beneath two sheets of black 0.125 mm polythene (IS 246 1989). These are overlaid with a layer of touching tyres. The latter prevent movement of the polythene sheets that could draw air across the top surface of the silage. They also provide limited protection from some vertebrates. This system can produce silage free of visible surface waste and involves relatively modest material costs (tyres normally obtained free-of-charge). However, labour input in placing and removing the tyres is an additional cost. Some countries, due to perceived environmental risks, require farmers to have a licence to place tyres over silage. Tyres are susceptible to degradation over time and pericarditis and traumatic reticulitis have been diagnosed in cows - this was attributed to ingestion of tyre wire fragments with silage. The efficacy of Genatex® (a polyethylene woven black mesh sheet made from a combination of tape and monofilament) as a protective sheeting for silage was evaluated in terms of its effects on silage surface waste compared to the standard system of using a complete layer of tyres.

Materials and Methods: Two outdoor, walled, concrete silos (each 24.2m long x 6.5m wide) were filled with grass (16 June and 5 August, 2003) to a mean height of 2.4m and sealed beneath two sheets of black polythene. Polythene was not placed along the inner surface of the silo walls before filling with grass. The two sheets were securely weighted around their edges with a continuous layer of silt. Their top surface (excluding ramp) was divided into four bands (6.5m wide x 5.0m long), and alternate bands were covered with car tyres or Genatex® (Westfalia Farm Ireland Ltd., Coolroe, Ballincollig, Cork). The latter had a row of weights placed around its edges and along its centre. The silos were opened in early November and early January and the silage removed during a 65 and 61 day duration, respectively. During feedout, polythene was maintained tightly in place on top of the silage, but was kept off the silage face. Three silage samples per silo were chemically analysed. On two faces per band, the pH of the top 1m of silage was profiled (in 0.1m horizons and 0.5 to 1.0 m widths). Because of the probable non-independence of the values for corresponding grid positions in the two faces per band, these values were treated as duplicate estimates and averaged.

Results: The mean (s.d.) composition of the silage in each silo was dry matter (DM) 185 (2.6) and 239 (4.7) g/kg, pH 3.9 (0.06) and 3.9 (0.15), crude protein 133 (7.9) and 152 (4.6) g/kgDM and *in vitro* DM digestibility 640 (4.2) and 618 (38.5) g/kg. The pH profile of the top 0.8m silage is summarised in Table 3.1.1. The value for each position on the 0.9 and 1.0 m horizons was 3.9 (s.e. 0.01). Elevated pH likely reflects aerobic metabolism of fermentation acids and breakdown of N products. In general, higher pH values were found towards the top and sides of the silage reflecting the greater access by oxygen in these locations. Higher variances (s.e.) were also found towards the sides and top of the silages. Treatment effects were not significant ($P>0.05$; Table 3.1.1) at any of the 110 grid positions examined in the top 1m of silage. Similarly, when mean values for each horizon were compared, there was not a significant ($P>0.05$) treatment effect.

Conclusions: Genatex® was as effective as the standard system involving tyres for restricting aerobic deterioration on the top surface of silage. It was observed that polythene placed between the silo wall and the forage at ensiling, and folded onto the top of the forage, was required to limit aerobic losses below the top corners of the silage.

Table 3.1.1. pH profile of top 0.8m of silage feed face

H[1]	Incremental distances from left-hand side of feed face (m)[2]									
	0.5	1.0	1.5	2.0	3.0	4.0	5.0	5.5	6.0	6.5
Tyres - mean value for each grid position on feed face										
0	6.0	4.9	4.4	4.3	4.2	4.0	4.2	4.2	4.9	6.0
0.1	6.0	4.5	4.2	4.3	4.2	3.9	4.2	5.2	4.7	5.8
0.2	5.4	4.7	4.2	3.9	3.9	3.9	4.2	3.9	4.5	6.0
0.3	5.2	4.0	3.9	3.9	3.9	3.9	3.9	3.9	4.2	5.0
0.4	5.0	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	4.8
0.5	4.5	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	4.4
0.6	4.1	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9
0.7	4.0	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9
0.8	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9
Genatex® - mean value for each grid position on feed face										
0	6.0	4.6	4.5	3.9	4.1	3.9	4.0	4.3	4.8	6.0
0.1	6.0	4.5	4.0	3.9	3.9	3.9	3.9	5.2	4.5	5.6
0.2	5.3	4.4	4.2	3.9	3.9	3.9	4.2	3.9	4.5	5.6
0.3	4.2	4.1	3.9	3.9	3.9	3.9	3.9	3.9	3.9	4.5
0.4	4.2	3.9	3.9	3.9	3.9	3.9	3.9	3.9	4.2	5.0
0.5	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	4.0	3.9
0.6	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9
0.7	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9
0.8	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9
Standard error of mean value for each grid position on feed face										
0	-[3]	0.38	0.43	0.15	0.20	0.05	0.18	0.29	0.30	-[3]
0.1	-[3]	0.43	0.18	0.15	0.19	0.01	0.19	0.23	0.39	0.27
0.2	0.32	0.44	0.19	0.01	0.01	0.01	0.19	0.01	0.32	0.32
0.3	0.50	0.13	0.01	0.01	0.01	0.01	0.01	0.01	0.19	0.26
0.4	0.32	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.19	0.28
0.5	0.21	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.08	0.16
0.6	0.11	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.7	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.8	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

H[1]: horizon of feed face (m; relative to top surface); [2]i.e. 0.5 = 0-0.5, 1.0 = 0.5-1.0, etc.; [3]mean = 6.0 or higher and no estimate of variance.

Experiment 3.2 An alternative plastic film for sealing ensiled forage

[P. O'Kiely and P.D. Forristal]

In Ireland, the standard system for achieving anaerobiosis in bunker or clamp silos is to place the harvested forage beneath two layers of black 0.125 mm thick polyethylene sheeting, weighting the edges of the sheets with a continuous layer of soil, silt, sandbags, etc., and covering the remainder with a complete layer of tyres. When conducted properly surface waste should not be visible when the silages are opened for feedout. Polyethylene is not totally impermeable to oxygen diffusion and thus will not completely prevent oxygen ingress. Other plastics are known to provide more effective barriers to oxygen ingress, but traditionally they have been considered either unnecessary, too expensive or inferior in other important characteristics. A co-extruded polyethylene-polyamide film has been developed for covering bunker silages. It is 0.045 mm in thickness and comprises two outer layers of polyethylene with a central layer of polyamide. Its longitudinal and transversal breaking load (N/mm^2) were reported to be greater than for standard silage sheets and its permeability to oxygen considerably lower. The manufacturers recommend that it be placed on the ensiled forage and covered with a separate layer of material that will prevent contact with direct sunlight. This experiment compared this alternative system of sealing to the standard practice.

Materials and Methods: A permanent grassland sward was mown (Pottinger model Nova 310 T; A. Pottinger, Maschinenfabrik GmbH, A-4710 Grieskirchen, Austria) on 13 June and picked up without wilting using a precision-chop harvester (Pottinger Mex VI). Eight separate dome-shaped clamps of grass (mean (s.d.) 8464 (300.1) kg) were formed outdoors on a hard base (polythene sheet on compacted sand), and were randomly allocated among two treatments. The standard treatment involved clamps being sealed beneath two sheets of black 0.125 mm polythene (I.S. 246 1989) (Visqueen; Irish Polythene Agri, Newbridge, Co. Kildare). The second treatment involved clamps being covered by a sheet of translucent triple co-extruded film (Silostop; Bruno Rimini Ltd., 305 Ballards Lane, London N12 8NP, England) overlaid with a sheet of black polythene (similar to standard treatment). In each case the plastic sheets were firmly pressed to the ground at the edge of the clamp by a continuous layer of silt. The sheets were tightened daily as the clamps subsided in height to maintain close contact between the sheets and the clamp surface. Each clamp was covered by a single, complete layer of car

tyres. After 246 days ensilage, the gaseous environment directly beneath the sheets was sampled by inserting a 0.4 x 19 mm needle attached to a 20 ml syringe through the sheets. Five such samples were taken from both the top and base of each clamp, and the concentrations of CO_2, N_2 and O_2 were determined. The plastic sheets were removed from the clamps after 250 days ensilage, estimates of surface waste and visible mould were made, and silages were weighed and sampled for laboratory analyses.

Results: The mean (s.d.) composition of the grass ensiled was dry matter (DM) 212 (8.9) g/kg, *in vitro* DM digestibility (DMD) 743 (11.6) g/kg, ash 98 (2.1) g/kg DM, water soluble carbohydrates (WSC) 28 (2.3) g/l, buffering capacity 447 (8.7) mEq/kg DM and NO_3 933 (50.1) mg/kg DM. Silages made using both standard and Silostop system treatments did not differ (P>0.05) in chemical composition, recovery rates or gaseous atmospheres (Table 3.2.1). Five of the clamps had no visible mould or surface waste, while three (one standard and two Silostop) each had a small patch of surface waste/mould beneath between 1 and 3 bird holes in the plastic sheeting. The gaseous composition at the top and base of the clamps did not differ (P>0.05) from one another or interact with sealing-system treatment.

Conclusion: Under the prevailing conditions, covering and sealing clamp silos using the Silostop system resulted in equally effective conservation of ensiled forage as the standard system involving two sheets of black polythene. Both systems were successful when operated properly and resulted in negligible surface waste or visible mould.

Table 3.2.1. Conservation characteristics of the treatments

	Standard	Silostop	se
Dry matter (g/kg)	207	213	5.4
C. protein (g/kg DM)	142	144	0.9
DMD (g/kg)	700	701	4.3
Ash (g/kg DM)	105	104	1.3
NH_3-N (g/kg N)	101	105	3.8
pH	4.29	4.31	.036
Lactic acid(g/kg DM)	77	75	3.1
Ethanol (g/kg DM)	18	17	1.3
Acetic acid(g/kg DM)	31	28	2.0
Prop. acid(g/kg DM)	3	3	0.4
Butyric acid(g/kg DM)	10	10	2.4
Fresh recovery(g/kg)	964	968	2.9
DM recovery (g/kg)	970	956	20.0
O_2 (ml/l)	23	28	2.3
CO_2 (ml/l)	197	230	24.8
N_2 (ml/l)	781	744	23.4

Experiment 3.3:The use of plastic film on Irish farms

[W.J. Hamilton, P. O'Kiely, P.D. Forristal, J.Crowley, A.Buttimer and W.Nolan]

European Union policy strongly encourages a sustainable and multifunctional agriculture. Therefore, in addition to providing European consumers with quality food produced within approved systems, agriculture must also contribute positively to the conservation of natural resources and the upkeep of the rural landscape. Plastics are widely used in agriculture and their post-use fate on farms must not harm the environment - they must be managed to support the enduring economic, ecological and social sustainability of farming systems. This survey estimated the quantities of flexible plastic film used on Irish farms and their destinations post primary use.

Materials and Methods: The survey was a supplement to the Teagasc National Farm Survey. The 1167 farms involved represented 120678 farms nationwide. The 961 farms responding to the plastics survey questionnaire were a stratified sample representative of farm enterprise, hectarage and geographic location. The survey quantified the primary and post primary use of polyethylene- and polypropylene-based products used to package fertiliser, mulch maize, tie silage bales and seal silage. It related to the crop growing season of 2001 and the following winter.

Results: *Silage:* Silage is made on 87% of all farms. Plastic is used when making silage to create the air-free conditions necessary to restrict forage losses. Two layers of 125 μm thick plastic sheeting are normally used on pit silage while at least four layers of 25 μm thick stretch-film are used on baled silage. Most of the plastic used is black and is composed primarily of polyethylene.

Farmers generally use one new and one 'old' sheet when covering silage pits. The old sheet would have been new (i.e. used for the first time) the previous year, and removed carefully during feedout to minimise physical damage. The general practice is to place the new sheet directly on the forage being ensiled and to place the old sheet on top of it. Thus, the values in Tables 3.3.1 and 3.3.2 show that 57% of the plastic sheets used in 2001 were new (purchased that year) and 43% were old (had been used as 'new' the previous year). These proportions were not clearly influenced by farm size.

As farm size increased, the weight of plastic sheets and of stretch-film used per farm increased due to the increasing scale of operation - 92 kg/farm of less than 20 ha to 309 kg/farm of 100 ha or larger. This occurred despite the weight of plastic sheets plus stretch-film used per ha decreasing with increasing farm size (Table 3.3.1). The latter decline was due mainly to a reduction in the total amount of plastic sheeting used per ha conventional silage (12.8 to 5.5 kg). The likely cause of this reduction is the larger size of silos and in particular the greater depth to which silage is stored on larger farms. This results in a greater land area of ensiled grass being stored beneath each m^2 plastic sheeting. In contrast, the quantity of stretch-film per ha baled silage remained at approx. 21 kg/ha (725 g/round bale) across all farm size categories. This is much higher than the average values of 8.3 kg total plastic and 4.7 kg new plastic/ha of conventional silage.

Farm enterprise also had a significant effect. Dairy farms used more plastic for silage making than beef farms (224 vs. 165 kg/farm) but the rate of use/ha was higher for beef farms (10 vs. 15 kg/ha). Dairy farms tended to use more silage sheets than beef farms (148 vs. 68 kg/farm) whereas beef farms used more stretch-film (190 vs. 77 kg/farm). These reflect the tendency of dairy farms to make more conventional than baled silage compared to beef farms and of dairy farms on average being larger in size (i.e. area) than beef farms.

Once the primary use of silage sheets or stretch-film was complete (i.e. sheets no longer used for covering silage after one or more seasons; stretch-film from bales becomes waste after it is used once), approximately 5164 tonnes (40% of post primary use silage plastic) plastic were submitted to the Irish Farm Film Producers Group (IFFPG) recycling scheme who organise a collection and recycling scheme for all silage plastic types (Tables 3 and 5). The scheme is funded by a levy on sales of all new silage plastic. Collected polythene can be recycled into the manufacture of structural plastic - e.g. plastic garden furniture. The collection service stipulates a minimum collection volume and this may require a farmer to store used plastic for more than one season. As no additional recycling charge accrues to a farmer once the plastic film has been purchased, the volume sent to municipal dumps, at 636 tonnes (5%), was small. A total of 6557 tonnes (51%) was retained or disposed of on-farms (could include material for future submission to IFFPG recycling scheme) and 496 tonnes (4%) was disposed of by other means. Interestingly, the scheme is managing to access a higher proportion of the plastic used on bales (45%) than on silage pits (30%).

Baling twine and netting: Bales of silage, hay and straw are held together with plastic twine or net, the latter with large round bales only. Estimates are that *circa* 58g twine or 114g netting are used when tying a large round bale for silage. Overall, approx. 1059 tonnes of twine (polypropylene) and netting (polythene) were used in tying silage bales. As there is no recycling facility for twine or net most of this was subsequently disposed of on farms (Table 5). In the case of twine, some of the latter would be re-used for tying other objects.

Fertiliser: Inorganic fertilisers containing nitrogen, phosphorus and potassium are used mainly to produce economically viable crop yields. The NFS indicates that during 2001 purchased inorganic fertiliser was used on about 97% of all farms. This averaged at 14.8 tonnes per farm (0.46 t/ha). The use of fertiliser per ha was lowest on farms of less than 20 ha (0.37 t/ha) and on cattle and sheep (0.25 t/ha) compared to tillage (0.53 t/ha) or dairy (0.70 t/ha) farms.

Fertiliser is delivered to farms in bags containing 50 or 500 kg fertiliser (loosely termed 50 and 500 kg bags) or in bulk (no packaging) (Table 4). Small (50kg) bags and the inner liner of 500kg bags are made primarily of polythene. The load carrying outer packaging of the 500kg bag is usually a woven polymer. The main attraction of 500 kg bags is on well-mechanised farms where it eliminates manual handling of fertiliser. The primary reason for the increase in use of bulk fertiliser is one of cost and convenience on farms. The fertiliser is generally delivered from a merchants yard and spread by a specialised contractor, and therefore usually involved no farm storage of fertiliser. The absence of packaging is a useful benefit of this fertiliser trading system.

Most (95%) of the fertiliser delivered to small (less than 20 ha) farms was in 50 kg bags and this proportion decreased to 26% for farms of over 100 ha. The corresponding values for fertiliser in 500 kg bags was 4 and 40% while the values for bulk (non-bagged) delivery was 1 and 34%. Tillage farms used the lowest (30%) proportion of their fertiliser in 50 kg bags and higher proportions in bulk (22%) and in 500 kg bags (48%). In contrast, most of the fertiliser on beef farms was delivered in 50 kg bags (77%), followed by 500 kg bags (16%) and bulk (7%). Dairy farmers acquired only half of their

fertiliser in 50 kg bags and over one-third in 500 kg bags. On average the weight of plastic per tonne fertiliser was 2.4 and 2.2 kg where it was delivered in 50 and 500 kg bags, respectively.
There is no recycling scheme for fertiliser bag plastic although some might be mixed with silage plastic for recycling (Table 4). However, fertiliser bags are frequently used for storing a range of products on farms and are occasionally given or sold to others for storage use. This is evident from the relatively high proportions of plastic categorised as on-farm disposal and 'other' - particularly for the 50 kg bags.
Maize: Plastic film is used as mulch for maize to raise the temperature around the seed and seedling thereby advancing early growth. It is primarily clear polyethylene that was used, which was applied as 'punch' or 'complete cover' plastic. With punch plastic, the polythene (approx. 12 μm thick film) mulch was laid first and the maize seed sown through a hole that the seedling subsequently emerged through. Where complete cover plastic (approx. 7 μm thick film) was used, the seed was placed beneath the polythene film and emerged beneath it. The young plant subsequently forced its way through the thin polythene film. Maize mulch plastics are invariably left on or in the ground to degrade. Photo-degradation causes the sheets to degrade into small pieces of polythene. After harvest the remaining plastic is ploughed beneath the soil where degradation is slow, with some of the polythene potentially becoming visible again when ploughed in subsequent years.
CSO estimates are that forage maize was grown on approx. 19700 ha in 2001. The NFS data indicate that its production was concentrated more on larger sized and dairy farms. Furthermore, only 18% of all farms where maize was grown used plastic mulch, representing 20% of the maize area. Punch plastic accounted for 16% of the area mulched and complete cover for the remaining 84%.
The survey indicated that the total weight of punch and complete cover plastic used was 55 and 166 tonnes respectively, indicating a lower usage rate of plastic per ha for the complete cover system (i.e. 51 *vs.* 88 kg plastic/ha) where the thinner polythene was used. Clearly, the thickness of the plastic used for mulching maize has a major impact on the rate of plastic use per hectare. Assuming an 80% ground cover with plastic mulch, then as plastic thickness decreases from 12 to 6 μm the weight of plastic used per hectare decreases from 88 to 44 kg/ha.
Maize mulch plastic is currently left to degrade *in situ* in the field. It is therefore not collected for alternative disposal. While collection for recycling is unlikely to be economic, the mulching system may be particularly suited to the development and use of rapidly biodegradable films.
REPS: The Rural Environment Protection Scheme aims to reward farmers for operating practices that conform to specified environmental and other criteria. The results in Table 5 indicate that farms that were participating in the REPS scheme generally had a higher rate of recycling plastic than other farms. This highlights the need for proactive schemes that reward good environmental practices.
Conclusions: There is a significant quantity of silage, fertiliser and maize plastic used on farms that pose a potential environmental challenge after their primary use is complete. Table 3.3.6 summarises these amounts. There are many potential methods of reducing the environmental risks such as:

- reducing or eliminating the use of plastic in a process
- using alternative processes or systems which require less or no plastic
- using biodegradable plastics which rapidly breakdown into harmless products
- re-use of plastic
- recycling of plastic

The most suitable method will depend on the application. The recycling scheme currently in operation for silage sheets or stretch-film would seem to be the best option for silage plastic as the development of biodegradable films suitable for long term anaerobic storage of forages will prove difficult. For maize mulching, the development of suitable biodegradable films would seem to be the most sensible longer term approach. While the supply of fertiliser in bulk eliminates the need for plastic packaging, there are practical limitations on some farms to the bulk supply system that will ensure bagged deliveries will remain necessary. There is an urgent need to collect and recycle both sizes of fertiliser bag as some of the current on-farm disposal practices might not be environmentally benign and alternatives are not currently offered. Similarly, twine and net plastic should be recycled. Plastic containers not included in this survey such as agrochemical containers also pose a challenge and could be collected for re-use or recycling.
Provided suitable elimination/re-use/recycle schemes are available, farmers uptake can be improved by incentive or payment schemes such as REPS. The manner in which these payments are made could impact on the success of such initiatives.

Table 3.3.1. Plastic use (kg) per hectare silage made during 2001 categorised by farm size (ha)

Farm size (ha)	< 20	20 to < 30	30 to < 50	50 to < 100	100+	All sizes
Silage sheets - kg/ha conventional silage harvested						
- new sheets	7.2	5.5	5.3	4.0	3.7	4.7
- old sheets	5.7	5.5	4.0	3.0	1.9	3.6
- total sheets	12.8	11.1	9.3	7.1	5.5	8.3
Bale film - kg/ha baled silage harvested						
	21.0	20.1	20.5	20.4	20.4	20.5
All silage plastic - kg/ha silage harvested						
	18	15	13	9	8	12

Table 3.3.2. Quantities (tonnes) of plastic used for covering silage made during 2001

Plastic sheets for silage pits - new	4242
- old	3222
Plastic stretch film for baled silage	8617
Total plastic used	16081
Total plastic sold	12859

Table 3.3.3. Post primary use destinations (tonnes) for silage sheets and stretch-film

	Sheets from pits	Stretch-film from bales
Recycle scheme	1267	3897
Municipal dump	211	425
On-farm disposal	2533	4024
Other	226	270

Table 3.3.4. Use (2001) of plastic in delivery of fertilisers and post primary use destinations

Delivery unit size	50 kg	500 kg	Bulk
Fertiliser delivered (tonnes)	964562	541039	205773
% of farms	89	17	8
% of fertiliser	56	32	12
tonnes/farm (using that system)	9.4	27.3	21.8
Plastic used			
~ total tonnes	2315	1190	0
Post primary use destinations (tonnes)			
Recycle scheme	143	96	-
Municipal dump	70	55	-
On-farm disposal	1107	948	-
Other	995	92	-

Table 3.3.5. Post primary use destinations (%) of different plastics on farms[1]

	REPS	Non-REPS	All[2]
Silage sheets			
- recycled	49	27	33
- municipal dump	9	3	5
- on-farm disposal	36	65	57
- other	6	5	5
Bale stretch-film			
- recycled	54	33	40
- municipal dump	9	5	6
- on-farm disposal	32	60	51
- other	5	2	3
Twine and netting (from baled silage)			
- recycled	14	4	7
- municipal dump	10	3	5
- on-farm disposal	73	92	86
- other	3	1	2
Bags for 50 kg fertiliser			
- recycled	7	6	7
- municipal dump	6	2	3
- on-farm disposal	37	51	46
- other	50	41	44
Bags for 500 kg fertiliser			
- recycled	8	8	7
- municipal dump	11	2	4
- on-farm disposal	67	81	79
- other	14	9	10

[1]Plastic used as a mulch with maize is allowed degrade *in situ*; [2]Discrepancy between the proportions in Tables 3.3.3 and 3.3.5 reflects the absence of cell weightings for the data in Table 3.3.5.

Table 3.3.6. Summary of usage of plastic film on farms

	kg plastic/ha	tonnes nationally
Silage		
- conventional silage: new sheets only	3.7-7.2 (av. 4.7)[1]	4242
: all sheets	5.5-12.8 (av. 8.3)[1]	7476
- baled silage stretch-film	21[2]	8617
Maize mulch	44-88[3]	221
Fertiliser	1.1[4]	3505

[1]per ha conventional silage; [2]per ha baled silage; [3]per ha maize under plastic; [4]per ha treated with bagged fertiliser

4. Computer programme to investigate prototype beef production systems

The objectives of this section were to:

1. Develop a schematic model for defined, selected beef production systems
2. Identify components needing more detailed model development
3. Conduct economic analysis on limited number of prototype beef systems
4. Validate the technical and economic output of the schematic model

Experiment 4.1. The development of a mathematical model to investigate irish beef production systems

[Crosson P., O'Kiely P. , O'Mara F.P. and Wallace M.]

This research had two principal objectives. Firstly, to describe the structure of a mathematical model of Irish beef production systems (i.e. develop the Grange Beef Model). Secondly, to demonstrate the application of the model by investigating how farmers might optimally react to a series of scenarios comprising: (a) potential variations in beef and concentrate prices, (b) technical development through the use of an alternative forage (maize silage) and (c) participation in an agri-environmental scheme that limits nitrogen usage.

Model details: the model employs a single year steady-state design that comprises 1013 activities and 432 constraints. The equations are specified in a microsoft excel spreadsheet and solved using the 'add-in' optimisation software "what's best!" (Lindo Systems inc., 2002). A schematic outline of the model framework is presented in figure 4.1.1. Budgets are formulated for each activity using the most recently available Irish data. These budgets assign a cost or revenue to each activity and based on these the model identifies the optimal beef production system. The objective function of the model maximises farm gross margin.

A number of key assumptions underpin model construction:

- 22% of cattle rearing farms are between 30 and 50 ha and thus, farm size is assumed to be 40 ha.
- The model is constructed around a typical suckler beef herd based on spring-calving Limousin x (Limousin x Friesian) cows with animal groups based on the average animal within that group.
- Animal feed requirements and forage characteristics are based on well established biological functions.
- Grass production response to nitrogen is estimated using data from experiments conducted at Teagasc, Grange Research Centre for the period 2001 – 2004.
- Diets for animal groups are based on a combination of grazing, grass silage, concentrate and maize silage if available. All feeding activities are specified on a monthly basis to incorporate the seasonal variation in animal diets during the year.
- Price and cost estimates are those used by Teagasc (Teagasc, 2004) for farm management planning.

Animal activities: The activities included are those that occur in spring-calving suckler beef production systems in Ireland. Included are suckler beef cow, replacement heifer, calf, store (yearling) and finishing activities. Cows are described as either young (first lactation) or mature (more than one lactation). Because of the predominance of spring-calving in Irish suckler beef herds, all breeding females are assumed to calve in mid-March. Expected liveweight changes of cows throughout the year are specified. A 20% replacement rate is assumed with replacement heifers purchased as one-month-old calves. The heifers are assumed to calve at 24 months of age. The milk yield of mature and young beef suckler beef cows follow typical lactation curves found in Irish suckler beef systems, yielding 12 and 10 kg fresh weight milk per day respectively at peak lactation. All breeding cows and heifers are mated to a Charolais sire with the progeny taken to beef within an integrated suckler calf to finish system. Trading options are specified facilitating sale of weanlings and stores. Male progeny can be finished as bulls at 16 months or as steers at 20, 22, 24, 26, 28 or 30 months. Female progeny can be finished at 20, 22 or 24 months.

Nutritional specifications are described in terms of animal energy requirements subject to a maximum intake capacity. The energy requirements of growing and lactating animals are specified in UFL's (Feed Unit for lactation) and the energy requirements of finishing animals are specified in UFV's (Feed Unit for maintenance and meat production). The intake capacity of all animals are specified in CFU's (Fill Unit for cattle). The INRAtion software feeding program (INRAtion 3.0; INRA (2003)), which

has been adapted for Irish conditions, was used to estimate the energy requirements of growing and finishing beef cattle. The functions used to calculate intake capacities and the maintenance and lactation energy requirements of cows are presented in Table 4.1.1. Pregnancy requirements are as follows: sixth month, 0.56 UFL.d^{-1}; seventh month, 1.08 UFL.d^{-1}; eighth month, 1.86 UFL.d^{-1} and ninth month, 2.93 UFL.d^{-1}. For growing animals, discrete growth rates are specified in the model. These can be changed within allowable limits at the input stage.

Intake capacities of growing and finishing animals are calculated using equations as presented in Table 4.1.1. The breed composition of progeny in the model is 50% Charolais, 37.5% Limousin and 12.5% Friesian. Equations to determine intake capacity for this mixed breed of animal are not available. Thus the relevant equations for Charolais cattle (which represent 50% of the genes of the modelled animals and are quite representative of another 37.5% of their genes in terms of intake capacity) are used. Transfer rows in the model facilitate the movement of animals through subsequent stages in the life cycle. Mortality rates are also factored into these transfer rows.

In the current version of this model, protein contents of the diets have not been considered. For the livestock categories specified in the model, the fulfilment of energy requirements by the forage simultaneously satisfies protein requirements. A crosscheck is made in the model output to ensure that the protein requirements of animals, as specified in INRAtion 3.0, are satisfied. If the protein requirements have not been satisfied, the user must specify to feed appropriate concentrates until requirements are met.

Feeding activities: The feeding activities available in the model are pasture, grass silage, maize silage and concentrates. Due to the predominance of pasture-based systems in Ireland, the model specifies a detailed set of grazing options that are typical of those available to Irish cattle farmers. Grass growth is modelled on historical data from Teagasc, Grange Research Centre and is responsive to inorganic nitrogen (N) application rates with annual yields ranging from 6.2 t.ha^{-1} for 0 kgN.ha^{-1} to 13.3 t.ha^{-1} for 300 kgN.ha^{-1} for the grazing area. The distribution of this herbage throughout the year is given by the following: March, 3.5%; April, 13.0%; May, 21.3%; June, 16.7%; July, 15.3%; August, 13.2%; September, 8.4%; October, 4.3% and November, 3.4%. The balance of the annual herbage yield is available as opening cover at turnout to pasture. The expected yield of herbage is thus specified for each month. In addition, pasture is available for grazing after either one cut or two cut grass silage harvest regimes with maximum N application rates of 120 kgN.ha^{-1} and 60 kgN.ha^{-1} respectively. The model allows transfer of pasture into subsequent months with consequential losses in quality and quantity. The nutritional specifications of the herbage are based on functions taken from Jarrige (1989). The functions describing the energy content of pasture are presented in Table 4.1.2. Fill values of pasture are modelled as discrete values of 0.92 CFU.kgDM^{-1} and 0.95 CFU.kgDM^{-1} for early season and late season grazing respectively.

Thresholds for minimum pasture herbage cover regulate turnout and housing. Insufficient growth in the winter period compels the model to provide conserved forage and/or concentrates as the feed source. A number of options are included to facilitate winter feeding and feeding in periods of temporary grass shortage during the grazing season. Within grassland-based Irish beef production systems, two grass harvests for silage are often taken. The first harvest is typically in late May or early June with the second harvest approximately eight weeks later. In more extensive systems i.e. lower stocking rates, a single harvest is taken in June. These conservation strategies are provided for in the model. The growth duration prior to harvest may be modified to reflect system options. These growth durations correspond to early, intermediate and late first harvest in one-cut and two cut systems and short, medium and long regrowths for second-cut harvest in two-cut systems. Thus, in total there are 3 (first-cut harvest options) x 3 (first harvest of two cut options) x 3 (second harvest of two cut options) grass silage harvesting options available. Energy and fill values for grass silage are shown in Table 4.1.2. Grass silage yields and digestibilities are based on Teagasc, Grange Research Centre data. Planned nutrient input recommendations for grass grown for pasture and silage production and for maize silage are those developed by Teagasc.
Maize silage has also been included as a feed option in the model. Yields and digestibilities used are typical of those achieved under Irish conditions with nutritional specifications as per INRAtion 3.0. Thus energy contents are 0.75 UFV.kgDM^{-1} and 0.81 UFL.kgDM^{-1}. Concentrate feeding, being a crucial element of beef production, is a key activity available to all animal categories. The default purchased concentrate ration is a barley-based mixture containing soyabean meal and maize gluten feed. The respective proportions of the feed ingredients can be adjusted as required. Default values represent concentrates with energy values of 1.01 UFV.kgDM^{-1} and 1.08 UFL.kgDM^{-1}. Substitution

rate, the reduction in forage intake caused by the addition of concentrate feedstuffs to the diet, was addressed using the 'apparent fill' method.

Labour: Labour data used in the model are based on on-farm surveys relating to labour use on Irish beef farms (Leahy, 2003). A constraint on available farmer and family labour is included and where labour is required above this level, there is the option to hire temporary labour at a cost specified by the model user. Silage harvesting and slurry spreading operations are assumed to be carried out by agricultural contractors.

Environmental considerations: To avail of various government grants and EU premia and to be compliant with legislation, farmers must operate within codes of good practice and must avoid over-application of organic and inorganic fertiliser. The two primary programmes currently operated are:

1. Rural environment protection scheme (REPS). REPS is a program co-funded by the EU and the Irish government whereby farmers are rewarded financially for operating to a set of guidelines consistent with an agri-environmental plan drawn up by an approved planning agency. Farmers are paid an annual fee based on the area of land farmed and receive €200.ha^{-1} for the first 20 ha farmed, €175.ha^{-1} for the next 20 ha, €70.ha^{-1} for the next 15 and €10.ha^{-1} for each ha over 55 ha. A significant requirement is the N application limit of 170 kg organic N.ha^{-1} and 260 kg total N.ha^{-1} imposed on the area farmed. Over 38,000 farmers participated in REPS in 2004 with 76% being beef farmers.

2. Nitrates directive. The Nitrates Directive of the EU (Directive 91/676/EEC) requires measures be taken in respect to farm practices so as to ensure the EU standard for nitrates in potable water of 50 mgNO_3.l^{-1} is not breached. The implications of this Directive are that farmers cannot exceed organic nitrogen (N) application rates of 170 kgN.ha^{-1}. In addition closed periods for application of organic manure together with minimum requirements for slurry storage facilities are specified.

The ultimate impact of these programmes is a limit on inorganic and organic N use and thus on the maximum stocking rates on farms.

Within the model, environmental issues are considered by means of maximum organic and inorganic N application constraints. Each animal is assumed to produce a specified quantity of organic N and this combined with inorganic N applied to grassland represents the total farm N usage. Maximum organic and total N usage limits are imposed either in adherence to environmental regulations e.g. if the farm is participating in REPS or as user defined limits and these constrain production intensity.

Model evaluation: During the model building process, systems researchers at Teagasc, Grange Research Centre were routinely consulted to ensure appropriate biological relationships were specified and to verify coefficients used in the model. This satisfies the "validation by construct" provisions of McCarl and Apland (1986). Due to the absence of a robust dataset of representative suckler beef farms, expert opinion involving subjective assessment by "knowledgeable individuals" was also used to evaluate the model (Rykiel, 1996). Presentations were made at Grange Research Centre to systems researchers whereby a number of scenarios involving changing resource constraints (land area, animal facilities, N application limits, etc.), input and beef prices and performance indicators (liveweight gains, carcass weights, forage yields, etc.) were outlined. Following a number of such group meetings in addition to a number of individual meetings, researchers were satisfied that the model accurately replicated system processes in terms of financial (revenues, costs, net and gross margin) and technical (stocking rates, N use, land use, concentrates fed) performances within the range of expectations.

Application: A number of scenarios presented in Table 4.1.3 were investigated. The first scenario is a base scenario and represents the conditions typically found on Irish beef farms in 2005. The second and third scenarios represent an increase and decrease in beef prices of 10%. The fourth and fifth scenarios represents an increase and decrease of 10% in concentrate price. The following two scenarios investigate varying herbage utilisation of grazing animals. Changes of 15% from the base scenario of 65% are investigated. The integration of maize silage into beef production systems and its potential to increase gross margin is then investigated. The value of REPS both in contributing to farm gross margin and in limiting N usage is studied by including a scenario where non-participation is assumed. For all scenarios, land area owned is 40 ha with additional land available for rent at €210.ha^{-1} and the SFP payable is €400.ha^{-1}. It is assumed that rented land does not have SFP entitlements attached.

Results: Table 4.1.4 presents the key production results for all the scenarios investigated. The base solution is characterised by a high proportion of land area used exclusively for grazing and the main

part of the grass silage conserved as late harvested silage. Late harvest is defined in this case as those harvests taken after 20 June. N usage is limited by REPS specifications and thus total application is therefore 260 kgN.ha^{-1}. The preferred finishing option for male and female progeny identified at 24 months and 22 months respectively on grass silage/concentrate diets.

An increase in beef price leads to an increase in area farmed facilitated by renting over 20 ha of land. The relative proportion of grassland and grass silage area is similar to the base solution. Suckler beef cow numbers increase by 52% with male progeny finished as steers at 24 months of age and heifers finished at 22 months. If beef price were to decrease, results indicate that the optimal system involves a slight reduction in animal numbers; in this scenario suckler beef cow numbers are 4% less than the base solution. Therefore, there is no requirement to rent land in this scenario and N usage is somewhat reduced.

An increase in concentrate price leads to little change in the production system when compared to the base solution. Land usage, N application rates and animal production system are similar. In contrast, decreasing concentrate price has a considerable impact on the optimal system of production. A sizable increase in the area of land farmed of over 14 ha is allied to an increase in animal numbers. In this case, suckler beef cow numbers are 56% greater than in the base solution. Finishing of male progeny also shifts somewhat towards finishing as bulls at 16 months with a consequential increase in concentrates fed.

Improvement in grassland utilisation also leads to an increase in the area of land farmed when compared to the base solution; in this case over 16 ha is rented. Suckler beef cow numbers increase by 53% compared to the base with male and female progeny finished at 24 and 22 months of age respectively. Where herbage utilisation is poor, there is no land rented. N usage and animal numbers are lower than the base solution. Finishing of male progeny, whilst primarily based on 24 months, also includes some finishing of bulls at 16 months of age. Heifer finishing is at 22 months.

With maize harvest included in the production system, land area farmed increases, concentrate feeding decreases and suckler beef cow numbers increase compared to the base solution. In this scenario, the area rented is 12 ha and finishing is at 24 months and 22 months for steers and heifers respectively. There is no grass silage harvested and all forage conserved is as maize silage with 16 ha grown.

The final scenario investigates the impact of not participating in REPS. The result is an intensification of production with an increase in animal numbers and area farmed when compared to the base solution. Additional feed requirements are met largely by an increase in N usage; in this instance N application rates are not limited by the REPS limit of 260 kg total N.ha^{-1} and thus the total N application rate is 365 kg.ha^{-1}. Finishing is similar to the base solution with steers finished at 24 months and heifers finished at 22 months.

Table 4.1.5 presents the financial results of the scenarios investigated and follows from the production systems specified in Table 4.1.4. The major revenue item in all scenarios is animal sales. Despite this, non production-based revenue, REPS payments and SFP receipts, contribute substantially to revenue ranging from 20% for the non-REPS scenario to 38% for the beef price decrease and the grass utilisation scenarios. The highest revenue earned is where an increase in beef price is investigated which is 43% greater than the base solution. The scenarios investigating decreases in concentrate price, good grass utilisation and maize harvesting have revenues more than 30% greater than the base solution. Where beef prices decrease by 10% and in the poor grass utilisation scenario, the lowest revenue are observed being 9% lower than the base solution.

Feed costs are the primary costs in all scenarios although, in particular in scenarios where land is rented and animal numbers are greater, animal expenses and land rental costs are also sizeable. The highest costs are for the beef price increase scenario and the non-REPS scenario with total direct costs of over 60% greater than the base solution. The lowest costs are for the poor grass utilisation scenario with direct costs 8% less than the base solution.

The base solution has a gross margin of €32,500. Relative to this the highest gross margins are earned by the scenarios investigating increases in beef price and maize harvesting where gross margins are approximately 20% greater than the base solution. The lowest gross margin is earned in the non-REPS scenario which has a gross margin 23% lower than the base solution. All the other scenarios are intermediate between these margins.

Conclusions: It has been shown that the model can be used to analyse current or prospective scenarios of interest. Future changes in agricultural policy can be routinely investigated. The sensitivity of optimal systems to price changes can be analysed. Whilst much of the production data is based on performances obtained at Grange Research Centre, the parameters can be modified to reflect other situations.

Table 4.1.1: Daily animal intake and energy requirement equations used in the Grange Beef Model

[a] $nelc \geq 0.041 \times W^{-0.75}$

[a] $nel \geq 0.45 \times MP$

[a] $nedc \geq 0.037 \times W^{-0.75}$

[a] $iclc \leq 0.083 \times W^{0.75} + 0.244 \times MP + 2.52$

[a] $icdc \leq 0.09 \times W^{0.75} + 1.46$

[b] $icgs \leq 0.0368 \times W^{0.9}$

[b] $icfs \leq 0.2087 \times W^{0.6}$

[b] $icfb \leq 0.1970 \times W^{0.6}$

where: nelc = maintenance net energy requirements of lactating cows (UFL.kgDM^{-1}); nel = lactation net energy requirements (UFL.kgDM^{-1}); nedc = net energy requirements of dry, pregnant cows (UFL.kgDM^{-1}); iclc = intake capacity of lactating cows (CFU.kgDM^{-1}); icdc = intake capacity of dry, pregnant cows (CFU.kgDM^{-1}); icgs = intake capacity of growing steers/heifers (CFU.kgDM^{-1}); icfs = intake capacity of finishing steers/heifers (CFU.kgDM^{-1}); icfb = intake capacity of finishing bulls (CFU.kgDM^{-1}); W = animal liveweight (kg); MP = milk production (kg fresh weight.d^{-1}); [a]Taken from Jarrige (1989); [b]Taken from Crowley (2001)

Table 4.1.2: Forage energy content equations used in the Grange Beef Model

[a] $negv = ME \times k_{mf} \div 1820$

[a] $negl = ME \times k_{l} \div 1700$

[b] $nesv = 1.48 \times DMD - 0.294$

[b] $nesl = 1.29 \times DMD - 0.1166$

[b] $fvs = -0.0018 \times DMD + 2.65$

where: negv = net energy content of grazed herbage (UFV.kgDM^{-1}); negl = net energy content of grazed herbage (UFL.kgDM^{-1}); nesv = net energy content of grass silage (UFV.kgDM^{-1}); nesl = net energy content of grass silage (UFL.kgDM^{-1}); fvs = fill value of grass silage (CFU.kgDM^{-1}); ME = metabolisable energy (Mcal.kgDM^{-1}); k_{mf} = overall efficiency of ME utilisation (which depends on the proportion of net energy used for maintenance and that used for gain); k_l = efficiency of lactation and maintenance; DMD = in vitro dry matter digestibility of grass silage (g/kg); [a]Taken from Jarrige (1989); [b]Taken from O'Mara et al. (1997)

Table 4.1.3: Description of the nine scenarios investigated using the Grange Beef Model

		Beef price (c/kg carcass)	Concentrate price (€.tDM^{-1})	Grass utilisation (%)	Harvest maize	REPS
Base[1]		290	200	65	No	Yes
Beef price (c/kg carcass)	Increase	319	200	65	No	Yes
	Decrease	261	200	65	No	Yes
Concentrate price (€.tDM^{-1})	Increase	290	220	65	No	Yes
	Decrease	290	180	65	No	Yes
Pasture utilisation (%)	Good	290	200	80	No	Yes
	Poor	290	200	50	No	Yes
Harvest maize		290	200	65	Yes	Yes
No REPS		290	200	65	No	No

[1]Base scenario: values reflect those found on farms in Ireland in 2005.

Table 4.1.4: Selected production results of the nine scenarios investigated using the Grange Beef Model

SCENARIO	Base	Beef price		Concentrate price		Grass utilisation		Harvest maize	No REPS
		Increase	Decrease	Increase	Decrease	Good	Poor		
Area farmed (ha)	40.0	60.6	40.0	40.0	54.2	56.2	40.0	52.1	50.6
Pasture area (ha)[1]	22.1	33.5	23.0	22.1	30.2	29.0	23.4	36.1	22.4
Early silage harvest (ha)[2]	5.5	8.4	5.2	5.5	3.9	8.4	4.5	0.0	8.1
Late silage harvest (ha)[3]	17.9	27.1	17.0	17.9	24.0	27.2	16.6	0.0	28.2
Maize silage harvest (ha)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.0	0.0
Concentrates fed per cow unit (tDM)	0.8	0.8	0.8	0.8	1.2	0.8	0.9	0.3	0.8
Inorganic N applied ($kgN.ha^{-1}$)	114.9	114.7	99.9	114.4	105.9	102.6	104.1	93.2	191.1
Organic N applied ($kgN.ha^{-1}$)	145.1	145.3	138.5	145.6	154.1	157.4	124.4	166.8	173.5
Total N use ($kgN.ha^{-1}$)	260.0	260.0	238.4	260.0	260.0	260.0	228.5	260.0	364.6
Suckler beef cow numbers	38.6	58.6	36.9	38.8	60.2	58.9	34.0	57.8	58.4
Males finished[4]	24St; 17.4	24St; 26.4	24St; 16.6	24St; 17.4	24St; 8.8, 16Bu; 18.3	24St; 26.5	24St; 11.8, 16Bu; 3.5	24St; 26.0	24St; 26.3
Females finished[5]	22Hf; 17.4	22Hf; 26.4	22Hf; 16.6	22Hf; 17.4	22Hf; 27.1	22Hf; 26.5	22Hf; 15.3	22Hf; 26.0	22Hf; 26.3

[1]Land used for grazing only. [2]Land can also be used for late silage harvest and is available for grazing. [3]Land is also available for grazing. [4]24St, steers finished at 24 months; 16Bu, bulls finished at 16 months. [5]22He, heifers finished at 22 months.

Table 4.1.5: Selected financial results of the nine scenarios investigated using the Grange Beef Model (all results in € 000's)

SCENARIO	Base	Beef price		Concentrate price		Grass utilisation		Harvest maize	No REPS
		Increase	Decrease	Increase	Decrease	Good	Poor		
Revenue									
Animal sales	42.5	71.0	36.4	42.6	63.3	64.8	36.8	63.6	64.2
Interest[1]	1.3	1.9	1.1	1.3	1.2	1.7	1.0	1.8	1.4
REPS payments	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	0.0
SFP[2] receipts	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0
Total	**67.1**	**96.2**	**60.8**	**67.2**	**87.8**	**89.8**	**61.2**	**88.7**	**81.6**
Direct costs	7.2	10.9	6.7	7.3	9.7	8.6	7.0	9.9	12.4
Pasture	11.8	17.9	11.2	11.8	14.1	17.9	10.6	0.0	18.3
Grass silage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.1	0.0
Maize silage	6.7	10.2	6.4	7.4	13.7	10.2	6.5	4.1	10.1
Concentrate purchases	8.9	13.5	8.5	8.9	13.7	13.6	7.8	13.3	13.5
Animal expenses[3]	0.0	4.3	0.0	0.0	3.0	3.4	0.0	2.5	2.2
Land rental and interest[4]	7.2	10.9	6.7	7.3	9.7	8.6	7.0	9.9	12.4
Total	**34.6**	**56.8**	**32.8**	**35.4**	**54.2**	**53.7**	**32.0**	**49.8**	**56.5**
Gross margin	32.5	39.4	28.0	31.8	33.6	36.1	29.2	38.9	25.1
Gross margin relative to base		1.21	0.86	0.98	1.03	1.11	0.90	1.20	0.77

[1]Interest earned on cash surpluses. [2]Single Farm Payments. [3]Expenses include veterinary, transport, breeding and miscellaneous animal costs.

[3]Interest payable on overdrafts.

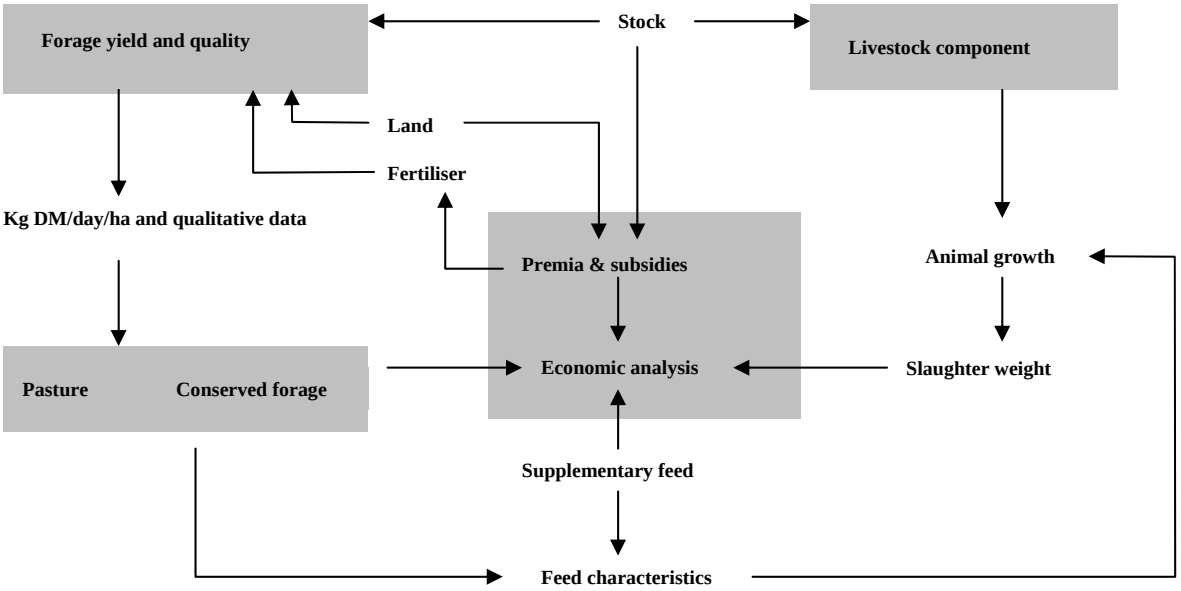

Figure 4.1.1: Schematic outline of the Grange Beef Model.

Experiment 4.2: investigating development options for irish suckler beef producers using mathematical programming

[Crosson P., O'Kiely P. , O'Mara F.P. and Wallace M.]

This section presents the results of a study in which a number of development options in a new policy scenario were investigated. Five farm development scenarios were investigated representing a static scenario, a de-stocking scenario and three expansion scenarios. The technical and financial implications of these options are presented.

Model details: The model is as described for Experiment 4.1. With regard to cash flow, each model activity is associated with a financial budget that determines the cost or revenue imputed to the activity. For the purposes of cash flow, the budgets are allocated according to the timing of receipts and payments. Transfer rows transmit surpluses or deficits to subsequent months. Deficit balances are also transferred into overdraft rows, which impose a charge on the overdraft (interest). This overdraft row also imposes limits on the maximum overdraft allowed which is set by the user. Surplus balances also attract interest albeit at a lower rate.

The model is solved using the optimisation software "What's Best!". It was designed in Microsoft Excel and consists of 1009 activities and 425 constraints and ties. The intersect values of the activities and the constraints are termed the "coefficients" of the model with the suite of coefficients within the linear programming structure termed the "model matrix". To facilitate the development scenarios investigated end of year cash balances, stock inventory changes, yearling cattle numbers and store cattle numbers are used as input parameters for subsequent years and the model is re-solved. Other year-dependent parameters not dependent on the operation of the farm in the previous year, such as the single farm payment and loan repayments, are calculated in a "scenario" worksheet. Since suckler cow numbers, and hence calf numbers, are a function of the scenarios investigated, these values are specified in the scenario worksheet, are read directly into the linear programming matrix and are unchangeable within each model solution. The model thus identifies the optimal feeding system, nitrogen application policy and finishing system for the various systems investigated. The farm modelled at the beginning of all scenarios i.e. in January 2005, is based on an average Irish cattle rearing farm greater than 50 ha as defined by the Teagasc National Farm Survey. The farm size is 65 ha with 38 suckler cows. Based on Irish agricultural census data this group of cattle farmers with between 30 and 50 cows represent 8.6% of farms with suckler cows but own 23% of the suckler cows in Ireland.

Development scenarios: to investigate optimal systems in developmental scenarios a number of options were investigated for an eight year time horizon, 2005-2012. All scenarios were based on a spring-calving suckler herd. Cows calved in march and were allocated fresh pasture if it was available. Calves were weaned at eight months of age following which both cows and calves were housed for the winter period.

Five farm development alternatives were investigated. These scenarios were designed to represent options available to beef farmers and are presented in Table 4.2.1. Scenario 1 is a static scenario and involves no change in the production system. Table 4.2.2 shows the prices and costs used for all scenarios. Beef and cattle prices are taken from projections by FAPRI-Ireland. Input costs are subject to inflation at 2.8% per annum. Scenario 2 is a de-stocking scenario whereby cow numbers were reduced from 38 in 2005 to 18 in 2007. Scenarios 3, 4 and 5 are expansion scenarios and involve increases in cow numbers from 38 in 2005 to 58 in 2006. This expansion of approximately 50 per cent represented an aggressive growth strategy within the context of available capital resources. Suckler cow replacements were purchased as in-calf heifers at 22 months of age. This was preferred to rearing replacements since it facilitated rapid expansion. Purchase of replacements was facilitated by means of a term loan (Table 4.2.3) payable over five years from 2005 to 2009. In S3 it was assumed that no capital development was required for expansion i.e. surplus capacity existed in 2005, whereas in S4 and S5 capital development was required to facilitate expansion. In the case of S4 capital development was by means of a slatted-floor shed whereas for S5, development was by means of an out-wintering pad for accommodation and an earth bank tank for slurry storage. Both of these development options provide accommodation for 20 additional adult animals.

Adult animals are classified as suckler cows, replacement heifers and progeny greater than 18 months of age. Animals less than 18 months of age are classified as "young animals". In model solutions, one adult space can accommodate two young animals thus providing a greater range of potential finishing systems to model solutions. The technical and financial assumptions for these developments are presented in Table 3. No grant aid was assumed and all developments are subject to a 10 year write-off.

In all scenarios a number of features remained constant:

- An overdraft limit of €30,000 was imposed on the farm. The rate of interest on overdrafts was 7.5%. This overdraft limit was considered an upper limit for farm holdings of this scale. Consequently, increasing overdraft limits above this level was considered unrealistic.
- Opening cash balance in 2005 is €5,000 for all scenarios.
- The entitlements established under the LA were €500ha^{-1} in 2005. Modulation reduces this by 3% in 2005, 4% in 2006 and 5% each year from 2007 to 2012.
- Participation in the Rural Environment Protection Scheme (REPS) was assumed in all cases. REPS involves payments to farmers for carrying out farming activities in an environmentally friendly manner. Farmers

participating in REPS receive €200.ha^{-1} for the first 20ha farmed, €175.ha^{-1} for the next 20ha, €70.ha^{-1} for the next 15 and €10.ha^{-1} for each ha over 55ha.

- Land can be rented in or out at a cost of €267ha^{-1} for the years 2005 to 2012. This land was rented without any associated single farm payment entitlements. This value represents a significant reduction from 2004 rental prices as is predicted to occur following implementation of LA.
- Family labour availability is 3000 hours per annum. Additional hired labour is available at €8.60 per hour. Labour costs are subject to inflation at 2.8% per annum.

For the purposes of calculating end-of-year cash balances, it was necessary to specify the contribution of farm income to family living expenses. Family living expenses were estimated to be €27,000 in 2005 and were subject to inflation at 2.8% per annum. It is estimated that on 63% of the cattle rearing farms of the size modelled here, the farmer and/or the farmer's spouse has off-farm employment. Given that estimated off-farm income for family farms is €20,700, it was assumed that only one third of family living expenses were met by drawings from the farm business each year. Farm profits were also subject to taxation at the Irish tax rates of 20% on profits up to €56,000 and 42% on profits greater than €56,000 with tax payable the subsequent year.

To evaluate the growth of the farm business for the alternative scenarios, assets and liabilities were calculated in balance sheets. From these balance sheets, the growth of the farm business was calculated as the change in net worth. Land was assumed to appreciate in line with inflation whilst buildings and machinery were subject to depreciation at a declining balance rate of 5% and 10% per annum respectively.

Results: The key technical results are presented in Table 4.2.4. Production systems for all scenarios were based on finishing heifers at 20 months and finishing steers at 22, 26 or 28 months. Intake of grazed grass was high in all cases with grazed grass accounting for over 60% of the annual feed budget for all years in all scenarios and over 80% for 2007 to 2012 in S2. N usage is low in all cases particularly for S2 following de-stocking. In the expansion scenarios (S3, S4 and S5), N usage increases but still does not approach the 260kgN.ha^{-1} limit set by REPS specifications.

In terms of labour requirements, the differences between the scenarios are pronounced. In the base, static scenario (S1) labour requirements are approximately 2,300 hours for all years. This is reduced by over 30% in the de-stocking scenario (S2) from 2008 to 2012. For the expansion scenarios (S3, S4 and S5) the labour requirements are almost 30% greater than S1 and 47% greater than S2 from 2009 to 2012.

Table 4.2.5 presents the revenues, costs and margins associated with the five scenarios investigated. The expansion scenarios have the highest revenues following 2006 when revenue is over €55,000 and rises to almost €90,000 in 2012. These scenarios have almost identical revenues illustrating the similarities of the production systems. S2 has the lowest revenue after 2005 dropping to approximately €24,400 in 2009. S1 is intermediate between S2 and the three expansion scenarios in all years except 2005. As expected the expansion scenarios (S3, S4 and S5) incurred the highest variable costs for all years, rising from approximately €30,000 in 2005 to almost €44,000 in 2012. S2 had the lowest variable costs in all years and decreased by over €9,000 between 2005 and 2012. Again, S1 was intermediate between S2 and the expansion scenarios in terms of variable costs. Feed costs and animal expenses represented the main costs in all scenarios.

The net margin figure illustrates the risk associated with expansion but also the potential financial rewards. S2 initially has the highest farm margin of over €41,000 in 2005 due to income from de-stocking sales. This margin quickly drops as animal sales in subsequent years drop sharply. In contrast, S3, S4 and S5 have low margins initially, particularly in 2007 but subsequently margins increase sharply with an increase in animal sales and beef price to between €43,600 for S4 and €46,200 for S3 in 2012. As expected, of the three expansion scenarios, S3 achieves higher margins followed by S5 with S4 the lowest of the three. S1 has higher net margins than S3, S4 and S5 in 2005 and 2007, however in all other years the expansion scenarios have greater margins. In 2008 net margin is increased for the expansion scenarios due to a decrease in tax payable. This decrease is a result of a considerable reduction in net margin in 2007.

Family farms must also take into account cash surpluses or deficits when evaluating different systems of production. This cash flow position takes into account drawings from the farm business for family living expenses. The cash surpluses/deficits are presented in Figure 4.2.1. For S2, large cash surpluses in 2005 due to de-stocking sales are largely mitigated against by much reduced surpluses from 2007 to 2012. Surpluses range from over €32,000 in 2005 to over €9,500 in 2012. In contrast, the expansion scenarios have very low surpluses during the initial period of expansion to 2007. In 2006 in particular, cash surpluses are low although from 2008 surpluses rise sharply and are over €30,000 in 2012 for the three expansion scenarios. In contrast, there is a relatively moderate change in cash flow between 2005 and 2012 for S1 with surpluses in 2005 of approximately €20,000 and dropping to €8,000 in 2006 before rising to almost €21,000 in 2012.

Discounted farm net margin and returns on investments (ROI) are presented in Table 4.2.6. Discounted net margin represents the net present value of future farm margins using a 5% discount rate. The expansion scenarios have the greatest discounted net margin with S3 in particular over €20,000 greater than S1. S2 has the lowest discounted net margin being almost €44,000 less than S1. The return on investments is presented for the expansion scenarios S3-S5 and is the average additional annual profit earned relative to S1 for each additional

Euro invested in herd expansion, building development costs and working capital. The greatest ROI is for S3 which has an ROI of 0.24. This represents a reasonable ROI given that it indicates the cost of investment can be repaid in approximately four years. The ROI for S4 and S5 are 0.04 and 0.15 respectively.
In measuring the rate of growth of a business, change in net worth is a useful indicator. Figure 4.2.2 illustrates the average annual change in net worth for the scenarios investigated. The change in net worth is similar for the three expansion scenarios at over 4% with the greatest average annual increase for S3 which increases by an average of greater than 4.3% per year. For S1 the average growth is 4% whereas the lowest growth is for S2 at just over 3%. The relatively modest differences between scenarios can be attributed to the large proportion of net worth attributable to the value of land which does not change between scenarios.
Conclusions: Results indicate that farmers will face a difficult period as the effects of implementation of the LA materialize. Farmers may adopt a "wait and see" approach whilst other farmers may chose to contract production. Farmers who elect to de-stock must be aware of its long term effects as they will be unable to capture the full effects of beef price increases predicted, particularly post 2007. Despite this, reduced labour requirements and the resulting opportunity to take up off-farm employment may make this alternative attractive to many farmers. Farmers who wish to expand should identify the associated costs and carefully prepare budgets to measure the impact of expansion. Results presented here indicate that expansion may result in difficult cash flow and net margin situations in the years immediately following investment. Farmers should be aware that drawings from the farm business may become more severely limited than the level of drawings modelled here during the period of expansion but that if this period can be endured future benefits may be substantial. Afforestation and/or renting out land may be an attractive option given the stacking provisions of the LA and increased possibilities to participate in off farm employment.

Table 4.2.1: Expansion and herd culling and replacement policy

Base (S1)	2005	2006	2007-2012
Cow numbers	38	38	38
Replacement purchased	6	6	6
Cows culled	6	6	6
Destocking (S2)	2005	2006	2007-2012
Cow numbers	38	28	18
Replacement heifers purchased	0	0	2
Cows culled	10	10	2
Expansion with no capital development[1] (S3)	2005	2006	2007-2012
Cow numbers	38	58	58
Replacement heifers purchased	25	9	9
Cows culled	5	9	9
Expansion with development of SFS[2] (S4)	2005	2006	2007-2012
Cow numbers	38	58	58
Replacement heifers purchased	25	9	9
Cows culled	5	9	9
Expansion with development of OWP[3] (S5)	2005	2006	2007-2012
Cow numbers	38	58	58
Replacement heifers purchased	25	9	9
Cows culled	5	9	9

[1]Assumes surplus capacity in 2005. [2]Slatted-floor shed. [3]Out-wintering pad.

Table 4.2.2: Cost and price projections used

	2005	2006	2007	2008	2009	2010	2011	2012
Spring beef price (€.kg^{-1})	2.95	2.80	2.86	2.97	3.19	3.48	3.83	4.23
Autumn beef price (€.kg^{-1})	2.85	2.70	2.76	2.87	3.09	3.38	3.73	4.13
Cull cow beef price (€.kg^{-1})	2.15	2.00	2.06	2.17	2.39	2.68	3.03	3.43
Yearling heifer (9 month) price (€)	315.00	264.60	251.90	249.63	260.87	274.17	299.12	327.83
Yearling steer (9 month) price (€)	440.00	352.00	317.50	298.77	297.28	306.49	322.12	340.16
Store heifer (16 month) price (€)	600.00	504.00	479.81	475.49	496.89	522.23	569.75	624.45
Store steer (16 month) price (€)	750.00	600.00	541.20	509.27	506.72	522.43	549.08	579.82
Concentrate cost (€.t^{-1})	200.00	205.60	211.20	216.80	222.40	228.00	233.60	239.20
Urea fertiliser cost (€.t^{-1})	230.00	236.44	242.88	249.32	255.76	262.20	268.64	275.08
CAN[1] fertiliser cost (€.t^{-1})	220.00	226.16	232.32	238.48	244.64	250.80	256.96	263.12
0-10-20 fertiliser cost (€.t^{-1})	230.00	236.44	242.88	249.32	255.76	262.20	268.64	275.08

[1]Calcium Ammonium Nitrate fertiliser.

Table 4.2.3: Investment options for the expansion scenarios (S3-S5)

	No capital development (S3)	Slatted-floor shed (S4)	Out-wintering pad & earth bank tank (S5)
Number of replacement heifers purchased	25	25	25
Cost of replacements @ €900/heifer (€)	22,500	22,500	22,500
Loan interest	7.5%	7.5%	7.5%
Loan duration (years)	5	5	5
Annual repayments (€)	4,837.50	4,837.50	4,837.50
Building cost (€)	-	21,160	6,140
Loan interest	-	7.5%	7.5%
Duration of loan (years)	-	10	10
Annual repayments (€)	-	2,274.70	660.05
Annual operational cost (€)	-	60.00	400.00

Table 4.2.4: Technical results

S 1	2005	2006	2007	2008	2009	2010	2011	2012
Grazed grass fed per cow unit (tDM)	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.8
Grass silage fed per cow unit (tDM)	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
Concentrates fed per cow unit (tDM)	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1
Inorganic N used (kgN.ha^{-1})	24.0	24.1	24.1	24.1	24.1	24.2	24.5	24.5
Total N used (kgN.ha^{-1})	110.6	111.4	111.4	111.4	111.4	111.5	111.8	111.8
Heifers finished (20m)	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0
Steers finished (26m)	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Steers finished (28m)	13.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0
Labour use (hrs)	2,322	2,329	2,329	2,329	2,329	2,328	2,328	2,328
S 2								
Grazed grass fed per cow unit (tDM)	4.7	5.2	6.1	5.7	5.4	5.4	5.4	5.6
Grass silage fed per cow unit (tDM)	1.8	1.7	1.4	1.2	1.1	1.1	1.1	1.1
Concentrates fed per cow unit (tDM)	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1
Inorganic N used (kgN.ha^{-1})	23.0	15.6	8.8	7.6	6.6	6.6	6.6	6.6
Total N used (kgN.ha^{-1})	104.4	81.3	56.6	50.3	47.1	47.1	47.1	47.1
Heifers finished (20m)	17.0	17.0	12.0	8.0	8.0	8.0	8.0	8.0
Steers finished (22m)	0.0	3.6	8.1	3.1	0.0	0.0	0.0	0.0
Steers finished (26m)	4.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Steers finished (28m)	12.6	13.4	8.9	8.9	8.0	8.0	8.0	8.0
Labour use (hrs)	2,157	1,929	1,707	1,638	1,600	1,600	1,600	1,600
S 3								
Grazed grass fed per cow unit (tDM)	4.7	3.8	3.9	4.3	4.5	4.5	4.5	4.5
Grass silage fed per cow unit (tDM)	2.1	2.3	2.4	2.2	2.2	2.2	2.2	2.2
Concentrates fed per cow unit (tDM)	0.2	0.1	0.2	0.2	0.2	0.2	0.1	0.1
Inorganic N used (kgN.ha^{-1})	27.5	47.5	52.0	70.9	80.5	80.6	84.7	84.7
Total N used (kgN.ha^{-1})	130.4	166.0	176.9	201.1	213.8	213.8	217.9	217.9
Heifers finished (20m)	17.0	17.0	26.0	26.0	26.0	26.0	26.0	26.0
Steers finished (22m)	0.0	0.0	0.0	6.3	0.0	0.0	0.0	0.0
Steers finished (26m)	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Steers finished (28m)	14.3	17.0	17.0	19.7	26.0	26.0	26.0	26.0
Labour use (hrs)	2,843	2,918	3,000	3,021	3,045	3,045	3,033	3,033

Table 4.2.4 cont'd: Technical results

S 4	s2005	2006	2007	2008	2009	2010	2011	2012
Grazed grass fed per cow unit (tDM)	4.7	3.8	3.9	4.3	4.5	4.5	4.5	4.5
Grass silage fed per cow unit (tDM)	2.1	2.3	2.4	2.2	2.2	2.2	2.2	2.2
Concentrates fed per cow unit (tDM)	0.2	0.1	0.2	0.2	0.2	0.2	0.1	0.1
Inorganic N used ($kgN.ha^{-1}$)	27.5	47.5	52.0	70.9	80.5	80.5	84.7	84.7
Total N used ($kgN.ha^{-1}$)	130.4	166.0	176.9	201.1	213.8	213.8	217.9	217.9
Heifers finished (20m)	17.0	17.0	26.0	26.0	26.0	26.0	26.0	26.0
Steers finished (22m)	0.0	0.0	0.0	6.3	0.0	0.0	0.0	0.0
Steers finished (26m)	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Steers finished (28m)	14.3	17.0	17.0	19.7	26.0	26.0	26.0	26.0
Labour use (hrs)	2,843	2,918	3,000	3,021	3,045	3,045	3,033	3,033
S 5								
Grazed grass fed per cow unit (tDM)	4.7	3.8	3.9	4.3	4.5	4.5	4.5	4.5
Grass silage fed per cow unit (tDM)	2.1	2.3	2.4	2.2	2.2	2.2	2.2	2.2
Concentrates fed per cow unit (tDM)	0.2	0.1	0.2	0.2	0.2	0.2	0.1	0.1
Inorganic N used ($kgN.ha^{-1}$)	27.5	47.5	52.0	70.9	80.5	80.5	84.7	84.7
Total N used ($kgN.ha^{-1}$)	130.4	166.0	176.9	201.1	213.8	213.8	217.9	217.9
Heifers finished (20m)	17.0	17.0	26.0	26.0	26.0	26.0	26.0	26.0
Steers finished (22m)	0.0	0.0	0.0	6.3	0.0	0.0	0.0	0.0
Steers finished (26m)	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Steers finished (28m)	14.3	17.0	17.0	19.7	26.0	26.0	26.0	26.0
Labour use (hrs)	2,843	2,918	3,000	3,021	3,045	3,045	3,033	3,033

Table 4.2.5: Financial results (all values in €)

S 1	2005	2006	2007	2008	2009	2010	2011	2012
Revenue exc. SFP[1]	46,028	37,987	40,510	42,486	46,115	50,082	55,445	61,138
Variable costs	28,063	27,688	27,701	27,740	27,803	27,887	27,990	28,110
Gross margin	17,966	10,299	12,809	14,746	18,313	22,194	27,455	33,028
SFP	32,500	31,675	30,608	29,328	28,111	26,956	25,858	24,815
Net margin[2]	33,108	21,587	24,190	24,063	26,017	28,027	31,445	35,030
S 2								
Revenue exc. SFP	53,827	35,836	25,262	25,428	24,370	28,253	30,718	33,325
Variable costs	27,460	23,650	19,965	18,982	18,393	18,323	18,273	18,241
Gross margin	26,367	12,185	5,296	6,446	5,976	9,930	12,445	15,084
SFP	32,500	31,675	30,608	29,328	28,111	26,956	25,858	24,815
Net margin	41,509	22,129	16,221	16,594	14,709	17,449	18,083	19,165
S 3								
Revenue exc. SFP	50,861	55,390	49,608	63,864	66,123	72,175	80,363	89,052
Variable costs	28,970	36,362	37,901	40,933	42,533	42,834	43,149	43,467
Gross margin	21,891	19,027	11,707	22,931	23,590	29,341	37,214	45,585
SFP	32,500	31,675	30,608	29,328	28,111	26,956	25,858	24,815
Net margin	32,196	25,624	18,345	28,461	25,930	35,160	40,036	46,219
S 4	2005	2006	2007	2008	2009	2010	2011	2012
Revenue exc. SFP	50,861	55,388	49,606	63,860	66,118	72,169	80,356	89,044
Variable costs	30,109	37,477	38,993	41,840	43,394	43,652	43,926	44,206
Gross margin	20,751	17,912	10,612	22,019	22,723	28,517	36,429	44,838
SFP	32,500	31,675	30,608	29,328	28,111	26,956	25,858	24,815
Net margin	28,721	22,897	15,510	25,816	23,290	32,552	37,453	43,662
S 5								
Revenue exc. SFP	50,861	55,389	49,607	63,862	66,120	72,172	80,359	89,048
Variable costs	29,311	36,701	38,234	41,197	42,783	43,071	43,374	43,681
Gross margin	21,550	18,688	11,373	22,665	23,338	29,101	36,985	45,367
SFP	32,500	31,675	30,608	29,328	28,111	26,956	25,858	24,815
Net margin	30,795	24,486	17,158	27,335	24,793	34,022	38,894	45,074

[1]SFP = Single Farm Payment; [2]Net margin = gross margin - overheads

Table 4.2.6: Total discounted farm net margin and return on investment (all values in €)

Scenario	Discounted net margin	Return on investment
S1	188,114	
S2	144,511	
S3	209,424	0.24
S4	190,538	0.04
S5	201,398	0.15

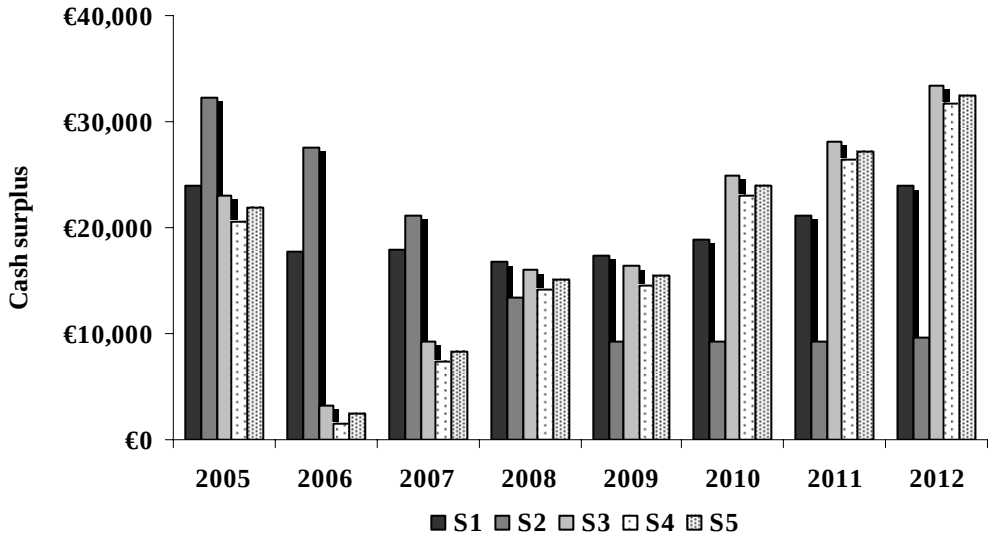

Figure 4.2.1: Cash surplus

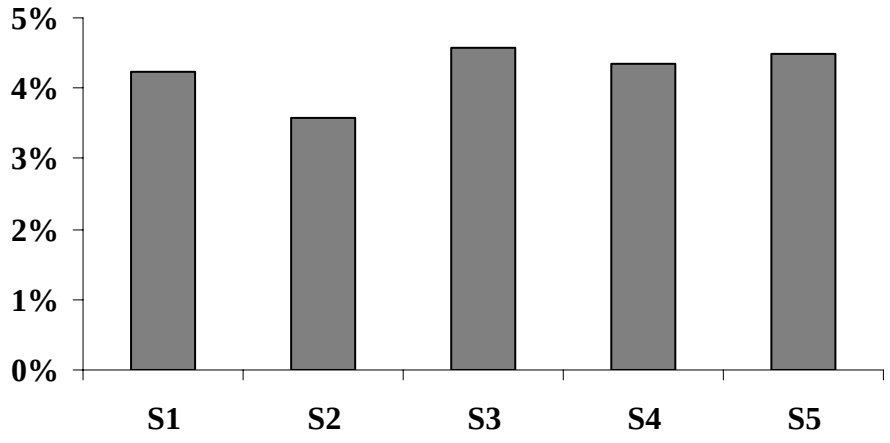

Figure 4.2.2: Average annual change in net worth

Experiment 4.3: Modeling the nitrogen and phosphorus inputs and outputs of financially optimal Irish beef production systems

[P. Crosson, C.A. Rotz, P. O'Kiely, F.P. O'Mara, M. Wallace and R.P.O. Schulte]

The goal was to evaluate the environmental consequences of economically optimal beef production systems in Ireland. Specific objectives were to 1) use the Grange Beef Model to identify economically optimal systems of beef production given the physical and regulatory restrictions under which Irish farmers operate, and 2) use the Integrated Farm System Model (Rotz *et al.*, 2005) to investigate the impact of these systems identified on farm level N and P fluxes.

Methodology: *Scenarios:* Two beef production strategies from within beef cow herd systems, calf-to-stocker and calf-to-finish, were specified with cows calving in March. In the calf-to-stocker scenarios, stocker heifers and steers were sold at 290 kg and 315 kg liveweight, respectively, at eight months of age. In the calf-to-finish scenarios, finishing animals were finished at 24 months of age at 660 kg and 740 kg for heifers and steers, respectively. The land area farmed was 40 ha with all the land farmed as permanent grassland. Additional land was available with a rental price of $300/ha. Grass silage was harvested in a one cut system, with a single harvest taken in June, or a two cut system with an early harvest taken in May and a second harvest taken 6 to eight weeks later. Purchased

concentrates complete the feed ration. Participation in REPS was assumed in all cases and the SFP receipts were $361/ha. The soil type specified was a loam soil with good drainage.

Beef prices were predicted to rise by over 20% by 2010 relative to 2005 levels. Calf and stocker prices were predicted to rise accordingly although, not equally for heifers and steers. The negative price impact on steers of decoupling of premia, which was payable per steer, is such that the price increase was projected to be less for steers than for heifers. Therefore, two price scenarios, high and low, representing 2005 and 2010 price scenarios were also investigated (Table 4.3.1). In the low price scenario, cattle and beef prices were set to 2005 levels. In the high price scenario, stocker steer prices were assumed to rise by 10% while stocker heifer prices and beef prices were assumed to rise by 20%. Since it was assumed that the low price and high price scenarios represented the market and policy conditions prevailing in Ireland in 2005 and 2010 respectively, input costs, including labor, concentrate and fertilizer, were adjusted to account for inflation for the high price scenario. An inflation rate of 2.8% per annum was assumed.

Thus four cattle scenarios were investigated; calf-to-stocker low price (SL), calf-to-stocker high price (SH), calf-to-finish low price (FL) and calf-to-finish high price (FH), all within beef cow herd systems. Soil drainage capacity is an important property determining N losses in Ireland - thus for the scenarios investigated, two soil drainage capacities were considered; well drained soils and poorly drained soils.

Environmental evaluation: Within the model, all animals were housed over the winter period of four to five months in free stall barns. Manure deposited in the barn was handled as slurry with a dry matter content of 8-10%. The slurry was assumed to be stored up to six months in a concrete tank with top surface loading. Slurry was applied using the splash-plate technique with no soil incorporation.

Model evaluation: Prior to using both models, it was necessary to ensure that IFSM accurately replicated GBM results in terms of animal performance and forage yields on Irish beef farms. Therefore, a component-based comparison was undertaken. The forage yield and response to N fertilizer were first compared. Then GBM was solved to find the financially optimal system in the policy and market environment prevailing in 2005. The Integrated Farm System Model was subsequently run using the resulting optimal system parameters predicted by GBM in terms of land use, fertilization rate and animal production. Animal intake and total feed use predicted by the two models was then compared.

Forage yield: The Grange Beef Model specifies forage yield for the grazing area based on seven N application rates; 0 kg N/ha to 300 kg N/ha in 50 kg N/ha increments. Simulations for each of these application rates were performed using IFSM. Initial results indicated that some yield adjustment was required. A yield adjustment factor is available in IFSM to adjust pasture yield for the effects of management practices such as crop variety, soil fertility, weed control and general pasture management. Following appropriate adjustments, simulations were run with the yields in reasonable agreement between the two models. Relative to the growth curves assumed in GBM, IFSM underestimated production in spring and overestimated production in fall. However, the annual production across all fertilization strategies indicated a yield differential of only 2% between the two models.

Intake prediction: To evaluate intake predictions, the two main categories of cattle, cows and stocker/finishing cattle, were compared. Similar predictions of intake were obtained from both models. Some deviation was evident in the intake of beef cows at the start and at the end of the grazing season (the grazing season begins in February/March and finishes in October/November). This difference can be explained by a small deviation in calving dates between the models. In IFSM, the average calving date was the middle of the month selected, in this case March; whereas, in GBM, the average calving date was the beginning of March. Therefore, March energy requirements for beef cows were lower in IFSM than in GBM and consequently herbage intake was also lower. A similar situation occurred in November where IFSM requirements were higher. These different model specifications resulted in IFSM predicting beef cow intakes 9% greater than GBM. For finishing animals, intake predictions were closer with IFSM intake predictions only 5% greater than GBM.

Feed consumption and beef output: In general, the production systems were similarly represented by the two models. There was a modest difference between the two models with IFSM predicting 6% greater total feed consumed relative to GBM. Due to the cost advantage of grass, systems were based on grazed grass with grass silage and concentrates completing the feed ration. Beef output using GBM was 354 kg carcass beef per hectare with the equivalent value using IFSM being 360 kg carcass beef per hectare. It can be seen from these comparisons that model results were similar and thus, both models provided similar representations of the respective components of beef production systems.

Results: *Economically optimal system:* Key production and financial results of the optimal beef cow production systems as predicted by GBM are presented in Tables 4.3.2 and 4.3.3. Both calf-to-stocker scenarios, SL and SH, were characterized by low N fertilizer rates receiving 14 kg/ha and 23 kg/ha of inorganic N and 72 kg/ha and 95 kg/ha of total N, respectively. The extensive nature of these systems is illustrated by land use where grazing land was predominant and only a small area of land was used for grass silage conservation. The small silage harvest area was also due to the sale of progeny prior to the wintering period. Since all progeny were sold at eight months of age, concentrates fed in the stocker scenario were low. System intensity increased in the high price scenario, SH, with beef cow numbers 25% greater than those of the low price scenario. Despite the increase in production

intensity, the high price scenario only returned a modestly higher gross margin. In both cases, gross margin was only slightly greater than SFP receipts and lower than the sum of SFP and REPS payments. Thus, both production systems were greatly financially dependent on non-production based payments.

The calf-to-finish scenarios were considerably more intensive than the calf-to-stocker scenarios, particularly FH which was the most intensive of all scenarios investigated in terms of land area farmed, feed consumed, fertilizer use and animal numbers. In this scenario, 28.2 ha were rented and cow numbers were increased by 70%. Nitrogen use for FL and FH was higher than either SL or SH and was restricted only by the REPS total N limit of 260 kg N/ha. The calfto-finish scenarios had considerably greater gross margins than the calf-to-stocker scenarios due to the increase in animal sales. Despite this, REPS and SFP payments still represented a considerable proportion of gross margins, being 73% and 52% for FL and FH respectively.

Environmental implications: Table 4.3.4 presents the environmental results for the four scenarios investigated. The N imported onto the farm included all N crossing the farm boundary including N fixed by pasture legume species. As expected, N imported was directly related to organic and total N application with the more intensive systems requiring the highest quantities of imported N. Nitrogen exported from the farm was that in animals sold off the farm. Therefore, similar to the N imported value, N exported was directly related to system intensity in the form of sales. It was apparent that the N exported was much lower than that imported and thus the potential for environmental losses was considerable, particularly for FL and FH where N imported was over nine times and almost eight times that exported, respectively. In general, losses for the calf-to-stocker scenarios were much less than losses for the calf-to-finish scenarios. Of the three pathways for N loss investigated, leaching was greater than volatilization or denitrification. The nitrate concentrations in leachate were low in SL and SH, but in FL and FH they were much higher with concentrations of over 45 mg NO_3/l. These values, although within the Nitrates Directive maximum allowable concentration in potable waters, approached this limit of 50 mg NO_3/l. Despite the difference in N exported and N imported, crop removal was between 71% for FL and 88% for SL which suggests that these scenarios were successful in capturing and using a major portion of available soil N.

The data for P losses and accumulation on the farm were similar to N in that P imported represented the P that crossed the farm boundary and P exported was that leaving in animal sold. Since all farm land was in permanent grassland, predicted total P loss in runoff was negligible in all scenarios. There was a sizable difference between P imported and P exported with the difference ranging from 6.2 kg/ha for SL and FH to 7.5 kg/ha for FL. Crop removal rates were between 70% and 91% for SL and FH with the remaining portion accumulating in the soil. This accumulation on the farm is a concern in that it may lead to higher P losses in the future due to increasing soil P levels.

Effects of soil drainage capacity: Results presented thus far were for farms on soils with good drainage. Soil drainage has an important impact on the movement of N through the soil. Figure 4.3.2 presents the effect of soil drainage capacity on nitrogen losses within the four scenarios investigated. Two drainage capacities were considered representing well drained (as per results presented above) and poorly rained soils. There were considerable differences in N losses and N pathways for the two drainage classes. There was a substantial increase in total N loss ranging from 25% for SL to 38% for FL. More specifically, leaching losses increased considerably on well drained soils. In contrast to well drained soils, N lost by leaching was the lowest of the three N loss pathways on poorly drained soils with volatilization and denitrification losses being greater.

Effects of decreasing inorganic N use: From the results presented in Table 4.3.4, it is apparent that finishing systems under both high and low price scenarios (FL and FH) were of most concern with regard to nutrient losses. In particular, N volatilization and leaching losses were high with denitrification losses also considerably greater than those found in either SL or SH. Thus, the impact of reducing inorganic N use for FH by placing a maximum threshold on the farm was explored. The effects on N losses and farm gross margin are presented in Figure 4.3.2

On average, for each 10 kg/ha reduction in applied inorganic N, total N losses were also reduced by 10 kg/ha. More specifically, the reduction in leaching loss was greatest with total leaching losses reduced by almost 40 kgN/ha over the range studied. However, concomitant with the reduction in N losses was a reduction in farm gross margin of over $1,000 for each 10 kg/ha decrease in inorganic N applied. The total reduction in farm gross margin over the range studied was over $6,250.

Conclusions: The management of financially optimum beef production systems leads to intensification of production in many cases particularly where beef prices increase. Such intensification can result in greater N losses to the environment. In scenarios investigated, where beef prices (and input costs) increase, beef cow numbers and net farm gross margin increased by 25% and $1,700, respectively, compared to the low price scenario where progeny were sold as stockers rather than finished. Where progeny were finished, land area farmed increased to facilitate increased cow numbers in the FH scenario and thus, there was little difference in nutrient losses between this and the FL scenario. Leaching of N was of most concern on well-drained soils with volatilization losses greatest on poorly drained soils. Further investigation indicated that there was little incentive for farmers to reduce N application given that such a reduction in inorganic N use resulted in markedly lower gross margins. Agri-environmental programs will continue to be important in promoting more extensive, low N input systems.

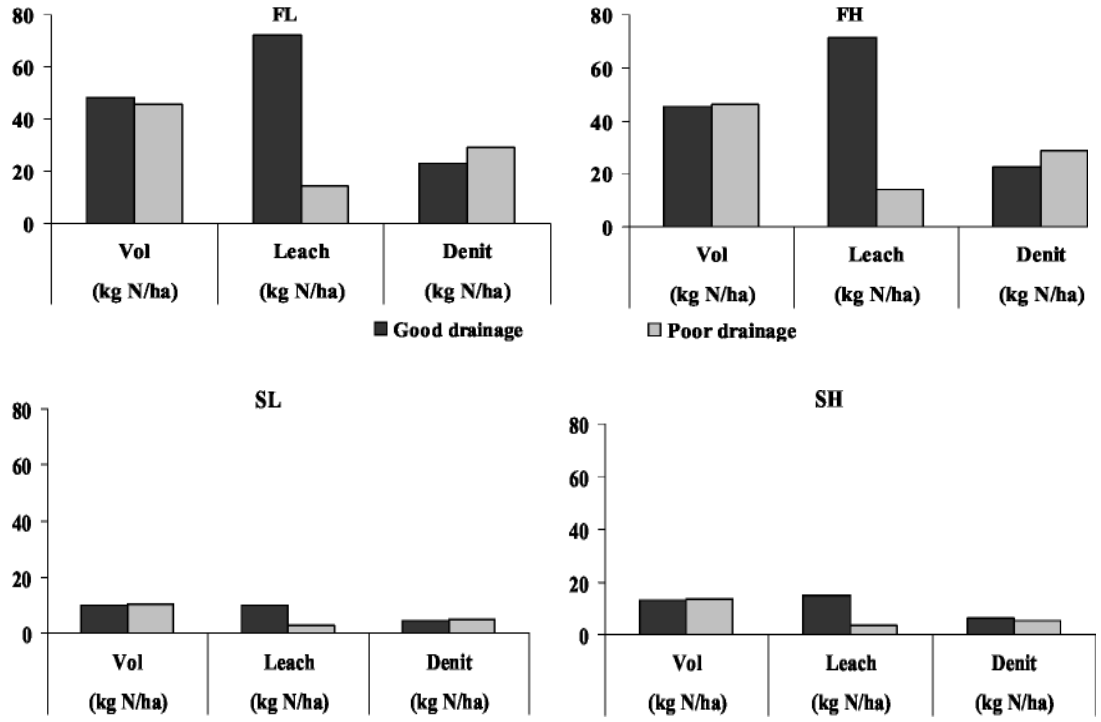

Figure 4.3.1: Impacts of soil drainage capacity on nitrogen losses (Vol, volatilization losses; Leach, leaching losses; Denit, denitrification losses) for the four scenarios investigated using the Integrated Farm System Model (IFSM). The four scenarios are calf-to-stocker low price (SL), calf-to-stocker high price (SH), calf-to-finish low price (FL) and calf-to-finish high price (FH).

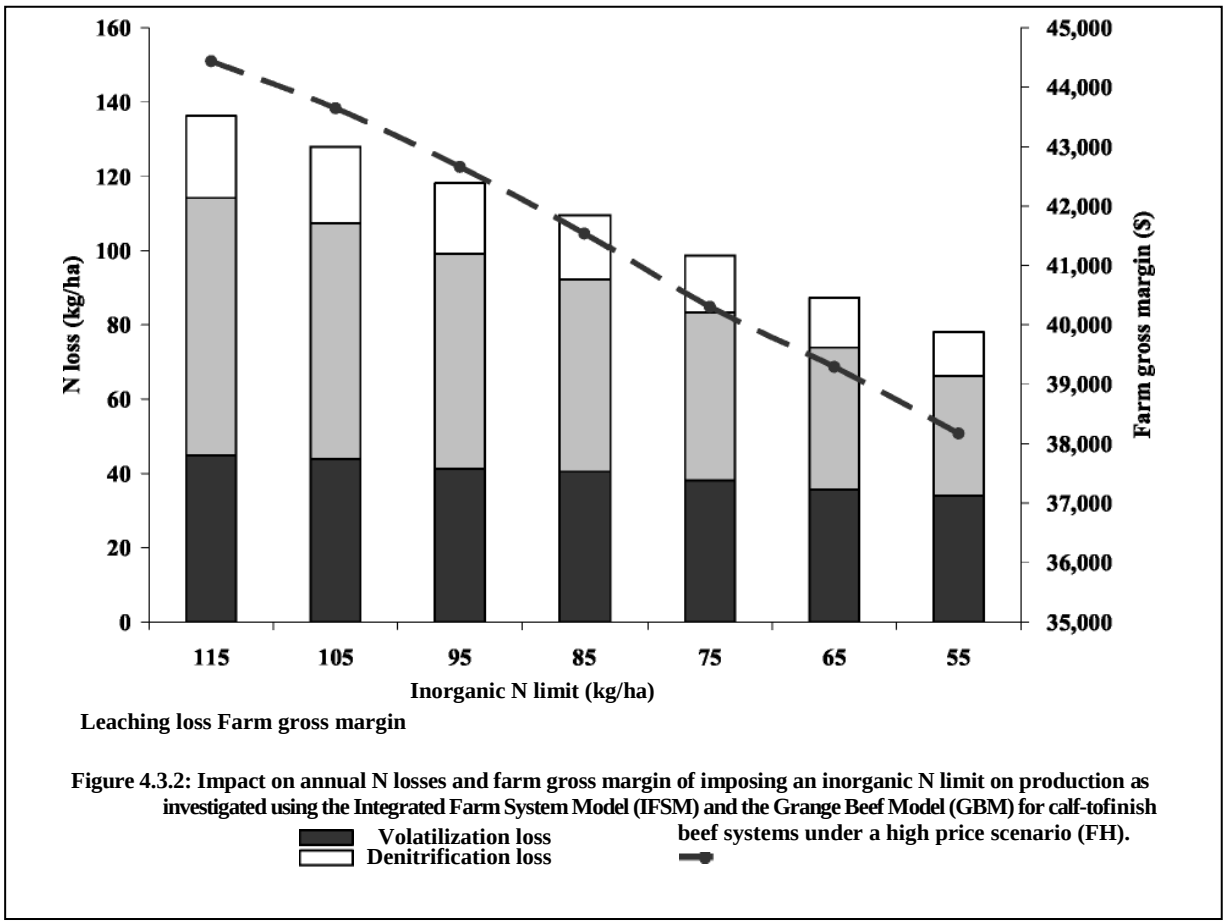

Figure 4.3.2: Impact on annual N losses and farm gross margin of imposing an inorganic N limit on production as investigated using the Integrated Farm System Model (IFSM) and the Grange Beef Model (GBM) for calf-tofinish beef systems under a high price scenario (FH).

Table 4.3.1: Cattle and beef prices for the high price and low price scenarios solved using the Grange Beef Mode(GBM).l

	Low price	High price
Stocker steer price ($[1] per head)	422	464
Stocker heifer price ($ per head)	361	434
Fall beef price (c/kg carcass)	337	404
Spring beef price (c/kg carcass)	349	422
Cull cow price (c/kg carcass)	229	277

[1]$1 = 0.83 €

Table 4.3.2: Optimal production systems for four scenarios investigated using the Grange Beef Model. The four scenarios are calf-to-stocker low price (SL), calf-to-stocker high price (SH), calf-to-finish low price (FL) and calfto-finish high price (FH).

	SL	SH	FL	FH
Land area farmed (ha)	40.0	40.0	40.0	68.2
Land used for grazing only (ha)	35.1	32.1	19.5	32.2
Land used for grass silage harvests (ha)	4.9	7.9	20.5	36.0
Grazed grass consumed (t DM)	87.6	102.2	174.6	295.1
Grass silage consumed (t DM)	22.2	35.4	92.3	161.7
Total concentrates fed (t DM)	0.23	0.28	30.20	48.48
Inorganic N applied (kg N/ha)	14.2	22.6	117.7	118.3
Total N applied (kg N/ha)	72.3	95.4	260.0	260.0
Inorganic P applied (kg/ha)	16.4	17.3	20.9	21.1
Number of beef cows	24.3	30.4	36.9	62.6
Weanling heifers sold (8 months)	10.9	13.7	0.0	0.0
Weanling steers sold (8 months)	10.9	13.7	0.0	0.0
Heifers finished (24 months)	0.0	0.0	16.6	28.2
Steers finished (24 months)	0.0	0.0	16.6	28.2

Table 4.3.3: Financial performance of optimal production systems as predicted using the Grange Beef Model. The four scenarios are calf-to-stocker low price (SL), calf-to-stocker high price (SH), calf-to-finish low price (FL) and calf-to-finish high price (FH).

Scenario	SL	SH	FL	FH
Revenue , $				
Animal sales	11,826	17,189	50,258	102,629
REPS[2]	8,795	8,795	8,795	8,795
SFP[3]	14,458	14,458	14,458	14,458
Interest[4]	97	104	1,303	2,269
Total	35,176	40,547	74,813	128,151
Direct costs, $				
Forage production	9,278	11,132	21,847	39,172
Concentrate purchases	50	71	6,641	12,151
Animal expenses[5]	3,970	4,970	8,113	13,777
Replacement heifers	1,462	2,086	2,222	4,301
Other[6]	4,972	5,179	4,337	14,139
Total	19,732	23,438	43,160	83,540
Gross margin	15,445	17,108	31,653	44,611

1$1 = 0.83 €;[2]Payments received under the Rural Environment Protection Scheme. [3]Single farm payment receipts; [4]Interest earned on cash surpluses; [5]Expenses include veterinary, transport, breeding and miscellaneous animal costs. [6]Includes land rental payments, interest on overdrafts and depreciation.

Table 4.3.4: Environmental indicators of four scenarios as investigated using the Integrated Farm System Model. The four scenarios are calf-to-stocker low price (SL), calf-to-stocker high price (SH), calf-to-finish low price (FL) and calf-to-finish high price (FH).

Scenario	SL	SH	FL	FH
Nitrogen imported to farm (kg/ha)[1]	29.8	42.2	161.0	159.6
Nitrogen exported from farm (kg/ha)[2]	5.8	7.9	17.7	20.3
Nitrogen lost by volatilization (kg/ha)	9.8	13.1	48.2	45.2
Nitrogen lost by leaching (kg/ha)	9.8	14.7	72.1	71.6
Nitrogen lost by denitrification (kg/ha)	4.4	6.5	23	22.5
Nitrate concentration in leachate (mg NO_3/l)	5.3	8.4	46.5	45.1
Crop removal over that available on farm (%)	88	86	71	72
Phosphorous imported to farm (kg/ha)[3]	7.7	8.3	11.9	11.4
Phosphorous exported from farm (kg/ha)[4]	1.5	2	4.4	5.2
Total phosphorous loss in runoff (kg/ha)	0	0	0	0
Soil phosphorous accumulation (kg/ha)	6.2	6.3	7.5	6.2
Crop removal over that available on farm (%)	70	79	89	91

[1] N imported in rainfall, feed purchases, inorganic fertilizer purchases, replacement heifer purchases and N fixed in the soil by micro-organisms; [2] N exported in animal sales; [3] P imported in rainfall, feed purchases, inorganic fertilizer purchases, and replacement heifer purchases; [4] P exported in animal sales.

5. Other

Experiment 5.1: Rates of change in yield and digestibility of grasses grown for silage

[P. O'Kiely]

This experiment determined the rates of change in DM yield and DMD of permanent grassland swards managed for silage under two different cutting frequency schedules.

Materials and Methods: Plots within a *Lolium perenne* (cv. Talbot) dominant sward in five successive years (years 1-5), an old permanent grassland (OPG1) sward in 6 successive years (years1-6) and an alternative old sward (OPG2) in two successive years (years 5-6) were managed as described in Experiment 5.2. On each of these 13 occasions, a split-plot design with 4 replicate blocks was used. The main plots (primary growth and regrowths) were randomly positioned within each block, as were sub-plots (8m x 2m) within main plots. Under harvest schedule A, a primary growth and 3 regrowths were taken on mean dates of 22 May, 3 July, 14 Aug. and 16 Oct. (growths 1-4), respectively, while under schedule B a primary growth and 2 regrowths were taken on 12 June, 14 Aug. and 16 Oct. (growths 1 and 5-6), respectively. On these designated harvesting dates, the main plots allocated to the subsequent regrowths were cleared of herbage (5cm stubble height). Sub-plots within appropriate main plots were harvested at weekly (biweekly for growths 4 and 6) intervals. Individual sub-plots were harvested from late April to the end of June for the primary growth and for regrowths from 3 weeks after the preceding harvest to up to 3 weeks after the subsequent nominal harvest date for that regrowth. Linear regression analyses (Genstat 5, Release 3.2) for each growth related DM yield or DMD to the duration of growth (days from 1 April or from preceding harvest, as appropriate), using data from across years and replicate blocks.

Results: Within each of the 3 grass types or for all grasses combined (Table 5.1.1) the 6 growths had different ($P<0.001$) intercepts and slopes. The linear regressions were significant ($P<0.001$) for all models of DM yield, and for all models of DMD except growths 4 and 6 of *L.perenne* ($P>0.05$), growths 4 ($P<0.01$) and 6 ($P>0.05$) of OPG1, growth 4 ($P>0.05$) of OPG2 and growth 6 ($P>0.05$) when all crops were combined.

Conclusions: The relativity among growths in the rate of increase in DM yield or the rate of decrease in DMD was similar for the 3 grass swards. Growth rates for the first regrowth under harvest schedule A were higher than for the primary growth, with subsequent regrowths being lower. Under harvest schedule B, grass growth rates decreased as the season progressed. The rate of decrease in DMD slowed with successive growths within a harvest schedule.

Table 5.1.1. Linear relationships between yield or digestibility with duration of growth (days)

Growth	Intercept	Slope(m)	s.e. (m)	R^2	MSE	Obs.
Lolium perenne (years 1-5): DM yield (kg/ha)						
1	-900	124.4	4.77	.77	$1.982*10^6$	204
2	-1920	137.3	3.59	.92	$3.296*10^5$	136
3	-975	91.6	5.06	.70	$7.017*10^5$	140
4	164	53.7	4.73	.62	$4.382*10^5$	80
5	-1686	114.2	5.29	.79	$6.063*10^5$	128
6	-170	52.4	5.70	.53	$5.762*10^5$	76
Lolium perenne (years 1-5): DMD (g/kg)						
1	915	-2.9	0.11	.78	$1.027*10^3$	204
2	812	-1.6	0.16	.42	$6.329*10^2$	136
3	772	-0.8	0.20	.09	$1.051*10^3$	140
4	766	-0.2	0.21	.01	$8.343*10^2$	80
5	806	-1.5	0.22	.27	$1.036*10^3$	128
6	750	0.1	0.28	0	$1.339*10^3$	76
OPG1 (years 1-6): DM yield (kg/ha)						
1	707	103.6	4.02	.73	$1.680*10^6$	244
2	-1442	107.6	3.03	.89	$2.694*10^5$	160
3	-1175	85.6	5.14	.62	$8.713*10^5$	168
4	57	52.5	3.80	.67	$3.400*10^5$	96
5	-1390	89.9	6.34	.58	$9.526*10^5$	148
6	-219	54.4	3.98	.67	$3.430*10^5$	92
OPG1 (years 1-6): DMD (g/kg)						
1	932	-3.8	0.16	.72	$2.491*10^3$	244
2	813	-1.5	0.17	.32	$8.405*10^2$	160
3	776	-0.8	0.19	.08	$1.242*10^3$	168
4	786	-0.6	0.20	.08	$9.561*10^2$	96
5	793	-1.4	0.24	.18	$1.397*10^3$	148
6	762	-0.2	0.21	.01	$9.106*10^2$	92
OPG 2 (years 5-6) DM yield (kg/ha)						
1	-307	106.2	4.98	.85	$8.131*10^5$	80
2	-1994	119.5	7.24	.84	$4.757*10^5$	52
3	-225	80.8	3.06	.93	$1.028*10^5$	56
4	210	51.1	4.57	.80	$1.634*10^5$	32
5	-1416	107.0	4.57	.91	$2.294*10^5$	56
6	92	52.7	4.26	.83	$1.424*10^5$	32
OPG 2 (years 5-6) DMD (g/kg)						
1	903	-3.4	0.14	.88	$6.779*10^2$	80
2	811	-1.7	0.34	.33	$1.050*10^3$	52
3	809	-1.8	0.23	.53	$5.846*10^2$	56
4	781	-0.4	0.18	.08	$2.590*10^2$	32
5	804	-1.6	0.24	.45	$6.040*10^2$	56
6	794	-0.6	0.14	.38	$1.624*10^2$	32
All crops combined (n=13) DM yield (kg/ha)						
1	-62	111.9	2.82	.75	$1.783*10^6$	528
2	-1697	120.6	2.82	.84	$5.083*10^5$	348
3	-952	87.1	3.28	.66	$7.674*10^5$	364
4	121	52.8	2.62	.66	$3.502*10^5$	208
5	-1514	102.3	3.88	.68	$8.516*10^5$	332
6	-144	53.2	2.92	.63	$4.024*10^5$	200
All crops combined (n=13) DMD (g/kg)						
1	922	-3.4	0.10	.70	$2.159*10^3$	528
2	812	-1.5	0.11	.35	$8.031*10^2$	348
3	780	-0.9	0.12	.13	$1.100*10^3$	364
4	778	-0.4	0.13	.05	$8.107*10^2$	208
5	800	-1.5	0.14	.25	$1.127*10^3$	332
6	763	-0.2	0.14	.01	$9.842*10^2$	200

MSE = mean square error; Obs. = no. of observations

Experiment 5.2: Yield and digestibility of grasses grown for silage under two contrasting harvest schedules

[P. O'Kiely]

This experiment determined the DM yield and DMD of permanent grassland swards managed for silage under two different cutting frequency schedules.

Materials and Methods: Experimental plots were repositioned within a *Lolium perenne* (cv. Talbot) sward in 5 successive years (years 1-5), an old permanent grassland (OPG1) sward in 6 successive years (years 1-6) and an alternative old sward (OPG2) in 2 successive years (years 5-6). On each of these 13 occasions, a split-plot design with 4 replicate blocks was used. The main (primary and regrowth) plots were randomly positioned within each block, as were sub-plots (8m x 2m; for weekly sampling) within main plots. Under harvest schedule A, a primary growth and three regrowths were taken on mean dates of 22 May (H1), 3 July (H2), 14 Aug. (H3) and 16 Oct. (H4), respectively, while under schedule B a primary growth and 2 regrowths were taken on 12 June (H1), 14 Aug. (H2) and 16 Oct. (H3), respectively. On these designated harvesting dates, the main plots allocated to the subsequent regrowths were cleared of herbage (5cm stubble). Sub-plots within appropriate main plots were harvested at weekly intervals - the latter results are not reported here. N was applied at 126, 114, 101 and 77 kg/ha for H1 to H4 in schedule A and at 126, 114 and 77 kg/ha for H1 to H3 in schedule B. The DM concentrations were determined following drying in an oven with forced-air circulation (98^0C; 16 h), while *in vitro* DMD was determined on samples dried at 40^0C (48h). Data were analysed as a randomised complete block design using models with harvest (n=7), crop (n=13) and block (n=4) and, when combining data across harvests, models with schedule (n=2), crop and block.

Results: The proportion of tillers contributed by different plant types in OPG1 was *Poa trivialis* 0.501, *Agrostis spp*. 0.220, *L. perenne* 0.193, *Alopecuris pratensis* 0.033, *Poa pratensis* 0.029, *Holcus lanatus* 0.015, Festuca rubra 0.003, *Trifolium repens* 0.004 and others 0.002. The corresponding values in OPG2 were 0.350, 0.269, 0.035, 0, 0.002, 0.070, 0.017, 0.018 and 0.041, together with *Bromis mollis* 0.147, *Cynosurus cristatus* 0.019 and *Juncus spp.* 0.019. The mean annual yield of harvested DM was 15717 and 16354 (s.e. 100.8; P<0.001) kg/ha in schedule A and B, respectively. Yields of harvested DM were highest (P<0.001) for H1 in both harvest schedules, and were higher (P<0.001) when H1 was harvested on 12 June rather than 22 May (Table 5.2.1). In both schedules, DM yield for H3<H2<H1 (P<0.05). The combined DM yield for H1+H2 in schedule A was greater than the yield for H1 in schedule B (s.e. 76.5; P<0.001), whereas H1+H2+H3 in schedule A was lower than H1+H2 in schedule B (s.e. 96.3; P<0.001). In schedule A, H1 through to H4 accounted for 0.38, 0.23, 0.19 and 0.20 of the annual DM yield, while in schedule B, H1 to H3 accounted for 0.52, 0.30 and 0.19. Grass DMD in schedule A was in the order H1>H2>H3 or H4 (P<0.05) and for schedule B was in the order H1<H2<H3 (P<0.05). Neither H3 nor H4 in schedule A differed from H3 in schedule B (P>0.05).

The mean weighted DMD for H1+H2 in schedule A (761g/kg) was higher than for H1 in schedule B (679g/kg; P<0.001), while the mean for H1+H2+H3 in schedule A (756g/kg) was higher than for H1+H2 in schedule B (685g/kg; P<0.001), and the annual mean for schedule A (754g/kg) was greater than for schedule B (696g/kg; P<0.001). The corresponding values for the yield of digestible DM were 7288 and 5754 (s.e. 59.3; P<0.001) kg/ha, 9456 and 9125 (s.e. 73.3; P<0.001) kg/ha and 11836 and 11382 (s.e. 75.8; P<0.001) kg/ha. Grass DM concentrations for H1>H2>H3 (P<0.05) in both schedules. The lower values later in the season reflected the more vegetative nature of that herbage. Across years 1-5, annual DM yields were 16620 and 15250 (s.e. 109.4; P<0.001) kg/ha for *Lolium perenne* and OPG1, respectively, with corresponding values for the yield of digestible DM of 12220 and 11030 (s.e. 82.8; P<0.001) kg/ha and for the weighted annual DMD of 737 and 724 (s.e. 2.2; P<0.001) g/kg.

Conclusions

High yields of harvested grass were achieved. Harvest schedule influenced grass digestibility, particularly for H1 and H2. Grass DMD of at least 740g/kg was achieved at a range of stages during the season using schedule A. Even though schedule A resulted in a lower total annual yield of DM than schedule B, it had a 0.04 higher yield of digestible DM.

Table 5.2.1. Grass yield, DMD and DM content for each harvest within the two harvest schedules

	Yield (t/ha)			
	Dry matter (DM)		Digestible DM	
Schedule	A	B	A	B
H1	5955	8483	4537	5754
H2	3642	4828	2751	3371
H3	2926	3043	2168	2257
H4	3194		2380	
s.e.	54.4		40.5	
Signif.	***		***	
	DM digestib. (g/kg)		DM (g/kg)	
Schedule	A	B	A	B
H1	766	679	164	173
H2	756	701	157	148
H3	740	744	136	142
H4	747		144	
s.e.	2.7		1.3	
Signif.	***		***	

Experiment 5.3: Aerobic stability and deterioration of grass silages after mixing with concentrates at feedout

[P. O'Kiely]

This experiment determined the aerobic stability of grass silages and quantified the impacts of mixing with concentrates at feedout.

Materials and Methods: A 50 kg sample was obtained from each of ten precision-chop grass silages. Three sub-samples (each 6 kg) per silage were not mixed with concentrates and three others (also 6 kg silage) were mixed with concentrates (498 g barley, 120 g soyabean meal, 100 g palm kernel expeller, 125 g citrus pulp, 80 g maize gluten, 50 g molasses, 25 g mineral+vitamin premix and 2g oil blend per kg) at an inclusion rate of 75 g per kg silage. Aerobic stability was assessed at 20^0C. Aerobic stability and deterioration data were subjected to two-way analysis of variance using a model that included the effects of silage, concentrates and their interaction.

Results: The mean composition of the concentrates was: dry matter (DM) 852 g/kg, *in vitro* DM digestibility (DMD) 858 g/kg, neutral detergent fibre 222 g/kgDM, ash 72 g/kgDM and crude protein 171 g/kg DM. The silages differed in DM, DMD and fermentation (Table 5.3.1) and ranged from being aerobically stable with minimal aerobic deterioration (Silage I) to unstable with extensive deterioration (Silage C) (Table 5.3.2). Across a wide range of silage aerobic stabilities, inclusion of concentrates did not alter (P>0.05) aerobic stability (indicated by Durations 1 & 2; see footnote to Table 5.3.2). It did not influence the scale of aerobic deterioration (indicated by Accumulated ^{O}C rise) until between 144 and 168 h exposure to air (P<0.05). Only in the case of Silage A did mixing with concentrates affect stability, increasing (P<0.05) Duration 2 and thereby improving stability. Whereas the correlation between Duration 1 and the accumulated ^{O}C rise to 72, 120 and 168 h for silage alone was r = –0.78, -0.87 and –0.93 (all P<0.01), respectively, the corresponding values between Duration 2 and the accumulated ^{O}C rises were r = 0.03, 0.23 and 0.43 (all P>0.1). Thus, using Duration 1 as an index of aerobic stability, the longer it took for silage temperature to rise by >2 ^{O}C the less the extent of subsequent aerobic deterioration (as indicated by the accumulated temperature rises), particularly when the latter were measured over longer durations. In contrast, the relationship between Duration 2 and the extent of aerobic deterioration was relatively weak.

Correlations between silage chemical composition variables (n = 15) and aerobic stability (Duration 1) were between -0.25 and 0.25 (all P>0.2), except for DM (r = 0.50; P = 0.07), ethanol (r = -0.37; P = 0.14) and crude protein (r = -0.34; P = 0.17). Comparable correlations with aerobic deterioration (to 120 h) were between -0.25 and 0.25, except for water-soluble carbohydrates (r = -0.46; P = 0.09) and DM (r = -0.40; P = 0.13). Aerobic stability and deterioration were thus not well related to chemical composition.

Conclusions: Mixing dry concentrates with silage at feedout did not make silage aerobically less stable. However, once aerobic deterioration commenced, having mixed silage with dry concentrates increased the overall extent of deterioration (i.e. with more respirable substrate in silage + concentrates, total aerobic losses increased).

Table 5.3.1. Silage chemical composition

Silage	DM[1] g/kg	DMD[2] g/kg	pH	Lactic g/kgFP[3]	NH_3-N g/kgN
A	202	729	3.7	759	97
B	197	721	3.7	729	94
C	226	722	3.8	767	78
D	224	736	3.9	752	93
E	256	704	3.6	782	58
F	209	664	3.9	689	109
G	183	684	3.9	754	87
H	173	527	4.4	125	157
I	278	650	4.0	557	76
J	250	707	4.0	684	96

[1]Dry matter (corrected for loss of volatiles); [2]*in vitro* DM digestibility; [3]Fermentation products.

Table 5.3.2. Silage aerobic stability and deterioration

	Dur. 1[1]	Dur. 2[2]	ATR[3] 72h	ATR[3] 120h	ATR[3] 168h
Silage (S)					
A	83	66	1	19	62
B	85	42	1	18	54
C	14	27	51	97	144
D	58	24	6	38	62
E	34	24	28	55	90
F	107	53	0	5	35
G	25	71	38	99	14
H	14	31	46	88	124
I	192	-	1	1	2
J	52	34.7	16	42	73
Concentrates (C)					
None	65	34	18	44	73
+ C	68	40	19	49	84
sem[4]	7.5	8.2	3.6	7.2	11.0
P= S	<0.001	<0.001	<0.001	<0.001	<0.001
C	0.478	0.127	0.394	0.102	0.029
SxC	0.928	0.048	0.346	0.133	0.130

[1]Duration (h) until >2°C rise; [2]Duration from >2°C to max. rise; [3]Accumulated °C rise; [4]SxC

Experiment 5.4: Aerobic stability and deterioration of grass silages differing in glucose content

[P. O'Kiely and M. O'Brien]

This experiment quantified the effects of incrementally increasing silage glucose content on aerobic stability and deterioration, and sought to separate the simultaneous effects of increasing soluble substrate and decreasing water activity (a_w).

Materials and Methods: A 250 kg sample was obtained from each of two precision-chop grass silages. Each was thoroughly mixed and thirty 6 kg samples were individually placed in polythene-lined polystyrene boxes. Glucose or NaCl were mixed with the silages at 0, 8.3, 16.7, 25.0 and 33.3 g/kg in a 2 x 5 factorial arrangement of treatments that were replicated in triplicate. Aerobic stability and deterioration were assessed at 20^0C for 192 h as per O'Kiely and Marron (2003). The data were subjected to three-way analysis of variance using a model that separated the effects of silage, added compound, rate of application and all of their interactions.

Results: Silage B fermented more extensively than Silage A but otherwise they had a relatively similar composition (Table 5.4.1). The mean count of yeast and mould colony forming units was 0 and 5 per g Silage A, respectively, and 132 and 5 per g Silage B, respectively, when first exposed to air.

Silage A was aerobically stable and underwent negligible aerobic deterioration, reflecting the low initial yeast and mould counts. Silage B was aerobically less ($P<0.001$) stable (124 vs. 192 h until temperature rose by > 2^0C) and underwent more ($P<0.001$) deterioration (accumulated temperature rise of 43.5 and 2.3 ^{0}C after 192 h) than Silage A (Table 5.4.2). This reflected the higher yeast count in Silage B. Treatment effects were thus larger within Silage B.

Overall, NaCl extended ($P<0.001$) aerobic stability and restricted ($P<0.001$) deterioration more than glucose. There was a trend with Silage B for these effects to be most evident with 16.7 – 33.3 g NaCl/kg. Glucose did not ($P>0.05$) alter the maximum ^{0}C rise whereas 16.7 – 33.3 g NaCl per kg elicited a reduction ($P<0.01$).

Conclusions: Increasing the glucose content of grass silage by up to 33.3 g/kg had little effect on aerobic stability. The responses to incremental levels of glucose or NaCl suggest that whereas additional glucose might promote more extensive aerobic deterioration (i.e. more substrate available to respire), the corresponding reduction in a_w (due to the higher concentration of solute) likely restricted fungal activity and thus prevented such an increase from occurring.

Table 5.4.1. Chemical composition of the two silages when first exposed to air

	Silage A		Silage B	
	Mean[5]	s.d.	Mean[5]	s.d.
DM[1,a]	238	6.4	220	5.2
DMD[2,a]	707	6.4	725	27.6
Crude protein[b]	139	0.6	161	4.7
WSC[3,b]	18	3.6	10	0.1
pH	4.0	0.38	4.0	0.25
Lactic acid[b]	77	16	102	2
Lactic/FP[4,a]	589	165.0	598	56.9
Ethanol[b]	21	10	31	7
Acetic acid[b]	29	24	36	20
Propionic acid[b]	3.4	1.27	2.2	1.38
Butyric acid[b]	2.7	1.43	0.9	0.42
FP[4,b]	134	13.0	172	14.9
NH_3-N[c]	105	26.7	83	27.9

[1]Dry matter; [2]DM digestibility; [3]Water-soluble carbohydrates; [4]Fermentation products; [5]n = 3 [a]g/kg; [b]g/kgDM; [c]g/kgN

Table 5.4.2. Silage aerobic stability and deterioration

Silage (S)	Add. (A)[1]	Rate (R)[2]	Dur.[3]	Max. TR[4]	ATR[5] 120 h	ATR[5] 192 h
A	G[6]	0	192	0.8	2	2
A	G	8.3	192	1.0	2	3
A	G	16.7	192	1.1	2	3
A	G	25.0	188	1.7	2	3
A	G	33.3	192	0.6	1	2
A	Na[7]	0	192	0.5	1	1
A	Na	8.3	192	0.6	1	2
A	Na	16.7	192	0.7	2	2
A	Na	25.0	192	1.0	3	3
A	Na	33.3	192	0.9	2	3
B	G	0	103	22.8	8	61
B	G	8.3	97	26.9	14	73
B	G	16.7	102	23.5	9	65
B	G	25.0	118	24.4	6	53
B	G	33.3	122	22.6	5	47
B	Na	0	109	22.4	5	55
B	Na	8.3	101	23.1	11	47
B	Na	16.7	168	8.8	0	10
B	Na	25.0	163	6.9	1	12
B	Na	33.3	157	6.8	1	13
	s.e.m.[8]		9.4	1.87	3.2	6.7
Significance (P =)						
	S		<0.001	<0.001	0.005	<0.001
	A		<0.001	<0.001	0.096	<0.001
	R		0.006	<0.001	0.242	0.005
	SxA		<0.001	<0.001	0.093	<0.001
	SxR		0.003	<0.001	0.173	0.003
	AxR		0.102	0.005	0.961	0.139
	SxAxR		0.128	0.005	0.963	0.138

[1]Added material; [2]Rate applied (g/kg silage); [3]Duration (h) until > 2[0]C rise; [4 0]C rise; [5]Accumulated [0]C rise; [6]Glucose; [7]NaCl; [8] SxAxR

6. Conclusions

a. Tassilo (early cultivar; FAO 210) reached successive stages of physiological development before Benicia ('late' cultivar; FAO 270). With both cultivars, plastic mulch increased crop DM yield and increased the proportion of crop yield contributed by the cob. This advanced crop maturity and increased starch content. However, in the year with lower sunshine hours (2002) Benicia proved an unsuitable option when grown without plastic mulch. Furthermore, in the less favourable year, the digestibility of the stover fraction of all crops (both cultivars, without or with plastic mulch) fell markedly (by 100 to 200 g digestible DM/kg DM) between early September and early November – for a component contributing approximately half of crop DM, this could have a major impact on crop quality. This highlights the need to be prepared to harvest such crops at earlier rather than later dates.

b. Maize silage of high starch content and digestibility, and supplemented with 3 kg concentrates per day, supported similar growth and feed conversion efficiency by finishing steers as an *ad libitum* concentrates based diet. Fermented whole crop wheat silage made from a crop with 0.5 grain on a DM basis and supplemented with 3 kg concentrates daily supported similar performance as the maize silage diet. Urea-treated, processed whole-crop wheat (716 gDM/kg) supported a poorer feed conversion efficiency than the same crop harvested earlier (404 gDM/kg) as fermented whole-crop. Grass silage with an *in vitro* DM digestibility of 674 g/kg supported a poorer growth rate than any of the other diets. Furthermore, the grass silage based diet produced the yellowest and the urea-treated, processed whole-crop wheat the whitest fat in the carcasses of cattle offered forage-based diets. The maize silage diet supported the highest output of carcass per hectare, due mainly to its high crop DM yield per ha.

c. Feeding whole-crop wheat or barley containing a high proportion of grain (>0.50 g DM/kg) can support a similar level of animal performance to that achieved with good quality maize silage, but with a poorer FCE. Raising the cutting height of wheat or barley (as done here) may not confer an intake, performance or FCE advantage in steers fed the head-cut forage, over and above that achievable from the whole-crop form, and may in fact result in a lower carcass output per hectare. Feeding an *ad libitum* concentrate-based diet to finishing steers offers a superior level of animal performance and FCE compared to that achieved from the forage-based diets examined in this study.

d. Whole-crop cereal silage of higher grain content (relative to straw + chaff) will support higher voluntary intake of nutrients by cattle. This should lead to higher growth rates and improved feed conversion efficiency (on a DM basis).

e. Moist grain systems operate satisfactorily on most farms. The feeding of high-moisture grain could provide an alternative to dry grain when managed properly.

f. The relatively constant grain DM yield, nutritive value and harvesting losses, together with the favourable indices of ensilability, as grain DM concentration of winter barley, wheat and triticale advanced from approximately 550 to over 800 g/kg, indicate that farmers harvesting grain produced using high input practices under Irish conditions can employ a range of conservation technologies without compromising the yield or quality of the harvested grain. In some cases, crops (e.g., barley) allowed to ripen beyond 813 g/kg may suffer grain loss via shattering prior to harvesting, but the qualities of the grain from these ripe crops are similar to the more moist grains.

   Because grain DM concentration increased by an average of 16 to 29 g/kg per day the interval for which grain is at a target DM concentration to harvest can be quite short and grain needs to be monitored at least daily if a target DM concentration is to be achieved at harvest.

- High-moisture grain (HMG - barley, wheat or triticale) stored anaerobically for durations in excess of 100 days can undergo efficient conservation with relatively small quantitative or qualitative losses. Such conservation can be conducted over a wide range of stages of ripeness (above a grain DM concentration of 550 g/kg) and with whole or rolled (i.e. crimped) grain. The additives evaluated differed in mode of action and thus in the types of effects expressed. Even in the absence of additive application, no grain could be described as having preserved badly. Acid 1 generally lead to HMG of lower pH and better aerobic stability than Acid 2. Urea had differential effects on whole and rolled grain, but improved aerobic stability. It was not feasible to determine if it would obviate the requirement for rolling grain prior to feeding to ruminants. Biol 1 was effective at improving aerobic stability subsequent to silo opening, while such benefits were not evident with Biol 2. It was also demonstrated that rewetting grain, as might happen during heavy rain, did not prevent applying these technologies to effective and efficient conservation of grain. Finally, some caution may be required when extrapolating the results presented here to efficiently conserving HMG at a farm scale.
- The ER treatment of wheat (crimped, acid-treated, ensiled moist grain) can be an acceptable alternative to the more traditional PR treatment (propionic acid treated, dry grain rolled at feeding) in conventional finishing beef production systems in Ireland. Good flexibility in time of harvest is required in order to harvest at the desired DM concentration, and excellent silo management is needed to minimize qualitative and quantitative conservation losses or the production of mycotoxins. Since HMG can be successfully conserved and fed to cattle at higher moisture contents than in the present experiment, there is the flexibility to harvest such crops between *circa* 600 and above 700 g DM /kg and obtain comparable animal performance as with conventional ripe grain. Thus, beef farmers have the option to vary their system of cereal grain conservation without major changes to animal performance or product quality. In contrast, the UN treatment (urea-treated, moist whole grain) as used in this experiment was not satisfactory due to the high loss of apparently undigested whole

wheat grains through the animals. In farming practice such grain would have to undergo a processing such as rolling or crimping. Finally, the environmental implications of treatments such as UN need careful assessment.

- The inclusion of grass with red clover gave a clear improvement in herbage yield and digestibility during the first season after reseeding. Comparable improvements in yield and digestibility were mediated by red clover cultivar and harvest schedule, respectively. In contrast, the application of inorganic N in spring resulted in no benefit.

  Swards with Merviot tended to have a higher WSC but a lower crude protein than those with Ruttinova. Red clover in binary mixture with ryegrass generally resulted in higher WSC and ash contents but a lower buffering capacity and crude protein content than when in monoculture. Spring application of inorganic N had little impact on herbage chemical composition, while the early harvest schedule usually resulted in a higher WSC content and a lower buffering capacity and crude protein content compared to the late harvest schedule.
- During the third season after sowing, herbage yield was increased in swards with red clover by including ryegrass in the seed mix, by not applying inorganic N fertiliser in mid-March and by adopting the early harvest schedule. Red clover cultivar did not affect annual yield. The optimum red clover treatment combinations gave herbage yields equivalent to ryegrass mono-culture plus fertiliser N as follows: Cut 1 - grass plus 47 kg N, Cuts 2 and 3 - > grass plus any rate of N fertiliser, and Cut 4 - < grass plus 0 kg N.
- Genatex® (a polyethylene woven black mesh sheet made from a combination of tape and monofilament) was as effective as the standard system involving tyres for restricting aerobic deterioration on the top surface of silage. It was observed that polythene placed between the silo wall and the forage at ensiling, and folded onto the top of the forage, was required to limit aerobic losses below the top corners of the silage.
- Under the prevailing conditions, covering and sealing clamp silos using the Silostop (a co-extruded polyethylene-polyamide film for covering bunker silages. It is 0.045 mm in thickness and comprises two outer layers of polyethylene with a central layer of polyamide) system resulted in equally effective conservation of ensiled forage as the standard system involving two sheets of black polythene. Both systems were successful when operated properly and resulted in negligible surface waste or visible mould.
- Nationally, estimated total (mean) plastic use was 4242 t (4.7 kg/ha) for new pit silage sheets, with corresponding values of 8617 t (21 kg/ha) for baled silage stretch-film, 1059 t (2.5 kg/ha) for baled silage twine/netting, 221 t (56 kg/ha) for maize mulch and 3505 t (1.1 kg/ha) for fertiliser bags. A range of post primary uses of these plastics occurrs which differ depending on the primary use of the plastic and the type of plastic.
- A computer-based model (The Grange Beef Model) that can simulate the physical and financial activities on farms operating suckler beef systems was developed. It has been shown that the model can be used to analyse current or prospective scenarios of interest. Future changes in agricultural policy can be routinely investigated. The sensitivity of optimal systems to price changes can be analysed. Whilst much of the production data is based on performances obtained at Grange Beef Research Centre, the parameters can be modified to reflect other situations. A range of scenarios were investigated, including the effects of altering input or output costs, modifying technical efficiency, increasing stock numbers and investing in capital, as were the implications for the N and P balance on a farm (the latter in conjunction with the use of the Integrated Farm System Model)

7. Acknowledgements

The authors acknowledge the considerable contribution of many people to the research summarised in this report: James Hamill, John Marron, Belynda Weldon and other research technicians at Grange, Grange Laboratories technicians, and farm staff (particularly Jack Lynch and Gabriel Costello), clerical/administration staff and researchers at Grange.

Go raibh míle maith agaibh!!

8. References

Dunne, P.G., Keane, M.G., O'Mara, F.P., Monaghan, F.J. and Moloney, A.P. (2004). Colour of subcutaneous adipose tissue and *M. longissimus dorsi* of high index dairy and beef × dairy cattle slaughtered at two liveweights as bulls and steers, *Meat Sci.* **68**, 97–106.

INRA (2003) INRAtion 3.0 www.inration.educagri.fr

Jarrige R. (1989) Ruminant Nutrition. Recommended allowances and feed tables. John Libbey Eurotext, London, UK, 389pp

Leahy H. (2003) Labour use on beef farms. M.Agr.Sc. Thesis, National University of Ireland, University College Dublin, 2003

Lindo Systems Inc (2002) What's Best! The spreadsheet solver. www.lindo.com

McCarl B.A. and Apland J. (1986) Validation of linear programming models. Southern Journal of Agricultural Economics, 18, 155-164

Rotz C.A., Buckmaster D.R. and Comerford J.W. (2005) A beef herd model for simulating feed intake, animal performance and manure excretion in farm systems. J. Anim. Sci., 83, 231-242

Rykiel E.J. (1996) Testing ecological models: the meaning of validation. Ecological Modelling, 90, 229-244

Teagasc (2004) Management Data for Farm Planning, Teagasc, 19 Sandymount Avenue, Dublin 4, Ireland, 247pp

9. Publications (to date)

Scientific

Crosson, P., O'Kiely, P., O'Mara, F.P. and Wallace, M. (2006). Investigating development options for Irish suckler beef producers using mathematical programming. Journal of Farm Management, 12 (7): 369-383.

Crosson, P., O'Kiely, P., O'Mara, F.P., Wallace, M. (2006) The development of a mathematical model to investigate Irish beef production systems. Agricultural Systems, 89 (2/3): 349-370.

Crosson P., Rotz C.A., O'Kiely P., O'Mara F.P., Wallace M. and Schulte R.P.O. (2007) Modeling the nitrogen and phosphorus inputs and outputs of financially optimal Irish beef production systems. Applied Engineering in Agriculture, 23 (3), 369-377

O'Kiely, P. (2007). Alternative forages to grass for ensilage and as feeds for beef cattle. Zbornik Radova, 44 (2):135-142.

Stacey, P., O'Kiely, P., Hackett, R., Rice, B. and O'Mara, F.P. (2006). Changes in yield and chemical composition of wheat, barley and triticale grains harvested during advancing stages of ripening. Irish Journal of Agricultural and Food Research, 45: 197-209.

Stacey, P., O'Kiely, P., Moloney, A.P. and O'Mara, F.P. (2007). Feeding value for finishing beef steers of wheat grain conserved by different techniques. Livestock Science, 106: 154-168.

Stacey, P., O'Kiely, P., Rice, B. and O'Mara, F.P. (2003). A note on the on-farm moist grain storage and feeding practices in Ireland. Irish Journal of Agricultural and Food Research, 42: 131-136.

Walsh, K., O'Kiely, P.. Moloney, A, P. and Boland, T.M. (2007). Intake, performance and carcass characteristics of beef cattle offered diets based on whole-crop wheat or forage maize relative to grass silage or *ad libitum* concentrates. Livestock Science (in press).

Walsh, K., O'Kiely, P.. Moloney, A, P. and Boland, T.M. (2008). Intake, digestibility, rumen fermentation and performance of beef cattle offered diets based on whole-crop wheat or barley harvested at two cutting heights relative to maize silage or *ad libitum* concentrates. Animal Feed Science and Technology, (in press).

Walsh, K., O'Kiely, P., Taweel, H.Z., McGee, M., Moloney, A, P. and Boland, T.M. (2008). Intake, digestibility and rumen characteristics in cattle offered whole-crop wheat or barley silages of contrasting grain to straw ratios. Animal Feed Science and Technology (submitted).

Technical

Crosson, P., O'Kiely, P., Drennan, M.J., Keane, M.J., O'Mara, F.P. and Wallace, M. (2005). The impact of concentrate price on the utilization of grazed and conserved grass. Proceedings of the 20th International Grassland Congress: offered papers (ed. F.P. O'Mara, R.J. Wilkins, L.t'Mannetje, D.K. Lovett, P.A.M. Rogers & T.M. Boland), Dublin, 26 June to 1 July, 2005. Wageningen Academic Publishers, p901.

Crosson, P., O'Kiely, P., Drennan, M.J., Keane, M.J., O'Mara, F.P. and Wallace, M. (2005). The impact of concentrate price on the utilization of grazed and conserved grass. Utilisation of grazed grass in temperate animal systems. Proceedings of a satellite workshop of the 20th International Grassland Congress (ed. J.J. Murphy), Cork, 3 to 6 July, 2005. Wageningen Academic Publishers, p192.

Crosson, P., O'Kiely, P., O'Mara, F.P. and Wallace, M. (2007). Optimal beef production systems in differing concentrate price and grass utilisation scenarios. Proceedings of the Agricultural Research Forum, Tullamore, 12 & 13 March, 2007, p51.

Crosson, P., O'Kiely, P., O'Mara, F.P. and Wallace, M. (2007). The Grange Beef Model – a mathematical model of Irish suckler beef production systems. Making science work on the farm – a workshop on decision support systems for Irish agriculture (eds. N.M. Holden, T. Hochstrasser, R.P.O. Schulte and S.Walsh), p55-59 [Also: Proceedings of Agmet – making science work on the farm. Thurs. 25 January, 2007 at Teagasc, Johnstown Castle. 1 page.]

Crosson, P., O'Kiely, P., O'Mara, F.P. and Wallace, M. (2003). The development of a whole-farm model to investigate beef production systems. Proceedings of the Seventh British Grassland Society research meeting, University of Wales, Aberystwyth, 1-3 September, p29.

Crosson, P., O'Kiely, P., O'Mara, F.P. and Wallace, M. (2004). The development of a mathematical model to investigate Irish beef production systems. Proceedings of 20th general meeting of European Grassland Federation, Lucerne, Switzerland, 21-24 June, 2004. (Edited), p1205-1207.

Hamilton, W.J., O'Kiely, P. and Forristal, P.D. (2005). Plastic film use on Irish farms. . Proceedings of the Agricultural Research Forum, Tullamore, 14 & 15 March, 2005, p77.

Little, E.M., O'Kiely, P., Crowley, J.C. and Keane, G.P. (2005). Yield and composition of forage maize: interaction of harvest date, cultivar and plastic mulch. Proceedings of the International Silage Conference (in press). Proceedings of the 14th International Silage Conference (and a satellite workshop of the 20th International Grassland Congress) (eds. R.S. Park and M.D. Stronge), Belfast, 3 to 6 July 2005. Wageningen Academic Publishers, p176.

Little, E.M., O'Kiely, P., Crowley, J.C. and Keane, G.P. (2005). Cob development in forage maize: influence of harvest date, cultivar and plastic mulch. Proceedings of the 14th International Silage Conference (and a satellite workshop of the 20th International Grassland Congress) (eds. R.S. Park and M.D. Stronge), Belfast, 3 to 6 July 2005. Wageningen Academic Publishers, p175.

Little, E.M., O'Kiely, P., Crowley, J.C. and Keane, G.P. (2005). Composition of maize stover: interaction of harvest date, plastic mulch and cultivar. Proceedings of the Agricultural Research Forum, Tullamore, 14 & 15 March, 2005, p76.

Little, E.M., O'Kiely, P., Crowley, J.C. and Keane, G.P. (2007). Cob development in forage maize: interaction of harvest date, plastic mulch and cultivar. Proceedings of the Agricultural Research Forum, Tullamore, 12 & 13 March, 2007, p97.

Little, E.M., O'Kiely, P., Crowley, J.C. and Keane, G.P. (2007). Stover development in forage maize: interaction of harvest date, plastic mulch and cultivar. Proceedings of the Agricultural Research Forum, Tullamore, 12 & 13 March, 2007, p98.

Moloney, A.P., O' Kiely, P., Vidal, M., Troy, D.J., O'Sullivan, A. and Kerry, J.P. (2002). The appearance and sensory characteristics of beef produced from grass silage or wheat silage based rations. Proceedings of 13th International Silage Conference, Scottish Agricultural College, Auchincruive, Scotland, 11-13 September, 2002, p18-19.

O'Kiely, P. (2007). Aerobic stability and deterioration of grass silages after mixing with concentrates at feedout. Proceedings of the Agricultural Research Forum, Tullamore, 12 & 13 March, 2007, p99.

O'Kiely, P. (2007). Alternative forages to grass for ensilage and as feeds for beef cattle. Irish Grassland Association Journal, 40: 44-61.

O'Kiely, P. and Drennan, M.J. (2005). Genatex as a protective sheeting for silage. . Proceedings of the Agricultural Research Forum, Tullamore, 14 & 15 March, 2005, p109.

O'Kiely, P. and O'Brien, M. (2007). Aerobic stability and deterioration of grass silages differing in glucose content. Proceedings of the Agricultural Research Forum, Tullamore, 12 & 13 March, 2007, p100.

O'Kiely, P., O'Riordan, E.G. and Black, A.D. (2006). Red clover for silage: management impacts on yield and digestibility during the season after sowing. In: J.Lloveras, A. Gonzalez-Rodriquez, O. Vazquez-Yanez, J. Pineiro, O. Santamaria, L. Olea and M.J. Poblaciones (eds) Sustainable grassland productivity – Proceedings of the 21st general meeting of the European Grassland Federation, Badajoz, Spain. 3-6 April, 2006. p243-245.

O'Kiely, P., O'Riordan, E.G. and Black, A.D. (2006). Red clover for silage: management impacts on yield during the third year after sowing. Proceedings of the Agricultural Research Forum, Tullamore, 15 & 16 March, 2006, p75.

O'Kiely, P. (2004). Rates of change in yield and digestibility of grasses grown for silage. Proceedings of the Agricultural Research Forum, Tullamore, 1-2 March, p51.

O'Kiely, P. (2004). Yield and digestibility of grasses grown for silage under two contrasting harvest schedules. Proceedings of the Agricultural Research Forum, Tullamore, 1-2 March, p93.

O'Kiely, P. and Forristal, P.D. (2003). An alternative plastic film for sealing ensiled forage. Proceedings of the Agricultural Research Forum, Tullamore, 3-4 March, p27.

Rice, B., O'Kiely, P. and Stacey, P. (2001). A fresh look at the preservation and storage of feed grain. Proceedings of Teagasc National Tillage Conference, 31 January, Carlow, p67-79.

Stacey, P., O'Kiely, P. and O'Mara, F. (2001). Optimal growth stage and dry matter concentration for urea or propionic acid treatment of whole crop wheat at ensiling. Proceedings of Agricultural Research Forum, 3 and 4 September, Tullamore p 60.

Stacey, P., O'Kiely, P. and O'Mara, F. (2002). Conservation characterisation of dry concentrates co-ensiled with grass. Proceedings of the Agricultural Research Forum, 11 & 12 March, Tullamore, p43.

Stacey, P., O'Kiely, P., Hackett, R., Rice, B. and O'Mara, F.P. (2006). Changes in yield and chemical composition of wheat, barley and triticale grains harvested during advancing stages of ripening. Irish Journal of Agricultural and Food Research, 45: 197-209.

Stacey, P., O'Kiely, P., Moloney, A.P. and O'Mara, F.P. (2005). Nutritive value for finishing beef steers of wheat grain conserved by different techniques. Proceedings of the 14th International Silage Conference (and a satellite workshop of the 20th International Grassland Congress) (eds. R.S. Park and M.D. Stronge), Belfast, 3 to 6 July 2005. Wageningen Academic Publishers, p154.

Stacey, P., O'Kiely, P., Rice, B. and O'Mara, F. (2002). Survey of on-farm moist grain storage and feeding practices in Ireland. Proceedings of the Agricultural Research Forum, 11 & 12 March, Tullamore, p71.

Stacey, P., O'Kiely, P., Rice, B., Hackett, R. and O'Mara, F.P. (2005). Alternative conservation strategies for high-moisture wheat grains. Proceedings of the Agricultural Research Forum, Tullamore, 14 & 15 March, 2005, p65.

Stacey, P., O'Kiely, P. and O'Mara, F.P. (2002). Conservation characterisation of dry concentrates co-ensiled with grass. Proceedings of 13th International Silage Conference, Scottish Agricultural College, Auchincruive, Scotland, 11 to 13 September, 2002, p222-223.

Stacey, P., O'Kiely, P., Hackett, R., Rice, B. and O'Mara F.P. (2002). Identification of the optimal harvest stage for cereal grains in order to achieve the best balance between yield and composition. Proceedings of 13th International Silage Conference, Scottish Agricultural College, Auchincruive, Scotland, 11 to 13 September, 2002, p392-393.

Stacey, P., O'Kiely, P., Rice, B., Hackett, R. and O'Mara, F. (2003). Changes in yield and composition wheat, barley and triticale grains with advancing maturity. Proceedings of the Agricultural Research Forum, Tullamore, 3-4 March, p128.

Walsh, K., O'Kiely, P. and O'Mara, F.P. (2006). Intake and performance of beef cattle offered conserved whole-crop wheat and barley harvested at two cutting heights relative to maize silage and ad-libitum concentrates. Proceedings of the Agricultural Research Forum, Tullamore, 15 & 16 March, 2006, p52.

Walsh, K., O'Kiely, P., Moloney, A.P. and O'Mara, F.P. (2005). Behaviour and meat colour from beef cattle offered conserved whole-crop wheat and forage maize and ad libitum concentrates and an assessment of the aerobic stability of these forages. . Proceedings of the Agricultural Research Forum, Tullamore, 14 & 15 March, 2005, p66.

Walsh, K., O'Kiely, P., Moloney, A.P. and O'Mara, F.P. (2005). Conserved whole-crop wheat and forage maize feeding value relative to grass silage and *ad libitum* concenrates for beef cattle. Journal of Animal Science, 83 (suppl.1):274-275 and Journal of Dairy Science, 88: 274-275.

Walsh, K., O'Kiely, P., Moloney, A.P. and O'Mara, F.P. (2005). The feeding value of conserved whole-crop wheat and forage maize relative to grass silage and *ad-libitum* concentrates for beef cattle. Proceedings of the 14th International Silage Conference (and a satellite workshop of the 20th International Grassland Congress) (eds. R.S. Park and M.D. Stronge), Belfast, 3 to 6 July 2005. Wageningen Academic Publishers, p166.