grasses for the future

International Conference

Perennial ryegrasses current and future genetic potential

Silver Springs Moran Hotel and Teagasc, Moorepark Research Centre, Cork, Ireland

Organised by Teagasc, Animal & Grassland Research and Innovation Centre, Moorepark, Fermoy, Co. Cork in conjunction with the Department of Agriculture, Fisheries and Food.

Grasses for the Future

International Conference, Cork, Ireland

Thursday, 14 October, 2010

Day 1 of the conference will examine grass breeding and evaluation, and the possibilities of influencing a more accelerated uptake of grass breeding progress at farm level. The conference will provide a forum for stakeholders, breeders, evaluators, grassland scientists and the industry to discuss the grassland traits required to improve livestock production systems.

Friday, 15 October, 2010

Day 2 will feature a workshop at which all stakeholders in the chain from breeder to farmer will be able to discuss their priorities for grassland and seek to influence the future advances in variety development. Two site visits focusing on delivering the advances generated by grass breeding to the industry will take place to the Department of Agriculture, Fisheries and Food Crop Variety Evaluation Site at Ballyderown Farm and Teagasc Moorepark's Grassland Research Programme following the workshop.

Organising Committee

Dr. Pat Dillon (Teagasc)
Dr. Trevor Gilliland (AFBI)
Dr. Padraig O'Kiely (Teagasc)
Mr. Dermot Grogan (DAFF)
Dr. Michael O'Donovan (Teagasc)
Dr. Laurence Shalloo (Teagasc)
Dr. Emer Kennedy (Teagasc)
Dr. Mary McEvoy (Teagasc)
Dr. Deirdre Hennessy (Teagasc)
Ms. Margie Egan (Teagasc)
Dr. Eva Lewis (Teagasc)
Mr. Patrick Conaghan (Teagasc)
Dr. Tommy Boland (UCD)

Compiled by Ms. Margie Egan
Editorial Team: Dr. Michael O'Donovan and Dr. Deirdre Hennessy,
Grassland Science Research Department,
Animal & Grassland Research and Innovation Centre,
Teagasc, Moorepark, Fermoy, Co Cork.

Foreword

Teagasc and the Department of Agriculture, Fisheries and Food are very pleased to host this conference - '**Grasses for the Future**' in Cork, today, October 14th, 2010.

There is renewed interest in grazing systems in many temperate and subtropical regions of the world (especially Europe and USA). This is as a result of lower inflation-adjusted prices, the proposed removal of some subsidies and tariffs, and rising labour, machinery and housing costs. Research shows that the utilization of grass by grazing can provide the basis of sustainable livestock systems in temperate climates as grazed grass is the cheapest source of nutrients for ruminants.

The ongoing reform of the Common Agricultural Policy (CAP) by the European Union (EU), designed to make production more market focussed, suggests more unstable and unpredictable meat and milk prices in the future. Europe is now moving towards a more deregulated market, with milk quotas to be abolished in 2014 and CAP to be further reviewed. International markets and prices are the major factors determining the price farmers receive for their products. Alongside these changes, farmers are making greater use of pasture as the base feed and this aspect of their industry has gained more interest in the last decade. Europe is four years from a free dairy market and we in Ireland need to embrace this challenge. Harnessing any and all competitive advantages we may have is vital if milk and meat production systems in Ireland are to remain viable into the future.

Ireland possesses significant advantages that place the agriculture sector in a strong position to progress and take advantage of the rising long-term demand for food. The livestock industry produces meat and milk products for some of the highest value and highest specification markets in the world. Ireland's temperate climate ensures a long grazing season. New cultivars of perennial ryegrass offer the potential to further increase this by increasing grass growth in the shoulders of the year. Grass breeding and evaluation must now focus on selection of perennial ryegrass cultivars to ensure economic, environmental and social sustainability of the dairy, beef and sheep sectors of Irish agriculture.

This conference and workshop will give all elements of the grassland industry an input into discussing and focussing the future of the sector. This conference provides a unique opportunity for all grassland industry stakeholders (breeders, merchants, farmers, advisors, evaluators and scientists) to participate in strengthening progress in the grassland sector.

Conference Programme - Day 1

SILVER SPRINGS HOTEL, CORK	
08:00	Registration
09:30	Conference Opening
09:45	**SESSION 1: THE IDEAL GRASS**
	Chair: Pat Dillon, Head of Teagasc, Animal & Grassland Research and Innovation Centre, Moorepark **REQUIREMENTS OF FUTURE GRASS BASED SYSTEMS** Michael O'Donovan, Teagasc, Animal & Grassland Research and Innovation Centre, Moorepark **GRASS BREEDING – WHERE WE ARE NOW!** Pete Wilkins, Former Head of Plant Breeding, IGER, Aberystwyth
11:00	Coffee
11:20	**SESSION 2: BREEDING GRASSES FOR THE FUTURE**
	Chair: Michael Casler, USDA-ARS, U.S. Dairy Forage Research Center, Madison, US **PRIORITY TRAITS FOR IMPROVEMENT** Alan Stewart, PGG Wrightsons, New Zealand **OPPORTUNITIES USING NEW TECHNOLOGIES** Pat Conaghan, Teagasc, Animal & Grassland Research and Innovation Centre, Oak Park
12:40	Lunch
14:00	**SESSION 3: IDENTIFYING THE BEST GRASSES**
	Chair: Andrew Cromie, Irish Grassland Association **VARIETY EVALUATION AND GRASSLAND MARKET REQUIREMENTS** Dermot Grogan, Department of Agriculture, Fisheries and Food **CAPTURING THE ECONOMIC BENEFIT OF VARIETY PERFORMANCE** Mary McEvoy, Teagasc, Animal & Grassland Research and Innovation Centre, Moorepark
15:15	Coffee
15:30	**SESSION 4: INDUSTRY UPTAKE OF GRASS BREEDING PROGRESS**
	Chair: Sinclair Mayne, Departmental Scientific Advisor, DARDNI **WHAT ARE THE ECONOMICS OF RESEEDING?** Laurence Shalloo, Teagasc, Animal & Grassland Research and Innovation Centre, Moorepark **MIXTURE CONSTRUCTION – WHAT ARE THE GUIDELINES?** Trevor Gilliland, Agri-Food and Biosciences Institute (AFBI), Plant Testing Station, Crossnacreevy **MARKETING OF IMPROVED GRASS VARIETIES** David Long, Barenbrug, UK
16:45	General Discussion
17:15	Conference Summary – Michael Casler
17:30	Conference Close
19:00	Conference Dinner

Conference Programme - Day 2

MOOREPARK CONFERENCE CENTRE, FERMOY, CO. CORK	
09:00	Introduction and discussion openers from a farmer, advisor and researcher
09:30	**WORKSHOP - DELEGATES WILL BE DIVIDED INTO GROUPS FOR DISCUSSIONS**
11:00	Coffee
11:30	**ROUNDTABLE DISCUSSION INCLUDING FEED BACK FROM GROUPS**
12.45	**SUMMARY OF WORKSHOP** Michael Casler, USDA-ARS, U.S. Dairy Forage Research Centre, Madison, USA
13:00	Lunch
14:00	**FIELD VISITS TO**
	GRASS VARIETY EVALUATION PROGRAMME AT DAFF, BALLYDEROWN FARM **GRASS VARIETY TRIALS AT TEAGASC MOOREPARK**
16:30	Conference close

grasses for the future

Contents

Requirements of future grass based ruminant production systems in Ireland

M. O'Donovan[1], E. Lewis[1], T. Boland[2] and P. O'Kiely[3]

[1]*Animal & Grassland Research and Innovation Centre, Teagasc, Moorepark, Fermoy, Co. Cork, Ireland;* [2]*School of Agriculture, Food Science and Veterinary Medicine, University College Dublin, Belfield, Dublin 4, Ireland;* [3]*Animal and Grassland Research and Innovation Centre, Teagasc, Grange, Dunsany, Co. Meath, Ireland*

Email: michael.odonovan@teagasc.ie

Abstract

There is a renewed interest in grazing systems in many temperate and subtropical regions of the world (especially Europe and USA). This is as a result of lower inflation-adjusted prices, the proposed removal of some subsidies and tariffs, and rising labour, machinery and housing costs. Research shows that the utilization of grass by grazing should provide the basis of sustainable livestock systems as grazed grass is the cheapest source of nutrients for ruminants. Indeed, the competitiveness of grass as a feed in Ireland is unparalleled. This is hugely important as there are approximately 130,000 farmers involved in primary production in Ireland and the value of goods produced by these primary producers was €4.7 billion in 2009. For the future, the key objective for grazing systems is to ensure high grass utilisation, allowing increased output per hectare for all sectors. The primary emphasis in grass breeding needs to be (i) seasonal growth, rather than overall annual growth; (ii) nutritive value, including digestibility, particularly in the mid-season period; (iii) ensuring a sward canopy structure which is suitable for grazing, and (iv) producing persistent varieties that perform under farm conditions. Evaluation programmes should also consider adding an estimate of production potential and persistency at field level as well as at plot level, and evaluation under grazing management systems, as well as under mixed grazing/silage management systems. It is difficult to accurately quantify the breeding achievements for grass mainly because its value, whether grazed or conserved, must be indirectly realised through the output of animal product. There is a challenge to quantify the improvements gained from plant breeding and to integrate these fully into livestock production systems. Better synchronisation of the requirements of grassland farmers with the efforts of researchers, evaluators and breeders will improve the grassland varieties produced in the future, and enable further increases in output per hectare to be achieved.

Keywords: Livestock, grassland, grazing, performance, ruminant nutrition

Introduction

Agricultural policy has major implications for the types of ruminant production systems that develop in different countries. The European Union (EU) Common Agriculture Policy (CAP) was established in 1957 to guarantee food security at stable and reasonable prices to producers, by maximising production and protecting domestic agriculture from foreign competitors. The ongoing reform of the CAP is designed to make production more market focussed, suggesting more unstable and unpredictable meat and milk prices in the future. Europe is now moving towards a more deregulated market, with milk quotas to be abolished in 2014 and CAP to be further reviewed. The deregulation of some southern hemisphere markets has taken place already. For example, the Australian dairy industry was deregulated in 1999. This spelled a decline in dairy farm numbers from 22,000 in 1980 to 10,000 in 2004. Australian dairy farmers, like New Zealand dairy farmers, now operate in a deregulated industry environment. International markets and prices are the major factors determining the price these farmers receive for their products. Alongside these changes, farmers are making greater use of pasture as the base feed and this element of their industry has gained more interest in the last decade.

Future farming systems need to be economically, ecologically and socially sustainable. Ireland possesses significant advantages that place the agriculture sector in a strong position to progress and take advantage of the rising long-term demand for food. The livestock industry produces meat and milk products for some of the highest value and highest specification markets in the world. Our temperate climate and resulting grass production advantage allows us to exploit the competitive advantages associated with grass-based production systems compared with high input systems.

Economic value of ruminant production to the Irish economy

There are approximately 130,000 farmers involved in ruminant production in Ireland. The goods they produce were valued at €5.8 billion at farm-gate level in 2008 (DAFF, 2010). Over 73% of this figure was made up of sales from milk, meat and other livestock. The number of people engaged in ruminant production agriculture decreased by almost a quarter between 1990 and 2008, but because of increased productivity the value of the sector's gross output increased by 24% over the same period.

Dairy

Irelands dairy industry is an export driven sector with 85% of dairy products exported, representing 27% of all food and drink exports in 2008. Ireland has experienced a significant reduction in dairy farm numbers since the introduction of the EU milk quota regime in 1984, from 68,000 in that year to approximately 19,700 in 2008. In 2008 milk accounted for the second-largest share of Ireland's gross agriculture output at 28%, but this decreased to an estimated 22.5% in 2009 due to the decrease in dairy product prices. The value of these exports was €2.3 billion in 2008 (estimated at €2 billion in 2009), with the UK accounting for 32% and the rest of the EU accounting for a further 48% of these exports.

Beef

Ireland exports over 90% of its beef and, in the period since 2000 the share of Irish exports to the lower value and more volatile non-EU markets has declined from over 50% to less than 3%. In addition, fresh beef which is supplied to retail, food services and manufacturing clients in Ireland, and across the EU, now comprises over 90% of all output. This contrasts with the situation less than 10 years ago when the majority of product from the beef processing industry was lower value frozen product. Specialist beef production is the dominant type of farming in Ireland accounting for more than half of all farm enterprises and ranging from 26% to 31% of agricultural output at producer prices in recent years. In 2008 annual turnover was some €2 billion, with beef exports amounting to €1.7 billion, representing 20% of total Irish food and drink exports. As with the decrease in the agricultural sector's total export values in 2009, beef exports also fell considerably, to an estimated €1.4 billion.

Sheep

There are approximately 32,000 sheep flocks in Ireland. Production systems and productivity are significantly different between hill and lowland producers. The national sheep flock has declined steadily over the last 15 years (from 1995), having risen sharply over the previous ten years. The decline has been more pronounced since decoupling and the introduction of the EU - Single Farm Payment (SFP). The number of ewes fell to 2.6 million in June 2008 and, largely as a consequence of this decrease, the output value of sheep and lamb fell to an estimated €159 million in 2009, from €171 million in 2008. The sector is also contending with reduced demand in its export markets. France accounted for more than 50% of Irish sheep meat exports in 2009, at an estimated 21,000 tonnes.

Ireland is an exporting nation in terms of the products from our grassland ruminant industry, and therefore it is imperative that we be competitive. The further exploitation of our grassland systems will require the use of improved grass (and clover) varieties, technologies that greatly increase the intake of high nutritive value grazed herbage throughout an extended grazing season and the rapid transmission of best practice sustainable knowledge and skills to farmers. In the past the achievements and progress in grass breeding have been neglected by the industry, as evidenced by low pasture reseeding rates (Creighton *et al*., 2010). The objective of this paper is to set out the future requirements of livestock systems in Ireland to maximise output from grass.

Exploiting the competitive advantage of Irish production systems

One of the major competitive advantages that Ireland has over many EU countries is the potential production of between 12 and 16 t grass dry matter (DM)/hectare (ha) over a long growing season. This is highlighted in Figure 1 which shows a strong relationship between the total costs of production and the proportion of grass in the dairy cow's diet in a number of countries (Dillon *et al*., 2005). The relationship shows that the average cost of milk production is reduced by 1 cent/litre for a 2.5% increase in grazed grass in the cow's diet. The data also demonstrates that a considerable proportion of the dairy cows diet (50% +) must comprise of grazed grass before a significant impact on cost of production is realised.

In recent years grazing management strategies have been identified to increase the proportion of grazed grass and reduce the dependency on indoor feeding in Irish systems of milk and meat production. Lengthening the grazing season by 27 days has been shown to reduce the cost of milk production by 1 cent/litre. Continued technical innovation in grazing management will further reduce the cost of milk and meat production and therefore underpin the viability of these industries. The efficiency of grass utilization on average Irish dairy and beef farms is relatively low and can be improved significantly through increased stocking rate (SR), adopting new grass varieties and applying modern grazing management technologies.

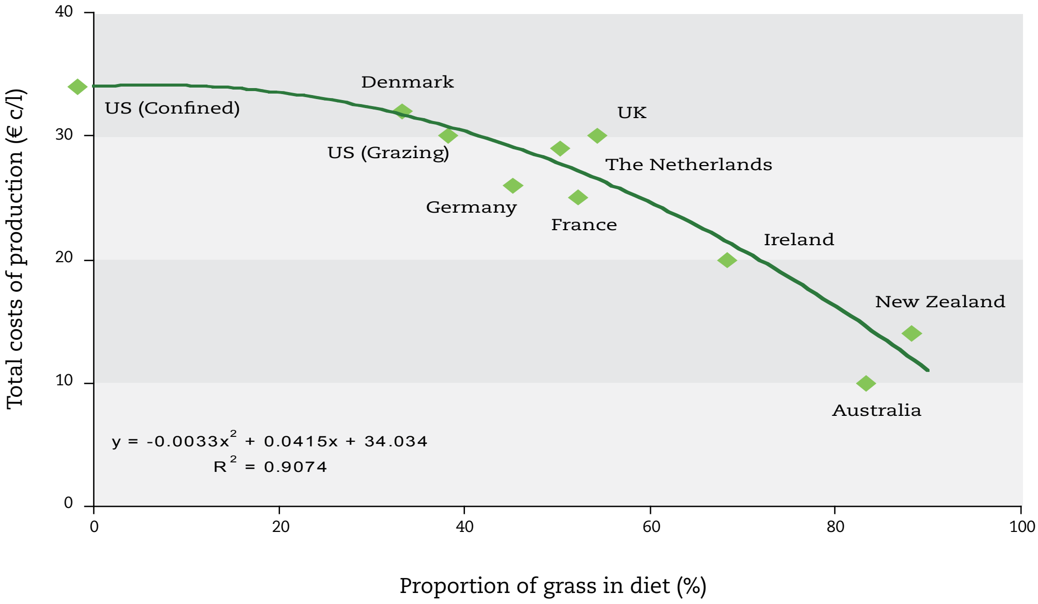


Figure 1: Relationship between total cost of production and proportion of grazed grass in the dairy cow's diet, ranging from total confinement (0% grass) to grass based feed systems (90% grass)

Table 1 shows the relative cost of grazed grass, grass silage, maize silage, rolled barley and kale on a DM basis (with and without land costs) and on a UFL basis at land rental charges of €250, €350 and €450/ha. Costs were calculated using a range of stocking rates and corresponding herbage production: 2.5 livestock units (LU)/ha and 13.5 t DM/ha grown; 2 LU/ha and 12.2 t DM/ha grown and 1.65 LU/ha and 10.3 t DM/ha grown. Different levels of utilisation were also factored into the scenarios. A scenario with perennial ryegrass (PRG) and white clover (WC) at 2 LU/ha was also considered. Using a land rental charge of €350/ha, first cut grass silage is 3.15 times as expensive as grazed grass, second cut silage is 3.18 and rolled barley at €150/ton is 2.2 times as expensive. Maize silage had a slightly lower cost than first cut silage. In addition, the results show that grazed grass is the lowest cost feed, and therefore should be the base feed for ruminants in Ireland. The relative competitive advantage of grazed grass is expected to increase over the next number of years due to higher concentrate price and grass silage costs. Conserved feed costs (both grass silage and maize) are expected to continue to increase relative to grazed grass due to increases in contractor charges associated with inflation in labour, energy and machinery costs.

TABLE 1: The relative cost of grass, silage, kale and concentrate feed at a range of stocking rates, utilisation rates and land costs

	PRG, 2.5LU/ ha, 80% utilised	PRG, 2LU/ ha, 75% utilised	PRG + WC, 2LU/ ha, 75% utilised	PRG 1.65LU/ ha 60% utilised	First cut silage 6.0 t DM/ha	Second cut silage 4 t DM/ ha	Maize silage No-plastic - 13 t DM/ha	Grazed Kale 10 t DM/ ha	Pur-chased Rolled Barley €150/t
Land Cost (€250/ha)									
Total costs (€/t UDM)	65	67	63	87	177	173	148	163	188
No land cost ((€/t UDM)	42	40	31	47	156	150	126	119	-
€/1000 UFL	64	65	62	90	219	221	189	158	162
Relative to grass total cost UFL	1.00	1.02	0.97	1.41	3.42	3.45	2.95	2.47	2.53
Land Cost (€350/ha)									
Total costs (€/t UDM)	75	78	75	104	185	182	157	181	188
No land cost ((€/t UDM)	42	40	31	47	156	150	126	119	-
€/1000 UFL	73	76	74	107	230	232	200	175	162
Relative to grass total cost UFL	1.00	1.04	1.01	1.47	3.15	3.18	2.74	2.40	2.22
Land Cost (€450/ha)									
Total costs (€/t UDM)	84	89	88	120	194	192	166	198	188
No land cost ((€/t UDM)	42	40	31	47	156	150	126	199	-
€/1000 UFL	82	87	86	124	240	244	212	202	162
Relative to grass total cost UFL	1.00	1.06	1.05	1.51	2.93	2.98	2.59	2.46	1.98

UDM – Utilisable Dry Matter, PRG – Perennial ryegrass, WC – White Clover
Source: Finneran and Crossan (2010)

Dairy production systems

Table 2 outlines the overall changes in and impact of management practice at Curtins Farm, Teagasc Moorepark over the last 25 years, from 1984 to current management. The overall objective of the farm systems research is to increase farm profitability per ha by implementing practices to increase the quantity of grass harvested per ha for milk solids production, whilst improving nutrient use efficiency. As illustrated in Table 2, the SR on the farm increased from 2.5 LU/ha in 2005 to 2.8 LU/ha in 2009, while at the same time both concentrate use and inorganic fertiliser use decreased. Improved grazing management practices have resulted in total pasture production increases of 25%, from 12.5 t DM/ha on grazing paddocks in the 2001 to 2005 period to 15.7 t DM/ha in 2009. This increase in total growth resulted in a surplus of 1.6 t DM/ha. Milk solids production per cow fell from 500 kg to 430 kg (2001-2005) due to increased grazing intensity and reduction in concentrate use. The focus of the research in more recent years has been to identify significant quantities of extra feed within the system which, when coupled with a further increase in overall farm SR to 3.3 LU/ha, will facilitate the realisation of increased milk solids production per hectare from home grown feed in future years.

TABLE 2: A comparison of the dairy production systems from 1984 to 2009 at Curtins Farm, Teagasc Moorepark

Year	1984	2001-2005	2007	2009	Target
Stocking rate (LU/ha)	2.91	2.5	2.65	2.82	3.3
Concentrate (kg/cow)	725	350	190	175	300
Fertilizer (kg N/ha)	423	300	305	246	250
Grass growth (t DM/ha/yr)	12.8	12.5	14.7	15.7	18.0
Surplus feed (t DM/ha)	-	-	1.6	1.8	-
Milk solids (kg/cow)	354	500	478	430	460
Milk solids ((kg/ha)	1029	1,250	1,254	1,220	1,518

Source: McCarthy (1984); McCarthy *et al*. (2005); McCarthy *et al*. (2007); Coleman *et al*. (2009)

When capturing the maximum benefits of grazed grass, a key management practice is to have the correct number of cows calving compactly at the beginning of the grass growing season. Stocking rate, traditionally expressed as cows per ha, is the major factor governing productivity from grass. A recent review of SR experiments reported that an increase in SR of 1 cow per ha will result in an increase in milk production per ha of 20% (McCarthy *et al*., 2010). With a current average national mean SR of 1.9 LU/ha, mean calving date of mid-March and calving rate of 59% in first 42 days, the Irish dairy industry is missing out on significant milk production and grass utilisation potential. From a grassland management perspective, recommended best practice is to have a SR of 2.5 to 3.3 cows per hectare on the grazing area platform, with 90% of the herd calving in the first 42 days after calving start date. The focus of efficiency in dairying must target higher grass utilisation per ha. Shalloo (2009) has clearly set out the gains that can be achieved from this. These efficiencies are necessary if swards with high growth capacity are to have a realistic impact in grazing systems. Key targets for the success of this system are to increase grass production to 18 t DM/ha and grass utilisation to 90%; the ultimate output target of the dairy production system should be the production of 1400-1500 kg milk solids/ha.

Beef production systems

There are now, approximately the same number of dairy and suckler cows (1.1 million of each) in Ireland. There are a wide range of beef production systems in use with the two predominate systems today being the grass based dairy calf–to-beef system and suckler calf-to-beef system.

Dairy calf-to-beef

The standard Irish system for taking spring-born male calves from the dairy herd through to finish as steers at 24 months of age, was largely developed on research farms with heavy soils (Keane, O'Riordan and O'Kiely, 2009; Flynn, 1979). In the earliest form of this system Friesian steers were used and grazed grass constituted almost the sole source of feed between March and November, while the average grass silage:concentrate (DM basis) input during the winter was 3.5:1 (Table 3; Flynn, 1979). The guidelines for this early version of the system provide little detail regarding grazing management practices other than to advise that SR should be at a level appropriate to the grass growth and utilisation potential of the farm, and that calves would be rotationally grazed ahead of yearlings (Table 4 and 5; Flynn, 1979). The current calf to beef system described by Keane *et al.* (2009) has grass, silage and concentrate in the proportions of 2.9:1.7:1, respectively, with grazed grass comprising just over half of the feed (51%; Tables 3).

TABLE 3: Feed inputs to steers in spring-born dairy calf-to-beef (24 month) systems in 1979 and 2009

Feed (kg)	Flynn (1979)	Keane *et al.* (2009)
Milk replacer DM	15	25
Grazed grass DM	Not specified	2450
Grass silage DM	1800	1460
Concentrates DM	510	850

The advent of anabolic implants in the early 1980's resulted in a direct increase in carcass weight and carcass output/ha (Table 5; Keane, Flynn and Harte, 1986). With the banning of anabolic implants after the mid-1980's carcass weight per animal and carcass output per ha decreased. In order to retrieve this loss, SR was relaxed and concentrate input increased so that by the late 1980's the output which had been possible a decade earlier with implants was now achieved without them, but carcass output/ha was lower (Table 5; Harte, 1989). Intensification continued into the early 1990s (Table 5; Keane and Drennan, 1991) and was further improved by the replacement of half of the Friesians with Charolais x Friesians and an increase in concentrate input (Keane and Darby, 1992). The system was then de-intensified in order to maximise profits following the reform of the CAP in 1992 together with the need to conform with an upper SR limit of 2 LU/ha for eligibility for the special beef premium and the declining carcass weight threshold for eligibility for selling carcasses into the EU intervention scheme. By the mid 1990s the system sought to minimise costly inputs such as calves and concentrates and maximise carcass value and premia entitlements. This resulted in Friesian and Charolais steers being finished at 24 and 30 months, respectively (Table 5; Keane and Drennan, 1995). In anticipation of future decoupling of premia from cattle in the CAP, the system was modified to achieve an output of 1000 kg carcass/ha using Charolais x Friesian steers (Table 5; Keane and O'Riordan, 1998). Thus, cattle were turned out earlier to pasture and grazed the silage area until the normal turnout date, the number of paddocks in the grazing area was doubled, and herbage in excess of that required for grazing was harvested as round bale silage. Approximately 0.54 of the animals lifetime weight gain was derived from grazed grass, 0.24 from grass silage and 0.22 from supplementary concentrates.

TABLE 4: Target live weight and carcass weight for steers in spring-born dairy calf-to-beef (24 month) systems in 1979 and 2009

	Flynn (1979)	Keane *et al.* (2009)
Liveweight (kg)		
End of first summer grazing	190	240
End of first winter indoors	265	320
End of second summer grazing	445	510
End of second winter indoors	555	650
Carcass weight (kg)	290	350

Source: Flynn (1979) and Keane *et al.* (2009)

The current day system is illustrated in Tables 3 and 5. There is a major emphasis on maximising the intake of grazed grass during an extended grazing season, while the average grass silage:concentrate (DM basis) input during the winter is 1.7:1. The rate of individual animal growth has increased considerably between 1979 and 2009 (Table 4), with the increase coming during both the grazing season and the winter period (mainly due to an increase in the rate of supplementation with concentrates and a consequent reduction in silage intake).

The most immediate constraining limitation to further increasing carcass output/ha is the SR rate restrictions that have been imposed as a result of various EU policies. To show the potential that exists to considerably increase beef output/ha when finishing steers at 24 months of age on a grass and grass silage diet, O'Riordan and O'Kiely (1996) described how achievable increases in grass production, in the proportion of annual feed intake contributed as grazed grass, and in the quality and efficiency of utilisation of grazed grass and grass silage, could increase carcass output from 553 to 970 kg/ha year.

Suckler calf-to-beef

The evolution of Irish suckler beef systems based on spring-calving cows rearing their own calves through to weaning at the end of the first grazing season, and with the weanlings taken through to beef within the system, is summarised in Table 6. Many of the same market forces described above for dairy calf-to-beef systems (i.e. SR restrictions imposed as a result of EU policies, availability/withdrawal of anabolic implants, etc.) also impacted on developments within suckler calf-to-beef systems. Major changes in the system from 1976 to 2010 have included the replacement of traditional early-maturing beef breed sires with late-maturing 'continental' breed sires, the replacement of early-maturing by late-maturing beef breeds in the cross breeding of suckler cows, higher animal growth rates, finishing male progeny as bulls and at a younger age, an earlier start to the grazing season (from mid-April to early March) resulting in an increased contribution of grazed grass to total intake, an increased input of concentrates, a reduced requirement for grass silage, an increase in carcass output/ha and an increase in the number of cow units (cow plus progeny through to finish)/ha. The proportional DM contribution of grazed grass, grass silage and concentrates per cow unit per year within the Grange system was approximately 0.57, 0.39 and 0.04, respectively, in 1976 and is currently 0.6, 0.3 and 0.1 respectively. The target is to move the feed inputs to corresponding values of 0.65, 0.25 and 0.10 for grazed grass, grass silage and concentrate, respectively, in the next three years.

TABLE 5: Evolution of dairy calf-to-beef system in terms of stocking rate, breed, carcass weight, concentrate input and output/ha

Period	Stocking rate[1]	Breed type[2]	Carcass weight (kg)	Concentrates (kg/animal)[3]	Output (kg/ha)[4]	Reference
Late 1970s	0.45	Fr	290	600	640	Flynn, 1979
Early 1980s	0.45	Fr	330	600	730	Keane, Flynn & Harte, 1986
Mid 1980s	0.50	Fr	310	600	620	Harte, 1987
Late 1980s	0.50	Fr	330	750	660	Harte, 1989
Late 1980s	0.45	Fr	320	850	710	Keane & Drennan, 1991
Early 1990s	0.48	Fr	320	850	730	Keane & Darby, 1992
		Ch	380	1150		
Mid 1990s	0.60	Fr	320	1000	600	Keane & Drennan, 1995
		Ch	380	400		
Late 1990s	0.40	Fr	320	1120	830	Keane & O'Riordan, 1998
		Ch	340	1120		
Late 1990s	0.36	Ch	360	1100	1000	Keane, 2000
2009	0.56	Ch	350	1000	630	Keane *et al.*, 2009

[1]ha/animal unit (yearling + calf); [2]Fr = Friesian; Ch = Charolais x Friesian; [3]Lifetime total; [4]Carcass (cold) weight; [5]Finished at 30 months of age

Source: Modification of Keane (2000)

TABLE 6: Evolution of suckler calf-to-beef systems at Grange from 1976 to 2010

Period	Stocking rate (ha/cow unit)[1]	Gender of progeny	Weaning weight (kg)	Yearling weight (kg)	Slaughter age (months)	Slaughter weight (kg)	Carcass weight (kg)	Carcass output (kg/ha)[2]	kg conc / cow unit1	Grazed grass -GG Grass silage -GS Concentrates - C (kg DM/cow unit/ yr)[3]	Reference
1976	0.73	Steer	270	354	25	636	331	384	300		Drennan (1976)
		Heifer	255	309	19	436	230				
1985	0.73	Steer	273	354	25	600 (670[4])	340 (380[4])	395 (438[4])	-		Drennan (1985a, b)
		Heifer	250	309	18	440 (485[4])	236 (260[4])				
	0.63	Bull	295		16		320 (355[4])	441 (488[4])	-		
		Heifer	250		18		236 (260[4])				
1987	0.77	Steer	275	350	25	620-680	340-380	377-429	550	GG: not specified GS: 2700 C: 470	Drennan (1987)
		Heifer	250	325	20	450-520	240-280				
1993	0.77	Steer	300	380	24	700	390	448	600		Drennan (1993)
		Heifer	275	350	20	540	300				
	0.65	Bull			16		350	500	-		
		Heifer			20		300				
1999	0.71	Steer	316	404	24	700	396	497	610		Drennan (1999)
		Heifer	288	373	20	565	310				
2009	0.71	Steer			24	657	368	458	590	GG: 4701 GS: 2477 C: 500	Drennan & McGee (2009)
		Heifer			20	518	282				
	0.88	Steer			24	658	370	370	590		
		Heifer			20	513	281				
	0.56	Bull			15	571	333	549	775	GG: 3940 GS: 1880 C: 660	
		Heifer			20	518	282				
	0.69	Bull			15	582	335	446	775		
		Heifer			20	513	281				
2010	0.54	Bull	320	400	18	665	390	640	685		McGee, Minchin and Crosson (2010)
		Heifer	295	375	20	565	310				

[1] Cow unit = Cow plus progeny to finish [i.e. cow + calf + yearling (excluding replacements)] [2] Mean of male + female progeny only (i.e. cull cow excluded) [3] Annual feed budget [4] Anabolic implants used

Source: McGee (2010)

Sheep production systems

Grass, either grazed or conserved, provides 95-100% of the energy requirements of sheep compared to 90% for dairy cows and 70% for beef cattle. As a result of its high contribution, any improvement in the efficiency of production and utilisation of grass would significantly increase the profitability of sheep farming. Nolan (1972), in a four year SR trial (Low SR - 10 ewes/ha and Medium SR - 15 ewes/ha), found that the mean production of lamb meat was 203 kg/ha (Low SR) and 301 kg/ha (Medium SR). Keady *et al.* (2009) evaluated the performance of mid season lambing ewes on two contrasting management systems - year round grazing (YRG) and a normal seasonal grazing followed by indoor feeding during winter (GWF) (Table 7). Two breed genotypes Belcare and Cheviot-x were also evaluated within this study. The lamb carcass outputs were 501, 458, 365 and 334 kg for the Belcare-GWF, Cheviot-x-GWF, Belcare-YRG, Cheviot-x-YRG, respectively. Carcass output in the Keady *et al.* (2009) study was increased by 40% relative to that reported by Nolan (1972), at similar SR and N inputs. Much of the efficiency of these systems has been from an increase the number of lambs reared per ewe, better synchrony of lambing rate and the earlier onset of grass growth as described in Table 7.

TABLE 7: Increases in output in sheep production systems between 1972 and 2009

Production system	Nolan (1972)		Keady *et al.* (2009)	
	LSR	MSR	GWF	YRG
Ewes/ha	10	15	14.4	10.5
Days at grass	250	245	270	322
Mean lambing date	April 1st	April 1st	March 20th	March 30th
Nitrogen/ha	77	77	85	92
Lambs reared/ewe	1.27	1.24	1.77	1.78
Age at slaughter (days)			168	156
Carcass weight (kg)	15.5	15.3	18.8	18.8
Carcass output/ha (kg)	203	301	479	351
Perennial ryegrass content (%)	5.5	7.5	n/a	n/a
DM Production (t DM/ha)	10.7	10.9		
Concentrates offered/ewe	29.5	29.5	25*	25*
Silage offered (kg DM/ewe)	94	103	220	-

LSR – Low stocking rate; MSR –Medium stocking rate; YRG –Year round grazing; GWF – Grass with winter feeding; *concentrate offered pre lambing

On Irish sheep farms, grassland systems involve a low input of inorganic nitrogen (N) fertiliser. Perennial ryegrass white clover systems can offer production advantages in these circumstances. Humphreys, Casey and Laidlaw (2009) showed that herbage DM production in PRG white clover swards can range from 8.6 to 17.8 t DM/ha, with a range in clover content of 6 to 38.5% in the herbage. Davies and Penning (1996) compared grass clover swards receiving 200 kg N/ha with two SR (15 and 18 ewes/ha) and receiving 50 kg N/ha with three SR (9, 12 and 15 ewes/ha), (Table 8). Lambs were finished at 34 kg live weight. Total lamb output decreased as SR decreased, from 801 to 449 kg/ha. Feed sufficiency in terms of silage made per ewe varied from less than 100% to nearly 300% of the annual requirement of 120 kg/ewe, increasing with reducing SR.

TABLE 8: Inputs and outputs from grass clover swards at different stocking rates and fertiliser N levels, mean of 4 years

Ewes per ha	200N		50N		
	18	15	15	12	9
Lamb output/ha*	801	693	649	542	449
Silage made (kg DM ewe)	98	147	103	179	322
Concentrate fed (kg/ewe)	17	10	24	17	5
Clover (% DM)	4	3	10	11	11

*Liveweight/ha

Source: Davies and Penning, 1996

Nolan (1998) compared old permanent and mainly perennial ryegrass (PRG) pastures with PRG/clover pastures and allocated daily herbage allowances of 1.5, 3.0 and 5.0 kg DM/head/d over two periods (July/September and October/November) (Table 9). There was a significant linear response in live weight gain to increasing herbage allowance on each pasture in each period. Lamb growth rates were similar on the two grass swards but were higher on the grass clover sward.

TABLE 9: Effect of herbage allowance and of pasture type content on lamb growth rate

	Herbage allowance (kg DM/lamb/day)		
	1.5	3.0	5.0
		July/September	
Old Pasture	96	140	152
Perennial Ryegrass pasture	90	139	153
Perennial Ryegrass/clover	117	173	222
		October/November	
Old Pasture	66	134	162
Ryegrass pasture	89	132	146
Ryegrass/clover	111	167	197

Source: Nolan (1998)

Higher animal output with weaned lambs (28%) can be achieved on high clover content pasture. The growth rate achieved on PRG white clover swards depends very much on clover content and intensity of grazing and SR. The potential exists to double lamb output/ha in intensive sheep systems compared to what is achieved nationally on Irish lowland sheep farms. The best technical lowland sheep farms are stocked at 8.3 ewes/ha, achieve weaning levels 25% lower than research flocks, but have 60% higher concentrate input than these flocks (Hanrahan, 2010).

Hanrahan (2010) suggested that intensive sheep systems have the ability to deliver a gross margin of >€1190/ha (Table 10) by applying the most appropriate grazing technology and breed type. Considerable increases in productivity, as output/ha, can be achieved in the sheep sector by adopting current technologies. To further lift lamb output from grazing systems, more focussed innovation is required in the area of PRG white clover to target higher output/ha.

TABLE 10: Potential system performance for mid season lamb production

Item	Performance scenario	
	A	B
Ewes/ha	13	14
Litter size	1.9	2.06
Lambs reared per ewe to ram	1.64	1.78
Concentrate input (kg/ewe)	30	25
Carcass weight	19	19
Carcass output (kg/ha)	405	475
Gross margin per ewe(€)	77	85
Gross margin per hectare (€)	1001	1190

Source: Hanrahan 2010

Silage production on Irish farms

Apart from providing feed primarily for the winter, the production of grass silage also facilitates efficient grazing management, recycling of nutrients from slurry and biological control of internal parasites. Just over 1 mn of ha Irish grassland is harvested for silage at least once during the year (CSO, 2001), and grass silage is made on 87% of Irish farms (Table 11). The average proportions of this total area harvested for first, second and subsequent cuts of silage were 78, 21 and 1%, respectively. These proportions vary among enterprise, with dairy farms placing the highest emphasis on taking a second cut (69:30:1) and sheep farms the least (92:8:0). The emphasis on second and particularly on third harvests of grass for silage has declined in recent years, and this trend is likely to continue as the length of the grazing season increases into the shoulders of the grazing season.

At least twice as much land is used for silage-making on farms involved in dairying (20 ha or more) compared to other enterprises, with the smallest areas being on cattle rearing (7.9 ha) or sheep (7.1 ha) farms (Table 11). Round bale silage (99% of all baled silage) is made on 74% of all farms, and although it is popular across all enterprises (Table 11) and farms sizes, it is particularly common (and often the primary silage-making system) on cattle rearing (84%) and sheep (81%) farms, and smaller sized (82%) farms. In many cases where it is a secondary system (usually dairy farms), it is used tactically to remove grass from paddocks that are surplus to the short-term needs of the herd (thereby facilitating improved grazing management and overall animal nutrition) or to remove small yields that would be difficult or expensive to successfully ensile.

Most estimates of silage digestibility during the past few decades have shown annual national average DM digestibility's between 630-700 g/kg. Grass for silage preservation should always be of good quality and, on average this has been the case (Wilson and O'Kiely, 1990; Keating and O'Kiely, 1997). However, these national averages masked a proportion of unsatisfactorily

TABLE 11: Scale and characteristics of grass silage production in Ireland within different farming enterprises

	Dairying	Dairying/ cattle	Cattle rearing	Cattle fattening	Mainly sheep	Tillage	All systems
% farms making silage	99	98	90	82	71	75	87
Average area of silage (ha/farm)[1]							
- first cut	14.7	14.4	7.0	8.5	6.5	8.0	9.7
- second cut	6.3	5.5	0.9	1.4	0.6	1.7	2.6
- later cut	0.4	0.1	0	0	0	0.1	0.1
- total	21.3	20.0	7.9	9.9	7.1	9.8	12.4
Average area (ha/farm/year)[2]							
- precision chop	15.8	15.3	2.3	4.9	2.1	5.9	7.3
- single/double chop	1.5	1.5	0.9	0.8	1.1	0.6	1.0
- round baler	3.8	2.8	4.6	4.2	3.9	3.0	3.9

[1 & 2] differences in total ha/farm between [1] and [2] due to omission of large square bale, pick-up wagon and other minor harvesting systems from [2]

Source: Teagasc, National Farm Survey (2002)

preserved silages which were more frequent when grass was harvested at an early stage of maturity during wet weather conditions.

Due to the emphasis on grazing silage swards early in spring, crops used for silage production need to grow rapidly between spring grazing and the first silage harvest, and to re-grow rapidly where a second harvest of silage is required. It is desirable that grass cultivars be developed that use soil N more efficiently and/or have a lower requirement for N input. Optimal seed mixtures that boost yield and persistency due to synergies between compatible grasses (Helgadóttir *et al.*, 2008) must be identified. Grasses in a mixture should have similar heading dates to make it easier for a farmer to estimate the optimal growth stage at which to harvest the crop.

Grass clover systems

Current grazing systems employ management practises which are optimised for grass growth, with minimal focus on clover. Grass clover swards are not regularly used despite the low national average SR in Ireland. In New Zealand, despite higher stocking rates, clover is an integral component of grazing dairy systems (Woodfield, 1999). The challenge is to integrate clover more into grazing systems and to develop an understanding of the interactions between grass and clover under grazing. Humphreys *et al.* (2009) reported high levels of milk solids output (1000 kg/ha) from a reasonable SR (2 cows/ha) in high clover content systems. Genetic improvements in white clover have resulted in 1% annual improvements in herbage yield, N fixation and resultant animal performance (Woodfield, 1999). Recent innovations in New Zealand using semi hybrid clover in grazing systems are encouraging. A recent evaluation of semi hybrid clover showed that it produced 50% more DM than conventional clovers over three years. The need for clover is clear in grazing systems, but its successful integration into these systems on farms has yet to be achieved.

Dry matter production increases – targeting the improvements

Potential grass production

Parsons (1988) demonstrated that although the grass sward initially produces the equivalent of 65 t DM/ha (Table 12), because of losses in the system only some 20% of this is eventually harvested. A key component of this loss is death and decay within the sward and this should be minimised.

TABLE 12: Grass production resulting from the growth processes within a sward defoliated at intervals during the year. Data is converted from OM to DM

Total photosynthesis within the grass plant	65.0 t DM/ha
Respiration (nutrients used by plant)	
Shoot	27.6 t DM/ha
Roots (including growth)	8.1 t DM/ha
Shoot decay	16.3 t DM/ha
Harvested DM yield	13.0 t DM/ha

Source: Parsons, 1988

Wright (1978) suggested that a potential yield of 30 t DM/ha was possible and recorded a yield of 24 t DM/ha from experimental plots in Northern Ireland. Cooper and Breese (1971) recorded a top yield of 29 t DM/ha. Teagasc Moorepark has recorded an average DM yield of 14.0 t grass DM from 1982-2009, with variation ranging from 11.0 to 18.6 t DM/ha between years. The potential for grass production is high; if grass breeders can continue progress at a rate of 4-5% per decade (Wilkins and Humphreys, 2003) then there is potential in grassland to produce upwards of 18 t DM/ha. Within Ireland, although growth patterns differ between locations, overall DM production is relatively consistent across sites. Dry matter yields of 15-15.5 t DM/ha can be consistently achieved. These figures are for DM production under plots managed optimally; grass DM production at farm level is more variable due to on farm management factors. Grass DM production on intensive dairy farms ranged from 9.6 t DM/ha to 14.4 t DM/ha in 2009 (O'Donovan, unpublished). There is a challenge for grassland systems, both grazing and silage, to accurately quantify field level DM production.

Dry matter yield gains from forage grass breeding vary widely across Europe. Over the last 50 years gains in DM yield of the important forage grass species, such as PRG, have been 4-5% per decade in North Western Europe, in southern France for Italian ryegrass and in Italy for tall fescue and cocksfoot. Grass DM production from the Northern Ireland recommended variety list (Gilliland, 2007) has increased by 0.04 t DM/year in grazed swards (frequent harvesting) and 0.114 t DM/ha/year in silage swards (infrequent harvesting). These data (Table 13) show a progressive increase in DM production; on average a net increase of 5% DM yield/ha/year over the last decade.

TABLE 13: Increases in herbage production (kg DM/ha/year) in 1994/5, 2003/4 and 2008/9 taken from the Northern Ireland recommended list data 1994-1995 to 2008/09

	Grazing DM yield (t/DM/ha)	Silage DM yield (t/DM/ha)	
1994/5	11.8	13.6	Mean of 50 varieties
2003/4	12.2	14.8	Mean of 50 varieties
2008/9	12.4	15.2	Mean of 52 varieties
Increase (t/ha)	0.6	1.6	
Increase/year	0.04 t DM	0.114 t DM	

Source: T Gilliland - Northern Ireland Recommended List

Seasonality of grass production

Regardless of system or enterprise, on a proportional basis grazed grass is the largest constituent of the ruminant feed budget on Irish farms. (Kennedy *et al*., 2007; Drennan and McGee, 2009; Keady *et al*., 2009). The economic value of grass varies across the growing season (McEvoy, O'Donovan and Shalloo, 2010; Doyle and Elliot, 1983). In particular, improving winter, spring and autumn DM yield is particularly important as this enables an increased inclusion of grazed grass in the diet which can displace other more costly feeds and improve animal performance (Kennedy *et al*., 2005).

A grass growing day is classified in the context of Figure 2 as a day where soil temperature is >5° at 09:00 am. Figure 2 shows a substantial increase in the number of growing days at Teagasc Moorepark from 1990 to the present day. As expected, large year to year variations occurs. Much of this variation occurred during the early 1990's. In 1996, there were 300 growing days, while in 2005 a total of 349 grass growing days were recorded. In total there has been an 18-day increase in growing days from 1990 (319 days) to date.

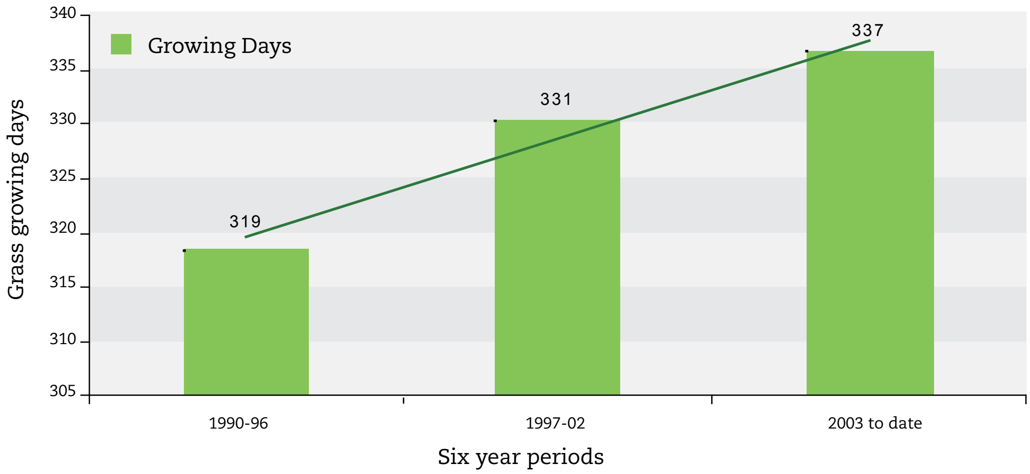


Figure 2: The increase in growing days from 1990 to present day

Broad and Hough (1983) reviewed the climatic factors that affect grass production during the growing season. They point out that in a maritime climate there is a marked lag of temperature behind solar radiation. In spring, the main limiting factor to grass growth is low temperature as radiation levels are relatively high. In autumn, growth is more restricted by low solar radiation, especially in milder areas where temperature does not fall below 6°C until late December. In scenarios of low solar radiation and mild temperatures plant energy reserves are diminished by growth and respiration more quickly than they are replenished through photosynthesis. The potential for growth in late autumn and early spring is also influenced by the physiological state of the grass plant. Initiation of reproductive development towards flowering acts as a stimulus to leaf growth. The estimated leaf extension rate associated with reproductive growth in March and April is 1.1 mm/day/°C compared to 0.4 mm/day/°C for vegetative growth in July to December. A collection of PRG's from the Swiss uplands provides evidence that early spring growth and winter hardiness could evolve together (Tyler, 1988). This suggests that there is potential to extend grass growth earlier in the spring through growth at lower temperatures.

Winter/spring grass growth

Wilkins, Allen and Motton (2000) reported gains in spring grass DM production of 15-18% per decade due to selection of late heading and intermediate heading varieties for early spring growth. Anderson *et al*. (1999) found a 14% difference in winter yield between PRG varieties over a four year period, but a 316% difference in winter yield between tall fescue varieties. In recent years some New Zealand grass varieties have been examined at Moorepark to specifically investigate their winter/spring (October to February) DM production relative to European bred varieties. Table 14 shows the production of these varieties during the winter. Such varieties have the capacity to increase grass growth by up to 500 kg DM/ha during winter.

TABLE 14: Effect of closing date and opening date on the DM production (kg DM/ha) of 12 perennial ryegrass varieties defoliated in February, March across two years (2007-2008)

Opening date	February grazing		March grazing	
Closing date	October	November	October	November
Alto (NZ)	1203	429	1815	1165
Arrow (NZ)	1114	488	1978	1249
Bealey (NZ)	1183	512	1928	1341
Dunloy (NI)	711	175	1211	681
Dunluce (NI)	698	219	1503	878
Glencar (IRE)	707	250	1470	909
Greengold (IRE)	881	203	1517	824
Lismore (DE)	604	184	1234	850
Malone (NI)	726	181	1345	813
Navan (NI)	808	198	1271	736
Portrush (NI)	639	160	1276	774
Tyrella (NI)	747	183	1370	859

NZ- New Zealand; IRE- Republic of Ireland; NI – Northern Ireland; DE- Germany.

Over two years, the winter/spring DM production (October to March) of the three New Zealand varieties were substantially higher yielding than the Irish and European bred varieties - 50% higher in October closed swards and 28% higher in November-closed swards. Such differences can have positive effects on animal output from grazed grass. Varieties such as these, when combined with an appropriate autumn closing strategy, can transform the winter closed period into a period of DM accumulation on Irish farms. Some winter active varieties may have negative quality effects mid-season. The challenge for the future is therefore to capture high levels of spring/winter grass growth and maintain quality throughout the mid season period.

Summer DM production

High peak DM production in May/June, with little emphasis on early-spring/late-autumn DM production, was a characteristic of animal production systems based on a high requirement for conserved grass silage for winter feeding. In recent years, with increased practice of earlier grazing in spring and later grazing in the autumn, characteristics such as early spring and late autumn DM production have become much more important, and the requirement for high peak DM production in May/June is much reduced. High peak DM production in mid-season may trigger sward quality problems that result in reduced animal performance, e.g. low milk protein content, poor live weight gain in growing lambs and beef animals. To overcome this, there has been a large increase in the use of late heading PRG varieties in preference to both early- and mid-season heading PRG varieties.

Autumn DM production

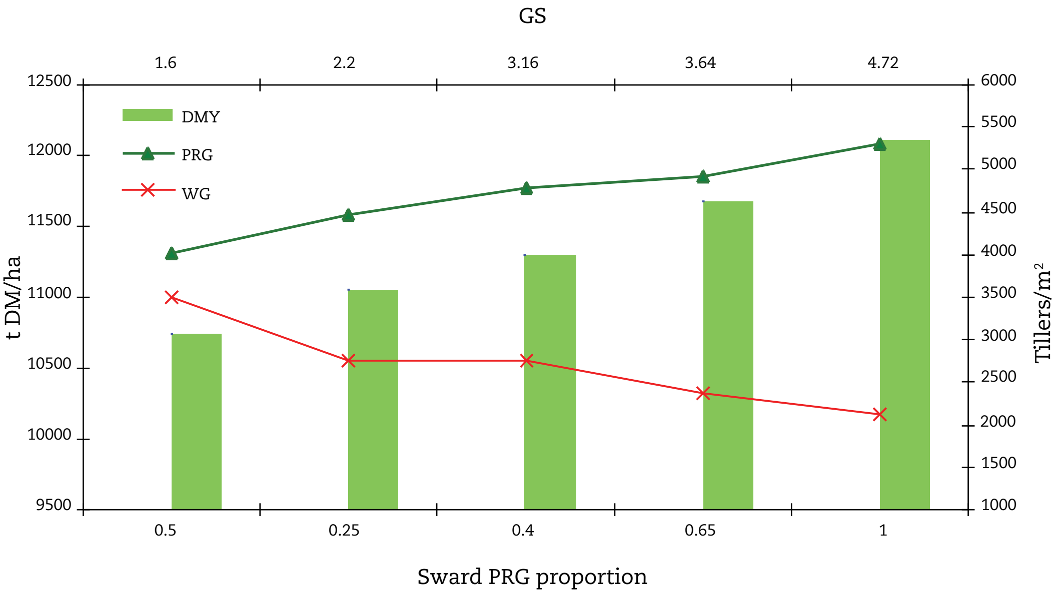
Autumn grass DM availability is crucial and is a major requirement of dairy and beef farmers. The availability of herbage DM in autumn is easy to manipulate with N application level and rotation length (Roche, 1996). O'Donovan *et al*. (2002) reported that each day delay in closing date from October 10th decreases spring grass supply by 10 kg DM/ha/day. If closing date could be delayed and initial spring grazing date maintained (for example by using varieties with significant over-winter growth) animal production performance from grazed grass in late autumn could be greatly improved.

Persistency

Pasture reseeding is an expensive practise, so sward persistence and life time DM performance are important aspects of new grass varieties. Forage grasses and varieties of the same species vary in the rate of tiller survival (Camlin and Stewart, 1978). Over time most swards lose grass tillers and become invaded by unsown species. Persistency of grasses can be measured by evaluating the decline in percentage of ground covered by the sown species or by documenting the DM yield stability of the variety over a number of years. Grasses do differ in their tolerance to heavy treading, which influences their persistency under grazing, however good persistency is difficult to combine with high yield potential (Gilliland and Mann, 2001). In general grasses which persist under frequent close cutting persist well under grazing (Wilkins and Humphreys, 2003).

Wilman and Goa (1996) reported a different response to sward ageing. Italian ryegrass (cv. Multimo), PRG (cv. Bastion) and hybrid ryegrass (cv. Augusta) were sown in 1989 and harvested annually until 1993. Italian ryegrass (IRG) produced a significantly greater DM yield in the first harvest year than either PRG or hybrid ryegrass. In the second, fourth and fifth years, PRG yielded significantly more than either IRG or hybrid ryegrass. The authors suggested that the decline in yield of IRG was as a result of persistency differences. After the third year harvest there were fewer plants in the IRG sward but the tiller density in PRG had increased. Gilliland and Mann (2001) found that PRG and timothy swards maintained significantly higher sward tiller densities than either IRG or hybrid ryegrass.

Grass species which develop a high level of reproductive tillers tend to have less persistence and retain less non structural carbohydrate (NSC) in the stubble. Little green material remains after reproductive growth is harvested and direct regrowth depends on mobilisation of carbohydrate and N reserves in the stubble (Fulkerson and Donaghy, 2001). Figure 3 shows the DM production, tiller density (PRG and weed grass (WG)) and ground cover score (GCS) (% of PRG in the sward) differences of swards with different levels of PRG. As the GS and PRG percentage of the swards increased the DM yield of the swards increased. The DM yield ranged from 10.7 t DM/ha (GCS-1) to 12.1 t DM/ha (GCS - 4.7), (Creighton, unpublished). It is clear from these preliminary data that GCS has a positive effect on the DM yield of a PRG sward. The future challenge is to quantify the lifetime DM yielding ability of a sward within our grazing systems.



*DMY – Dry matter yield; PRG –perennial ryegrass content; WG – Weed grass

Figure 3: Relationship between perennial ryegrass content, DM production and ground score in simulated grazing swards

Improving sward quality attributes

Dairy cows on a grazed grass only diet can achieve a milk yield of approximately 30 kg/cow/day compared to 40 kg/cow/day from a nutrient–dense easy feed diet; of this difference 61% was attributed to reduced digestible DM intake (Kolver and Muller, 1998). Two questions arise at this point; firstly what is preventing the animal from consuming more grass to bring daily intake to a level that satisfies its potential to produce milk and meat; and secondly can we manipulate grass composition through breeding so that cattle and sheep can increase their nutrient intake? Assuming perfect herbage allowance and management conditions, feed intake in ruminants is most likely controlled by both physical and physiological factors. As the energy density of the diet increases and fibre content decreases, physical factors pose less constraint on feed intake and physiological factors become more important. Both the digestibility of forages and rumen fill are strongly related to the cell wall content and the lignification of the cell wall (Van Soest, 1994). The intake of low to medium quality herbage will be mainly limited by rumen fill, but with high quality herbage physiological factors have a role to play. Physiological factors which inhibit microbial activity in the rumen and reduce rumination, saliva flow and rumen contractions would be expected to slow the rate of breakdown of plant material and decrease throughput, and consequently intake. Choosing varieties that have rapid fibre clearance and degradation rates may reduce the residence time of material in the rumen, allow more space for extra grass to be ingested and thereby increase DM intake.

Sward structure is an important quality aspect of grass in relation to DM intake by grazing animals. In order to increase intake, ruminants need to consume plants that have characteristics that allow rapid consumption. Sward structure includes herbage mass, sward surface height, bulk density, tiller density and morphological and botanical composition. Differences in sward structural characteristics and subsequent animal performance between grass varieties are well recognised (Gately, 1984; Gowen *et al*., 2003). O'Donovan and Delaby (2005) obtained higher DM intake and milk production from late heading compared to intermediate heading PRG cultivars, when cows were stocked at different SR's during the main grazing season. The higher performance reported from the late heading PRG cultivars was associated with a higher proportion of green leaf in the grazed horizon (lower stem proportion), leading to higher digestibility coefficients (Table 15). Gately (1984) found a similar result to the low SR treatment. On rotationally grazed swards the herbage availability may be partly determined by the proportion of green leaf in the grazed horizon.

TABLE 15: Effects on milk yield, milk solids yield, grass dry matter intake (GDMI) and organic matter digestibility (OMD) of cows grazing swards of different heading date (HD), grass ploidy (PL) and stocking rate (SR) during a two year study (2000-01)

Heading date	**Intermediate**				**Late**			
Grass ploidy	Diploid		Tetraploid		Diploid		Tetraploid	
Stocking rate	HSR[1]	LSR[2]	HSR	LSR	HSR	LSR	HSR	LSR
Milk Yield (kg/d)	23.2	24.8	24.0	25.2	24.1	25.7	23.7	26.8
Milk Solids (kg/d)	1.47	1.60	1.54	1.66	1.52	1.70	1.52	1.75
GDMI (kg DM)	16.5	18.0	16.4	18.0	17.5	17.9	18.1	19.1
OMD (g/kg DM)	0.83	0.83	0.79	0.80	0.85	0.85	0.85	0.84

[1] HSR – High stocking rate; [2]LSR – Low stocking rate

Source: O'Donovan and Delaby (2005)

Wade *et al*. (1989, 1995) first concluded that herbage availability increased with an increased proportion of green leaf in the bottom of the sward when cows finished grazing. Peyraud, Mosquera-Losada and Delaby (2004) showed that daily allowance of green leaf was a better predictor of DM intake than daily herbage allowance. The challenge for the future will be to develop swards through grass breeding and management that will maintain high DM intake while at the same time allowing high grass utilisation.

Nutritional factors

Traditionally, the traits which were most important in PRG breeding and selection were high forage production and disease resistance (Smit *et al*., 2005). Some of the traits which are important for feeding value, or nutritive value, include the concentrations of crude protein (CP), water soluble carbohydrates (WSC), neutral detergent fibre (NDF), and organic matter digestibility (OMD; Wilkins and Humphreys, 2003).

Crude protein

Nitrogen use efficiency on intensive dairy farms is low, with an average efficiency of N retention in product of between 15 and 26% (Castillo *et al*., 2001). Corresponding values for beef production are <10%. The most limiting factor in the efficiency of N use is the conversion of feed N to milk or meat N. The theoretical maximum efficiency of conversion of dietary N to milk N is 40 to 45% of N uptake (Van Vuuran, Van der Koelen and Vroons-De Bruin, 1986). This efficiency is rarely achieved in pasture-based systems. The CP of well-fertilised, well-managed grass is usually in excess of the requirement of dairy cows, beef cattle or sheep. In Ireland the pasture CP concentration can remain greater than 200 g/kg DM throughout the grazing season in well managed, fertilised pasture (French *et al.*, 2001a; Kennedy *et al.*, 2005; Wims *et al.*, 2010) or in clover rich swards. Thus, increases in CP concentration should not be of primary concern in future grass breeding programmes. The excretion of excess N in urine is potentially polluting and also energetically inefficient. Once the limit for rumen degradable protein use is reached the only way for extra dietary protein to be utilised by the animals is if it bypasses the rumen and is digested in the small intestine. The provision of rumen undegradable, or bypass, protein that is available for degradation in the small intestine may increase milk protein synthesis (Nocek and Russell, 1988). Perhaps future grass breeding programmes should consider the possibility of increasing the undegradable:degradable protein ratio of grass.

Water soluble carbohydrates

Many comparisons of different grasses have inferred that an observed improvement in DM intake (DMI) or animal production was a response to an increase in WSC concentration (MacRae *et al.*, 1985; Moorby *et al.*, 2006). However, it can sometimes be unclear why the response could not equally have been due to a reduction in NDF concentration. Among the mechanisms that can be suggested to explain how higher WSC concentration in grass can directly increase feed DMI and animal performance are increased digestibility of the forage, optimised balance between rapidly fermentable substrate and N in the rumen and improved palatability. The direct effect of elevating WSC on grass digestibility is relatively modest - each 10 g/kg DM increase in the WSC concentration of grass with a DM digestibility (DMD) of 800 g/kg will increase overall DMD by just 2 g/kg. Under such circumstances an increase in WSC concentration of 50 g/kg DM would be required to produce a 10 g/kg increase in DMD. Numerous studies have shown that synchronising the supply of energy and N to rumen microbes can improve the efficiency of microbial protein synthesis (Johnson, 1976; Hoover and Stokes, 1991) with the inference being that this in turn would benefit animal performance. There is evidence that at similar digestibility, PRG varieties of higher WSC concentration are more palatable under conditions where grazing animals had a choice of the varieties to consume (Jones and Roberts, 1991). It is unclear if this palatability effect impacts on DMI or performance of animals offered such cultivars as the sole dietary source.

When Howard *et al.* (2007) fortified zero-grazed grass with a series of rates of added sucrose (i.e. +30 to +120 g/kg DM), DMI increased on average from 6.6 to 7.2 kg/day. This difference in total DMI was equal to the intake of added sucrose. The resultant 0.15 kg liveweight gain response per day was larger than might be expected solely from the supplementary energy provided by the added sucrose. It appears that the scale of elevation of grass WSC concentration needs to be sufficiently large before any improvements in animal performance are recorded. Lee *et al.* (2001) and Miller *et al.* (2001) recorded improvements in animal production in response to increases in grass WSC concentration of 40-50 g/kg DM and 39 g/kg DM, respectively. In contrast, when O'Kiely *et al.* (2005) compared two grasses differing in WSC concentration by an average of 12 g/kg DM throughout a 154 day grazing duration, no measurable differences occurred in the performance of finishing steers. Similarly, Taweel *et al.* (2005; 2006) reported no effect on DMI or milk production by dairy cows where the elevations in grass WSC concentration were 24-31 g/kg DM and 32 g/kg DM, respectively.

Fibre content

Ruminants have a requirement for fibre in order to maintain rumen function and health. Low dietary fibre content can have negative effects on ruminating activity, rumen pH, milk fat concentration and hoof health (Kleen *et al.*, 2003; Owens *et al.*, 1998). The National Research Council (2001) indicates a requirement of 350 g/kg DM forage NDF in the diet. Grass has an NDF content of 350-670 g/kg DM (Dillon *et al.*, 2002; O'Donovan, Delaby and Peyraud, 2005; McEvoy *et al.*, 2008; Owens, McGee and Boland, 2008; Hart *et al.*, 2009) which should be sufficient to meet the dietary fibre requirements of lactating dairy and beef cows. Low rumen pH is often used as an indicator of a deficiency in dietary fibre, and the rumen pH of dairy cows grazing high quality pasture can be low (Gibbs *et al*., 2007; Lewis *et al*., 2010). Yet, there is also evidence to suggest that dairy cows grazing high quality pasture do not need additional NDF (Wales *et al*., 2001). Fibre is potentially 100% digestible in the rumen, thus it is not fibre content but the digestibility/degradability of the fibre that is important (McDonald *et al*., 2002). Minson (1982) confirmed that DM digestibility (DMD) and OM digestibility (OMD) are negatively correlated with the fibre concentration in several forages including grasses. Indeed, lignin concentrations have been used to predict digestibility in-vitro with a correlation coefficient of -0.97 (Morrisson, 1980). When comparing forages with different NDF digestibility but similar NDF and CP contents offered to lactating dairy cows, Oba and Allen (2000) reported significant increases in DMI and milk yield with increased NDF digestibility. A one unit increase in forage NDF digestibility was associated with a 0.17 kg increase in DMI and a 0.25 kg increase in 4% fat corrected milk. It is likely that this increase will occur at a diminishing rate (Oba and Allen, 1999). When considering fibre as a target trait for change via grass breeding and selection programmes, attention needs to be focused on both fibre digestibility and concentration.

Digestibility

The available energy value of grass is frequently characterised by its digestibility (Lukas *et al*., 2005; Agabriel, 2007). The digestibility of a pasture species is mainly influenced by its stage of growth. Vegetative swards in spring consist mainly of live leaf and tend to be of high digestibility (McEvoy *et al*., 2008). Stockdale (1999) and Wales *et al*. (1999) also found that irrigated pastures in spring are usually of high digestibility, with a high CP concentration and possibly low NDF. As the plant matures, the proportion of leaf decreases while stem and dead material accumulates. Consequently the digestibility of the sward tends to decrease. This was demonstrated by Minson (1990) who concluded that the rate of decline in digestibility is associated with an increase in the proportion of leaf sheath, stem and flowering head, a reduction in the proportion of CP and a rise in cellulose, hemicellulose and lignin and an acceleration of the progressive lignification of the cell walls (Gowen, 2002) as the plant matures. Stakelum and O'Donovan (1998) reported that a 5.5% change in leaf content was equal to a 1-unit change in digestibility.

High digestibility has a number of important effects on animal production. Herbage DMI and milk production increase as the digestibility of a sward is increased (Stakelum and Dillon, 1990). Milk composition is also effected, as illustrated by a survey of the management practices of a number of Irish dairy farmers. This survey indicated that the depression in milk protein concentration in the summer period was associated with a reduction in the quality of the grass on offer to the cows at this time (Murphy *et al*., 2008). In beef systems autumn herbage quality is important and Neilan, O'Riordan and Keane (1996) and French *et al*. (2001) have reported major declines in sward digestibility, especially when ceiling pre grazing yield increases.

Previous research has shown that genetic improvements in the digestibility of forages does result in improvements in animal performance by increasing both the energy content of the diet and its DMI (Wilkins and Humphreys, 2003). Breeding programs sometimes focus on digestibility in the vegetative sward. This results in breeding for improved digestibility at one time point during the year and not necessarily improving grass digestibility across the season. Increasing mid-season digestibility is a major factor in increasing ruminant intake during the main grazing season, as illustrated by Murphy *et al*. (2008). It is important that future breeding programmes focus on increasing digestibility across the entire growing season.

Fatty acids

The fatty acid profile of milk and meat is important from a human health perspective and, in the case of milk, from a processability perspective. Decreasing the quantity of saturated fat in milk and meat has beneficial consequences for human health (Mensink *et al*., 2003). In addition, milk and meat also contain specific fatty acids that are positively associated with human health, e.g. cis-9, trans-11 linoleic acid which has anti-carcinogenic properties (Parodi, 2002). It is known that the diet of the lactating cow can significantly alter the fatty acid composition of the resultant milk through the quantity of fatty acid substrate in the feed, biohydrogenation in the rumen and the desaturase activity of the mammary tissue. Fresh grass is an excellent source of the fatty acid C18:3. This fatty acid is an important substrate for the production of some of the key unsaturated fatty acids in milk and meat. This is demonstrated by the results of some recent French research, where Couvreur *et al.* (2006) found that increasing the proportion of fresh grass in the diet, at the expense of maize silage, induced a linear increase in milk unsaturated fatty acids at the expense of saturated fatty acids. The nutritional value of the butter was thus improved, by halving the atherogenicity index. Ferlay *et al.* (2006) demonstrated that, compared with a concentrate diet, pasture decreased milk fatty acids with a putative negative effect (C12:0 to 16:0), and increased those having a potential positive effect (c9 t11 C18:2 and c9 c12 c15 C18:3) on human health. French *et al.* (2001) and Moloney *et al.* (2007) also reported high c9 t11 C18:2 in the meat grazing steers relative to animals fed indoors on concentrate diets. Species, leaf proportion, growth stage, re-growth period and form of grass offered (grazed in situ, zero-grazed, silage) can all affect the grass fatty acid content (Dewhurst *et al.*, 2003; Dewhurst *et al.*, 2001; Elgersma *et al.*, 2003; Mohammed *et al.*, 2009). Elgersma *et al.* (2003) demonstrated that cows fed two cultivars of PRG, differing in C18:3 concentrations, produced milk varying in fatty acid concentration. This indicates that selection for increasing levels of (particular) fatty acids should be considered in grass breeding programmes.

Environmental considerations of grass-based feeding systems

Increased grass digestibility is important from an environmental perspective. Blaxter and Clapperton (1965) demonstrated that at feeding levels greater than three times maintenance, as digestibility increases, methane (CH_4) per kg DMI decreases. Increasing grass available energy content should enable the rumen microflora to utilise more of the ingested N, thus increasing animal production and decreasing N excretion. This would result in a more efficient system for achieving higher performance and less CH_4 emissions per unit grass input. The higher the quality of the feed offered the lower the proportion of energy intake lost as CH_4. This was demonstrated by Wims *et al.* (2010) who compared swards of differing digestibility. Reduced digestibility is often visible in terms of nutritive value as reduced CP and increased cellulose and hemicellulose. This combination is likely to increase enteric CH_4 production by ruminants as the fermentation of structural carbohydrates leads to a greater loss of CH_4 than the fermentation of soluble sugars, starches and protein (Hegarty and Gerdes, 1998).

Urine excretion by grazing cattle can result in point application rates equivalent to 500-1000 kg N/ha in a single event and, although some of this N is lost as ammonia (NH_3), taken up by the sward or immobilised by soil organic matter (OM), a substantial proportion is nitrified to nitrate (NO_3). This soil NO_3 is prone to loss via leaching and denitrification (Whitehead, 1995). The findings of both Miller *et al.* (2001) and Moorby *et al.* (2006) of significant reductions in urinary N excretion by dairy cows grazing grass of high WSC concentration indicate the potential of the WSC to reduce N losses within a grazing system. This effect was confirmed by Howard *et al.* (2007) who reported a linear reduction in the proportion of ingested N excreted via urine and a corresponding increase in the proportion in faeces when zero-grazed steers were supplemented with 0, 30, 60, 90 or 120 g sucrose/kg grass DM. Lee *et al.* (2003) found a reduction in rumen NH_3 concentration in response to sequential increases in WSC intake, suggesting that the partitioning of N from urine to faeces reported by Howard *et al.* (2007) likely reflects an improved efficiency of microbial protein synthesis in the rumen. It has been suggested that grasses of elevated WSC concentration could reduce the amount of energy lost from the rumen as CH_4 (Minson, 1990) due to a shift towards a higher proportion of glucogenic volatile fatty acid (VFA) (Taweel *et al.*, 2005). The limited amount of evidence available to date (Lovett *et al.*, 2004; Taweel, Smit and Elgersma, 2007) are not supportive of this suggestion.

A review by Martin, Morgavi and Doreau (2010) showed that supplements rich in polyunsaturated fatty acids had a negative effect on enteric CH_4 production. The data indicated that supplementation with C18:3-rich supplements caused a decrease in CH_4 production of 4.8% per unit added C18:3; grass is a rich source of C18:3 fatty acid. Johnson and Johnson (1995) explained that fatty acids reduce CH_4 emissions by decreasing ruminal OM fermentation, the activity of methanogens and protozoal numbers, and for lipids rich in unsaturated fatty acids, through hydrogenation of fatty acids. From an environmental perspective grass breeding programmes of the future should focus on increasing digestibility, WSC and polyunsaturated fatty acid content.

Current reseeding rates in Ireland

There is currently a low rate of reseeding practised in Ireland (Creighton, unpublished). For many livestock farmers the initiation of a grassland reseeding program is one of the key changes required to improve the performance and profitability of the livestock production enterprise. The total amount of reseeding in Ireland is low with about 2% of the agricultural area (c. 140,000 ha) being reseeded annually. Given our low SR and poor performance nationally per ruminant animal and per ha it appears that the quality of grass swards on-farm is often substandard. In order to improve our ability to grow grass, further increases in the amount of pastures being reseeded is required.

Summary

The permanent variability in market forces continuously impacts on the relatively short term management practises employed by farmers. All current indications are that any competitive advantage for Irish dairy, beef and sheep production in the coming decades will depend on increased and more efficient utilisation of grass for the sustainable production of high quality milk and meat. In particular, the proportion of annual feed intake contributed by grazed herbage will have to increase to the highest amount practical. This will require the widespread adoption of best practise grassland and grazing management techniques. Central to this on many farms will be introduction of improved varieties of grass and of optimal mixtures of ryegrasses and white clovers, via reseeding of existing pastures.

Plant breeding is a progressive long term process. The primary requirements of grass breeders by the Irish ruminant industry are:

i. to increase grass production, particularly in winter/spring rather than simply on an annual basis,

ii. to improve grass digestibility, particularly mid-season,

iii. to develop grasses that produce sward canopy structures particularly suited to grazing (high green leaf content),

iv. to produce varieties that are persistent under grazing.

Breeding programmes must impose selection pressures relevant to producing varieties suited to grazing only, as well as to grazing/silage management options.

Environmental factors such as greenhouse gas emissions and efficient nutrient use are and will continue to be crucially important. These are affected by many on-farm factors and it is likely that the major contribution of grass breeding to the environmental aspects of sustainable systems will be via their indirect contribution to the overall efficiency and productivity of the system (as outlined above) in the four major breeding requirements. However, a benefit should accrue to the N cycle in grazing systems from a lower crude protein and/or higher WSC concentration.

Grass variety evaluation programs must identify grasses that increase the profitability of Irish dairy, beef and sheep production systems. Simultaneously Irish research must identify optimal grasses, or combinations of grasses and white clover proportions to continually build efficient and sustainable ruminant production systems. Greatly improved mechanisms will be required to facilitate the rapid transfer of new knowledge and the adoption of new technologies by grassland farmers. This will include increased quantification of grass growth and efficiency of utilisation on farms, more accurate and current knowledge of farm costs and the more widespread use of on-farm joint participatory research and development programs.

References

Agabriel, J. 2007. Tables INRA 2007: Alimentation des bovines, ovins et caprins: Besoins des animaux – valeurs des aliments. Editions Quae, c/o INRA, RD 10, 78026 Versailles Cedex.

Anderson, M.W., Cunningham, P.J., Reed, K.F.M. and Bron, A. 1999. Perennial grasses of Mediterranean origin offer advantages for central western Victorian sheep pasture. *Australian Journal of Experimental Agriculture*, **39**: 275-284.

Blaxter, K. L. and Clapperton, J. L. 1965. Prediction of the amount of methane produced by ruminants. *British Journal of Nutrition*, **19**:511-522.

Broad H.J. and Hough M.N. 1983. The growing and grazing season in the United Kingdom. *Grass and Forage Science*, **48**: 26-3.

Camlin, M and Stewart, R.H. 1978. The assessment of persistence and its application to the evaluation of mid season and late perennial ryegrass cultivars. *Journal of the British Grassland Society*, **33**: 275-282.

Castillo, A.R., Kebreab, E. Beever, D.E., Barbi, J.H., Kirb, H.C. and France, J. 2001. The effect of energy supplementation on nitrogen utilisation in lactating dairy cows fed grass silage diets. *Journal of Animal Science*, **79**: 240-246.

Coleman, J., Pierce, K.M. Berry, D.P. and Horan, B. 2009. The influence of genetic selection and feed system on the reproductive performance of spring calving dairy cows within post EU milk quota pasture based production system. *Journal of Dairy Science*, **92**; 5258-5269.

Cooper, J.P. and Breese, E.L. 1971. In: Potential Crop Production. Ed. P.F. Waring and J.P.Cooper.

Couvreur, S., Hurtaud, C., Lopez, C., Delaby, L. and Peyraud, J.L. 2006. The linear relationship between the proportion of fresh grass in the cow diet, milk fatty acid composition and butter properties. *Journal of Dairy Science*, **89**: 1956-1969.

Creighton P., Kennedy, E.,Gilliland, T, Boland, T.M and O'Donovan, M. (2010). The effect of sward lolium Perenne content and defoliation method on seasonal and total dry matter production. EGF, Kiel, Germany. Grassland Science in Europe, Vol 15, pp 904-905.

Creighton, P. 2010. Unpublished.

CSO - Central Statistics Office. 2001. http://www.cso.ie.

CSO - Central Statistics Office. 2010. http://www.cso.ie.

Davies, A. and Penning, P. 1996. Prospects for improving the efficiency of sheep production from grass. *Irish Grassland and Animal ProductionAassociation Journal*, **30**: 129-147.

Department of Agriculture, Fisheries and Food (DAFF). 2010. Future Outlook for Agricultural Commodities. Agri Food Industry Strategy, 2020. www.agriculture.gov.ie.

Dewhurst, R.J., Scollan, N.D., Lee, M.R.F., Ougham, H.J. and Humphries, M.O. 2003. Forage breeding and management to increase the beneficial fatty acid content of ruminant products. *Proceedings of the Nutrition Society*, **62**: 329-336.

Dewhurst, R.J., Scollan, N.D., Youell, S.J., Tweed, J.K.S. and Humphries, M.O. 2001. Influence of species, cutting date and cutting interval on the fatty acid composition of grasses *Grass and Forage Science*, **56**: 68-74.

Dillon, P., Crosse, S., O'Brien, B. and Mayes, R.W. 2002. The effect of forage type and level of concentrate supplementation on the performance of spring-calving dairy cows in early lactation. *Grass and Forage Science*, **57**: 212-223.

Dillon, P., Roche, J.R. Shalloo, L. and Horan, B. 2005. Optimising financial return from grazing in temperate pastures. In: J.J. Murphy (ed.), Utilisation of grazed grass in temperate animal systems. Pp: 131-148.. Proceedings of a satellite workshop of the XXth International Grassland Congress, Cork, Ireland. Wageningen Academic Publishers, The Netherlands.

Doyle, C. J. and Elliot, J.G. 1983. Putting an economic value on increases in grass production. *Grass and Forage Science*, **38**: 169-177.

Drennan, M. 1987. Planned Suckler Beef Production. An Foras Taluntais, Grange/Duninea Research Centre, Dunsany, Co. Meath, Beef Series No. 4, ISBN 0-948321-21-0.

Drennan, M. 1993. Planned Suckler Beef Production, Teagasc, Grange Research Centre, Dunsany, Co. Meath, Beef Series No. 4, ISBN 0 948321 70 9.

Drennan, M.J. 1976. Beef from the Suckler Herd. An Foras Taluntais, Grange, Dunsany, Co. Meath, Handbook Series No. 9, ISBN 0-905442-01-6.

Drennan, M.J. 1985a. Beef production from the suckler herd. Irish Grassland and Animal Production Association Journal 19: 3-12.

Drennan, M.J. 1985b. Feeding the progeny of the suckler herd to slaughter and Suckling systems. In: Beef from the Suckler Herd, Cattle Production Seminar – Grange Research Centre, An Foras Taluntais, 13-19.

Drennan, M.J. 1999. Development of a competitive suckler beef production system. Teagasc, Grange Research Centre, Dunsany, Co. Meath, Beef Production Series No. 18.ISBN 1 84170 087 8.

Drennan, M.J. and McGee, M. 2009. Performance of spring-calving beef suckler cows and their progeny to slaughter on intensive and extensive grassland management systems. *Livestock Science*, **120**: 1-12.

Elgersma, A., Ellen, G., Dekker, P.R., van der Hosrt, H., Boer, H. and Tamminga, S. 2003. Effects of perennial ryegrass (Lolium perenne) cultivars with different linolenic acid contents on milk fatty acid composition. *Aspects of Applied Biology*, **70**: 107-114.

Ferlay, A., Martin, B., Pradel, Ph., Coulon, J.B. and Chilliard, Y. 2006. Influence of grass-based diets on milk fatty acid composition and milk lipolytic system in Tarentaise and Montbéliarde cow breeds. *Journal of Dairy Science*, **89**: 4026-4041.

Finneran, E. and Crosson, P. 2010. Cost of feedstuffs to ruminants, Teagasc Grange, Teagasc internal document.

Flynn, V. 1979. The calf-to-beef system approach to developing the beef production industry. Cattle Production Seminars, An Foras Taluntais, Grange Research Station.15-18 May, 1979, Paper 1, 21 pages.

French, P., Moloney, A.P., O'Kiely, P., O'Riordan, E.G. and Caffrey, P.J. 2001. Growth and rumen digestion characteristics of steers grazing autumn grass supplemented with concentrates based on different carbohydrate sources. *Animal Science*, **72**: 139-148.

French, P., Moloney, A., O'Riordan, E.G. A.P., O'Kiely, P., Caffrey, P.J. 2001. Effects of concentrate level and grazing system on the performance of beef cattle grazing autumn herbage. *Irish Journal of Agricultural and Food Research*, **40**: 33-40.

French, P., Stanton, C. Lawless, F., O'Riordan, E.G., Monahan, F.J., O'Kiely, P., Caffrey, P.J, Moloney, A. 2001. Fatty acid composition, including conjugated linoleic acid of intramuscular fat from steers offered grazed grass, grass silage or concentrate based diets. *Journal of Animal Science*, **78**: 2849-2855.

Fulkerson, W.J. and Donaghy, D.J. 2001. Plant soluble carbohydrate reserves and senescence - key criteria for developing an effective grazing management system for ryegrass-based pastures; a review. *Australian Journal of Experimental Agriculture*, **41**: 261-275.

Gately, T.F. 1984. Early versus late perennial ryegrass (Lolium perenne) for milk production. *Irish Journal Agricultural Research,* **23**: 1-9.

Gibbs, J., Laporte-Uribe, J., Trotter, C. and Noel, J. 2007. Rumen function and lameness in pasture-based dairy cows of the South Island of New Zealand. *Journal of Dairy Science*, **90** (Supp 1): 655 (Abstract).

Gilliland, T. and Mann, R.L. 2001.The silage yield potential of hybrid ryegrass over a 5 year period in Northern Ireland relative to other ryegrasses and timothy. *Grass and Forage Science*, **56**: 305-310.

Gilliland, T. 2007. Recommended Varieties (Grasses and Clover) for Northern Ireland (2007/08). Department of Agriculture and Rural development annual publication.

Gowen, N. 2002. The effects of ploidy and heading date of perennial ryegrass (Lolium perenne) cultivars on sward characteristics and milk production by dairy cows in Ireland. PhD Thesis, National University of Ireland, Dublin.

Gowen, N., O'Donovan, M., Casey, I., Rath, M., Delaby, L., and Stakelum, G. 2003. The effect of grass cultivar differing in heading date and ploidy on the performance and dry matter intake of spring calving dairy cows at pasture. *Animal Research*, 321-336.

Hanrahan, S. 2010. Technical efficiency in the sheep industry- opportunities and potential. Irish Grassland Association Sheep Conference June, 2010.

Hart, K. J., Martin, P.G, Foley, P.A, Kenny, D.A. and Boland, T.M. 2009. Effect of sward dry matter digestibility on methane production, ruminal fermentation, and microbial populations of zero-grazed beef cattle. *Journal of Animal Science*, **87**: 3342-3350.

Harte, F.J. 1987. A comparison of bulls and steers in a two-year-old beef system. Animal Production Research Report, 1987, Teagasc, p13.

Harte, F.J. 1989. Targets for a Friesian steer system. Grange seminar for Teagasc advisors (unpublished).

Hegarty, R. S., and Gerdes, R. 1998. Hydrogen production and transfer in the rumen. *Recent Advances in Animal Nutrition*, **12**: 37–44.

Helgadóttir, A., Connolly, J., Collins, R., Fothergill, M., Kreuzer, M., Lüscher, A., Porqueddu, C., Sebastià, M.T. and Wachendorf, M. 2008. The benefits of sward diversity for cultivated grasslands. In: (eds. Hopkins-A, Gustafsson-T, Bertilsson-J, Dalin-G, Nilsdotter-Linde-N, Spörndly-E.) Biodiversity and animal feed: future challenges for grassland production. Proceedings of the 22nd General Meeting of the European Grassland Federation, Uppsala, Sweden, 9-12 June 2008. *Grassland Science in Europe*, **13**:39-51.

Hoover, W.H. and Stokes, S.R. 1991. Balancing carbohydrates and proteins for optimum microbial yield. *Journal of Dairy Science*, **74**: 3630-3644.

Howard, H., O'Kiely, P., Moloney, A.P. and O'Mara, F.P. 2007. Intake, digestibility, N metabolism and growth in growing steers offered zero-grazed grass supplemented with sucrose. Proceedings of the Agricultural Research Forum, Tullamore, 12 & 13 March, 2007, p12.

Humphreys, J., Casey, I.A. and Laidlaw, A.S. 2009. Comparison of milk production from clover based and fertiliser N based grassland on a clay loam soil under moist temperate climatic conditions. *Irish Journal of Agriculture and Food Research*, **48**: 189-208.

Johnson, K.A. and Johnson, D.E. 1995. Methane emissions from cattle. *Journal of Animal Science,* **73**: 2483-2492.

Johnson, R.R. 1976. Influence of carbohydrate solubility on non-protein nitrogen utilization in the ruminant. *Journal of Animal Science*, **43**: 184-191.

Jones, E.L. and Roberts, J.E. 1991. A note on the relationship between palatability and water-soluble carbohydrates content in perennial ryegrass. *Irish Journal of Agricultural Research*, **30**: 163-167.

Keady, T., Hanrahan, J.P. and Flanagan, S. 2009. An evaluation of two grassland based systems of mid season prime lamb production using proloific ewes of two genotypes. *Irish Journal of Agricultural and Food Research*, **48**: 87-101.

Keane, M.G. 2000. Producing 1000 kg carcass beef per ha per annum in a dairy calf-to-beef system. Farm & Food, Teagasc, Autumn, 10 (2): 4-7.

Keane, M.G. and Darby, T.E. 1992. Production systems (steers and heifers). In: Essential Technology for Beef Farmers, Beef Series No. 10, Teagasc.

Keane, M.G. and Drennan, M.J. 1991. Two-year-old beef production from Friesian and beef x Friesian steers. Beef Series No. 9, Teagasc.

Keane, M.G. and Drennan, M.J. 1995. Dairy calf-to-beef systems and prospects for extensification in Ireland. In: Extensification of beef and sheep production in grassland, Occasional Publication No. 2 for EU AIR3-CT93-0947. Editors M.G. Keane and A. Pflimlin, p107-122.

Keane, M.G. and O'Riordan, E.G. 1998. Development of a competitive forage-based dairy calf-to-beef system. Beef Production Series No. 2, Teagasc.

Keane, M.G., Flynn, A.V. and Harte, F.J. 1986. Responses to sequential use of different anabolic agents in young bull, young steer and two-year-old steer beef systems. *Irish Journal of Agricultural Research*, **25**: 153-166.

Keane, M.G., O'Riordan, E.G. and O'Kiely, P. 2009. Dairy calf-to-beef production systems. Teagasc, Grange Beef Research Centre. 55 pages.

Keating, T. and O'Kiely, P. 1997. Irish farm silages 1993-1996. Proceedings of the Agricultural Research Forum, 3-4 April. Teagasc. p123-124.

Kennedy, E., O'Donovan, M., Murphy, J.-P., Delaby, L. and O' Mara, F. 2005. Effects of grass pasture and concentrate-based feeding systems for spring-calving dairy cows in early spring on performance during lactation. *Grass and Forage Science,* **60**: 310-318.

Kennedy, E., O'Donovan, M., Murphy, J.P., O'Mara, F. and Delaby, L. 2007. The effect of initial spring grazing date and subsequent stocking rate on the grazing management, grass dry matter intake and milk production of diary cows in summer. *Grass and Forage Science,* **61**: 375-384.

Kleen, J.L., Hooijer, G.A., Rehage, J. and Noordhuizen, J.P. 2003. Subacute ruminal acidosis (SARA): a review. *Journal of Veterinary Medicine Series A Physiology Pathology Clinical Medicine,* **50**: 406-414.

Kolver, E.S. and Muller, L.D. 1998. Performance and nutrient intake of high producing Holstein cows consuming pasture or a total mixed ration. *Journal of Dairy Science*, **81**: 1403-1411.

Lee, M.R.F., Jones, E.L., Moorby, J.M., Humphreys, M.O., Theodorou, M.K., MacRae, J.C. and Scollan, N.D. 2001. Production responses from lambs grazed on *Lolium perenne* selected for an elevated water-soluble carbohydrate concentration. *Animal Research*,, **50**: 441-449.

Lewis, E., Coughlan, F., O'Donovan, M. and Wims, C. 2010. The effect of grazing different pasture herbage masses on rumen pH in lactating dairy cows. In: Proceedings of the British Society of Animal Science and Agricultural Research Forum, Belfast, Northern Ireland, p. 293.

Lovett, D.K., Bortolozzo, A., Conaghan, P., O'Kiely, P. and O'Mara, F.P. 2004. In vitro total and methane gas production as influenced by rate of nitrogen application, season of harvest and perennial ryegrass cultivar. *Grass and Forage Science*, **59**: 227-232.

Lukas, M., Südekum, K.-H., Rave, G., Friedel, K. and Susenbeth, A. 2005. Relationship between faecal crude protein concentration and diet organic matter digestibility in cattle. *Journal of Animal Science*, **83**: 1332-1344.

MacCarthy, D. 1984. Milk production from grassland, p1-66 In Moorepark 25th Anniversary Publication. Part 1; Milk production; AFT publication.

MacRae, J.C., Smith, J.S., Dewey, P.J.S., Brewer, A.C., Brown, D.S. and Walker, A. 1985. The efficiency of utilisation of metabolisable energy and apparent absorption of amino acids in sheep given spring and autumn harvested dry grass. *British Journal of Nutrition*, **54**: 197-209.

Martin, C., Morgavi, D.P. and Doreau, M. 2010. Methane mitigation in ruminants: from microbe to the farm scale. *Animal*, **4**: 351-365.

McCarthy S., Horan, B., Dillon, P., Berry, D.P., O'Connor, P., Rath, M. and Shalloo, L. 2007. Economic Comparison of Divergent Strains of Holstein-Friesian Dairy Cows in Various Pasture-based Production Systems. *Journal of Dairy Science*, **90**: 1493-1505.

McCarthy, B. Delaby, L. Pierce, K. Journoy, F. and Horan, B. 2010. A meta analysis of the impact of stocking rate on the productivity of pasture based milk production systems. Advances in Animal Biosciences. Proceedings of the British Society of Animal Science and Agricultural Research Forum, pp148.

McCarthy, S. Horan, B. Rath, M. Linnane, M. O'Connor, P. and Dillon, P. 2005. Influence of strain of Holstein Friesian and pasture-based feeding system on grazing behaviour, DM intake and milk production of pluriparous dairy cows. *Grass and Forage Science*, **62**: 13-26.

McDonald, P., Edwards, R.A., Greenhalgh, J.F.D. and Morgan, C.A. 2002. Animal Nutrition. Pearson Education Ltd., Harlow, Essex, UK.

McEvoy, M. O'Donovan, M. and Shalloo L. 2010. Evaluating the economic performance of grass varieties. Advances in Animal Biosciences. In: Proceedings of the British Societ of Animal Science and Agricultural Research Forum, pp328.

McEvoy, M., Kennedy, E., Murphy, J.P., Boland, T.M., Delaby, L. and O'Donovan, M. 2008. The effect of herbage allowance and concentrate supplementation on milk production and dry matter intake of spring-calving dairy cows in early lactation. *Journal of Dairy Science*, **91**: 1258-1269

McGee, M. 2010. Unpublished.

McGee, M., Minchin, W. and Crosson, P. 2010. Background and overview to the Derrypatrick Herd. In: Suckler Beef – Achieving a gross margin of €1000/hectare. Beef 2010, Tuesday, 15th June 2010, Teagasc, Animal & Grassland Research and Innovation Centre, Grange, Dunsany, Co. Meath, p6-9.

Mensink, R.P., Zock, P.L., Kester, A.D.M. and Katan, M.B. 2003. Effects of dietary fatty acids and carbohydrates on the ratio of serum total to HDL cholesterol and on serum lipids and apolipoproteins: a meta-analysis of 60 controlled trials. *American Journal of Clinical Nutrition*, **77**: 1146-1155.

Miller, L.A., Moorby, J.M., Davies, D.R., Humphreys, M.O., Scollan, N.D., MacRae, J.C.and Theodorou, M.K. 2001. Increased concentration of water-soluble carbohydrate in perennial ryegrass (*Lolium perenne* L.): milk production from late-lactation dairy cows. *Grass and Forage Science*, **56**: 383-394.

Minson, D.J. 1982. Effect of chemical composition on feed digestibility and metabolisable energy. Nutritional Abstract Review 592-615.

Minson, D.J. 1990. Forage in Ruminant Nutrition. Academic Press Inc., San Diego, USA.

Minson, D.J. 1990. Forage in ruminant nutrition. Academic Press, San Diego, CA, USA.

Moe, P. W. and H. F. Tyrrell. 1979. Methane Production in Dairy Cows. *Journal of Dairy Science*, **62**:1583-1586.

Mohammed, R., Stanton, C.S., Kennelly, J.J., Kramer, J.K.G., Mee, J.F., Glimm, D.R. O'Donovan, M. and Murphy, J.J. 2009. Grazing cows are more efficient than zero-grazed and grass silage-fed cows in milk rumenic acid production. *Journal of Dairy Science*, **92**: 3874-3893.

Moloney, A.P., Daly, C.M., Ermis, E. Shingfield, K.J. and Monahan, F.J. 2007. The composition and oxidative stability of lipids in longissimus muscle from grazing cattle supplemented with sunflower oil alone or with fishoil. Proceedings British Society of Animal Science.

Moorby, J.M., Evans, R.T., Scollan, N.D., MacRae, J.C. and Theodorou, M.K. 2006. Increased concentration of water-soluble carbohydrate in perennial ryegrass (*Lolium perenne* L.). Evaluation in dairy cows in early lactation. *Grass and Forage Science*, **61**: 52-59.

Morrisson, I.M. 1980. Changes in lignin and hemicellulose concentration of ten varieties of temperate grasses with increasing maturity. *Grass and Forage Science*, **35**: 287-293.

Murphy, J.J., Kavanagh, S., Patton, J. and Maher, J. 2008. Factors affecting mid season milk protein content. In: Proceedings of the Teagasc National Dairy Conference, Cork, Ireland and Athlone, Ireland, 26-27 November, pg. 80-85.

National Resarch Council (NRC). 2001. Nutrient requirements of dairy cattle, seventh revised edition. National Academy Press, Washington, D.C., USA.

Neilan, R. O'Riordan, E.G. and Keane, G. 1996. Effects of autumn grazing interval on herbage production and sward composition. In: Proceedings of the Agricultural Research Forum, Dublin (28-29 March 1996) pages 115-116.

Nocek, J.E. and Russell, J.B. 1988. Protein and energy as an integrated system. Relationship of ruminal protein and carbohydrate availability to microbial synthesis and milk production. *Journal of Dairy Science*, **71**: 2070.

Nolan, T. 1972 Fat lamb production in the west of Ireland. *Irish Journal of Agricultural Research*, **11**; 47-62.

Nolan, T. 1998. Effect of grazing management on the maintenance of while clover End of project report, Project 3158.

O' Donovan, M., and Delaby, L. 2005. A comparison of perennial ryegrass cultivars differing in heading date and grass ploidy with spring calving dairy cows at two different stocking rates. *Animal Research*, **54**: 337-350.

O' Donovan, M., Delaby, L. and Peyraud, J.L. 2005. Effect of time of initial grazing date and subsequent stocking rate on apsture production and dairy cow performance. *Animal Research,* **53**: 489-502.

O'Donovan, M. A. 2010. Unpublished.

O'Donovan, M., Dillon, P., Rath, M., and Stakelum. G. 2002. A note on the effect of autumn closing date and grass cover at closing on spring grass supply on 10 commercial dairy farms. *Irish Journal of Agricultural and Food Research*, **41:** 265-269**.**

O'Kiely, P., Conaghan, P., Howard, H., Moloney, A.P. and Black, A.D. 2005. Grazing and ensiling of energy-rich grasses with elevated sugar contents for the sustainable production of ruminant livestock. Beef Production Series No. 80, Grange, Dunsany, Co. Meath. 62 pages.

O'Riordan, E.G. and O'Kiely, P. 1996. Potential of beef production systems based on grass. *Journal of the Irish Grassland and Animal Production Association*, **30**: 185-217.

Oba, M. and Allen, M.S. 1999. Evaluation of the importance of the digestibility of neutral detergent fibre from forage: Effects on dry matter intake and milk yield of dairy cows. *Journal of Dairy Science*, **82**: 589-596.

Oba, M. and Allen, M.S. 2000. Effects of brown midrib 3 mutation in corn silage on productivity of dairy cows fed two concentrations of dietary neutral detergent fibre. 1. Feeding behaviour and nutrient utilization. *Journal of Dairy Science*, **83**: 1333-1341.

Owens, D., McGee, M. and Boland, T. 2008. Effect of grass regrowth interval on Intake, rumen digestion and nutrient flow to the omasum in beef cattle. *Animal Feed Science and Technology*, **146**: 21-41.

Owens, F.N., Secrist, D.S., Hill, W.J. and Gill, D.R. 1998. Acidosis in cattle: a review. *Journal of Animal Science*, **76**: 275-286.

Parodi, P.W. 2002. Conjugated linoleic acid. Pages 1587-1594 in Encyclopedia of Dairy Sciences. H. Roginski, J.W. Fuquay, and P.F. Fox, ed. Elseview Science Ltd., London, UK.

Parsons, A.J. 1988. The effects of season and management on the growth of grass swards. In: The grass crop. Ed M.B. Jones and A. Lazenby, pp129-177.

Peyraud, J.L., Mosquera-Losada, R. and Delaby, L. 2004. Challenges and tools to develop efficient dairy systems based on grazing: how to meet animal performance and grazing management. European Grassland Federation.

Roche, J. 1996. The effect of closing date in autumn and turnout date in spring on sward characteristics, dry matter output and the milk performance of spring calving dairy cows in early lactation. M.Agr.Sc Thesis, National University of Ireland, 114 pages.

Shalloo, L. 2009. Pushing the Barriers on milk costs/outputs. In Proceedings of Teagasc National Dairy Conference 2009, pp19- 38.

Smit, H.J., Tas, B.M., Taweel, H.Z., Tamminga, S. and Elgersma, A. 2005. Effects of perennial ryegrass (Lolium perenne L.) cultivaras on herbage production, nutritional quality and herbage intake of grazing dairy cows. *Grass and Forage Science*, **60**: 297-309.

Stakelum, G. and Dillon, P. 1990. Influence of sward structure and digestibility on the intake and performance of lactating and growing cattle. In Management issues for dairying in the 1990s. Mayne, C.S. (Ed.). British Grassland Society.

Stakelum, G. and O'Donovan, M. 1998. Grazing severity, sward digestibility and intake, and farm cover targets for profitable summer milk production. Then production of high quality milk from grass and other feeds, Cahir, Co. Tipperary, pp. 1-16.

Stockdale, C.R. 1999. Effects of season and time since defoliation on the nutritive characteristics of three irrigated perennial pasture species in northern Victoria. 1. Energy, protein and fibre. Australian *Journal of Experimental Agriculture,* **39**: 555-565.

Taweel, H.Z., Smit, H.J. and Elgersma, A. 2007. Will feeding high sugar grass reduce methane emission by grazing dairy cows? *Grassland Science in Europe*, **11**: 787-789.

Taweel, H.Z., Tas, B.M., Smit, H.J., Elgersma, A., Dijkstra, J. and Tamminga, S. 2005. Effects of feeding perennial ryegrass with an elevated concentration of water-soluble carbohydrates on intake, rumen function and performance of dairy cows. *Animal Feed Science and Technology*, **121**: 243-256.

Taweel, H.Z., Tas, B.M., Smit, H.J., Elgersma, A., Dijkstra, J. and Tamminga, S. 2006. Grazing behaviour, intake, rumen function and milk production of dairy cows offered Lolium pernne containing different levels of water-soluble carbohydrates. *Livestock Science*, **102**: 33-41.

Teagasc. 2002. National Farm Survey Publication.

Tyler B.F. 1988. Description and distribution of natural variation in forage grasses. In; Natural Variation and Breeding for Adaption, Lusignan, pp13-22.

Van Soest, P.J.1994. Nutricional ecology of the ruminant. Cornell University Press, Ithaca, pp.476.

Van Vuuren, A.M., Van der Koelen, C.J. and Vroons-De Bruin, J. 1986. Influence of level and composition of concentrate supplements on digestion and intestinal amino acids in dairy cows. *Netherlands Journal of Agricultural Science,* **34**: 457.

Wade, M.H., Peyraud, J.L., Cameron, E.A. and Lemaire, G. 1995. The dynamics of daily milk production and sward height under paddock grazing coditions. *Annuales de Zootechnie*, 44 Supplement, 127.

Wade, M.H., Peyraud, J.L., Lemaire, G., and Cameron, E.A. 1989. The dynamics of daily area and depth of grazing and herbage intake of cows in a five day paddock system, XVI International Grassland Congress, Nice, France, 1111-1112.

Wales, W.J., Doyle, P.T., Stockdale, C.R. and Dellow, D.W. 1999. Effects of variations in herbage mass, allowance and level of supplementation on nutrient intake and milk production of dairy cows in spring and summer. *Australian Journal of Experimental Agriculture,* **39**: 119-130.

Whitehead, D.C. 1995. Grassland Nitrogen. CAB International, Wallingford, UK. 397 pages.

Wilkins, P. W. and M. O. Humphreys. 2003. Progress in breeding perennial forage grasses for temperate agriculture. *Journal of Agricultural Science Cambridge,* **140**: 129-150.

Wilkins, P.W., Allen, D.K. and Mtton, L.R. 2000. Differences in the nitrogen use efficiency of perennial ryegrass varieties under simulated rotational grazing and their effects on nitrogen recovery and herbage nitrogen content. *Grass and Forage Science,* **55**: 69-76.

Wilman D and Gao, Y. 1996. Herbage production and tiller density in five related grasses, their hybrids and mixtures. *Journal of agricultural Science, Cambridge*, **127**: 57-65.

Wilson, R.K. and O'Kiely, P. 1990. A note on the chemical composition of Irish farm silages 1985-1988. *Irish Journal of Agricultural Research*, **29**: 71-75.

Wims, C.M., Deighton, M.H., Lewis, E., O'Loughlin, B., Delaby, L., Boland, T.M. and O'Donovan, M. 2010. Effect of pre-grazing herbage mass on methane production, dry matter intake and milk production of grazing dairy cows during the mid season period. *Journal of Dairy Science* submitted.

Woodfield, D.R. 1999. Genetic improvements in New Zealand forage cultivars. *Proceedings of the New Zealand Grassland Association* **61**: 3-7.

Wright, C.E. 1978. In Intensive Grassland use and livestock Health. British Grassland Society Symposium, p 11.

Appendix

Assumptions from Table 1

Assumed loam soil, index 3 for P and K for all crops. Assumed index 2 for N for the annual crops.

PRG 2.5LU: 279 kg N, 16 kg P, 25 kg K/ha/yr. 13.5 t DM grown/ha. 80% utilisation.

PRG 2.0LU: 201 kg N, 10 kg P, 15 kg K/ha/yr. 12.2 t DM grown/ha. 75% utilisation.

PRG 1.68LU: 122 kg N, 10 kg P, 11 kg K/ha/yr. 10.3 t 2 t DM grown/ha. 60% utilisation.

PRG & White Clover: 56 kg N, 10 kg P, 15 kg K/ha/yr. 10.6 t DM grown/ha. 75% utilisation.

GS1: Not spring grazed. Mowed and harvested 29th May. No rain. No additive. 217 g DM/kg and 717 g DMD/kg DM at feed-out. 6.6 t DM grown/ha. 80% utilisation.
115 kg N, 20 kg P, 145 kg K/ha.

GS2: Re-growth from GS1 harvest. Mowed and harvested 24th July. No rain. No additive. 217 g DM/kg and 700 g DMD/kg DM at feed-out. 5.5 t DM grown/ha. 80% utilisation.
85 kg N, 10 kg P, 35 kg K/ha.

Maize No Plastic: Sown 8th May, harvested 20th October. 303 g DM/kg and 664 g DMD/kg DM at feed-out. 13 t DM grown/ha. 86% utilisation.
140 kg N, 40 kg P, 190 kg K/ha.

Kale: Sown 27th May, grazed Nov-Feb. 120 g DM/kg and 722 g DMD/kg DM at feed-out. 10.1 t DM grown/ha. 80% utilisation.
80 kg N, 30 kg P, 170 kg K/ha.
CAN: €225/t
0.7.30: €523/t
18.6.12: €323/t

Reseeding 14 year interval for grazed sward, 10 year for silage.
All silages assumed stored in walled concrete silos, depreciated over 20 years.

Gains in dry matter yield and herbage quality from breeding perennial ryegrass

P. W. Wilkins[1] and J.A. Lovatt[2]

[1]*Weathertop, Salem, Penrhyncoch, Aberystwyth, SY23 3ET, UK;* [2] *IBERS, Plas Gogerddan, Aberystwyth, SY23 3EB, UK*

Email: prw@aber.ac.uk

Abstract

In Western Europe and elsewhere there has been considerable effort during the last 100 years devoted to improving perennial ryegrass (*Lolium perenne* L.) for agriculture. The first persistent cultivars to be widely used were more digestible than other common pasture species but were no higher yielding than the better wild populations of perennial ryegrass. Two main approaches (here called mainstream breeding and population improvement) have been used to further improve the species, but published information on progress by either means is very limited. In 2006, two plot trials were established at IBERS in the UK to compare the performance of some newer cultivars and candidate varieties with the first persistent cultivars to be widely used in the UK. One trial compared 10 intermediate-heading (6 diplod and 4 tetraploid) cultivars and candidate varieties with the intermediate-heading cv. Talbot, and the other compared 11 late-heading (4 diploid and 7 tetraploid) cultivars and candidate varieties with the late-heading cv. S23. During 2007-2009, one silage cut and six other cuts were harvested each year, dry matter (DM) yields were determined and DM samples analysed for *in vitro* DM digestibility (DMD), water soluble carbohydrate (WSC) and crude protein (CP) contents. Percentage ground covered by perennial ryegrass in November 2009 was estimated visually. Twenty of the 21 cultivars were significantly (12-38%) higher yielding, 15 were significantly (10-27 g kg^{-1}) higher in mean DMD, 15 were significantly (25-58 g kg^{-1}) higher in mean WSC and 7 (all diploids) were significantly higher in ground cover in autumn of the third harvest year than either Talbot or S23. There were no significant differences among the varieties in mean CP over all harvests. The newest intermediate-heading cultivar (the diploid Abermagic) produced 29% more DM, was 10 g kg^{-1} higher in DMD and 51 g kg^{-1} higher in WSC, and had significantly better ground cover at the end of the third harvest year than Talbot. The newest late-heading cultivar (the tetraploid Aberbite) produced 28% more DM than S23 and was 22 g kg^{-1} higher in DMD and 58 g kg^{-1} higher in WSC, although it was similar to S23 in ground cover. Both of these new varieties were developed entirely or partly by population improvement at IBERS over 25 years (1980-2005).

Keywords: Perennial ryegrass, breeding, population improvement, DM yield, digestibility

Introduction

Domestication of perennial ryegrass

The first major advance in the domestication of perennial ryegrass (*Lolium perenne* L.) was the introduction in the 20th century of leafy and persistent varieties bred from wild populations (ecotypes) that had adapted to intensive grazing (Beddows, 1953). For the first time, it became profitable to reseed many permanent pastures with mixtures based on perennial ryegrass. Although similar in DM yield to some other common pasture grasses, these varieties were considerably more digestible. One such variety (cv. Perma) was between 45 and 144 g kg^{-1} higher in mean *in vitro* organic matter digestibility (OMD) over all harvests than the 10 other common pasture grass species and varieties trialed by Frame (1991). Organic matter digestibility remains the best single predictor of ruminant animal production from high forage diets (Casler, 2000), determining both the metabolisable energy content and voluntary intake of forage.

Effective regulation and certification of commercial seed was introduced in most Western European countries, both to encourage breeding by seed companies and to control the quality of seed purchased by farmers. This included Plant Breeders Rights (which involves testing candidate varieties for distinctiveness, uniformity and stability) that are awarded to give breeders protection against fraud and enable them to collect royalties from seed sales. The introduction of Value for Cultivation and Use (VCU) trials in member states of the European Union (EU) after 1972 (following directive 72/180/EEC) provided level playing fields for competition between breeders. Such trials, and any associated lists of recommended varieties, have become an integral part of the breeding process because, to a large extent, they determine breeding priorities. Thus it is vital that such trials are regularly updated and kept relevant to the needs of the farming industry.

Subsequent breeding was facilitated by the introduction of new technologies during the second half of the 20th century: efficient plot harvesters to measure DM yield, inexpensive computers to record and rapidly analyse data, infrared reflectance spectroscopy to predict herbage quality traits, and affordable flow cytometers to determine ploidy level. Doubling the chromosome number from diploid to tetraploid by the use of colchicine widened the range of perennial ryegrass types available. However, none of the current commercial varieties (cultivars) are transgenic and, as far as we know, none have been produced by using marker-assisted selection.

Breeding strategies

Perennial ryegrass breeding is complicated by a wide range of variation in ear emergence (heading) dates (varying from early April to mid June in the UK) and the existence of two ploidy levels, diploid and tetraploid. In the UK there are significant markets for four categories of cultivar: intermediate-heading diploids, late-heading diploids, intermediate-heading tetraploids and late-heading tetraploids. Each category must be bred separately. Two different approaches have been used to raise the agronomic performance and herbage quality of perennial ryegrass beyond that of the best ecotypes.

The first, which we will call 'mainstream breeding', focuses on making as much gain as possible from a single breeding cycle. A new cycle may be started each year, although this could involve material in a different heading date category, or with a different ploidy level. A typical cycle begins with up to 1,000 pair crosses among plants selected mainly from the breeder's newest varieties and from competitor's varieties. Seed of the resultant families is multiplied outdoors in small plots separated by rye to reduce pollen flow between the families. A large number (often exceeding 100,000) of individual spaced plants reared from seed of these families is evaluated visually over two or three harvest years. Selected plants are clonally replicated. Subsequently they are evaluated as clonal rows or the clones are allowed to intercross and the progeny families are evaluated as plots. Four or more of best clones with similar heading date are later inter-crossed to produce the first generation seed of each new candidate variety. Several candidate varieties are produced and evaluated as small plots to identify the best for commercial development and for use as parents in further breeding. Depending on the exact procedure, each cycle takes between 9 and 15 years to complete.

The second approach, 'population improvement', is to form populations based on 8-20 carefully selected diploid parents and to progressively increase the frequency of desirable genes within each population by recurrent selection of individuals and their progeny families. Each generation of selection takes at least 4 years. One or more candidate varieties can be produced following each selection cycle. Recurrent selection within restricted breeding populations has proved to be highly effective in accumulating desirable genes that work well together. It has been used both to achieve very high levels of expression of single traits (e.g. the oil and protein contents of maize grain: Dudley and Lambert, 1992) and to combine several different traits (e.g. resistances to late blight and white potato cyst nematode, good fry colour and high DM yield in potato; Bradshaw, Dale and Mackay, 2009). But this is not easy to apply to perennial ryegrass. Pollination must be controlled strictly, selection must be sustained continuously over successive generations, and all important traits (including plot persistency) must be evaluated during each cycle of selection to avoid progressive deterioration in the population mean of any of them. As far as we know, the perennial ryegrass breeding programme at Aberystwyth (formerly the Welsh Plant Breeding Station and now incorporated in IBERS at Aberystwyth University) is the only one to sustain population improvement for 30 years (starting in 1980).

With both mainstream and population improvement procedures that involve progeny testing, it is possible to test the families in more than one way to ensure adequate seed yield, or at more than one site to ensure adequate tolerance or resistance to the range of environmental stresses, diseases and pests. Some tetraploid varieties (including Aberbite and the tetraploid candidate variety Ba13798) have been produced by a combination of recurrent selection and mainstream breeding (Wilkins and Lovatt, 2006).

Progress from breeding

The best way to assess gains from breeding would be to compare directly the performance of the newest perennial ryegrass varieties with the old ones. The only recently published data of this type comes from Belgium where the old cultivar Vigor (a late-heading cultivar, formerly called Melle Pasture) has been maintained and included as a control in VCU trials over a 40-year period (from 1963 to 2007; Chaves *et al.*, 2009). The results were very similar in the intermediate-heading and late-heading groups and in diploids and tetraploids. Relative to Vigor, total annual DM yield of candidate varieties over 2-3 harvest years under infrequent cutting increased by 12.4%, ground cover in autumn by 21% and resistance to crown rust by 44%. Herbage quality traits were not measured. None of these candidate varieties were bred at IBERS.

Here we report the results of two trials (one of intermediate-heading and the other of late-heading cultivars and candidate varieties) that were sown at IBERS in 2006 to monitor progress from breeding. In each trial, an old control cultivar of perennial ryegrass was included. These were the first persistent cultivars to be widely used in the UK, the intermediate-heading cv. Talbot and the late-heading cv. S23. Except for cv. Lasso, which was dropped from the list after the plots were sown, the other named cultivars are currently recommended for use in England and Wales (www.herbagevarietiesguide.co.uk). Recent research (reviewed by Edwards *et al.*, 2007) shows that increasing the ratio of water-soluble carbohydrate (WSC) to crude protein (CP) in perennial ryegrass herbage reduces the output of nitrogen (N) in the urine of grazing animals, which is likely to lead to lower losses of nitrous oxide (N_2O) to the atmosphere and of nitrate (NO_3-N) to ground water. As well as DM yield and *in vitro* dry matter digestibility (DMD), the WSC and CP contents of the herbage was determined at every harvest over the first three harvest years.

Materials and Methods

During 2003-2005, fresh seed of the old cultivars Talbot and S23 was generated by isolating approximately 100 randomly-selected plants of each in separate glasshouse compartments ventilated with pollen-free air. The seed was stored at 3^0C and 30-40% relative humidity. Eleven intermediate-heading perennial ryegrass varieties were sown in trial 1 (9 cultivars and 2 candidate varieties) and 12 late-heading varieties were sown in trial 2 (8 cultivars and 4 candidate varieties). Both trials were drilled into a fine seedbed and rolled in August 2006 in 4-replicate randomized block plot trials, with guard plots at both ends of each block. In October the plots were mowed and marked with herbicide, each plot measuring 3 × 1.25m. During each of the following 3 years (2007-2009) the plots were harvested at 5 cm with a Haldrup plot harvester on 7 occasions, once in April, once shortly after ear emergence (the silage cut) and on 5 subsequent days at approximately 4- week intervals. All plots in the same trial were harvested on the same day. The fresh herbage from each plot was weighed, a sample (300-400 g) oven-dried at 80°C, and DM yield determined. Plots were fertilized with a compound fertilizer (23:4:13:7; N:P_2O_5:K_2O:SO_3) in late February and after each harvest except the last at rates equivalent to 57, 86, 57, 57, 57, 35 and 35 kg ha^{-1} of N. *In vitro* DMD, WSC and CP content of milled samples of oven-dried herbage from every harvest was determined by the IBERS Analytical Services Unit with the aid of Near Infrared Reflectance Spectroscopy (NIRS). Dry matter digestibility was determined in the first harvest year only, while WSC and CP were determined in all three harvest years. Ten days after the final harvest in November of 2009, the percentage of ground covered by perennial ryegrass in each plot was estimated visually. Variance analysis of the data was carried out using GENSTAT (Genstat 9 or 10; VSN International Ltd., Hemel Hempstead, UK).

Results

Except for Lasso, which now has been removed from the list of recommended varieties for England and Wales, the cultivars and candidate varieties were significantly higher in mean total annual DM yield over the first three harvest years than their respective control varieties. In the intermediate-heading group (Table 1) varieties yielded 12-29% more than the old cv. Talbot, and in the late-heading group (Table 2) they yielded 15-38% more than the old cv. S23. However, the results indicate that the relative contribution of the first silage cut and the other (leafy) cuts to the total DM yield varied considerably among some of the varieties. The intermediate-heading candidate variety Ba13926 was similar in DM yield to cv. Talbot at the first silage cut but was 39% higher at the other cuts and the late-heading variety Aberchoice was similar to cv. S23 at the first silage cut but 36% higher yielding at the other cuts. This indicates that the percentage gains in DM yield over the respective control varieties and the exact ranking of some of these varieties in total annual DM yield would have been different if a management (such as simulated grazing throughout) that altered the contribution of the first silage cut to total annual yield had been applied. But other varieties (Abermagic, Aberglyn, Abercraigs and Ba13798) showed a similar proportional yield improvement over their respective control varieties at both the first silage cut and at the other cuts. Differences among varieties in mean *in vitro* DMD over all harvests in 2007, were highly statistically significant in both trials (Tables 1 and 2).

TABLE 1: Mean yield, in vitro dry matter digestibility (DMD,), water soluble carbohydrate content (WSC) and crude protein content (CP) of dry matter over 3 harvest years (2007-2009), and mean percentage of ground covered by ryegrass in November 2009 of 11 intermediate-heading perennial ryegrass cultivars and candidate varieties. The cultivars are named and the tetraploid varieties denoted by (T). Numbers in parentheses are a percentage of the control variety Talbot

Variety	Dry matter yield (t/ha^{-1}), 7 cuts per year			DMD g kg^{-1}	WSC g kg^{-1}	CP g kg^{-1}	% ground cover
	Silage cut	Other cuts	Total annual				
Talbot	5.57 (100)	7.44 (100)	13.01 (100)	763	199	157	49
Premium	6.67 (120)	7.86 (106)	14.53 (112)	756	195	152	54
Aberdart	6.02 (108)	9.27 (125)	15.30 (118)	766	226	147	76
Aberstar	6.32 (113)	9.70 (130)	16.02 (123)	768	229	147	67
Abermagic	6.69 (120)	10.14 (136)	16.83 (129)	773	250	142	61
Abersweet	6.33 (114)	9.31 (125)	15.64 (120)	775	250	142	57
Ba13926	5.83 (105)	10.33 (139)	16.16 (124)	769	243	139	70
Aubisque (T)	6.63 (119)	8.28 (111)	14.91 (115)	777	217	156	55
Magician (T)	6.21 (111)	8.62 (116)	14.83 (114)	777	213	144	47
Aberglyn (T)	6.57 (118)	8.50 (114)	15.07 (116)	767	201	159	49
Ba13743 (T)	6.44 (116)	8.51 (114)	14.95 (115)	771	203	158	49
L.S.D	0.631	0.851	1.242	8.3	24.9	-	6.9
Significance	**	***	***	***	***	NS	***

L.S.D. least significant difference from control cv. Talbot at P=0.05. NS = non-significant; * = P<0.05; **= P<0.01; *** = P<0.001

TABLE 2: Mean yield, in vitro dry matter digestibility (DMD), water soluble carbohydrate content (WSC) and crude protein content (CP) of dry matter over 3 harvest years (2007-2009), and mean percentage of ground covered by ryegrass in November 2009 of 12 late-heading perennial ryegrass cultivars and candidate varieties. The cultivars are named and the tetraploid varieties are denoted by (T). Numbers in parentheses are a percentage of the control variety S23

Variety	Dry matter yield (t/ha), 7 cuts per year			DMD g kg^{-1}	WSC g kg^{-1}	CP g kg^{-1}	% ground cover
	Silage cut	Other cuts	Total annual				
S23	5.57 (100)	7.86 (100)	13.43 (100)	765	182	163	46
Lasso	6.08 (109)	8.39 (107)	14.47 (108)	767	189	158	51
Aberavon	6.68 (120)	10.08 (128)	16.76 (125)	781	217	154	62
Aberchoice	5.54 (99)	10.69 (136)	16.23 (121)	784	239	150	52
Ba13942	5.46 (98)	10.36 (132)	15.82 (118)	781	237	148	58
Condesa (T)	5.50 (99)	9.91 (126)	15.42 (115)	788	223	154	48
Twymax (T)	6.72 (121)	9.70 (123)	16.42 (122)	787	218	153	48
Abercraigs (T)	7.05 (127)	9.64 (123)	16.69 (124)	792	218	155	46
Ba13744 (T)	5.91 (106)	9.53 (121)	15.44 (115)	784	211	154	44
Ba13798 (T)	7.64 (137)	10.94 (139)	18.58 (138)	790	240	146	46
Aberbite (T)	6.70 (120)	10.49 (133)	17.18 (128)	787	236	150	45
Ba13851 (T)	6.27 (113)	10.39 (132)	16.56 (123)	787	224	152	40
L.S.D	0.362	1.143	1.275	6.2	17.8	-	5.4
Significance	***	***	***	***	***	NS	***

L.S.D, least significant difference from control cv. S23 at P=0.05. NS = non-significant; * = P<0.05; **= P<0.01; *** = P<0.001

In the trial of intermediate-heading varieties, only 4 (the diploids AberMagic and Abersweet, and the tetraploids Aubisque and Magician) were significantly (10-14 g kg^{-1}) higher in DMD than cv. Talbot. All the varieties in the late-heading group were significantly (16-27 g kg^{-1}) higher in mean DMD than the control cv. S23. Differences in mean WSC content over all harvests were also highly statistically significant and were greater than for DMD. Five diploid varieties (Aberdart, Aberstar, Abermagic, Abersweet and Ba13926) were significantly (27-51 g kg^{-1}) higher in mean WSC than cv. Talbot, and all the late-heading varieties except for Lasso were significantly (35-58 g kg^{-1}) higher in mean WSC than S23. In both trials, differences among varieties in mean CP content over all harvests were small and not statistically significant.

Some diploid varieties, but none of the tetraploid varieties, were significantly higher in ground cover at the end of the third harvest year than their respective diploid control cultivars. This is a good indicator of relative persistency. In the intermediate-heading group AberDart, Aberstar, Abermagic, Abersweet and Ba13926 were 8-27 percentage units higher in ground cover than Talbot, and in the late-heading group Aberavon, Aberchoice and Ba13942 were 6-16 percentage units higher in ground cover than S23. Only one variety (the late-heading tetraploid Ba13851) was significantly lower in ground cover than its respective control variety (S23).

Discussion

These results come from only one site and one particular management regime. Thus the gains in annual DM yield of the currently recommended cultivars over the old cultivars Talbot and S23 should be interpreted with caution. Nevertheless, they do indicate a substantial improvement in yield from breeding; somewhat larger than the 12% higher yield of the Belgian candidate varieties over cv. Vigor cited earlier (Chaves *et al*., 2009). In earlier trials, Talbot was similar in DM yield to locally-adapted Belgian ecotypes (Limbourg and Leconte, 1997), and thus these results give an indication of the increase in yield that could be expected following the reseeding of an old ryegrass-dominated pasture with the newest cultivars available. The diploid varieties that had a higher ground cover than Talbot or S23 at the end of the third harvest year can be expected to persist better and thus to have a greater advantage in DM yield in subsequent harvest years. However, none of the tetraploid varieties were significantly higher in ground cover than their respective control cultivar.

Some intermediate-heading varieties (including the high yielding and persistent Abermagic) and most of the late-heading varieties showed modest improvement in mean DMD over all harvests in 2007 over their respective control cultivars. These can be attributed primarily to higher WSC content, WSC being completely digested. Such differences, combined with improvements in DM yield, can have substantial effects on animal production. Charolais cross steers grazing cv. Aberdart (mean WSC content 155-231 g kg^{-1}) gained between 18% and 35% more liveweight than those grazing cv. Fennema (mean WSC content 133-205 g kg $^{-1}$; Marley *et al*., 2005). Research from grazing experiments in the UK on the environmental benefits of these newer varieties has yet to be published.

The two experiments included six diploid cultivars that were produced by population improvement and only two that were produced by mainstream breeding (Premium and Lasso). Newer diploid varieties produced by mainstream breeding with higher DM yield have become available recently (www.herbagevarietiesguide.co.uk). Thus the current results do not provide a basis for comparing progress from the two breeding methods. They do, however, provide a measure of progress during 25 years of population improvement at IBERS (from 1980-2005). The newest intermediate-heading cultivar (the diploid Abermagic) produced 29% more DM yield, was 10 g kg^{-1} higher in DMD and 51 g kg^{-1} higher in WSC, and had significantly better ground cover at the end of the third harvest year than Talbot. The newest late-heading cultivar (the tetraploid Aberbite) produced 28% more DM yield than S23 and was 22 g kg^{-1} higher in DMD and 58 g kg^{-1} higher in WSC, although it was similar to S23 in ground cover. These gains are not far below those from forage maize breeding (14% per decade in DM yield and 5.4-6.1 g kg^{-1} respectively per decade in DMD; Laner, Coors and Flannery, 2001). In maize, however, it is possible to carry out a generation of selection each year whereas in perennial ryegrass, where persistency is a key trait which has to be balanced against the other objectives, the minimum generation time is 4 years.

Acknowledgements

This work was funded jointly by Defra and Germinal Holdings Ltd.

References

Beddows A. R. 1953. The ryegrasses in British Agriculture; a survey. Welsh Plant Breeding Station Bulletin Series H, No. 17, Aberystwyth Wales.

Bradshaw, J. E., Dale, M. F. B. and Mackay G. R. 2009. Improving the yield, processing quality and disease and pest resistance of potatoes by genotypic recurrent selection. *Euphytica*, **170**: 215-227.

Casler, M. D. 2000. Breeding forage crops for increased nutritional value. *Advances in Agronomy*, **71**: 51-107.

Chaves, B., De Vliegher, A., Van Waes, L., Carlier, L. and Marynissen, B. 2009. Change in agronomic performance of *Lolium perenne* and *Lolium multiflorum* varieties in the past 40 years based on data from Belgium VCU trials. *Plant Breeding*, **128**: 680-690.

Dudley, J. W. and Lambert, R. J. 1992. Ninety generations of selection for oil and protein content in maize. *Maydica*, **37**: 81-87.

Edwards, G. R., Parsons, A. J., Rasmussen, S. and Bryant, R. H. 2007. High sugar ryegrasses for livestock systems in New Zealand. *Proceedings of the New Zealand Grassland Association*, **69**: 161-171.

Frame, J. 1991. Herbage production and quality of a range of secondary grass species at five rates of fertilizer nitrogen application. *Grass and Forage Science*, **46**: 139-151.

Laner, J. G., Coors, J. G. and Flannery, P. J. 2001. Forage yield and quality of corn cultivars developed in different eras. *Crop Science*, **41**: 1449-1445.

Limbourg, P. and Leconte, P. H. 1997. Compared productivity of local ecotypes and selected cultivars of perennial ryegrass (*Lolium perenne* L.) in high Belgium. Proceedings of the 18th International grassland Congress, Canada, **1**: 15-16.

Marley, C.L., Davies, D. A., Vale, J. E., Evans, J. G., Scollan, N. D., Moorby, J. M., Macrae, J. C. and Theodorou, M. K. 2005. Effects of upland pastures sown with two contrasting *Lolium perenne* varieties on the performance of beef steers when compared to steers grazing permanent pastures. Proceedings of the British Society of Animal Science Annual Conference, York, p. 194.

Wilkins, P. W. and Lovatt, A. J. 2006. Chromosome doubling as a means of exploiting heterosis in perennial ryegrass. In 'Breeding and Seed Production for Conventional and Organic Agriculture', Proceedings of the 26th EUCARPIA Fodder Crops and Amenity Grasses Section and the 16th Medicago spp. Group Joint Meeting, Perugia: 52-55.

Ryegrass breeding – balancing trait priorities

A. Stewart[1] and R. Hayes[2]

[1]PGG Wrightson Seeds, PO Box 175, Lincoln, New Zealand 7640; [2]IBERS, Aberystwyth University, Aberystwyth, Ceredigion, SY23 3EB, UK

Email: astewart@pggwrightsonseeds.co.nz

Abstract

In all ryegrass breeding programs it is necessary to select for a range of traits and cultivar types, varying in ploidy and flowering time. The traits selected in ryegrass breeding can be broadly grouped into production traits such as yield, quality and persistence; those seed production traits crucial for delivery of the cultivar, as well as those traits that can benefit the environment or allow ryegrass to be used for biofuel production. The priority placed on each trait will depend on their economic value within the various farming systems where each cultivar will ultimately be used, as well as the potential to make genetic gain in each trait. In all cases multiple trait selection will be required to develop a cultivar improved for key traits of interest but importantly the cultivar must not have unacceptable performance for any trait.

Where the genetic variation is inadequate within perennial ryegrass it may be necessary to enhance ryegrass diversity. In the future this could be achieved through targeted introgression from closely related Festuca species, or through introduction of genes via genetic modification.

Funding of ryegrass breeding internationally will increasingly be subject to the economic success of a few larger seed companies as Government funding of field based breeding is diminishing and shifting focus to more basic research, often of a molecular nature. Ensuring this expensive basic research and associated molecular technologies are used effectively in ryegrass programs will remain a challenge when seed companies operating field based programs are vulnerable to considerable economic pressure.

Introduction

The question of prioritising traits under selection in ryegrass breeding programs is not always simple, because each cultivar must have excellent performance for a multiplicity of factors, and importantly must not have unacceptable performance in any. A cultivar may be used in different regions and different farming systems, as well as in pure or mixed swards with legumes. In the various farming systems there are also roles for different ryegrass species and types, from perennial ryegrass, hybrid ryegrass, Italian ryegrass (biennial) through to westerwolds ryegrass (annual), each varying in maturity date, ploidy level, seasonal growth pattern, forage quality and persistence.

The forage breeder's goal is to develop cultivars that will improve animal performance on farms, however, perennial cultivars need be able to persist under the local climatic extremes, cope with pests and diseases, as well as having adequate seed yields for competitive commercial delivery. The breeder must also work within the prevailing regulatory environment, as well as the changing economic and funding conditions.

Access to suitable germplasm or genetic variation for the trait of interest is crucial and suitable variation is not always available within the species. Although it is now possible to transfer genes from any other life form using genetic modification, this is not a viable option in many countries for regulatory, funding or public perception reasons.

In countries where cultivars may not be sold without first going through a compulsory Recommended or National List Trialling system, the traits that a breeder needs to select for are strongly dictated by the testing system. In addition the authorities may not measure, or not have the resources to measure, more complex traits which could be important in some on-farm situations. This is particularly true for persistence under grazing where animals are not utilised within these list trial systems. They may also only carry out trials to simulate certain farm management systems and ignore other systems.

The desirable traits selected for in ryegrass breeding programs can be broadly divided into those that influence production; forage yield, forage quality and persistence; those seed production traits crucial for delivery of the cultivar and those that influence the environment. The majority of production traits have been core breeding targets since modern ryegrass breeding began, but in recent years breeding to minimise environmental impacts has become very important, as agricultural practices have intensified and their consequences have become understood.

Production Traits

Forage Yield

One of the major objectives of all forage breeding programs is improving forage yield. This is not as simple for pasture as for single harvest grain crops, where harvest index can be improved. Pasture harvest involves the near total removal of above ground biomass with consequent loss of photosynthetic capacity, and there is a demand for a continuous supply of fodder throughout the year. Small increases in winter or early spring production may be worth disproportionately more than total spring production. McEvoy *et al.* (2010) have reported that winter yield is worth up to 5 times the value of spring and summer yield for Irish dairy systems. For this reason breeding for an appropriate seasonal yield must take precedence over total annual yield, and testing systems need to reflect this.

In New Zealand, winter growth has always been valuable as temperatures are milder than in the UK and Ireland. Such winter activity has been achieved in many pasture species in New Zealand by the incorporation of Mediterranean germplasm (Stewart, 2006). Care must be taken with breeding for winter growth in regions where cold winters occur, and a balance must be struck between the level of winter growth and winter hardiness. It is possible though to combine strong early spring growth with a suitable level of winter hardiness even for colder winter regions.

The time of heading of a cultivar can have a large effect on the timing of early spring growth and overall yield. Any benefits in seasonal and total yield due to early flowering must be balanced against the decline of mid-season quality and poorer persistence frequently observed with early cultivars in Ireland (Brereton and McGilloway, 1999). It is likely that with some breeding effort it should be possible to overcome these deficiencies.

The general trend in climate warming may allow more winter active cultivars to be used in the European region than in the past, but care will be required that winter hardiness is maintained for the occasional very cold winter. Although recently it has been suggested it is possible that Europe will experience more frequent, severe winters as either the Gulf Stream continues to weaken (Seager *et al.*, 2002; Minobe *et al.*, 2008) or the effects of Jet Stream blocking intensify (Woollings, 2010).

The genetic gain in annual dry matter (DM) yield of perennial ryegrass has been estimated from cutting trials in Europe and New Zealand as around 4 to 5% per decade, but less than 1% in the USA, where there is little perennial ryegrass breeding activity. Gains in seasonal yields may differ considerably reflecting the different breeding priorities. When the perennial nature of pasture is considered these genetic gains compare favourably with those achieved on major crops where there are more resources and a simple single-harvest (Woodfield, 1999; Easton *et al*., 2002; Wilkins and Humphreys, 2003; van der Heijden and Roulund, 2010).

Forage Quality

The ability of a cultivar to influence animal performance is not only related to feed quantity, but also to the metabolisable energy available to the animal, and any factor which can increase animal intakes. This is often very complex, reflecting the dynamics of rumen digestion of cell wall components and cellular contents, and any factors which can reduce feed transit time through the rumen. Feed quality also varies enormously with flowering behaviour, clover content, leafiness, diseases, growth rates and many other management related factors. Although the genetic variation of many quality factors is small compared to the environmental component, any advance in quality of a cultivar is valuable.

Metabolisable energy is prohibitively expensive to measure directly on cultivars so more simple approximations are commonly determined on herbage in most pasture research. These usually involve data where previous experiments have been used to calibrate digestibility, neutral detergent fibre (NDF), acid detergent fibre (ADF), protein, starches, lipids, water soluble carbohydrates (WSC), fatty acid profile and many other quality related factors, often using near infrared spectroscopy (NIRS).

One of the primary determinants of digestibility in all grasses relates to the decline in quality as flowering progresses. The timing of heading influences both the timing of this decline of quality and the timing of the spring growth flush. Effective use of a range of grasses with differing heading dates enables farmers to set up farming systems where seasonal feed availability more effectively meets animal demands. Often this will involve the additional use of brassica feed crops to both fill feed gaps and to enable the economic renewal of pasture.

Heading date also needs to be compatible with achieving an economic seed yield in the seed production region where seed is grown. For example, in NZ it is not possible to produce competitive seed yields of very late heading European perennial grasses.

The quality of ryegrass pastures once the flowering period is over, often termed mid-season quality, can be extremely important in many farming systems. This can be influenced by aftermath flowering in summer, and breeders normally select for minimal aftermath flowering behaviour to maximise digestibility. Reduced aftermath flowering can also enhance persistence as cultivars with a high proportion of reproductive tillers are often vulnerable to poor recovery from grazing (Fulkerson and Donaghy, 2001), but it can also reduce the ability to reseed which may be important in some extensive farm systems.

Even in cultivars with no aftermath seedheads the forage quality in mid-season can vary considerably, usually due to the ratio of plant parts, particularly leaf to psuedostem ratio, tiller size and other factors. In Ireland, late flowering cultivars generally have a higher proportion of green leaf and less psuedostem in the grazing horizon than intermediate flowering cultivars, resulting in a higher digestibility, greater DM intake (DMI) and milk production (O'Donovan and Delaby, 2005).

In pure ryegrass systems. where mid-season quality is a driver of production, breeders should select strongly for this and the cultivar testing systems should measure it. However, in mixed ryegrass and clover systems the clover content may potentially offer a larger improvement in quality than the small differences between cultivars.

The ploidy level of cultivars also influences forage quality with tetraploids having larger cells and a higher ratio of cell contents to cell wall resulting in a lower DM content. Typically, animals must consume more fresh weight of tetraploid cultivars to obtain the same DMI as from diploids. In pastures of similar digestibility, tetraploid perennial ryegrass cultivars have often, but not always, been shown to increase feed intake by 3-5%, with at least a similar improvement in animal production (van Bogaert, 1975; Connolly, Riberio and Crowley, 1977; Hageman *et al.*, 1993; Vipond, Swift and McClelland, 1993).

The value of these forage quality factors in tetraploids must be balanced against forage yield, as most of the tetraploid cultivars available today in the UK offer little advantage over diploids because they lack the yield and mid-season quality of the leading diploid cultivars (NIAB Recommended List 2009). Similarly, studies have shown that cattle may require more supplemental concentrates when reared for beef or milk production on current tetraploids rather than leading diploids (O'Donovan and Delaby, 2005; Orr *et al.*, 2005). However, in other countries, such as New Zealand, the leading tetraploid cultivars have competitive yields when compared to the leading diploids.

Breeding a ryegrass that allows more clover in the sward would be important for increased forage quality but little ryegrass breeding has been done for this. It is known however, that some grasses such as timothy and tall fescue allow a greater proportion of white clover than ryegrass, and that this contributes to an increase in milk production (Thomson and Kay, 2005). If this were due to less mid-spring suppression of clover, then breeding a ryegrass to maximise clover proportion may be possible, but it is clearly more complex than the challenge facing clover breeders who regularly breed and test their clover germplasm in ryegrass swards and select strongly for clover proportion (Evans, Williams and Evans, 1996; Woodfield, 1999; Annicchiarico and Proietti, 2010; Abberton and Marshall, 2010).

One of the few forage breeding programs in the world to sustain prolonged focus on a single forage quality trait has been at IBERS in the UK. They have concentrated on fructan accumulation to increase WSC levels in ryegrass, and this has resulted in a commercial range of "high sugar" grasses such as AberDart, AberMagic and AberGreen (Wilkins, 1998; Wilkins and Lovatt, 2007; Wilkins *et al.*, 2010). Similarly, in New Zealand, the cultivar Expo has been developed with high WSC (Stewart *et al.*, 2009; Easton *et al.*, 2009; Rasmussen *et al.*, 2009).

Water soluble carbohydrates consist of simple sugars and longer chain fructans which act as major storage carbohydrates in grasses. Their levels depend on a wide range of factors, including the plant part, ploidy level, plant maturity, diurnal and seasonal effects, temperature, light intensity, growth rates, endophyte, water status, as well as the inherent differences between cultivars. Application of N fertiliser allows more rapid growth, and thus tends to result in lower levels of fructan accumulation. Fructan accumulation is greatest when grasses are allowed to accumulate higher herbage mass, such as silage crops, with levels lower under very frequent grazing (Pollock and Cairns 1991; Rasmussen *et al.*, 2008).

In New Zealand, where frequent grazing is commonly practiced, expression of WSC in cultivars bred for elevated WSC is frequently no different to normal types (Francis *et al.*, 2006; Smith, 2008; Allsop, Nicol and Edwards, 2009) or only weakly expressed (Bryant *et al.*, 2009; Cosgrove *et al.*, 2010). It is expressed more under the longer cutting intervals of silage and biofuel crops, where it is valuable for silage fermentation and for biofuel extraction.

Animal grazing of pure swards with high versus low WSC pastures, have shown increases in animal performance over unselected cultivars in some trials but most trials report non-significant animal performance advantages (Marley *et al.*, 2007, Edwards, Parsons and Rasmussen, 2007; Cosgrove *et al.*, 2010, Parsons *et al.*, 2010).

New selections with even higher levels of WSC continue to be developed, largely for biofuel purposes, as ruminants run the risk of acidosis in the rumen if levels are excessive and horses frequently succumb to laminitis when WSC are high (Longland and Byrd, 2006). Further research will be required to determine the safe limits for WSC under a range of on-farm conditions for both horses and ruminants.

It is clear that there are many factors involved in improving the quality of ryegrass cultivars. It is likely that breeders will have to target multiple traits to ensure that cultivar improvements will consistently lift animal performance on farms.

Forage Persistence

It is important that perennial cultivars persist in pastures and trial data from the UK show that, in general, modern cultivars have greater persistence than older ones (Camlin, 1997). Many factors can be involved in lack of pasture persistence, pasture thinning and failure, only some of which may be genetic. Cultivars are known to vary in persistency and one of the factors providing a ryegrass cultivar with more capacity to survive adverse conditions and better persistence is high tiller density (Camlin and Stewart, 1978; Wilkins and Humphreys 2003), although this is often difficult for breeders to combine with high yield potential (Gilliland and Mann, 2001).

Almost all germplasm used in breeding programs today originates from plants from old persistent pastures, although many may have been subject to a number of cycles of crossing and selection. Usually persistence is determined by the stability of DM yield of a cultivar over a number of years, and generally grasses which persist under frequent close cutting persist well under grazing (Wilkins and Humphreys, 2003).

Cultivars must have adequate tolerance to the extreme stresses occurring on farms, such as winter cold stress, summer drought stress, intense defoliation, and treading damage. In Europe winter hardiness has long been crucial for persistence, while in New Zealand, summer drought tolerance is integrally associated with endophyte-mediated pest tolerance.

In situations where pests are damaging to pasture it is necessary to breed cultivars resistant or tolerant to these pests. This may include genetic resistances and/or endophyte-mediated resistance. In New Zealand insect pest damage usually manifests itself during dry summer conditions when growth and tillering capacity are severely reduced. Under moist conditions when ryegrass is actively growing pest damages are usually less apparent, despite often being present. These include a number of both indigenous and introduced pests: porina (*Wiseana cervinata*), grass grub (*Costelytra zealandica*), mealy bug (*Balanococcus poae*), root aphid (*Aploneura lentisci*), Argentine stem weevil (*Listronotus bonariensis*), black beetle (*Heteronychus arator*), black field cricket (*Teleogryllus commodus*), Tasmanian grass grub (*Aphodius tasmaniae*), and grey field slug (*Deroceras reticulatum*).

The seed-borne endophytic fungus (*Neotyphodium lolii*) that perennial ryegrass has co-evolved with, produces a series of quite potent alkaloids that can provide substantial pest protection, significantly poorer animal production and at times, ryegrass staggers (Easton, 2007; Thom, Waugh and Minneé, 2010). The influence of the endophyte on persistence varies depending on local conditions, but in pest prone environments of New Zealand endophyte-free plants may fail to survive one summer (Popay and Thom, 2009; Hume, Cooper and Panckhurst, 2009). Even in Ireland, where pest pressure is obviously much less, older pastures may contain a significant proportion of endophyte-infected plants, suggesting some degree of natural advantage, perhaps to overgrazing, if not pests (Ribeiro *et al.*, 1996).

The discovery and commercialisation of the “safer” endophyte strains, AR1 and AR37, have been a breakthrough for animal production and pest protection in New Zealand (Woodfield and Easton, 2004). However, pastures with “safer” endophytes appear to be more vulnerable to overgrazing than were the unpalatable “wildtype” endophytic pastures (Rennie, 2010).

Disease resistance

In general, perennial ryegrass has few major diseases that reduce forage yield but resistance to crown rust (*Puccinia coronata*) and, in some regions, Drechslera leaf spot (*Drechslera siccans*), mildew and rhyncosporium leaf spot is useful (Connolly, 2001). Similarly, resistance to diseases of seed production, such as stem rust (*Puccinia graminis*), is also important.

Breeding for diseases resistance can often be simply done in the field by removing susceptible plants but for some diseases, the grass population is not reliably and uniformly exposed to the disease, and glasshouse or laboratory screening techniques may be employed. In some programs molecular markers are being investigated for crown rust resistance (Thorogood *et al.*, 2001; Schejbel *et al.*, 2007).

Barley yellow dwarf virus and ryegrass mosaic virus are known to be widespread in older pastures and these may have a significant impact on performance and persistence, and some breeding programs have selected against them (Wilkins, 1974; Wilkins and Catherall, 1977; Latch, 1977; Webster *et al.*, 1996).

Seed Delivery Traits

Economic delivery of seed to farmers is crucial. Breeders report many instances of cultivars which have failed to be delivered successfully to farmers despite offering excellent or even exceptional production. A New Zealand example was the cultivar Tolosa that had exceptional forage yield but very poor seed production.

The most important trait involved in effective delivery is undoubtedly seed yield, and in New Zealand, endophyte infection levels. Seed yield can be influenced by many factors, including heading date, shattering resistance and resistance to stem rust, response to fungicides, N fertiliser and growth regulators (Elgersma, 1990). In New Zealand where novel endophytes are used it is often necessary for the breeder to co-select ryegrass to enable high transmission of endophyte into seed (Easton, 2007). Although seed crop management techniques have improved (Rolston *et al.*, 2006, 2007) a cultivar still needs to have a competitive seed yielding ability. In the future marker assisted selection may offer potential to improve seed yields within forage crops that are otherwise difficult to improve (Armstead *et al.*, 2008).

Environmental and Biofuel Traits

Nitrogen (N) in the environment is of concern, particularly in drinking water. In many farming regions part of the applied N fertiliser, N in animal urine and indeed from any source, including clovers, may be leached (Sprosen, Ledgard and Thom, 1977). This occurs primarily during winter when rainfall is often high and temperatures limit plant uptake and growth (Stewart, 2001). The introduction of the nitrate vulnerable zones (NVZ's) directive by the EU, has raised awareness among European farmers of the importance of legume fixed N and the use of crops which have been bred for improved N utilisation.

Breeding for N use efficiency and less leaching of N has become very important in the EU as regulations limit N fertiliser applications (Wilkins, Allen and Mytton, 2000). Increasing WSC increases the WSC/protein ratio leading to an increase in ruminal efficiency of N capture, leaving less N in the urine and less potential for N leaching into the environment (Merry *et al.*, 2006). Unfortunately, this mechanism is not very effective in heavily N fertilised pastures where it is most needed, but functions for low protein pastures where it is least needed (Edwards *et al.*, 2007, Abberton *et al.*, 2008; Morgavi *et al.*, 2010). In these situations intercepting N before it is leached may be a better option by selecting for improvements in rooting depth (Crush and Nichols, 2010).

Phosphate (P) in the environment is of concern and phosphatic rock supplies are limited. In contrast to the leaching losses of N most losses of P are due to soil erosion, and soil management practices will ultimately be more significant than plant factors in preventing losses. Breeding for P use efficiency though could be of considerable value, more so for clover use than ryegrass. Unfortunately, breeding for P use efficiency in clover has been difficult to achieve (Caradus, 1993) and this is also likely to be the case for ryegrass as well. There is also a risk that breeding for improved P utilisation in forages may reduce the availability of

P to ruminants, which could increase the occurrence of hypophosphatemia related diseases, particularly in dairy cattle (Grunberg, 2008).

Greenhouse gas emissions of CO_2 and N_2O are of concern to the environment. Internationally greenhouse gases are largely the result of fossil fuel use, while in New Zealand the low population of people and the high numbers of ruminants means emissions are largely from livestock with a smaller component from on-farm energy use.

The fossil fuel energy used to make N (or other) fertilisers is a major sustainability concern. Energy efficiency on many farms using high rates of N fertiliser can be very low when compared to mixed clover based systems which are usually much more resource efficient (Basset-Mens, Ledgard and Carran, 2005; Andrews *et al*., 2007; Abberton *et al*., 2008) and profitable despite offering a lower animal production to that of high rates of N (Clark and Harris, 1995; Humphreys, Casey and Laidlaw, 2009; Woodfield and Clark, 2009). It is clear that farms using high rates of N fertiliser developed from fossil fuels are unsustainable in the long term and breeding for more N-use efficiency in ryegrass may help mitigate this slightly, but the "ecological footprint" would be much lower if clovers were to become the major source of N.

Atmospheric CO_2 levels are increasing in an unsustainable way from the burning of fossil fuels, from 280 ppm in pre-industrial times to 390 ppm in 2010, an increase of 39%. Annually this is increasing by an alarming 2 ppm each year. The extra insulating effect on the earth contributes to the observed global warming. Elevated CO_2 also increases pasture productivity, as experiments with elevated CO_2 show that C3 grasses respond by producing more biomass (Newton and Edwards, 2007). Cultivars vary in their ability to utilise higher CO_2 levels and it is likely that part of the increase in pasture yields achieved through breeding has been due to adaptation to the higher CO_2 levels of today.

Perennial ryegrass pastures in Europe are already harvested for biofuel production, with substantial EU investment in biorefining infrastructure. Ryegrasses bred for large infrequent harvests are required, although the quality parameters for biofuel production may be quite different to those demanded for animal grazing or silage production.

The energy harvested from any biofuel crop needs to be much greater than the fossil fuel energy consumed during the manufacture of the N fertiliser and other inputs. Trials of new grasses bred for this purpose at IBERS, Aberystwyth have indicated annual yields and quality sufficient to allow a competitive cost of production. Countries within Europe developing or already running grass based biorefineries include: Ireland, Belgium, Austria, Denmark, Poland, Germany, the Netherlands and the United Kingdom (Charlton *et al*., 2009).

Farm and Trial Evaluation Systems

Increasing animal production on farms is the ultimate goal, but the difficulty and prohibitive expensive of measuring this directly for each new cultivar means that practical indirect trial systems are used. These usually involve measuring the DM yield and forage quality in replicated plot trials under a cutting management designed to simulate on-farm systems. Usually this is done at multiple locations around a region or country. In some trialling systems it is necessary to simulate 2 (or more) different farming systems, for example silage and grazing, as it is known that plant morphology and cutting frequency may interact and influence quality and subsequent animal production (Hazard and Ghesquière, 1997; Flores-Lesama *et al*., 2006).

Large-scale animal production trials have shown highly significant differences between cultivars under both grazing and conservation managements. These trials also demonstrated the importance of total yield, seasonal growth and quality in determining seasonal and total annual animal production (Connolly *et al*., 1977; Connolly, 1979).

In some countries the management of official trials has now been standardised and regulated, often to such an extent that breeder's trials will mimic the official trials very closely. In these situations breeders are not motivated to select for traits other than those measured in such trials. If a breeder selects to improve additional traits, these must demonstrate clear, marketable added value to farmers. Conversely, other countries lack any regulatory requirement, and even uncertified seed may be sold, sometimes under a cultivar name, to the detriment of the seed and livestock industries.

The question of how best to evaluate cultivars must always be critically examined. The trialling systems must not only be relevant to on-farm grazing systems, it must also provide clear motivation to breeders to select for the most relevant traits. Furthermore, trialling systems must be prepared to change to reflect any changing farm management practices (Gilliland *et al*., 2002; Conaghan *et al*., 2008). This can be particularly difficult when farm systems vary in their use of different cultivar types, grazing systems and clover management.

Although ryegrass yield and quality as measured in cutting trials are generally strongly associated with animal performance, this may not always be the case. In some situations there are differences in ranking between the results from cutting and grazing (Camlin and Stewart, 1975; Orr, Martyn and Clements, 2001). Particular disparity may occur between trials and farm use when the cutting system used allows a large herbage mass to develop while on-farm management involves grazing frequently or continuously. Grazing trials are also run in some situations, but they are more complex and expensive, requiring animals, as well as more sophisticated yield assessment, such as pre-trim and post harvest measurements, on rotating sub-samples of the plot.

In mixed swards of ryegrass and clovers, or indeed with any herb or weed components, ryegrass is only one component of the pasture ecosystem, and the factors driving animal production are naturally more complex (Luscher *et al*., 2008). Lifting the harvestable yield and quality of this mixed sward ecosystem, and hence the animal productivity, is much more difficult than breeding improved ryegrass cultivars for a ryegrass monoculture. For this reason the genetic gains for mixed sward yield will usually be much less than comparable single species situations (Frankow-Lindberg *et al*., 2009). Understanding the interactions that occur in mixed swards is crucial to improving productivity in these systems.

In mixed ryegrass clover situations it is possible for relatively small fluctuations in clover species composition to disproportionately influence animal production and outweigh the small changes in ryegrass yields (Hyslop *et al*., 2000). Yield of the ryegrass component may be a poor predictor of animal performance in such circumstances, particularly when any additional ryegrass yield may suppress the clover. Breeding high yielding ryegrasses which are less aggressive against clover would be the ideal solution, but despite observations that the more open tetraploid cultivars often support more clover in New Zealand, there are no reports of breeders targeting clover compatibility as a breeding trait.

In situations where animals are fed only a partial pasture diet the nutritional requirements from pasture are likely to be considerably different to those demanded from 100% pasture feeding. In situations where nutrient-rich supplements are fed, ryegrass yield is likely to be even more paramount than when pasture is whole diet.

The development of an effective farming system seldom relies upon a single ryegrass type over the whole farm, as farmers continually manipulate a broad range of pasture, supplementary crop and feed purchase options to provide a continuous economic seasonal flow of feed to match the animal feed demands. This may involve a range of ryegrass types on different areas of the farm, pure or in legume mixtures, combined with supplementary feed crops such as brassicas or maize, often backed up by more expensive feed purchase options. Systems like this make ryegrass trait prioritisation more difficult to determine than for simpler farm systems.

Trait Prioritisation

To place an economic priority on each trait in a breeding program requires knowledge of their relative values in farm systems. The relative economic value of various factors will usually coincide with the management factors that astute farmers have identified as important drivers of their production. In many cases the impact of management will be much larger than the magnitude of any genetic advance but this can often be further magnified by management on-farm. For the Irish dairy industry economic weights have been developed for important production factors (McEvoy *et al*., 2010). Converting farm economic weightings to ryegrass trait priorities will be easier to determine for farms using pure ryegrass swards than those using clover mixtures or supplementary brassica crops.

Once the on-farm economic priority for each trait has been determined the breeder must then balance these against the genetic variation, heritability and likely progress that can be made. Some traits may be particularly difficult to improve through lack of genetic variation, lack of a suitable selection methodology or indeed lack of funds. Detailed sustained research and focus may be required on such traits in order to make useful progress (Parsons *et al*., 2010).

In the end though, the breeder has to develop a cultivar with a strong overall balance of traits, none of which can be deficient.

Future Breeding Opportunities

A wide range of traditional breeding methods are employed by ryegrass breeders, including recurrent selection, mass selection of ecotypes, tetraploidy, hybridisation between elite cultivars, introgression of "new" germplasm, and hybrid production involving male sterility, to name a few. As breeding is a long term process it is possible to predict with some accuracy potential cultivar releases in the next 10 years as breeding programs have already commenced. Genetic progress over this period is likely to be similar to that in the past, with much slower progress possible in the more complex ecosystems of mixed swards than with pure ryegrass systems.

Fescue Introgression to enhance genetic variation

One of the more interesting breeding opportunities for perennial ryegrass improvement is to extend the genetic variation available to ryegrass breeders by introgression of chromosome segments or traits from closely related *Lolium* and *Festuca* species. This added genetic diversity opens prospects of making more progress in breeding for certain traits than is possible within perennial ryegrass alone. Much of this work has been led by Humphreys *et al*. (2006) and colleagues at IBERS in the UK. The similar but more general approach of crossing *Lolium* and *Festuca* species to develop *Festulolium* has been undertaken by many breeders. With the knowledge gained there is now significant potential to use introgression breeding from closely related *Festuca* species provided funding is maintained.

The role of GM breeding

Genetic modification (GM) is now becoming widespread in many major crops throughout the world with a number of valuable traits being marketed. Indeed it is clear that GM is expanding into more crop species and more regions of the world with a greater range of useful traits.

As yet we have not seen the release of any genetically modified forage grass, although a number of research projects are underway. These include such targets as improved quality through increased fibre digestibility, reduced lignin, condensed tannins, increased fructan accumulation, increased lipid content, improved salt tolerance, as well as increased drought tolerance (Smith, Spangenberg and Stewart, 2007; Puthigae *et al*., 2010). Field trials have been carried out with ryegrass plants in Europe, USA and Australia for different projects (Badenhorst *et al*., 2010).

It is highly probable that when appropriate genes are used we could expect improved animal production from ryegrass pastures. However, it is difficult to find valuable single genes due to complexity of pastures, rumen digestion and animal production systems. One of the barriers to the use of genetically modified perennial ryegrass is likely to be public acceptance. However, this lack of public acceptance seems unjustifiable when GM based medicines are widely used (and demanded), GM cotton products are widely worn, and many of the existing GM crops such as maize, soybean, and cotton seed are already imported and used in forage systems internationally, even in some jurisdictions where GM crops are not grown.

Perhaps the largest barrier to the introduction of GM forage crops is simply economic in that investment in forages is limited by the scale of the seed industry and GM regulatory processes pose an enormous economic limitation (Stewart and Woodfield, 2009).

In the future it is likely that research will continue with genetic modification in some jurisdictions although only a few of the current GM traits under investigation are likely to be of value on farms and result in commercial cultivars. Greater investment will be required in this area in order to incorporate genes of known value currently in use in other crops.

Funding of Ryegrass breeding

In many parts of the world Government investment in forage plant breeding is becoming more limited and breeding is being left increasingly to seed companies. The seed industry has a very limited scale when compared to the livestock industries. To put this in perspective it only requires 150m^2 of ryegrass seed crop to maintain the average Irish dairy farm when pasture is renewed at the current rate of 2% annually (O'Donovan *et al.*, 2010). The total amount of ryegrass used in Ireland annually could be grown on 2000 ha, which represents only a few large seed production farms in Oregon or New Zealand. Although small, it is crucial that the seed industry remains viable as it is not only responsible for delivery of seed but also for funding the majority of ryegrass breeding. This means that investment in breeding will be subject to the economic success of companies and is unlikely to increase. Indeed, continued changes in the seed industry could even leave many ryegrass breeding programs vulnerable in the future.

Limited funding may also mean that investment is unlikely to be focussed on necessary long term breeding programs, or the more expensive DNA based technologies. These technologies offer breeders a wider range of methods, many enabling very precise knowledge of genetic systems. Many of these methods require expensive research to implement and ryegrass breeders look forward to the day when it may be affordable enough to measure high numbers of plants. The best example of these technologies is that of molecular marker assisted selection but it is fair to say that ryegrass breeders are only beginning to use these tools.

We are also likely to see a greater disconnect between practical field breeding carried out by seed companies and the greater concentration of academic laboratory based high-tech DNA research promoted within state funded research institutes. Unless viable linkages can be made between seed companies and these research institutes, DNA based technologies are unlikely to contribute greatly to future cultivar improvement.

References

Abberton MT, Marshall AH, Humphreys MW, Macduff JH, Collins RP, Marley CL 2008 Genetic improvement of forage species to reduce the environmental impact of temperate livestock grazing systems. *Advances in Agronomy* **98**: 311-355.

Abberton MT, Marshall AH 2010 White clover. Handbook of Plant Breeding Volume 5, Fodder Crops and Amenity Grasses, Boller B, Posselt UK, Veronesi F Springer New York, ISBN:9781441907592, 457-476.

Allsop ARC, Nicol AM, Edwards GR 2009 Effect of water soluble carbohydrate concentration of ryegrass on the partial preference of sheep for clover. *Proceedings of the New Zealand Animal Production Society* **69**: 20-23.

Andrews, M., Scholefield, D., Abberton, M.T., McKenzie, B.A., Hodge, S. and Raven, J.A. 2007. Use of white clover as an alternative to nitrogen fertiliser for dairy pastures in nitrate vulnerable zones in the UK: productivity, environmental impact and economic considerations. *Annals of Applied Biology* **151**: 11–23.

Annicchiarico, P. and Proietti, S. 2010. White clover selected for enhanced competitive ability widens the compatibility with grasses and favours the optimization of legume content and forage yield in mown clover-grass mixtures. *Grass and Forage Science* **65**: 318-324.

Armstead, I.P., Turner, L.B., Marshall, A.H., Humphreys, M.O., King, I.P. and Thorogood, D. 2008. Identifying genetic components controlling fertility in the outcrossing grass species perennial ryegrass (*Lolium perenne*) by quantitative trait loci analysis and comparative genetics. *New Phytologist* **178**: 559-571.

Badenhorst, P.E., Dimech, A.M., Panter, S., Liu Z., Ramage, C., Stewart, A.V., Smith, K.F., Mouradov, A. and Spangenberg, G.C. 2010. Field Evaluation of transgenic Perennial Ryegrass (*Lolium perenne* L.) plants for enhanced fructan accumulation and biomass yield. *Molecular Breeding of Forage and Turf Conference*, Buenos Aires 15th-19th March 2010.

Basset-Mens, C., Ledgard, S. abnd Carran, A. First Life Cycle Assessment of Milk Production from New Zealand Dairy Farm Systems, AgResearch Ltd. www.anzsee.org/anzsee2005papers/Basset-Mens_LCA_NZ_milk_production.pdf.

Brereton, A.J. and McGilloway, D.A. 1999. Winter Growth of Varieties of Perennial Ryegrass (*Lolium perenne* L.) *Irish Journal of Agricultural and Food Research* **38**: 1-12.

Bryant, R.H., Parsons, A.J., Rasmussen, S. and Edwards, G.R. 2009. Pasture production and botanical composition of high sugar and control ryegrasses with or without endophyte under irrigation in Canterbury. *Proceedings of the New Zealand Grassland Association* **71**: 177-185.

Camlin, M.S. 1997. Plant breeding - Achievement and prospects - Grasses. Seeds of Progress. Occasional Symposium No. 31. British Grassland Society.(ed. Weddell, J.R.): 2-14.

Camlin, M.S. and Stewart, R.H. 1975. Reaction of Italian ryegrass cultivars under grazing as compared with cutting. *Grass and Forage Science* **30**: 121–130.

Camlin, M.S. and Stewart, R.H. 1978. The assessment of persistence and its application to the evaluation of mid season and late perennial ryegrass cultivars. *Journal of the British Grassland Society* **33**: 275-282.

Caradus, J.R. 1993. Achievements in improving adaptation of forages to acid, low P soils. *Proceedings of Workshop on Adoption of Plants to Soil Stresses*: 295-327.

Charlton, A., Elias, R., Fish, S., Fowler, P. and Gallagher, J.A .2009. Biorefining opportunities in Wales: Understanding the scope for building a sustainable, biorenewable economy using plant biomass. *Chemical Engineering Research and Design* **87**: 1147-1161.

Clark, D.A. and Harris, S.L. 1995. White clover or nitrogen fertiliser for dairying? *Agronomy Society of New Zealand Special Publication* **11** / *Grassland Research and Practice Series* **6**: 107-114.

Conaghan, P., Casler, M.D., McGilloway, D.A., O'Kiely, P., and Dowley, L.J. 2008. Genotype - environment interactions for herbage yield of perennial ryegrass sward plots in Ireland *Grass and Forage Science* **63**: 107–120.

Connolly, V. 1979. Influence of pasture type on animal production. *Irish Grassland and Animal Production Association Journal* **14**: 5-9.

Connolly, V. 2001. Breeding improved varieties of perennial ryegrass. Teagasc - Project Report – 3495, 17pp.

Connolly, V., Ribeiro, M.A.M. and Crowley, J.G. 1977. Potential of grass and legume cultivars under Irish conditions. *Proceedings of the International Meeting on Animal Production from Temperate Grassland*, Dublin (ed. Gilsenan, B.) 379-387.

Cosgrove, G.P., Koolaard, J., Potter, F., Luo, D., Burke, J.L. and Pacheco, D. 2010. Milksolids production from high water soluble carbohydrate ryegrasses: a combined analysis of multiyear data. *Proceedings of the 4th Australasian Dairy Science Symposium*, 31st August-2nd September, Lincoln University: 334-338.

Crush, J.R. and Nichols, S.N. 2010. Progress towards forage plant systems for sustainable dairying. *Proceedings of the 4th Australasian Dairy Science Symposium*, 31st August-2nd September, Lincoln University: 50-52.

Easton, H.S. 2007. Grasses and *Neotyphodium* endophytes: co-adaptation and adaptive breeding. *Euphytica* **154**: 95-306.

Easton, H.S., Amyes, J.M., Cameron, N.E., Green, R.B., Kerr, G.A., Norriss, M.G. and Stewart, A.V. 2002. Pasture plant breeding in New Zealand: Where to from here? *Proceedings of the New Zealand Grassland Association* **64**: 173-179.

Easton, H.S., Stewart, A.V., Lyons, T.B., Parris, M. and Charrier, S. 2009. Soluble carbohydrate content of ryegrass cultivars. *Proceedings of the New Zealand Grassland Association* **71**: 59-64.

Edwards, G.R., Parsons, A.J. and Rasmussen, S. 2007. High Sugar grasses for dairy systems. In: Meeting the Challenges for Pasture based dairying. *Proceedings of the 3rd Dairy Science Symposium*. September 2007 Melbourne.

Evans, D.R., Williams, T.A. and Evans, S.A. 1996. Breeding and evaluation of new white clover varieties for persistency and higher yields under grazing *Grass and Forage Science* **51**: 403–411.

Elgersma, A. 1990. Seed yield related to crop development and to yield components in nine cultivars of perennial ryegrass (*Lolium perenne* L.) *Euphytica* **49**: 141-154.

Flores-Lesama, M., Hazard, L., Betin, M. and Emile, J. 2006. Differences in sward structure of ryegrass cultivars and impact on milk production of grazing dairy cows *Animal Research* **55**: 25-36.

Francis, S.A., Chapman, D.F., Doyle, P.T. and Leury, B.J. 2006. Dietary preferences of cows offered choices between white clover and "high sugar" and "typical" perennial ryegrass cultivars *Australian Journal of Experimental Agriculture* **46**: 1579-1587.

Frankow-Lindberg, B.E., Brophy, C., Collins, R.P. and Connolly, J. 2009. Biodiversity effects on yield and unsown species invasion in a temperate forage ecosystem. *Annals of Botany* **103**: 913-921.

Fulkerson, W.J. and Donaghy, D.J. 2001. Plant soluble carbohydrate reserves and senescence - key criteria for developing an effective grazing management system for ryegrass-based pastures; a review. *Australian Journal of Experimental Agriculture* **41**: 261-275.

Gilliland, T.J. and Mann, R.L. 2001. The silage yield potential of hybrid ryegrass over a 5 year period in Northern Ireland relative to other ryegrasses and timothy. *Grass and Forage Science* **56**: 305-310.

Gilliland, T.J., Barrett, P.D., Mann, R.L., Agnew, R.E. and Fearon, A.M. 2002. Canopy morphology and nutritional quality traits as potential grazing value indicators for *Lolium perenne* varieties. *Journal of Agricultural Science* **139**: 257-273.

Grundberg, W. 2008. Phosphorus homeostasis in dairy cattle: Some answers, more questions. *Proceedings of the 17th Annual Tri-State Dairy Nutrition Conference*: 29-35.

Hageman, I.W., Lantinga, E.A., Schlepers, H. and Neyteboom, J.H. 1993. Herbage intake, digestibility characteristics and milk production of a diploid and two tetraploid cultivars of perennial ryegrass. *Proceedings of the XVII International Grassland Congress*: 459-460.

Hazard L. and Ghesquière, M. 1997. Productivity under contrasting cutting regimes of perennial ryegrass selected for short and long leaves *Euphytica* **95**: 295-299.

Hume, D.E., Cooper, B.M. and Panckhurst, K.A. 2009. The role of endophyte in determining the persistence and productivity of ryegrass, tall fescue and meadow fescue in Northland. *Proceedings of the New Zealand Grassland Association* **71**: 121-126.

Humphreys, J., Casey, I.A. and Laidlaw A.S. 2009. Comparison of milk production from clover-based and fertilizer-N-based grassland on a clay-loam soil under moist temperate climatic conditions *Irish Journal of Agricultural and Food Research* **48**: 189–207, 2009.

Humphreys, M.W., Yadav, R.S., Cairns, A.J., Turner, L.B., Humphreys, J. and Skot, L. 2006. A changing climate for grassland research. *New Phytologist* **169**: 9-26.

Hyslop, M.G., Fraser, T.J., Smith, D.R., Knight, T.L., Slay, M.W.A. and Moffat, C.A. 2000. Liveweight gain of young sheep grazing tall fescue or perennial ryegrass swards of different white clover content. *Proceedings of the New Zealand Society of Animal Production* **60**: 51-54.

Latch, G.C.M. 1977. Incidence of barley yellow dwarf virus in ryegrass pastures in New Zealand *New Zealand journal of agricultural research* **20**: 87-89.

Longland, A.C. and Byrd B.M. 2006. Pasture Nonstructural Carbohydrates and Equine Laminitis. *Journal of Nutrition* **136**:2099S-2102S.

Luscher, A., Finn, J.A., Connolly, J., Sebastia, M.T., Collins, R.P., Fothergill, M., Porqueddu, C., Brophy, C., Huguenin-Elie, O., Kirwan, L., Nyfeler, D. and Helgadottir, A. 2008. Benefits of sward diversity for agricultural grasslands. *Biodiversity* **9**: 29-32.

Marley, C.L., Fraser, M.D., Fisher, W.J, Forbes, A.B., Ones, R, Moorby, J.M., MacRae, J.C. and Theodorou, M.K. 2007. Effects of continuous or rotational grazing of two perennial ryegrass varieties on the chemical composition of the herbage and the performance of finishing lambs. *Grass and Forage Science* **62**: 255-264.

McEvoy, M., O'Donovan, M. and Shalloo, L. 2010. Evaluating the economic performance of grass varieties. Advances in Animal Biosciences. In: *Proceedings of the British Society of Animal Science and Agricultural Research Forum*, pp328.

Merry, R.J., Lee, M.R.F., Davies, D.R., Dewhurst, R.J., Moorby, J.M., Scollan, N.D. and Theodorou, M.K. 2006. Effects of high-sugar ryegrass silage and mixtures with red clover silage on ruminant digestion. 1. In vitro and in vivo studies of nitrogen utilization *Journal of Animal Science* **84**: 3049-3060.

Minobe, S., Kuwano-Yoshida, A., Komori, N., Xie, S.P. and Small, R.J. 2008. Influence of the Gulf Stream on the troposphere. *Nature* **452**: 206-U51.

Morgavi, D.P., Forano, E., Martin, C. and Newbold, C.J. 2010. Microbial ecosystem and methanogenesis in ruminants. *Animal* **4**: 1024-1036.

Newton, P.C.D. and Edwards, G.R. 2007. Plant breeding for a changing environment. Pp 309-319 In Newton PCD, Carran, RA, Edwards, GR & Niklaus, PA Eds. 'Agroecosystems in a Changing Climate' CRC Press.

O'Donovan, M. and Delaby, L. 2005. A comparison of perennial ryegrass cultivars differing in heading date and grass ploidy with spring calving dairy cows grazed at two different stocking rates. *Animal Research* **54**: 337-350.

M O'Donovan, M., Lewis, E., Boland, T. and O'Kiely, P. 2010. Requirements of future grass based ruminant production systems in Ireland (*Proceedings of this conference*).

Orr, R.J., Martyn, M. and Clements, R.O. 2001. Evaluation of perennial ryegrass varieties under frequent cutting or continuous stocking with sheep *Plant varieties & seeds* **14**: 181-199.

Orr, R.J., Cook, J.E., Young, K.L., Champion, R.A. and Rutter, S.M. 2005. Intake characteristics of perennial ryegrass varieties when grazed by yearling beef cattle under rotational grazing management. *Grass and Forage Science* **60**: 157-167.

Parsons, A.J., Edwards, G.R., Newton, P.C.D., Chapman, D.F., Caradus, J.R., Rasmussen, S. and Rowarth, J.S. 2010. Past lessons and future prospects: plant breeding for cool temperate pastures. *Proceedings of the 4th Australasian Dairy Science Symposium*, 31st August-2nd September, Lincoln University: 272-291.

Pollock, C.J. and Cairns, A.J. 1991. Fructan metabolism in grasses and cereals. *Annual Review Plant Physiology and Plant Molecular Biology* **42**: 77-101.

Popay, A.J. and Thom, E.R. 2009. Endophyte effects on major insect pests in Waikato dairy pasture *Proceedings of the New Zealand Grassland Association* **71**: 121-126.

Puthigae, S., Templeton, K., Sontam, D., Whittaker, D., Bryant, C., Jones, C., Gill, G., Richardson, K. and Hanley, Z. 2010. Engineering drought tolerance in Perennial Ryegrass (*Lolium perenne* L.) using its own genome. Poster presentation: Plant Biology 2010.

Rasmussen, S., Parsons, A.J., Fraser, K., Xue, H. and Newman, J.A. 2008. Metabolic profiles of *Lolium perenne* are differentially affected by nitrogen supply, carbohydrate content, and fungal endophyte infection *Plant Physiology* **146**: 1440–1453.

Rasmussen, S., Parsons, A.J., Xue, H. and Newman, J.A. 2009. High sugar grasses – harnessing the benefits of new cultivars through growth management. *Proceedings of the New Zealand Grassland Association* **71**: 167-175.

Rennie, G.M., King, W.M. and Bell, N.J. 2010. Delivering endophyte benefits on-farm: pasture renewal success and effects on pasture pests. *The International Symposium on Fungal Endophytes of Grasses*. June 28-July 1, Kentucky USA.

Ribeiro, M.A.M., Do Valle, Gurney, K.A. and Bush, L. P. 1996. Endophyte *Acremonium lolii* in ecotypes of perennial ryegrass (*Lolium perenne* L.) collected in old Irish pastures. *Irish journal of agricultural and food research* **35**: 151-157.

Rolston, M. P., Chynoweth, R. J. and Stewart, A.V. 2006. Forage Seed Production: 75 years applying science and technology. *Proceedings of the NZ Grassland Association* **68**: 15- 24.

Rolston, P., Trethewey, J., McCloy, B. and Chynoweth, R. 2007. Achieving forage ryegrass seed yields of 3000 kg/ha and limitations to higher yields. *6th International Herbage Seed Conference, Norway*: 100-106.

Schejbel, B., Jensen, L.B., Xing, Y. and Lübberstedt, T. 2007. QTL analysis of crown rust resistance in perennial ryegrass under conditions of natural and artificial infection *Plant Breeding* **126**: 347–352.

Seager, R., Battisti, D.S., Yin, J., Gordon, N., Naik, N., Clement, A.C. and Cane, M.A. 2002. Is the Gulf Stream responsible for Europe's mild winters? *Quarterly Journal of the Royal Meteorological Society* **128**: 2563-2586.

Smith, G. 2008. How endophyte and breeding for high sugar grasses affects allocation patterns in perennial ryegrass. Lincoln University, Dissertation.

Smith, K.F., Spangenberg, G. and Stewart, A. 2007. Breeding high energy grasses: how, why and what are the benefits to producers *Proceedings of the New Zealand Grassland Association* **69**: 173-177.

Sprosen, M.S., Ledgard, S.F. and Thom, E.R. 1997. Nitrate leaching is similar in N2-fixing grass-clover pasture and N-fertilised grass-only pasture at similar N inputs. *Proceedings of the New Zealand Grassland Association* **59**: 125–128.

Stewart, A.V. 2001. A comparison of nitrogen leaching from plots of perennial ryegrass (*Lolium perenne* L.) and winter active Swamp Phalaris (*Phalaris arundinacea* subsp. *oehleri* Pilger) Land Treatment Collective, Invercargill: 109-115.

Stewart, A.V. 2006. Genetic origins of New Zealand perennial ryegrass (*Lolium perenne*) cultivars. *Proceedings of the 13th Australasian Plant Breeding Conference*: 11-20.

Stewart, A.V., Easton, H.S., Lyons, T.B., Parris, M. and Charrier, S. 2009. Improving Soluble carbohydrates content of perennial ryegrass herbage. *Australasian Plant Breeding Conference*, Cairns, August 2009.

Stewart, A.V. and Woodfield, D. 2009. A Conventional Breeders view of GM. *New Zealand Institute of Agricultural and Horticultural Science, Genetic Modification Revisited* Lincoln 1st July 2009. 36: 11-13.

Thom, E.R., Waugh, C.D. and Minneé, E.M.K. 2010. Dairy cow responses to the wild-type endophyte in perennial ryegrass. *Proceedings of the 4th Australasian Dairy Science Symposium*, 31st August-2nd September, Lincoln University: 370-375.

Thomson, N. and Kay, J. 2005. Milksolids production from cows grazing timothy/white clover in comparison with ryegrass pastures. *Proceedings of the New Zealand Grassland Association* **67**: 123-130.

Thorogood, D., Paget, M.F., Humphreys, M.O., Turner, L.B., Armstead, I.P. and Roderick, H.W. 2001. QTL analysis of crown rust resistance in perennial ryegrass - implications for breeding. *International Turfgrass Society Research Journal* **9**: 218-223.

van Bogaert, G. 1975. A comparison between colchicine induced tetraploid and diploid cultivars of *Lolium* species. In: Nuesch, B. (Ed) Ploidy in fodder plants. *Report of the Eucarpia Fodder Crops Section*. Zurich 61-78.

van der Heijden, S.A.G. and Roulund, N .2010. Genetic gain in agronomic value of forage crops and turf: a review. *Sustainable use of Genetic Diversity in Forage and Turf Breeding*. Part **4**: 247-260.

Vipond, J.E., Swift, G. and McClelland, T.H. 1993. Sustainable clover-dominant swards for lamb production under low temperatures. *Proceedings of the XVII International Grassland Congress*: 674-675.

Webster, D.E., Forster, R.L.S., Sinclair, L. and Guy, P.L. 1996. Distribution of ryegrass mosaic virus in New Zealand perennial ryegrass pastures as determined by ELISA and RT-PCR *New Zealand Journal of Agricultural Research* **39**: 405-412.

Wilkins, P.W, 1974, Tolerance to ryegrass mosaic virus and its inheritance *Annals of Applied Biology* **78**: 187–192.

Wilkins, P.W. 1998. AberDart (Ba11778), IBERS Internal Reference 1830 4468.

Wilkins, P.W. and Catherall, P.L. 1977. Variation in reaction to barley yellow dwarf virus in ryegrass and its inheritance *Annals of Applied Biology* **85**: 257–263.

Wilkins, P.W., Allen, D.K. and Mytton, L.R. 2000. Differences in the nitrogen use efficiency of perennial ryegrass varieties under simulated rotational grazing and their effects on nitrogen recovery and herbage nitrogen content. *Grass and Forage Science* **55**: 69–76.

Wilkins, P.W. and Humphreys, M.O. 2003. Progress in breeding perennial forage grasses for temperate agriculture. *Journal of Agricultural Science* **140**: 129-150.

Wilkins, P.W. and Lovatt, J.A. 2007. AberMagic (Ba13582), IBERS Internal Reference 1340 4213.

Wilkins, P.W., Lovatt, J.A., Hayes, R.C. and Thomas, G.L. 2010. AberGreen (Ba13926) IBERS Internal Reference.

Woodfield, D.R. 1999. Genetic improvements in New Zealand forage cultivars. *Proceedings of the New Zealand Grassland Association* **61**: 3-7.

Woodfield, D.R. and Easton, H.S. 2004. Advances in pasture plant breeding for animal productivity and health *New Zealand Veterinary Journal* **52**: 300-310.

Woodfield, D.R. and Clark, D.A. 2009. Do forage legumes have a role in modern dairy farming systems? *Irish Journal of Agricultural and Food Research* **48**: 137–147.

Woollings, T. 2010. Dynamical influences on European climate: an uncertain future. *Philosophical Transactions of the Royal Society A-Mathematical Physical and Engineering Sciences* **368**: 3733-3756.

A theoretical and practical analysis of the optimum breeding system for perennial ryegrass

P. Conaghan[1] **and M.D. Casler**[2]

[1]*Animal & Grassland Research and Innovation Centre, Teagasc, Oak Park, Carlow, Co. Carlow, Ireland;*
[2]*USDA-ARS, U.S. Dairy Forage Research Center, 1925 Linden Drive, Madison, WI 53706-1108, USA*
Email: patrick.conaghan@teagasc.ie

Abstract

The goal of plant breeding is to develop and use methods that effectively and efficiently select for the best phenotypes leading to the development of improved cultivars. The objectives of this review are to describe and critically evaluate breeding methods appropriate to the improvement of perennial ryegrass (*Lolium perenne* L.) in a dedicated long-term breeding programme. The optimum breeding system is dependent on the traits for improvement, and the resources and skills available. Forage dry matter yield, persistence, disease resistance, nutritional value and seed yield are considered among the most important traits for improvement. Careful consideration should be given to the expression of the trait under the management regime imposed in the breeding programme and under real-world sward conditions in the target region. Recurrent selection programmes for intrapopulation improvement are most appropriate for breeding perennial ryegrass. Three distinct types of recurrent selection may be implemented: (i) phenotypic recurrent selection, (ii) genotypic recurrent selection and (iii) marker-assisted selection. Genotypic recurrent selection will be a necessary part of the breeding system if forage yield is a trait for improvement. Genotypic recurrent selection may be practised using full-sib or half-sib families, each with their own advantages and disadvantages to consider. Phenotypic recurrent selection in tandem (i.e. within family selection) or in succession with genotypic recurrent selection should be used to improve traits that have a high correlation between spaced plants and swards. Genome-wide selection represents the most interesting and exciting potential application of marker-assisted selection, although it remains to be seen how effective and efficient it will be in practise.

Keywords: *Lolium perenne* L; traits for improvement; breeding method; gain; efficiency

Introduction

The goal of the plant breeder is to create new phenotypes, improved in one or more important characteristics, in the most efficient manner possible. To achieve this end, the plant breeder will typically have a limited amount of resources which must be judiciously allocated for the development, evaluation and selection of improved phenotypes bearing in mind the genetic, reproductive and agronomic characteristics of the species being modified and the target traits for improvement.

Perennial ryegrass (*Lolium perenne* L.) is the main forage grass species sown in northwest Europe, New Zealand, and in the temperate regions of Japan, Australia, South Africa and South America (Humphreys *et al*., 2010). This species comprises a major, and arguably primary, focus and emphasis for forage grass breeding programmes in these areas. Forage grasses have a relatively short history of formal breeding (Casler *et al*., 1996). Genetic variation among and within populations is still extremely high, offering significant scope for further genetic improvements. The target traits for improvement are largely determined by the market requirements as dictated by the official cultivar evaluation trials and/or farmers in each area.

The objectives of this review are to describe and critically evaluate breeding methods appropriate to the improvement of perennial ryegrass in a dedicated long-term breeding programme, and to blend theory and practice in designing the optimum breeding system for a selection of the most important agronomic traits in this species. The emphasis will be on maximising the amount of genetic improvement or gain realised per year at the minimum cost.

Traits for improvement

In order to plan and direct an efficient and successful breeding programme knowledge and understanding of the crop and the traits for improvement is first required. The number of potential traits is limited only by human imagination. However, the more traits selected for improvement the slower the rate of gain for each individual trait, and the greater the difficulty and cost. Assuming selection is made on *n* uncorrelated traits, the breeding gain for a given trait is $1/\sqrt{n}$ times as great as the response obtained from selection for that trait alone (Hazel and Lush, 1942). This equates to a relative gain of 0.71, 0.50, 0.41, 0.35 and 0.32 for a given trait when selection is made simultaneously on 2, 4, 6, 8 and 10 traits, respectively. Therefore, the goal of the breeder is to select for the minimum number of only the most important traits, thus maximising the gain per individual trait.

The key traits for improvement in perennial ryegrass, as indicated by previous reviews (Wilkins and Humphreys, 2003; Casler and van Santen, 2010), are summarised in Table 1 and discussed below. In determining the appropriate breeding strategy, cognisance must be taken of the heritability of the trait, and the magnitude of the genotypic and phenotypic variances. Estimates of the heritability, and genotypic and phenotypic variances strictly only apply to a specific population in the environment in which the population is studied. However, an overall indication of the amount of the genetic variances and heritability for a particular trait in a crop species may be obtained by averaging across many populations and environments (Bernardo, 2002). Cognisance must also be taken of the correlation between the performance of the trait under the management scheme imposed in the breeding programme and under real-world swards on farm. Particular management schemes to consider include spaced plants *vs.* swards, cutting *vs.* animal grazing, and frequent (grazing) *vs.* infrequent (conservation) cutting. If in doubt, the breeder's axiom "you get what you select for" should be applied.

Forage dry matter yield

Forage dry matter (DM) yield is one of the most important traits of perennial ryegrass and is measured in nearly every cultivar evaluation trial. Estimates of narrow sense heritability (h^2) in plot swards are highly variable but typically low to moderate (0.20 to 0.50) (Frandsen, 1986; Jafari, 1998; Wilkins, 1991). The trait is subject to severe genotype × environment (G × E) interactions. In perennial ryegrass forage yield trials in Ireland and the UK, the G × E interaction variance (σ^2_{GE}) was on average 2.3 times the size of the genotypic variance (σ^2_G) (Talbot, 1984; Conaghan *et al.*, 2008a). This indicates that the response to selection for forage yield can be considerably improved through the judicious use of environmental replication or by developing cultivars for specifically defined environments (Bernardo, 2002).

There is generally a zero to low (≤ 0.20) correlation between the yield of sward plots and spaced plants (Jafari, 1998; Hayward and Vivero, 1984). Thus, progress in breeding perennial ryegrass for increased forage yield requires yield measurement and selection on sward plots. Genotypes may also rank differently in annual and seasonal yield depending on the frequency of cutting (Wilkins, 1989). The seasonal pattern of production is more important than annual production as the monetary value of grass at different points in the growing season may vary markedly (Doyle and Elliott, 1983). Accordingly, harvest frequency and timing in the breeding programme should be designed to reflect real-world practises in the target region (Casler and van Santen, 2010). Ryegrass yield under cutting and grazing is highly correlated (Camlin and Stewart, 1975; Jones and Roberts, 1986; Aldrich, 1987) facilitating indirect selection for grazing yield under cutting. The use of animal grazing trials for yield assessment is discouraged as they would require larger plot sizes and more replicates than used for cutting trials (Casler and van Santen, 2010), thereby increasing the total breeding programme costs or reducing the number of genotypes that could be evaluated for a fixed level of resources. Fresh-matter and DM yields are also highly correlated so that selection on fresh-matter yield alone can be used to increase DM yield within relatively narrow maturity groups (Conaghan *et al.*, 2008b).

Persistence

Persistence is an economically important trait for perennial forages because the cost of establishment, including the associated loss of production, is divided over the number of years the sward persists. Persistency may be defined as sustained forage yield and ground cover over several years. It is dependent on the vigour of a plant and its ability to survive and contribute to yield and ground cover. Persistency is not a single trait but rather a complex of traits that are each dependent on the environment and management of the crop (Casler and van Santen, 2010). Disease, insect and, environmental (e.g. heat, cold, drought, etc.) and management (e.g. cutting and grazing) stresses may play an important role in limiting persistence. Ryegrass yield and ground cover under cutting and grazing are highly correlated (Camlin and Stewart, 1975; Jones and Roberts, 1986; Aldrich, 1987). Thus, persistency under grazing can be indirectly selected and improved by measuring persistency under cutting. Persistency can be directly assessed by evaluating the decline in the percentage yield or ground covered by the sown genotype in sward plots over time under an appropriate management scheme (Wilkins and Humphreys, 2003). Alternatively, persistency may be indirectly improved by applying a greater weighting to genotype yield and ground cover in the second and subsequent harvest years rather than an equal weighting across all harvest years. A good assessment of persistence, especially for the extremes, can also be determined by assessing the vigour and survival of spaced plants of the target genotype planted into a sward of a contrasting, competitor species (van Dijk and Winkelhorst, 1978). Timothy (*Phleum pratense*) and cocksfoot (*Dactylis glomerata*) offer a moderate to very strong level of competition against perennial ryegrass, respectively.

Persistence is moderately heritable (*c.* 0.50) and readily amenable to selection (Novy *et al.*, 1995; Ravel and Charmet, 1996). However, selection should be practised in the target location as differences among locations in abiotic and biotic stresses can lead to large σ^2_{GE} (Ravel and Charmet, 1996).

Disease resistance

Diseases are one of the most important factors limiting the yield, persistency and nutritional value of perennial ryegrass. Crown rust (*Puccinia coronata* f. sp *lolii*), *Drechslera* leaf spots and *Rhynchosporium* leaf spots are probably the most widespread and damaging pathogens in ryegrass (Carr *et al.*, 1975; O'Rourke, 1976; Lam, 1983). The debilitating symptoms of these fungi in grass swards can often be overlooked. Rarely are the effects of diseases in grass swards as spectacular as those in other crops, such as cereals and potatoes, and the contribution to loss in animal production potential made by diseases can easily be underestimated (Carr *et al.*, 1975). O'Kiely (1991) found that under low levels of disease pressure in Ireland the application of a fungicide to ryegrass swards, managed for first-cut silage, increased the DM yield by proportionally 1.06 times. Considerably greater losses of production from diseases would be expected in areas with higher levels of disease pressure.

It is important for breeders to continually select for disease resistance, irrespective of the current level of resistance in their breeding populations and cultivars. If disease resistance is not continually monitored and selected for there is a serious danger of losing resistance to one or more pathogens (Wilkins and Humphreys, 2003). Genetic resistance could be lost via genetic drift, negative correlation with other selected traits or evolution of the pathogen to overcome resistance genes.

The h^2 for disease resistance to the common fungal pathogens is generally moderate to high (*c.* 0.50 to 0.75) (Kimbeng, 1999; Bonos *et al.*, 2006). However, essential for breeding improvement are a reliable screening method, even distribution of inoculum, and an environment favourable to disease development and infection. The incidence of disease infection tends to be highly variable between locations, years and between natural and artificial infection (Reheul and Ghesquiere, 1996). Ensuring a high intensity of infection, through repeated artificial inoculations if necessary, may be more important in improving heritability than increasing the number of replicates (Casler and Pederson, 1994).

The vast majority of selection for disease resistance is conducted on spaced or potted plants. Considerable realised gains for disease resistance in cut and grazed swards (Easton *et al*., 1989; Chaves *et al*., 2009) demonstrate that there is a high correlation (≥ 0.75) between spaced plants and swards in disease resistance. This indicates that indirect selection for improved disease resistance on spaced plants is an effective means to improve disease resistance in cut or grazed swards.

Nutritional value

Nutritional value may be considered a secondary trait in that it is only of consequence if a cultivar offers the minimum economic levels of yield, persistency and disease resistance for a particular farming system in a given location. If a cultivar offers high quality but marginal adaptation, its use in a particular farming system will depend on the economic trade off between perenniality and production *vs*. improved nutritional value (Casler, 1998).

There is almost universal agreement among agronomists, nutritionists and breeders that digestibility is the most important selection criterion for improving the nutritional value of grasses (Wheeler and Corbett, 1989; Smith *et al*., 1997). *In vitro* DM digestibility (IVDMD) may be increased by selection for IVDMD *per se* or other correlated traits such as water-soluble carbohydrate, neutral detergent fibre, acid detergent fibre and lignin (as reviewed by Casler, 2001). Genetic changes in reproductive development may also bring about changes in whole-plant IVDMD. The IVDMD of leaf lamina is typically higher than that of flowering stems consisting of leaf sheath, true stem and developing inflorescence (Buxton and Marten, 1989). Reproductive development or the ratio of leaf:stem may be modified by selecting for the timing and intensity of primary heading and the frequency and intensity of aftermath heading. However, in reducing the intensity of primary heading cognisance must be taken of the large contribution of stems to DM yield in first-cut silage swards and the necessity for adequate seed yield potential (Wilkins and Humphreys, 2003).

The h^2 of many laboratory estimates of forage nutritional value (e.g. IVDMD, water-soluble carbohydrate, neutral detergent fibre, etc.) in perennial ryegrass are typically low to moderate (*c*. 0.30 to 0.50) (Frandsen, 1986; Oliveira and Castro, 1994; Posselt, 1994). In contrast, the h^2 of reproductive development traits influencing leaf:stem ratio, such as the timing and intensity of the primary and aftermath heading, are generally high (≥ 0.75) (Cooper, 1960; Charmet and Ravel, 1991; Ravel and Charmet, 1996). Both sets of traits influencing nutritional value tend be far less sensitive to G × E interactions than agronomic traits such as forage yield (Casler and van Santen, 2010), reducing the need for the same extent of environmental replication as required to accurately estimate forage yield. The stability and consistency of realised gains for laboratory estimates of perennial ryegrass nutritional value across cutting and grazing managements, demonstrate that improvements in nutritional value under grazing can be indirectly selected for under cutting (Casler and van Santen, 2010).

Selection for IVDMD or leaf:stem ratio within or among populations during the primary reproductive phase of growth should be made only within narrow maturity classes or by adjusting forage quality data to a constant maturity stage. Selection for increased IVDMD or leaf:stem ratio based on sampling plants or plots on a given day, ignoring maturity stage, may lead to a later heading date. Conversely, selection for increased IVDMD or leaf:stem ratio based on sampling plants or plots at a given maturity stage, ignoring calendar date, may lead to an earlier heading date (Casler and Vogel, 1999; Casler, 2001).

The digestibility of leaf and stem are under independent genetic control to a large extent (Hides *et al*., 1983; Buxton & Marten, 1989). Improvements in leaf and stem digestibility can be made independent to changes in the leaf:stem ratio. There are therefore four main approaches to increasing plant digestibility: (i) increase leaf digestibility, (ii) increase stem digestibility, (iii) increase leaf:stem ratio or (iv) apply a combination of (i), (ii) and (ii). Leaf digestibility and stem digestibility measured in sward plots and spaced plants are highly correlated (Casler and van Santen, 2010). Beerepoot *et al.* (1994) significantly increased the total IVDMD of perennial ryegrass sward plots by selecting for high digestibility in mature flag leaves harvested individually from spaced plants. In contrast, there is often a low correlation between laboratory estimates of nutritional value measured on the whole spaced plant, which includes all herbage above a fixed cutting height, and that of sward plots cut to a similar height (Jafari, 1998; Beerepoot and Agnew, 1997). Cooper and Breese (1980) postulated that these differences are due to differences in the morphological characteristics of plants grown as spaced plants and under the competitive conditions of a sward. This is supported by Elgersma (1990) who found a negative to low positive correlation in the number of reproductive tillers on spaced plants and sward plots. Nevertheless, although spaced plants are a poor indicator of the intensity of heading in sward plots, they provide very accurate estimates of the date of primary heading (Cooper, 1960; Elgersma, 1990). Thus, the date of primary heading in sward plots is readily amenable to selection using spaced plants.

In order to minimise costs and considering laboratory estimates of nutritional value are subject to less σ^2_{GE} than forage yield, breeders tend to measure nutritional value on only a subset of the harvests that are taken for yield determination. This is a sensible strategy considering genotypes that differ in forage nutritional value are generally consistent in ranking across locations and years (Casler, 2001). However, the relationship between perennial ryegrass genotypes in nutritional value at different harvests within years is highly inconsistent (Frandsen, 1986), primarily due to the extreme variability between genotypes in reproductive development (Casler, 2001). This indicates that selection for improved IVDMD at a particular cut may not be fully translated into improved IVDMD at other cuts depending on the selection criterion and the degree of genetic variation for heading date within the population. For example, selection for improved leaf IVDMD will have only a moderate effect on total plant IVDMD when the sward is primarily reproductive. Likewise, selection for improved stem IVDMD will have only a marginal effect on total plant IVDMD when the sward is primarily vegetative. Selection should focus on improving IVDMD during the periods when nutritional value is most limiting animal production potential using the dominant plant morphological characteristic during this period as the selection criterion.

Digestibility tends to be lowest in mid-season (mid-April to July) identifying it as key target period for improvement. Variation among genotypes in digestibility also tends to be greatest in mid-season when mean IVDMD is at its lowest (Wilkins, 1997; Gilliland *et al*., 2003). This suggests that mid-season would be the best time to sample herbage to determine genotype ranking and differences in IVDMD (Wilkins, 1997), and would benefit the most from breeding improvement. The sward is primarily reproductive, or in a mixed vegetative and reproductive state in mid-season suggesting that the breeding focus should be on improving stem digestibility and the ratio of leaf:stem.

Seed yield

Seed yield is one of the more contentious selection criteria, drawing wide opinions from breeders, agronomists and the seed industry as to the level of attention it should be given compared to forage traits (Casler *et al*., 1996). Many seed production traits are negatively correlated with agronomic performance. However, the ability of a cultivar to produce reasonable seed yields is essential to ensure its commercial success. Sales of cultivars with below average seed yield potential are typically disappointing because seed growers are reluctant to grow unprofitable cultivars (Wilkins, 1991).

Selecting for seed yield is difficult because it is a complex trait that has low to moderate h^2 (*c.* 0.20 to 0.50) and is considerably influenced by the environment (Elgersma, 1990; Elgersma *et al.*, 1994). The correlation between the seed yield and individual seed yield components (e.g. number of reproductive tillers, number of spikelets per inflorescence, etc.) of spaced plants with that of drilled plots is generally low (Elgersma, 1990; Elgersma *et al.*, 1994). Thus, phenotypic data based on spaced plants are generally of limited value in predicting performance in drilled fields. However, the positive, albeit very low, correlation between the seed yield of spaced plants and drilled plots suggests that the seed yield of spaced plants may be used as an indication of extremes in performance in drilled plots, e.g. for eliminating the worst genotypes from a population.

Evaluation and selection on actual seed yield in drilled plots that mimic real seed-production conditions (Elgersma *et al.*, 1994). However, the location of the breeding trials may be far removed from the main areas used for commercial seed production. Grass seed production is a highly specialised operation that tends to take place in specific and often arable farming regions of countries with climates best suited to grass seed production. We estimate that almost all perennial ryegrass seed sown in Ireland and about two-thirds of the seed sown in the UK is produced outside of the country of use (Department for Environment, Food and Rural Affairs, UK, 2008; Department of Agriculture, Forestry and Food, Ireland, personal communication). Thus, even seed yield data from drilled plots at the breeding station may be of limited value in predicting seed yield in the commercial production environment if the ratio of σ^2_{GE}:σ^2_G is large. In seed yield trials conducted in two fields, one having sand and the other clay soil, within the confines of a single breeding station, van Eeuwijk and Elgersma (1993) estimated the ratio of σ^2_{GE}:σ^2_G as 0.60 resulting in highly significant cultivar × environment interactions. This suggests that the ratio of σ^2_{GE}:σ^2_G may be very large when the geographic distance between the selection and target environments is great.

Breeding methods

The focus of this review will be on breeding methods appropriate to recurrent selection for intrapopulation improvement in a long-term dedicated breeding programme. Recurrent selection is a cyclic population improvement method for increasing the frequency of favourable alleles in the population by repeated cycles of selection. A recurrent selection cycle consists of three aspects: (1) evaluation of individuals from the population, (2) selection of superior individuals from the population and (3) intercrossing the selected individuals to form a new population on which to begin the next selection cycle (Brummer, 2008). A cycle of selection is completed each time a new population is formed. Recurrent selection is most appropriate to breeding perennial ryegrass as most of this species' main traits for improvement are quantitative in nature, controlled by a large number of genes each with a small individual effect, and predominantly subject to additive gene action (Breese and Hayward, 1972). Recurrent selection programmes are most appropriate for long term (≥ 20 years) breeding efforts. An acceptable level of performance might be achieved only after several cycles of selection that facilitates a steady and progressive accumulation of favourable alleles each with a small effect. Intrapopulation improvement aims to improve the performance of a single open-pollinating population leading to the release of synthetic cultivars. The breeding methods and strategy discussed below are valid for diploid and tetraploid ryegrass (Gallais, 2003).

In general, three distinct types of recurrent selection may be implemented: (i) phenotypic recurrent selection (PRS) based on the phenotypic value of the individual genotype, (ii) genotypic recurrent selection (GRS) based on the phenotypic value of the progeny of the individual genotype under evaluation and (iii) marker-assisted selection (MAS) based on molecular (DNA) marker scores that have been associated with the phenotypic value of the individual genotype. The efficiency of alternative breeding strategies is typically judged in terms of the amount of genetic gain (ΔG) per cycle or year. Genetic gain describes the change in performance of a population that is realised with each cycle of selection (Fehr, 1987).

TABLE 1: Summary characteristics of the main traits for improvement in perennial ryegrass (see text for references)

Trait for improvement	Narrow sense heritability[1]	$\sigma^2GE:\sigma^2G$ ratio[2]	Genotypic correlation between		Selection character (SC)	Evaluation unit
			Spaced plants and swards[1]	Cutting and grazing[1]		
Forage dry matter yield	Low to moderate	Very high	Zero to low	High	Dry-matter or fresh-matter yield	Swards
Persistence	Moderate	Moderate to high	High	High	Change in yield or ground cover over years	Swards or spaced plants depending on SC
Disease resistance	Moderate to high	Moderate to high	High	High	Proportion of herbage infected	Swards or spaced plants
Laboratory estimates of nutritional value	Low to moderate	Low to moderate	High	High	In vitro dry matter digestibility or correlated traits	Swards or spaced plants
Reproductive development	Low to high	Low to moderate	Low to high	High	Timing or intensity of heading	Swards or spaced plants depending on SC
Seed yield	Low to moderate	Very high	Zero to low	Not applicable	Seed yield	Swards or drilled plots

[1] Typical values: Low = ≤ 0.20, moderate = c. 0.50 and high = ≥ 0.75.

[2] Typical ratio of the genotype × environment interaction variance to genotype variance: Low = ≤ 0.5, moderate = c. 0.5 to 1.0, high = c. 1.0 to 2.0 and very high = > 2.0.

Phenotypic recurrent selection

Phenotypic recurrent selection is the oldest and simplest breeding method (Figure 1). Typically, PRS has three stages: (i) a population of plants is grown in a manner that allows identification and evaluation of individual plants, (ii) the population is evaluated for the trait or suite of traits of interest and the best individual plants are identified, and (iii) a new 'improved' population from which the next cycle will begin is constituted by either (a) bulking open pollinated seed harvested from the selected plants or (b) intercrossing the selected plants in isolation (Brummer, 2008). If the new population is formed from open pollinated seed up to half the alleles transferred to the next generation will be from the pollen of unselected plants (uni-parental control) and will not contribute to ΔG. However, if the selected plants are intercrossed in isolation all the alleles passed to the next generation will be from the selected individuals (bi-parental control) and the theoretical rate ΔG, on a per cycle basis, will be doubled compared to uni-parental control (Fehr, 1987). Ultimately, the value of uni- and bi-parental control needs to be considered in terms of ΔG per unit time and cost. Although bi-parental control will increase ΔG, it will also increase cycle time and costs if the intercrossing needs to be done the following year in a new crossing block. In this review we consider PRS with uni-parental control from the point of view of reducing the cycle time by one year by facilitating evaluation and recombination in the same year.

There is considerable debate about the ideal number of parents (population size) to select for recombination to form the next population. The fewer parents selected for recombination, the greater the superiority of the selected fraction, but the more the population will suffer from inbreeding depression, the faster the loss of genetic variability and the lower the limits of selection (Posselt, 2010). Separate broad-based and narrow-based populations may be produced for use in recurrent selection and release as a synthetic cultivar, respectively. For a long-term selection programme, 50 to 100 parents are typically selected using PRS to form the next population (Vogel and Pederson, 1996; Brummer, 2008). This corresponds to a coefficient of inbreeding in a diploid population of 0.10 to 0.05 after five cycles of selection and 0.19 to 0.10 after 10 cycles of selection (Falconer and Mackay, 1996). The level of inbreeding will be lower in tetraploids (Gallais, 2003). When selection is based on only a subset of the target traits for improvement, 100 parents should be chosen for recombination. This will reduce the probability of fixing undesirable recessive genes for the non-selected traits through linkage with genes influencing the trait under selection (Wilkins and Humphreys, 2003). In the construction of synthetic cultivars as little as four parents may be used (Hill, 1971).

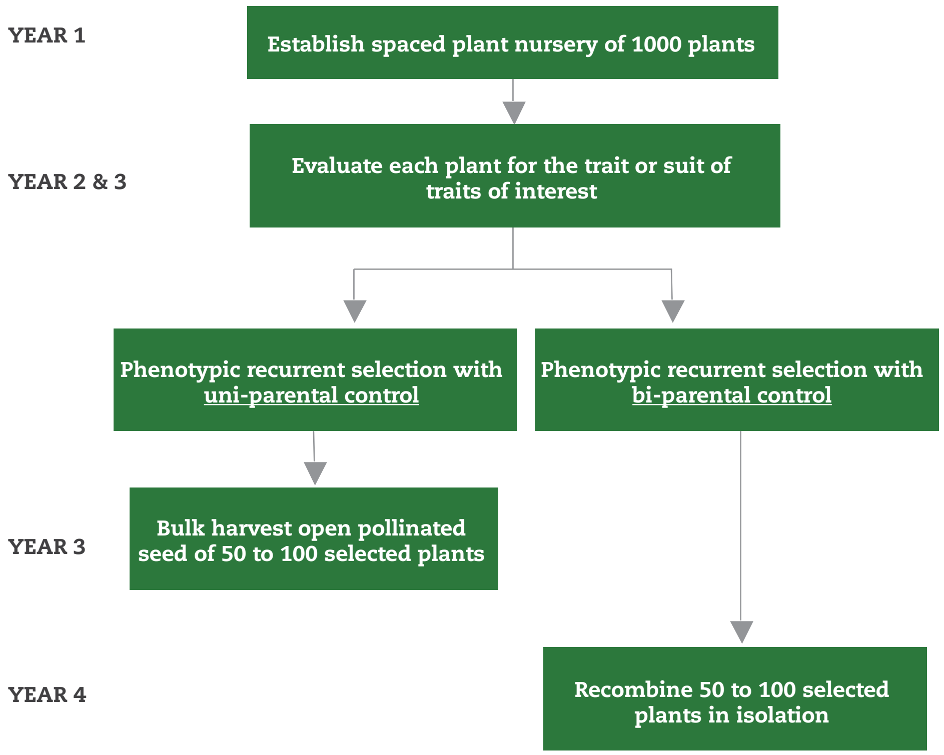


Figure 1: Schematic flow diagram of one cycle of phenotypic recurrent selection

Pros

The advantages of PRS are that it is an easy breeding system that makes full use of all additive genetic variance and offers the shortest possible breeding cycle. It facilitates the evaluation and selection of large numbers of individual plants offering the potential for high selection intensities, minimal inbreeding depression and the maintenance of high genetic variability. Phenotypic recurrent selection should be highly successful and effective for improving traits (i) whose performance when grown as spaced plants and swards traits is genetically correlated, and (ii) have heritability ≥ 0.10, assuming appropriate strategies are implemented to minimise the impacts of environmental variation on the phenotype (Fehr, 1987; Hallauer and Miranda, 1988).

Cons

One of the major weaknesses of PRS is that selection is practised on individual spaced plants. Depending on the trait, selection on spaced plants may be of limited use in improving performance in real-world swards on farm (see previous section).

A second major weakness of PRS is that selection is generally based on unreplicated, individual phenotypes. Clonal replication is unlikely to be used on a routine basis due to excessive time and expense (Casler and Brummer, 2008). Selection in a single location bears the risk of specific adaptation in that the ΔG achieved may not be realised in other locations (Posselt, 2010). The differences among individual plants within the field may also be significantly affected by microenvironmental variation e.g. soil type, fertility and moisture. It may be difficult to distinguish plants superior due to their genotype from plants superior due to environmental influences. However, a number of approaches have been devised to minimise the impact of environmental variation on selection decisions. One such approach is to apply gridding or stratified selection. This involves subdividing the population into equal-size subdivisions (grids). An equal number of plants are then selected within each subdivision (Fehr, 1987). Alternatively, the standardized phenotypic value for each plant within each subdivision can be calculated, and used to rank and select the best plants over the entire population irrespective of their position in the field (Brummer, 2008). The standardized phenotypic value is calculated by subtracting the mean value of all plants within the grid from each individual's value and dividing by the phenotypic standard deviation of the grid. The use of gridding facilities the successful application of PRS to the improvement of traits with very low heritability (c. 0.10 to 0.20) (Burton, 1974).

Genotypic recurrent selection

Genotypic recurrent selection (GRS) is based on assessing a genotype's merit by testing that genotype's progeny (Figures 2 and 3). In an outcrossing species such as perennial ryegrass there are two types of progeny that may be evaluated: (1) half-sib progeny and (2) full-sib progeny. Selfed progeny can also be produced on many ryegrass genotypes, but recent studies have shown self-progeny selection to be less efficient than previously presumed (Edwards, 2010). The terms 'half-sib' and 'full-sib' indicate the genetic relationship between the progenies of the individual plants under evaluation. The purpose of progeny testing is to estimate breeding value of selected parental plants by separating the genetic and environmental effects by means of replicated progeny trials (Posselt, 2010).

Half-sib families are progenies that have a common parent or pollen source and are typically produced using a polycross mating design (Posselt, 2010). This involves creating a polycross nursery by planting a number of clonal replicates of each genotype under evaluation (referred to as the parent) in a specific design so as to promote random mating among genotypes. Two to six clonal replicates per parent are most common (Brummer, 2008). Plants within the nursery are then allowed to intercross in isolation. Seed is harvested from individual plants and bulked by parent. Seed from each parent represents a half-sib family because all the progeny have the same maternal parent but the paternal contribution comes from the entire population (Brummer and Casler, 2009).

Full-sib families have no parent in common, although all the parents come from the same population. Full-sib families are produced by crossing pairs of plants in isolation. Each full-sib family will have two different parents and all progeny within a family arise from those two parents (Walsh, 1994). Therefore, full-sib families facilitate the evaluation of twice as many parents as with half-sibs for the same number of families produced. However, the production of full-sib families may require more work and cost than the production of half-sib families as controlled pollination is involved, whereas half-sib families can be accomplished using an open-pollinated polycross (Hallauer and Miranda, 1988). Furthermore, full-sib families derived from pair crosses may not give enough seed for sowing replicated sward plots of ≥ 5 m^2 in size. In this situation, each family must be multiplied in isolation which will increase the cost and the cycle time by one year compared with GRS using half-sib families. However, full-sib families allow better parentage control. As pair-crossing is generally undertaken in the glasshouse between potted plants, the heading date of each parent can be readily manipulated to facilitate wide crosses among plants of different maturity. In contrast, half-sib families are typically produced using plants sown in a polycross mating design in the field reducing the ease and flexibility of manipulating heading date. Therefore, half-sib families tend to be useful only for assessing breeding value of parents of similar heading date.

Each half-sib or full-sib family is evaluated in replicated plots of swards, seeded rows and/or spaced plants. Spaced plant trials alone or in combination with swards or seeded row trials offer a means of facilitating *among-and-within family* (AWF) selection. In AWF selection, plot/family means are used to select the best families and individual-plant data, generally unreplicated, are used to select the best plants within the best families (Vogel and Pederson, 1993; Casler and Brummer, 2008).

Three different units of recombination may be used for each mating system to form a new set of families for the next selection cycle: random plants from remnant seeds of the selected families [referred to as *half-sib family* (HSF) or *full-sib family* (FSF) selection], saved maternal plants of the selected families [referred to as *half-sib progeny test* (HSPT) or *full-sib progeny test* (FSPT) selection] or selected plants within the selected families [referred to as *AWF selection using half-sib families* (AWF-HS) or *full-sib families* (AWF-FS)]. The recombination unit can have a considerable effect on ΔG as it is related to parental control which is incorporated in the numerator of the prediction equation for genetic gain (Fehr, 1987).

In HSF, AWF-HS, FSF and AWF-FS selection the selected individuals become the parents for a new set of families. The individuals are established in a polycross or paired-cross block from which family seed for the next selection cycle is generated. The target is to select the best 5 to 20 families at each generation (Weyhrich *et al.*, 1998; Posselt, 2010), which ideally should equate to a selection intensity of 5 to 20% or less. An equal number of plants are then selected at random (HSF and FSF selection) or systematically (AWF-HS and AWF-FS selection) from each family to create a minimum population size of 100 (half-sib selection) or 200 (full-sib selection) genotypes to start the next selection cycle. Selecting plants from within families makes it is possible to maintain adequate population size which reduces inbreeding (Vogel and Pederson, 1993).

In HSPT and FSPT selection, the parental clones are recombined using a polycross mating design and the harvested seed bulked across all individuals. This recombined population is used as the source of the parents for a new set of families, which are then established in a polycross or paired-cross block. The double recombination event per cycle required in HSPT and FSPT selection adds one extra year to the cycle time. However, without this extra recombination event the process would simply involve re-evaluation of the same clones that were evaluated in the previous cycle except that the clones would be mated to a smaller number of male parents (Vogel and Pedersen, 1993).

In practise, FSPT selection is not undertaken. It requires a greater cost and workload to apply than FSF selection because the parental plants must be saved or cloned, and kept alive until the selection decisions have been made. However, the theoretical ΔG for FSPT and FSF selection is the same when only the best families are recombined because selection is then for both male and female parents (Hallauer and Miranda, 1988). This is the most common application of FSF selection in perennial forage crops (Casler and Brummer, 2008). Therefore, FSPT selection will no longer be discussed as part of this review.

Careful consideration must be given to the effects of HSPT selection on the levels of inbreeding in the population when the selection intensity is kept high. If 10 to 20 parental clones from the best families are selected and intercrossed at each cycle, the coefficient of inbreeding in a diploid population will be 0.26 to 0.14 after five cycles of selection and 0.43 to 0.24 after

10 cycles of selection (Falconer and Mackay, 1996). Selection of 10 or more parents in maize did not result in a loss of grain yield over four cycles of recurrent selection (Weyhrich *et al.*, 1998), although that is not to say the genetic variance was reduced and the long term limits to selection lowered. While HSPT selection may offer greater short-term gain than other family selection methods, new individuals from outside the population may have to be introduced after a number of generations to counteract the depletion of genetic variance.

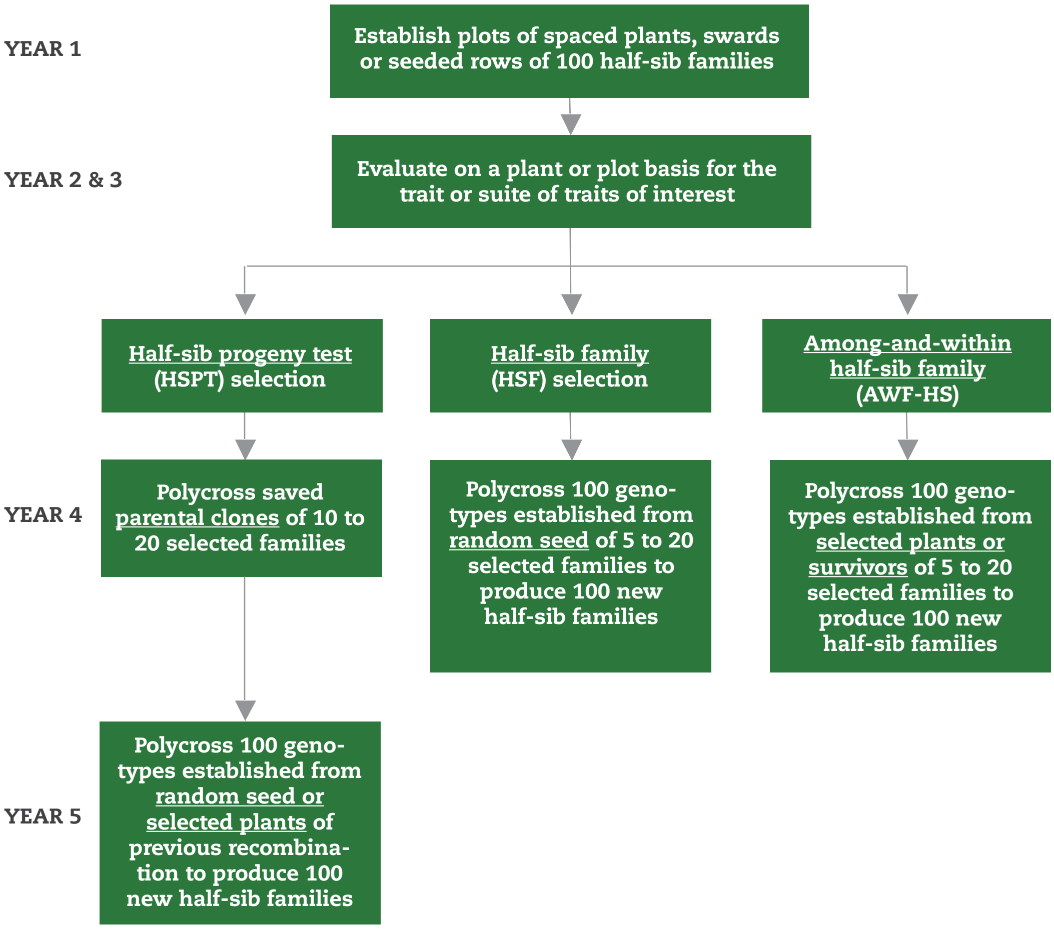


Figure 2: Schematic flow diagram of one cycle of genotypic recurrent selection using half-sib families (adapted from Casler and Brummer, 2008)

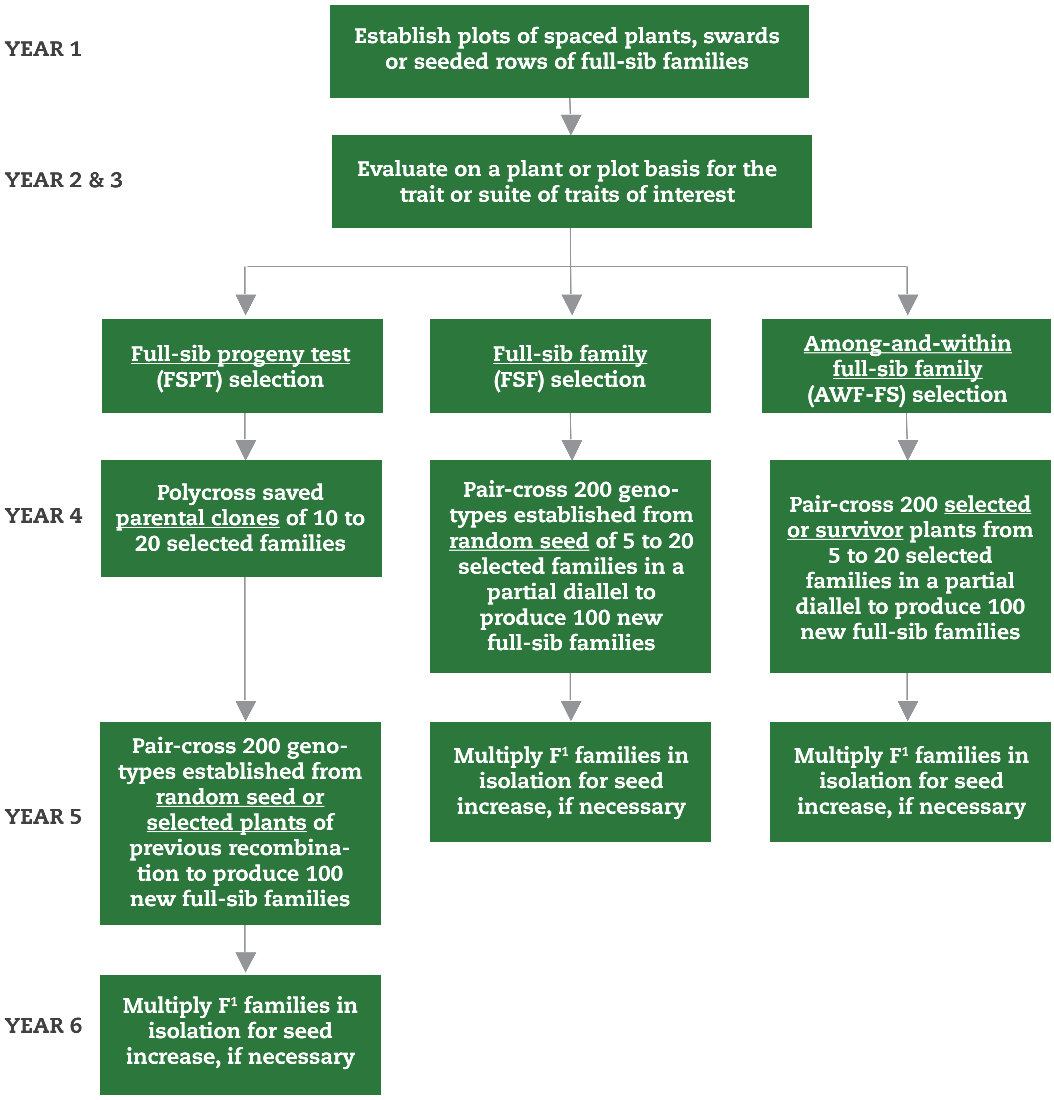


Figure 3: Schematic flow diagram of one cycle of genotypic recurrent selection using full-sib families (adapted from Casler and Brummer, 2008)

Pros

Genotypic recurrent selection enables the breeder to assess a number of progeny from each family using replicated, multi-location testing. The mean phenotypic value of a number of progeny per plot may provide a better index of breeding value than the individual genotype's own phenotypic value measured on a single, unreplicated plant. This is particularly the case when the heritability of the trait is low and rests on the fact that the environmental deviations of the individuals tend to cancel each other out in the mean value of the family (Falconer and Mackay, 1996). Replicated trials allow G × E interactions to be taken into account. These advantages will result in a higher heritability for the trait of interest than is possible with PRS and typically leads to greater genetic gain for traits with low heritability (Brummer and Casler, 2009).

Most importantly, the generation of seed also facilitates evaluation of the progeny in sward plots which is essential for improving traits, such as forage yield, which have a poor correlation between spaced plants and swards.

Cons

The greatest disadvantage of among family selection is that it utilises only a fraction of the additive genetic variation within the population (0.25 for half-sib and 0.50 for full-sib family structures). Among-family selection will be less successful at increasing ΔG than PRS for high heritability traits. Utilisation of all the additive genetic variation requires selection within families. Family selection methods may require a longer cycle time than PRS. They certainly will require a greater cost to implement than PRS as the recombination events must be highly controlled and managed, and the seed of each family managed individually. There is less flexibility and scope to increase the selection intensity with GRS than with PRS as the production of extra families requires significant additional work and cost. In contrast, PRS has an almost limited supply of extra genotypes readily available at no extra cost considering the quantity of seed generated at each recombination event.

Marker-assisted selection

The goal of MAS is the same as PRS and GRS: to improve the overall genetic value of a population with respect to some trait or suite of traits by increasing the frequency of favourable alleles in the population. The difference is that MAS is based on molecular marker scores that have been associated with the phenotypic value of the trait, as opposed to selection on the phenotypic value of the trait *per se* as practised with PRS and GRS. There are three principle methods by which MAS may be used for population improvement namely (i) marker-assisted introgression, (ii) marker-assisted recurrent selection (MARS), and (iii) genome-wide selection (GWS), also referred to as genomic selection.

The genes underlying quantitative traits have been dubbed QTL or quantitative trait loci (Brummer, 2008). Molecular markers represent guideposts on the chromosomes that indicate the location of specific QTL or ideally represent the actual QTL themselves.

The goal of marker-assisted introgression is to incorporate and concentrate one or several major QTL into individual plants or populations by selecting for the specific QTL. It may be considered gene pyramiding. In this instance, the QTL and their effects need to be clearly identified, and those QTL with strong statistical support and large effects will be most usefully selected (Brummer, 2008). However, a major limitation of marker assisted introgression is that pyramiding desirable QTL into a single cultivar becomes increasingly difficult as the number of QTL increases. In practise, only a limited number of QTL can be introgressed at any one time so as to avoid prohibitively large population sizes in the breeding programme. For example, assume a trait is controlled by multiple unlinked QTL, each with two alleles, and the probability that a plant is homozygous at any one QTL is 0.25. The average population size required to have one plant in the population homozygous dominant at one QTL is 4, but for 10 QTL this increases to 1,048,576 (4^{10}). This invariably indicates that the population sizes feasible in breeding programmes are not large enough to introgress more than a few QTL at a time. Brummer and Casler (2009) suggest that the best strategy would be to concentrate on moving a few (e.g. 2 to 5) alleles toward fixation at a time, and picking up subsequent alleles in later cycles of selection.

The MARS approach can target a larger number of QTL (typically 20 to 35) than marker-assisted introgression for selection at any one time. In MARS, the breeders' take advantage of all QTL that have been significantly associated with the trait of interest by combining the available information in the form of a selection index (Lande and Johnson, 1994). The selection index includes QTL with small effects and only marginal statistical support, and is constructed as follows. Weightings are applied to each QTL identified, according to the relative magnitude of their estimated effects on the trait. The alleles at each QTL are then scored and multiplied by the weight given to each QTL. The sum effect of all QTL identified in each genotype is calculated to give a single index value for each genotype under evaluation (Brummer, 2008). Genotypes are then selected on the basis of their index values. The use of MARS facilitates selection on a large number of QTL with the understanding that the improved genotypes selected may not have the favourable allele across all QTL included in the selection index (Bernardo, 2008). Less precision is required for pinpointing QTL locations when the purpose is to predict genotypic performance, as in MARS, than when the purpose is to combine favourable QTL alleles as in marker-assisted introgression (Bernardo, 2008).

A third approach, GWS, first proposed by Meuwissen *et al.* (2001), is a form of MAS that focuses purely on predicting performance based on estimating and then summing the joint effects of all markers across the entire genome. This approach contrasts greatly from marker-assisted introgression and MARS in that selection is practised without significance testing and without identifying the subset of QTL associated with the trait (Bernardo, 2008). Instead GWS applies dense genome-wide marker coverage to develop associations with many, and ideally all, QTL. With a dense marker map some markers will be very close to the QTL and probably in linkage disequilibrium which means the marker and QTL will be inherited together in the majority of progeny (Meuwissen *et al*., 2001). The effects of each marker on the expression of the phenotype can then be computed from an analysis of the phenotypic and marker data from a large number of individuals using a form of multiple regression analysis. The joint effects of all markers are summed to give the *genomic estimated breeding value* on which selection is practised. Estimations of the breeding value can be continually re-calculated and improved upon over time as more phenotypic and genotypic data becomes available. While selection is based on marker effects, the markers with large, highly significant effects may be considered as putatively linked to major QTL (Bernardo, 2008). Simulation studies have found GWS considerably more effective than marker assisted introgression and MARS in increasing breeding gain especially for complex traits controlled by many QTL and with low h^2 (Bernardo, 2008).

Pros

The use of MAS may increase the ΔG per unit time, cost and cycle in breeding programmes, particularly when phenotyping for the traits of interest is time-consuming, expensive, inconsistent and dependent on specific environments or developmental stages (Bernardo, 2008). Phenotyping for complex quantitative traits typically involves the evaluation of replicated, multi-location field trials over several harvest years. Progress in breeding for specific traits is dependent on the level of abiotic and biotic stresses imposed, naturally and/or artificially. In contrast, MAS facilities the selection of unreplicated plants, in a non-target environment, at the seedling stage under the most convenient and cheapest management scheme available, regardless of the stresses imposed (or not). The effect would be an increase in ΔG per unit time and ΔG per unit cost. If MAS can be applied more easily or cheaply than phenotypic selection it allows a greater selection intensity for a given level of resources which would increase ΔG per cycle. As the cost of genotyping decreases and the cost of phenotyping increases, the attractiveness of MAS increases. The current cost of genotyping ranges from about US$0.03 to 0.15 per data point, where one data point corresponds to one plant sample genotyped for one marker locus and where the lower costs are for larger numbers of single nucleotide polymorphisms (SNP) markers assayed at once (e.g. 1536 vs. 256 SNP markers) (Bernardo, 2008). However, this does not include the cost of growing the plants, collecting leaf tissue and extracting DNA, which must also be considered. These costs tend to remain high regardless of the number of SNP markers used. Recent developments toward multi-channel sequence-based SNP assays create promise for improving both throughput and costs of routine SNP analysis of large numbers of genotypes (Baird *et al*., 2008).

The development and application of MAS can be effectively integrated into a recurrent selection system to improve the overall ΔG per cycle and unit time (Brummer and Casler, 2009; Casler, 2010) (Figure 4). The essential part of this proposed system is the establishment of a marker selection index by using the DNA marker data of the parents and robust phenotypic data of their respective progeny collected from replicated, multi-environment trials. A molecular marker index created in such a fashion should be sufficiently robust to allow up to three cycles of selection and recombination before the DNA of the parents must be analysed again and the index recalibrated. In the first cycle, AWF selection would be conducted by selecting the best families using their phenotypic data and the best plants within these families using their molecular marker scores. Cycles 2 and 3 could be conducted as PRS using the marker selection index to identify the superior individuals at the seedling stage in the greenhouse, followed by rapid recombination. After cycle 3 the process should start afresh with the field-based evaluation of a new set of families, the DNA analysis of their parents and a recalibration of the marker selection index. The field-based evaluation is necessary to ensure the population has not lost any important adaptive traits in two cycles of greenhouse selection. The recalibration of the marker selection index is necessary to ensure the accuracy of the index because the association between marker and QTL is continually eroded by recombination, and the value of an allele changes as it approaches fixation.

The theoretical ΔG from MAS can be estimated using the theory of indirect selection (Falconer and Mackay, 1996). In this situation the marker selection index corresponds to the secondary trait used for improving the primary trait of interest (phenotype) (Bernardo, 2008; Casler and Brummer, 2008). Applying MAS to select the best plants within families (AWF-HS selection) as opposed to recombining random (HSF selection) or parental (HSPT selection) plants to form a new set of families for the next cycle of selection could increase the ΔG per cycle by up 4 fold for a modest number of plants analysed (Figure 5). A marker selection index that explains even a small proportion of the genetic variation could offer considerable improvements in ΔG compared with HSF and HSPT selection. The ΔG with MAS is conditional on the family structure, the selection intensity among and within families, the heritability of the trait and the proportion of the phenotypic variance explained by the marker selection index. Using MAS in PRS as per cycles 2 and 3 in Figure 4, could increase the ΔG per cycle by up to 2 fold compared with phenotypic selection, for the same number of plants evaluated (Figure 6), by halving the cycle time.

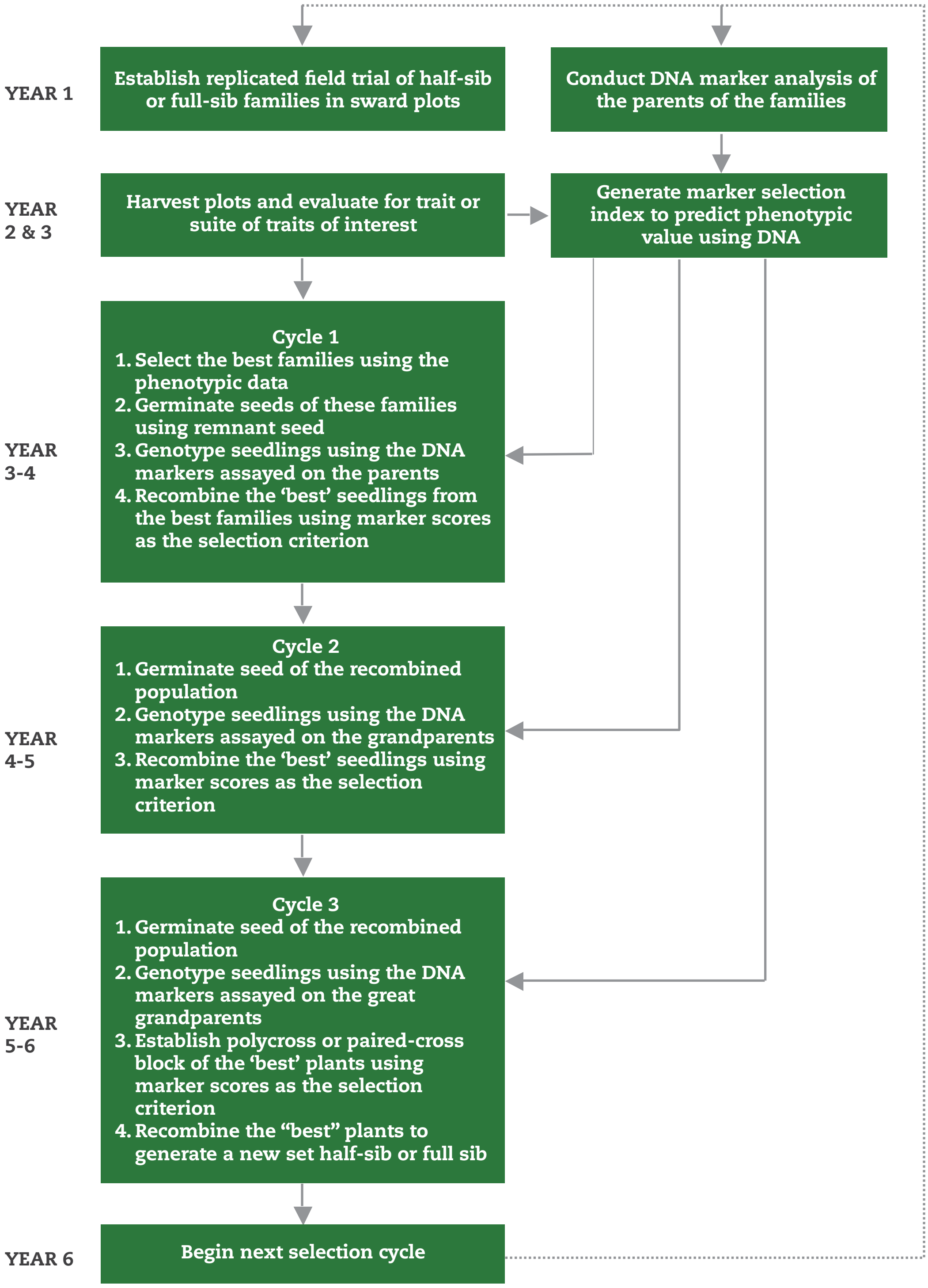


Figure 4: Schematic flow diagram of the development and application of three cycles of selection and recombination using molecular markers (adapted from Casler, 2010)

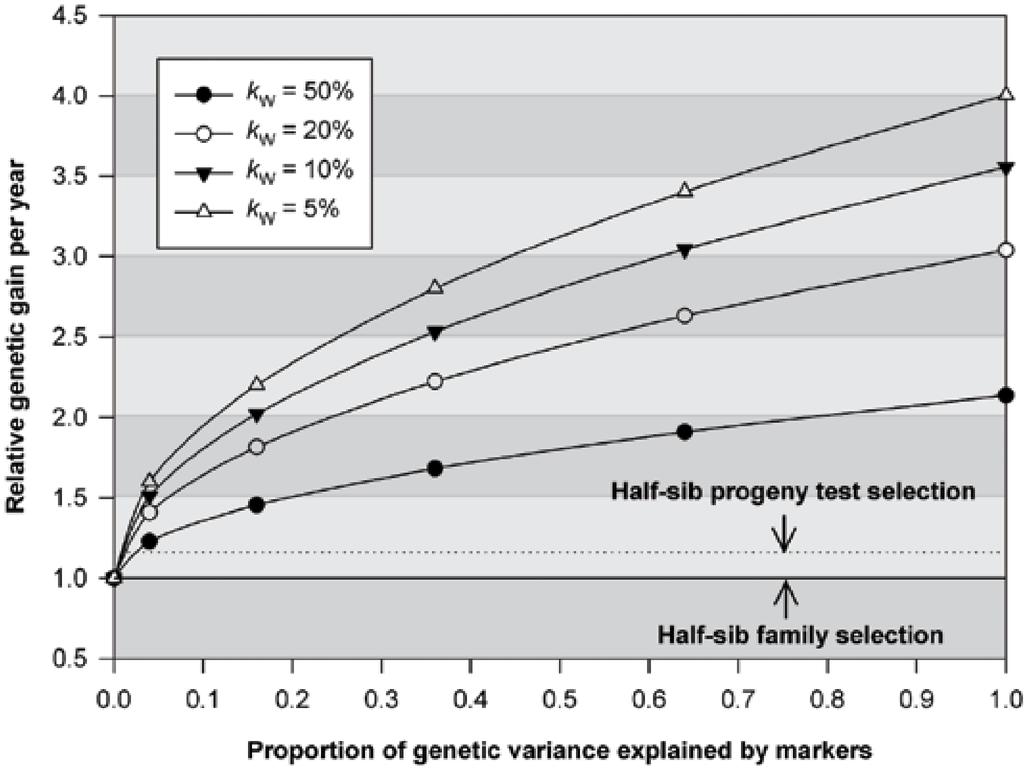


Figure 5. Expected genetic gain per year from among-and-within half-sib family (AWF-HS) selection using phenotypic data and molecular markers as the selection criteria, and half-sib progeny test (HSPT) selection and half-sib family (HSF) selection using phenotypic data as the sole selection criterion. The AWF-HS selection is conducted as per cycle 1 of Figure 4 with phenotypic data used to select the best 0.05 of families (n = 5) and molecular marker scores used to select 20 individuals within the selected families to provide a total of 100 genotypes. Four different within-family selection intensities (k) are considered: k_w = 50%, 20%, 10% and 5% requiring DNA analysis of 200, 500, 1,000 and 2,000 plants, respectively. Gain is expressed as a function of the proportion of genetic variance explained by the markers. The HSPT selection is based on an among-family k of 10% (n = 10) and recombining parental plants. All expected gains for AWF-HS and HSPT selection are expressed as a proportion of gains for HSF selection using phenotypic data as the selection criterion. The HSF selection is based on an among-family k of 5% (n = 5) and recombining remnant seed. Narrow sense heritability on the phenotypic data of family means and individual plants is assumed to be 0.20. The heritability of the molecular marker is 1.0, assuming there are no errors in scoring. The phenotypic variance of all methods is 1.0.

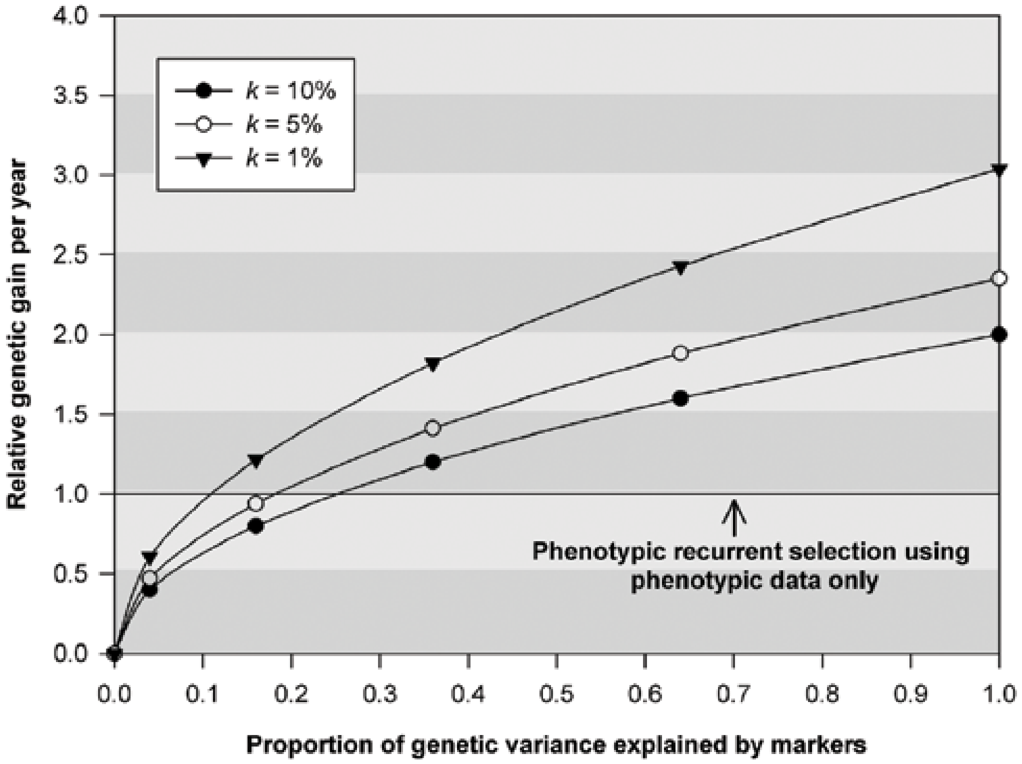


Figure 6: Expected genetic gain per year from biparental phenotypic recurrent selection (PRS) using molecular marker scores as the selection criterion. Three different selection intensities with molecular markers are considered: k = 10%, 5% and 1%, requiring DNA analysis of 1,000, 2,000, and 10,000 plants, respectively, assuming 100 genotypes are selected to form the next generation. Gain is expressed as a function of the proportion of genetic variance explained by the markers. All expected gains for PRS using markers are expressed as a proportion of gains for biparental PRS using phenotypic data as the sole selection criterion and a selection intensity of 10%. The cycle time using molecular markers is 2 years and using phenotypic data 4 years. Narrow sense heritability on the individual plant is assumed to be 0.20. The heritability of the molecular marker is 1.0, assuming there are no errors in scoring. The phenotypic variance of all methods is 1.0.

Cons

Marker-assisted selection is only as good as the phenotypic data on which the markers are based (Brummer, 2008). If the phenotypic data does not accurately describe the trait, no or few true QTL will be identified and their effects will be incorrectly estimated resulting in negligible breeding gain using MAS. The phenotypic data should be based on replicated, multi-environment (year and location) trials if necessary. Consideration should also be give to the expression of the trait in the management scheme imposed during marker development (i.e. spaced plants *vs*. sward plots, field *vs*. glasshouse, infrequent *vs*. frequent cutting, etc.) and in real-world conditions. If there is a poor correlation between the expression of the trait under the management scheme imposed during marker development and in the target real-world conditions then the potential gain from MAS must also be poor.

Identifying real and consistent QTL effects, and by extension molecular marker effects, is difficult. Reasons for the inconsistency of estimated QTL effects include (i) different QTL segregating in different populations, (ii) QTL × genetic background (population) interaction, (iii) QTL × environment interaction and (iv) the size of the reference (training) population used in QTL or marker identification (Bernardo, 2008). Inaccurate estimates of QTL or marker effects will have a great effect on the efficiency of marker-assisted introgression where selection is based on only a few QTL. The inclusion of more QTL or markers in the selection indices used for MARS and GWS may offset or minimise the effects of inaccurate estimates on breeding gain if their number are small. However, if the number and magnitude of inaccurate estimates used in MARS and GWS is large, the cumulative effects may be great and progress using either selection method limited. Accurate QTL and molecular marker estimates require the evaluation of multiple populations of large size in different environments.

Markers are not universally useful and need to be considered in the context of the population in which they are being used (Brummer, 2008). A desirable allele at a QTL can have a large effect on the deviation of an individual genotype from the mean when it is rare in the population. However, as the allele approaches fixation, selection for that allele will have a smaller and smaller effect on the population mean. When the allele is fixed, the allele has no breeding value as selection for that allele will have no effect on the population mean. Therefore, as desirable alleles are concentrated through MAS, the value of the QTL or marker must be constantly recalibrated (Brummer, 2008; Brummer and Casler, 2009). Over generations of MAS, the marker-trait associations will also be continually eroded by recombination such that the efficiency of MAS will decrease and the cost per unit ΔG will increase unless the marker-trait associations are recalibrated.

Markers will not explain more of the genotypic variation than the phenotypic data will. Therefore, MAS will always be somewhat less effective than phenotypic selection on a per cycle basis, unless MAS allows a greater selection intensity which may counteract its genetic inefficiency (Brummer, 2008).

Application

Despite predictions for more than two decades that MAS would reshape breeding programmes and facilitate rapid gains from selection (Heffner *et al.*, 2009), MAS has had limited and variable success in practical breeding, especially in low value crops such as perennial ryegrass. Past work on the detection of QTL for use in marker-assisted introgression and MARS was based on the analysis of biparental mapping populations. This proved impractical and costly in a breeding programme as it required the development and phenotypic evaluation of a dedicated mapping population used solely for marker development. Owing to the limited transferability of QTL effects across populations, biparental mapping populations and QTL mapping have to be repeated for each breeding population (Bernardo, 2008). Furthermore, the QTL identified from the biparental mapping population may not even be segregating or representative of all the major QTL in the breeding population undergoing recurrent selection, effectively limiting their utility for breeding improvement (Brummer and Casler, 2009).

Given the limitations of biparental populations to identify QTL for MAS, the emphasis has now shifted towards the use of association mapping strategies. Association mapping eliminates the need to develop dedicated mapping populations that pose additional burden on breeding programmes and allows the identification of QTL directly from the breeding populations. But the use of association mapping also faces several hurdles that may limit its utility. First and foremost, it revolves around the extent of linkage disequilibrium in the population. The extent of linkage disequilibrium in perennial ryegrass seems to be extremely low (Smith *et al.*, 2009). This means that the marker density required to identify a significant number of QTL must be extremely high, so that markers will reside close enough to the genes controlling the trait that sufficient linkage disequilibrium remains to show the association. This level of saturation is simply not feasible at this time (Brummer and Casler, 2009). Experiments investigating the potential use and application of association mapping are ongoing. It remains to be seen whether the application of association mapping approaches will significantly accelerate the use of MAS by commercial grass breeding programmes (Roldán-Ruiz and Kölliker, 2010). But current association mapping efforts allow identification of only a few QTL with overestimated effects (as reviewed by Heffner *et al.*, 2009).

The proposed solution lies not in seeking single markers associated with QTL with large effects but in harnessing (i) the developing capacity for scoring many markers at low cost and (ii) statistical methods that enable the simultaneous estimation of all marker effects. This method is referred to as GWS. However, it too has its limitations. Most importantly, the method depends on having dense marker coverage to maximise the number of QTL in linkage disequilibrium with at least one marker, thereby also maximising the number of QTL whose effects will be captured by markers (Heffner *et al.*, 2009). The required level of marker coverage is not currently available for most crops, including perennial ryegrass. The quality of marker-phenotype associations identified by GWS is still dependent on identifying accurate and consistent estimates of QTL effects and faces the same hurdles as other methods in identifying real and consistent QTL, and by extension marker effects. While GWS represents the most interesting and exciting application of MAS, its application to breeding gain has almost exclusively been tested through simulation. On these grounds, Heffner *et al.* (2009) argue that its potential value should be assessed with “cautious optimism”. Jannink *et al.* (2010) also offer caution. The GWS approach is currently experiencing an intense period of scientific research activity but its practise currently outpaces its theory. Jannink *et al.* (2010) argue that there is a need for theory to (i) guide the design of the training populations used for determining marker effects, (ii) predict the accuracy from GWS as a function of the training population size, genome-wide linkage disequilibrium and marker density and (iii) understand the reasons and context in which different methods work best and how to optimally combine their predictions.

Ultimately, a cost-benefit analysis is needed to determine whether the cost of applying MAS in a commercial grass breeding programme is worth the gain (Bernardo, 2002). This analysis would depend on the cost of applying MAS to achieve a given level of gain *vs*. the cost of applying different approaches to increase the response to phenotypic selection to a similar level. The decision will depend in part on the specific resources available to the breeding programme. If field staff and equipment are available, additional field work may be accommodated for relatively little extra expense. Laboratory work may require additional staff and expense, and still require the running of a field programme (Brummer, 2008).

Breeding gain

The most relevant breeding methods for perennial ryegrass are summarised in Table 2. Formulas for the calculation of the predicted ΔG per cycle for each method are presented in Table 3. The value of the variables in the prediction equation need to be modified for each breeding system to reflect the selection intensity, level of parental control (as determined by the recombination unit), magnitude of each variance component, and the number of replicates and locations for testing. The value of each variance component is the most difficult to estimate as they are highly variable and not normally measured in breeding programmes. However, theoretical values can be imputed to compare the different breeding systems across a broad range of potential scenarios. The efficiency of different breeding systems is best determined by comparing the genetic gain realised per year (ΔG/yr), as the length of time required to complete a cycle can vary considerably. In this review, phenotypic evaluation is assumed to be conducted for 2 consecutive harvest years (excluding the establishment year) for all breeding methods reflecting the perennial requirement of the perennial ryegrass crop and the often large genotype × year interaction variances associated with the traits for improvement (Casler, 1999; Conaghan *et al.*, 2008a). It was assumed that selections would be made at the end of each cutting season (around October) allowing establishment and vernalisation during the autumn and winter, and recombination in the following year. Each breeding method was compared across a number of scenarios spanning the potential extremes of each variance component (Table 4). It should be noted that although the predicted gain may not be realised, it still indicates which method has a better chance to show gain (Brummer, 2008).

TABLE 2: Summary characteristics of the intrapopulation breeding methods relevant to perennial ryegrass (adapted from Posselt, 2010)

Method of selection	Selection unit	Test unit	Recombination unit	Parental control	Cycle time (yrs)	Genetic variance[1]			
						σ2A	σ2D	σ2A	σ2D
Phenotypic recurrent selection									
Uniparental control	Plant	Plant	Plant	0.5	3	1	1		
Biparental control	Plant	Plant	Plant	1	4	1	1		
Half-sib (HS) family structure						Among families		Within families	
HS family selection	Family	Plot	HS seed	1	4	¼	0	¾	1
HS progeny test	Family	Plot	HS parent	2	4	¼	0	¾	1
Among-and-within HS family selection	Family & plant	Plot & plan	HS plant	1	5	¼	0	¾	1
Full-sib (FS) family structure[2]									
FS family selection	Family	F1 plot	FS seed	1	4	½	¼	½	¾
FS progeny test	Family	F1 plot	FS parent	1	4	½	¼	½	¾
Among-and-within FS family selection	Family & plant	F1 plot & plant	FS plant	1	4	½	¼	½	¾

[1] $ό^{2}_{A}$ and $ό^{2}_{A}$ = the additive and dominance genetic variances.

[2] Cycle time = 5 years if evaluation is conducted using F2 seed.

TABLE 3: Predicted genetic gain per cycle (ΔG) for different methods of intrapopulation improvement (adapted from Fehr, 1987)

Method of selection	Predicted genetic gain per cycle[1]	
Phenotypic recurrent selection (PRS)	$\dfrac{kc\sigma^2_A}{\sqrt{\sigma^2_A + \sigma^2_{AE} + \sigma^2_D + \sigma^2_{DE} + \sigma^2_W + \sigma^2_e}}$	
	Among families	Within families
Half-sib family structure[2]	$\dfrac{kc\,\frac{1}{4}\sigma^2_A}{\sqrt{\frac{1}{4}\sigma^2_A + \frac{\frac{1}{4}\sigma^2_{AE}}{e} + \frac{\sigma^2_e}{re}}}$	$\dfrac{kc\,\frac{3}{4}\sigma^2_A}{\sqrt{\frac{3}{4}\sigma^2_A + \frac{3}{4}\sigma^2_{AE} + \sigma^2_D + \sigma^2_{DE} + \sigma^2_W + \sigma^2_e}}$
Full-sib family structure[2]	$\dfrac{kc\,\frac{1}{2}\sigma^2_A}{\sqrt{\frac{1}{2}\sigma^2_A + \frac{1}{4}\sigma^2_D + \frac{(\frac{1}{2}\sigma^2_{AE} + \frac{1}{4}\sigma^2_{DE})}{e} + \frac{\sigma^2_e}{re}}}$	$\dfrac{kc\,\frac{1}{2}\sigma^2_A}{\sqrt{\frac{1}{2}\sigma^2_A + \frac{3}{4}\sigma^2_D + \frac{1}{2}\sigma^2_{AE} + \frac{3}{4}\sigma^2_{DE} + \sigma^2_W + \sigma^2_e}}$

[1] *k* = the standardised selection differential; *c* = parental control; *e* = the number of environments; *r* = the number of replications in each environment; σ^2_A and σ^2_D = the additive and dominance genetic variances; σ^2_{AE} and σ^2_{DE} = the additive × environment and dominance × environment interaction variances; σ^2_W and σ^2_e = the within-plot error and experiment error variances. Variables may differ in value for among and within families. Phenotypic recurrent selection and within-family selection was assumed to be conducted using unreplicated plants.

[2] ΔG for among-and-within family selection = the sum ΔG of among and within families

Bi-parental vs. uni-parental phenotypic recurrent selection

Bi-parental and uni-parental PRS differ in the level of parental control and, potentially, years per cycle. Bi-parental control is 2.0 times more efficient than uni-parental control if the cycle time is the same for both methods. If uni-parental control shortens the cycle time by one year by facilitating evaluation and recombination in the same year, as described in Figure 1, the advantage of bi-parental control over uni-parental control is reduced to 1.5 fold. Uni-parental control will offer the same level of ΔG/year as bi-parental control, with evaluation and recombination conducted in separate years, only if one evaluation year is used, and recombination and evaluation can be conducted in the same year.

However, if uni-parental control is to be practical and cost efficient, evaluation for the trait must also be completed before seed shattering. Otherwise, the seed of each individual plant evaluated must be harvested individually, uniquely identified and stored separately. Genotypes cannot be bulked at this stage if the evaluation is not complete and the selection decisions have been not been made. If evaluation is completed before heading, the selected plants may be relatively easily moved to an isolated crossing block thus offering bi-parental control and doubling ΔG/year. Therefore, the utility of PRS with uni-parental control in perennial ryegrass breeding programmes tends to be low and only applicable to seed production traits.

Half-sib family selection vs. half-sib progeny test selection

Half-sib progeny test selection is 1.6 times more efficient than HSF selection, assuming similar selection intensity and level of replication. This is due to a longer cycle time but better parental control with HSPT compared with HSF selection. But HSF selection has an advantage over HSPT selection in that it allows selection of a smaller number of recombination units (half-sib families *vs*. parental genotypes) to form the next cycle for the same level of inbreeding. Thus, HSF selection facilitates a higher selection intensity than HSPT selection. Nevertheless, HSPT selection at a selection intensity of 10% is still 1.4 times more efficient than HSF selection at a selection intensity of 5%.

TABLE 4: Predicted genetic gain per year (expressed as a percentage of additive genetic variance) for alternative breeding methods across different levels of selection intensity (k), phenotypic and genetic variances, and environmental replication

Selection method[1]	Selection intensity among families/variance components model[2]														
	20% selection intensity					10% selection intensity					5% selection intensity				
	Lo_e	Me_{AE}	Hi_{AE}	Me_D	Hi_D	Lo_e	Me_{AE}	Hi_{AE}	Me_D	Hi_D	Lo_e	Me_{AE}	Hi_{AE}	Me_D	Hi_D
One replicate in one environment (location)															
Biparental PRS	23	13	7	11	6	29	16	9	14	8	34	19	10	16	9
Uniparental PRS	16	9	5	7	4	20	11	6	9	5	23	13	7	11	6
HSF	12	7	3	7	3	16	9	3	9	3	18	11	4	11	4
HSPT	20	11	4	11	4	25	14	5	14	5	29	17	6	17	6
FSF (F_1)	20	12	5	11	5	25	16	6	14	6	30	18	7	16	7
FSF (F_2)	31	19	8	16	7	33	20	8	17	7	36	22	9	18	8
AW-HS$_{20}$ (F_2)	22	13	5	11	5	24	15	6	13	5	27	16	6	14	6
AW-HS$_{50}$ (F_2)	32	20	8	17	7	36	22	9	20	9	40	24	10	22	9
AW-FS$_{20}$ (F_2)	25	16	6	14	6	29	18	7	17	7	33	20	8	19	8
AW-FS$_{50}$ (F_2)	31	19	8	16	7	33	20	8	17	7	36	22	9	18	8
Two replicates in one location															
HSF	14	9	4	9	4	18	11	4	11	4	21	13	5	13	5
HSPT	23	14	6	14	6	29	18	7	18	7	34	21	8	21	8
FSF (F_1)	22	14	7	12	6	28	18	8	16	8	33	21	10	18	9
FSF (F_2)	18	11	5	10	5	22	14	7	12	6	26	17	8	15	7
AW-HS$_{20}$ (F_2)	32	20	9	17	8	35	22	9	19	8	38	24	10	20	9
AW-HS$_{50}$ (F_2)	23	15	6	13	6	26	16	7	14	6	29	18	8	16	7
AW-FS$_{20}$ (F_2)	34	21	9	19	9	38	24	11	22	10	42	27	12	24	11
AW-FS$_{50}$ (F_2)	27	17	8	16	7	31	20	9	19	9	35	22	10	21	10
Two replicates in each of two locations															
HSF	16	11	5	11	5	20	14	6	14	6	23	16	7	16	7
HSPT	25	18	8	18	8	31	22	10	22	10	37	26	12	26	12
FSF (F_1)	23	18	9	15	8	29	22	11	19	10	34	26	13	22	12
FSF (F_2)	19	14	7	12	6	23	18	9	15	8	28	21	11	18	9
AW-HS$_{20}$ (F_2)	34	22	10	19	9	37	24	11	21	10	39	26	12	23	11
AW-HS$_{50}$ (F_2)	24	16	7	14	7	28	19	8	17	8	30	21	9	19	9
AW-FS$_{20}$ (F_2)	35	24	11	21	11	40	27	13	25	13	44	31	15	28	14
AW-FS$_{50}$ (F_2)	28	20	10	18	9	33	23	11	22	11	37	26	13	25	13

[1] PRS = phenotypic recurrent selection; HSF and FSF = half-sib and full-sib family selection; F_1 and F_2 = evaluation on F_1 and F_2 seed; AWF-HS$_{20}$ and AWF-HS$_{50}$ = among-and-within half-sib family selection with within family *k* of 20 and 50%, respectively; AWF-FS$_{20}$ and AWF-FS$_{50}$ = among-and-within full-sib family selection with within family *k* of 20 and 50%, respectively; [2] Lo_e = (σ^2_A = 1, σ^2_{AE}, σ^2_D and σ^2_{DE} = 0, and σ^2_e = 0.25); Me_{AE} = (σ^2_A = 1, σ^2_{AE} = 1, σ^2_D and σ^2_{DE} = 0, and σ^2_e = 1); Hi_{AE} = (σ^2_A = 1, σ^2_{AE} = 3, σ^2_D and σ^2_{DE} = 0, and σ^2_e = 10); Me_D = (σ^2_A, σ^2_{AE}, σ^2_D, σ^2_{DE} and σ^2_e = 1); Hi_D = (σ^2_A 1, σ^2_{AE}, σ^2_D and σ^2_{DE} = 3, and σ^2_e = 10) where σ^2_A, σ^2_{AE}, σ^2_D, σ^2_{DE} and σ^2_e correspond to the additive genetic, additive genetic × environment interaction, dominance genetic, dominance genetic × environment interaction and within experiment error variances, respectively. For PRS, the plot-to-plot and within-plot environmental variance is assumed to sum to σ^2_e. Predicted gain per year is based on variables and formulas in Tables 2 and 3.

The cost of implementing HSPT selection is greater than HSF selection as it requires an additional recombination event, as well as the effort of saving and maintaining the parental clones. However, the extra cost and workload is relatively modest considering the additional recombination event consists of a bulk harvested, open-pollinated cross, and the parental plants once established in a nursery are sturdy and require relatively little attention. The greater efficiency of HSPT selection should more than compensate for the extra cost.

Full-sib family selection vs. half-sib family selection

The main advantage of FSF selection over HSF selection is that it can utilise twice as much additive genetic variance as HSF selection (0.5 *vs.* 0.25). But FSF selection also has two important disadvantages to consider. Firstly, the phenotypic variance (denominator in the prediction equation) will be greater for full-sibs than half-sibs as it contains a greater proportion of additive genetic variance, and a portion of dominance and genotype × dominance interaction variance which is not included in the phenotypic variance of half-sibs. Fortunately for FSF selection there is little evidence of dominance gene action in perennial ryegrass (Breese and Hayward, 1972). Secondly, FSF selection requires a longer cycle time if F_2 seed must be produced for trialling.

Nonetheless, FSF selection tends to be more efficient than HSF selection (Hallauer and Miranda, 1988). In all variance scenarios considered in Table 4, FSF selection based on the evaluation of F_2 seed (FSF-F_2) was more efficient than HSF selection by on average 1.3 times, assuming equal selection intensity and level of replication.

Full-sib family selection vs. half-sib progeny test selection

There is no difference in the numerator of the prediction equation for FSF and HSPT selection. Full-sib family selection utilises twice as much additive genetic variance as HSPT selection (0.5 *vs.* 0.25) but only half the level of parental control (1 *vs.* 2), nullifying the effect. However, the denominator in the prediction equation (phenotypic variance) will always be larger for FSF selection compared with HSPT selection as it contains a larger additive genetic variance component, and a portion of dominance genetic variance and dominance genetic × environment variance. Therefore, HSPT selection tends to be more efficient than FSF selection. Across the range of variance scenarios considered in Table 4, HSPT selection was on average 1.2 times more efficient than FSF-F_2 selection, assuming similar selection intensity and level of replication.

But FSF selection has an advantage over HSPT selection in that allows selection of a smaller number of recombination units (full-sib families *vs.* parental genotypes) to form the next cycle for the same level of inbreeding. Thus, FSF selection facilitates a higher selection intensity than HSPT selection. The mean advantage of HSPT selection at a selection intensity of 10% over FSF-F_2 selection at a selection intensity of 5% was negligible (proportionally 1.0), particularly considering that the level of dominance used in our variance scenarios is high and unlikely in reality. Therefore, the choice between FSF and HSPT selection largely comes down to practicality and cost which will depend on the particular skills and resources of the individual breeding station.

Among-and-within family selection vs. family selection

Among-and-within half-sib and full-sib selection will always be more efficient than HSF and FSF selection, respectively (Casler and Brummer, 2008). The advantage of AWF selection is increased by greater selection intensity within families and relatively low within-family phenotypic variance (i.e. high individual-plant heritability). The cost of implementing AWF selection is zero if phenotypic data is routinely determined on individual plants within families before calculating the family mean. However, the cost of AWF selection may be high, if family selection is based solely on plot values and within family selection requires the additional establishment and/or evaluation of individual spaced plants.

The cost of AWF selection may be reduced by delaying the within-family evaluation until one evaluation year of the family means is completed. Based on this one evaluation year a proportion (perhaps 0.50) of the best families could be selected for within-family evaluation. The possibility of practising this staggered AWF selection procedure depends on the strength of the first harvest year results to predict the top families. Alternatively, within-family evaluation could be postponed until the full evaluation of the family means is completed and only the selected families subjected to within-family evaluation. This AWF selection method using F_2 full-sib seed for evaluation could be completed in 7 years. Both options should be weighed against the combined cost and efficiency of one cycle of FSF-F_2 selection and recombination, followed immediately by one cycle of bi-parental PRS on the recombined population. The latter multistep breeding option could be completed in 8 years.

For a similar level of cost, the ΔG/year with AWF-FS selection, with family selection postponed until the best families are selected, is 1.1 times greater than the multistep FSF plus bi-parental PRS approach (Table 4). This assumes both methods have equal selection intensity and replication among families and on an individual plant basis. The greater efficiency of AWF-FS selection is primarily due to its one year shorter cycle time.

An alternative to using a dedicated spaced plant nursery is to base within-family selection on survivorship, by taking a random sample of surviving plants from the sward plots of the selected families (Casler, 2008; Casler and Brummer, 2008). Natural (i.e. abiotic and biotic stresses) and induced (e.g. cutting management) selective forces acting upon the sown grass between the sowing date and selection date may lead to a genetic shift in the surviving and original population. The survivors may have better agricultural fitness in the selection environment than a random sample of plants from the original population (Falkner and Casler, 2000). The amount of realised gain achievable, if any, using survivorship as the selection criterion within perennial ryegrass sward plots is unknown (Casler and Brummer, 2008). But, considering mortality rates are high within perennial-forage sward plots, with estimates of up to 0.90 mortality within the establishment year (Charles, 1961), significant selection pressures must be acting upon the sward and a genetic shift in the surviving and original population is likely.

For a comparable within and among family selection intensity, AWF-FS selection is more efficient than AWF-HS selection. The advantage of AWF-FS over AWF-HS increases as the within-family selection intensity increases.

Among-and-within family selection vs. half-sib progeny test selection

The advantage of AWF selection over HSPT selection is less than its advantage over HSF and FSF selection, as HSPT selection offers double the level of parental control. Again, primary to practising AWF selection is a requirement to conduct a cost-benefit analysis between AWF selection, among-family selection immediately followed by PRS selection, and HSPT selection. Consideration should also be given to the potentially higher selection intensity that may be imposed using family selection methods compared with HSPT selection for a similar level of inbreeding.

The AWF-FS selection (using F_2 seed for evaluation) at an among family selection intensity of 5% and within family selection intensity of 20% offered on average 1.2 times more ΔG/year than HSPT selection at a selection intensity of 10% (Table 4). This assumes that the within-family selection was not conducted until evaluation of the best families had been completed. It is based on evaluating families in two replicates at one location, and individual plants in one replicate at one location.

Phenotypic recurrent selection vs. genotypic recurrent selection

Genotypic recurrent selection in replicated plots may increase ΔG/year compared with unreplicated bi-parental PRS, particularly when the error variance and G × E interaction variance is large. However, the considerable extra cost of implementing GRS rarely justifies the extra ΔG/year, unless that trait of interest cannot be efficiently improved using spaced plants in which case the use of GRS is the only viable option. The average advantage of GRS (HSF, HSPT and FSF-F_2 selection) evaluated in two replicates in each of two locations at a selection intensity of 5% over bi-parental PRS evaluated in one replicate in one location at a selection intensity of 10% was proportionally 1.2, across the variance scenarios considered in Table 4. The cost of this extra ΔG/year was considerable. For the typical range of heritability (≥ 0.10) reported for perennial ryegrass traits, bi-parental PRS is the most cost efficient and cost effective breeding method, provided of course there is good correlation between the trait as measured in spaced plants and swards.

Conclusions

The optimum breeding system for perennial ryegrass is dependent on the traits for improvement, and the resources and skills available. Careful consideration should be given to the expression of the trait under the management regime imposed in the breeding programme and under real-world sward conditions in the target region. Genotypic recurrent selection will be a necessary part of the breeding system if forage yield is a trait for improvement. Genotypic recurrent selection may be practised using full-sib or half-sib families, each with their own advantages and disadvantages to consider. Phenotypic recurrent selection in tandem (i.e. within family selection) or in succession with GRS should be used to improve traits that have a high correlation between spaced plants and swards. Genome-wide selection represents the most interesting and exciting potential application of MAS, although it remains to be seen how effective and efficient it will be in practise.

References

Aldrich, D.T.A. 1987. Developments and procedures in the assessment of grass varieties at NIAB 1950-87. *Journal of the National Institute of Agricultural Botany* **17:** 313–327.

Baird, N.A., Etter, P.D., Atwood, T.S., Currey, M.C., Shiver, A.L., Lewis, Z.A., Selker, E.U., Cresko, W.A. and Johnson, E.A. 2008. Rapid SNP discovery and genetic mapping using sequenced RAD Markers. *PLoS ONE* **3:** e3376.

Beerpoot, L.J. and Agnew, R.E. 1997. Breeding for improved herbage quality in perennial ryegrass. In: “Seeds of Progress” (ed. J.R. Weddell), British Grassland Society, Reading, UK, pages 135–145.

Beerpoot, L.J., Bouter, W. and Dijkstra, J.A. 1994. Breeding for improved digestibility in perennial ryegrass. In: “Breeding for Quality” (ed. D. Reheul and A. Ghesquiere), *Proceedings of the EUCARPIA Fodder Crops and Amenity Grass Section*, EUCARPIA, Wageningen, The Netherlands, pages 237–245.

Bernardo R. 2008. Molecular markers and selection for complex traits in plants: learning from the last 20 years. *Crop Science* **48:** 1649–1664.

Bernardo, R. 2002. “Breeding for Quantitative Traits in Plants”. Stemma Press, Woodbury, Minnesota, USA, 369 pages.

Bonos, S.A., Clarke, B.B. and Meyer, W.A. 2006. Breeding for disease resistance in the major cool-season turfgrasses. *Annual Review of Phytopathology* **44:** 213–234.

Breese, E.L. and Hayward, M.D. 1972. The genetic basis of present breeding methods in forage crops. *Euphytica* **21:** 324–336.

Brummer, E.C. 2008. “Advanced Plant Breeding Course Notes”. University of Georgia, Athens, Georgia, USA, http://mulch.cropsoil.uga.edu/brummer/CRSS8140.htm (accessed June 2010), 99 pages.

Brummer, E.C. and Casler, M.D. 2009. Improving selection in forage, turf, and biomass crops using molecular markers. In: “Molecular Breeding of Forage and Turf” (ed. T. Yamada and G. Sprangenberg), Springer, New York, pages 193–209.

Burton, G.W. 1974. Recurrent restricted phenotypic selection increases forage yields of Pensacola bahiagrass. *Crop Science* **14:** 831–835.

Buxton, D.R. and Marten, G.C. 1989. Forage quality of plant parts of perennial grasses and relationship to phenology. *Crop Science* **29:** 429–435.

Camlin, M.S. and Stewart, R.H. 1975. Reaction of Italian ryegrass cultivars under grazing as compared with cutting. *Journal of the British Grassland Society* **30:** 121–129.

Carr, A.J.H., Catherall, P.L., A'Brook, J. and Wilkins, P.W. 1975. Diseases in the grass crop – problems and progress. *Report of the Welsh Plant Breeding Station* **1972:** 177–193.

Casler, M.D. 1998. Host resistance and tolerance and its deployment. In: "Grass for Dairy Cattle" (ed. J.H. Cherney and D.J.R. Cherney), CABI Publishing, New York, pages 23–47.

Casler, M.D. 1999. Repeated measures vs. repeated plantings in perennial forage grass trials: an empirical analysis of precision and accuracy. *Euphytica* **105:** 33–42.

Casler, M.D. 2001. Breeding forage for increased nutritional value. *Advances in Agronomy* **71:** 51–107.

Casler, M.D. 2008. Among-and-within-family selection in eight forage grass populations. *Crop Science* **48:** 434–442.

Casler, M.D. 2010. Improving efficiency in breeding forage crops. In: "2nd International Symposium on Forage Breeding" (ed. L. Jank), EMBRAPA, Campo Grande, Brazil (in press).

Casler, M.D. and Brummer, E.C. 2008. Theoretical expected genetic gains for among-and-within-family selection methods in perennial forage crops. Crop Science **48:** 890–902.

Casler, M.D. and Pederson, G.A. 1996. Host resistance and tolerance and its deployment. In: "Pasture and Forage Crop Pathology" (ed. S. Chakraborty, K.T. Leath, R.A. Skipp, G.A. Peterson, R.A. Bray, G.C.M. Latch and F.W. Nutter, Jr.), ASA-CSSA-SSSA, Madison, Wisconsin, USA, pages 475–507.

Casler, M.D. and van Santen, E. 2010. Breeding objectives in forages. In: "Fodder Crops and Amenity Grasses" (ed. B. Boller, U.K. Posselt and F. Veronesi), Springer, New York, pages 115–136.

Casler, M.D. and Vogel, K.P. 1999. Accomplishments and Impact from Breeding for Increased Forage Nutritional Value. *Crop Science* **39:** 12-20.

Casler, M.D., J.F. Pederson, G.C. Eizenga and Stratton S.D. 1996. Germplasm and cultivar development. In: "Cool-Season Forage Grasses", (ed. L.E. Moser, D.R. Buxton and M.D. Casler), ASA-CSSA-SSSA, Madison, Wisconsin, USA, pages 413–469.

Charles, A.H. 1961. Differential survival of cultivars of *Lolium, Dactylis* and *Phleum*. *Journal of the British Grassland Society* **16:** 69–75.

Charmet, G. and Ravel, C.G. 1991. Expected response to selection in synthetic populations of perennial ryegrass. *Plant Breeding* **107:** 148–155.

Chaves, B., De Vliegher, A., Van Waes, J., Carlier, L. and Marynissen, B. 2009. Change in agronomic performance of *Lolium perenne* and *Lolium multiflorum* varieties in the past 40 years based on data from Belgian VCU trials. *Plant Breeding* **128:** 680–690.

Conaghan, P., Casler, M.D., McGilloway, D.A., O'Kiely, P. and Dowley, L.J. 2008a. Genotype × environment interactions for forage yield of *Lolium perenne* L. sward plots in Ireland. *Grass and Forage Science* **63:** 107–120.

Conaghan, P., Casler, M.D., O'Kiely, P. and Dowley, L.J. 2008b. Efficiency of indirect selection for dry matter yield based on fresh matter yield in perennial ryegrass sward plots. *Crop Science* **48:** 127–133.

Cooper, J.P. 1960. Selection and population structure in *Lolium*. IV. Correlated response to selection. *Heredity* **14:** 229–246.

Cooper, J.P. and Breese, E.L. 1980. Breeding for nutritive quality. *Proceedings of the Nutrition Society* **39:** 281–286.

Department for Environment, Food and Rural Affairs (DEFRA) 2008. "United Kingdom Seed Certification Schemes – Statistical Information 2007-2008 (England and Wales)", DEFRA, Cambridge, UK, 29 pages.

Doyle, C.J. and Elliott, J.G. 1983. Putting an economic value on increases in grass production. *Grass and Forage Science* **38:** 169–177.

Easton, H.S., Cooper, B.M., Fraser, T.J. and Widdup, K.H. 1989. Crown rust on perennial ryegrass in field trials. *Proceedings of the New Zealand Grassland Association* **50:** 253–254.

Edwards, J. 2010. Testcross response to four cycles of half-sib and S2 recurrent selection in the BS13 maize (*Zea mays* L.) population. *Crop Science* **50:** 1840–1847.

Elgersma, A. 1990. Spaced-plant traits related to seed yield in plots of perennial ryegrass (*Lolium perenne* L.). *Euphytica* **51:** 151–161.

Elgersma, A., Winkelhorst, G.D. and den Nijs, A.P.M. 1994. The relationship between progeny seed yield in drilled plots and maternal spaced-plant traits in perennial ryegrass (*Lolium perenne* L.). *Plant Breeding* **112:** 209-214.

Falconer, D.S. and Mackay, T.F.C. 1996. "Introduction to Quantitative Genetics". 4th edition, Longman Press, Essex, England, 464 pages.

Falkner, L.K., and Casler, M.D. 2000. Genetic shifts in smooth bromegrass under grazing: Changes in nutritional value and preference for surviving vs. original genotypes. *Grass and Forage Science* **55:** 351–360.

Fehr, W. 1987. "Principles of cultivar development. Volume 1. Theory and technique". Macmillian, New York, 536 pages.

Frandsen, K.J. 1986. Variability and inheritance of digestibility in perennial ryegrass (*Lolium perenne*), meadow fescue (*Festuca pratensis*) and cocksfoot (*Dactylis glomerata*). II. F_1 and F_2 progeny. *Acta Agriculturae Scandinavica* **36:** 241–263.

Gallais, A. 2003. "Quantitative genetics and breeding methods in autopolyploid plants". INRA, Paris, 515 pages.

Gilliland, T.J., Barrett, P.D., Agnew, R.E. and Fearon, A.M. 2003. Variation in herbage quality traits and grazing value indicators among perennial ryegrass (*Lolium perenne* L.) varieties. *Vorträge für Plfanzensüchtung* **59:** 11-19.

Hallauer, A.R. and Miranda, Fo., J.B. 1988. "Quantitative genetics in maize breeding". 2nd edition, Iowa State University Press, Ames, Iowa, USA, 468 pages.

Hayward, M.D. and Vivero, J.L. 1984. Selection for yield in *Lolium perenne*. II. Performance of spaced plant selections under competitive conditions. *Euphytica* **33:** 787–800

Hazel, L.N. and Lush, J.L. 1942. The efficiency of three methods of selection. *Journal of Heredity* **33:** 393–399.

Heffner, E.L., Sorrells, M.E., Jannink, J-L. 2009. Genomic selection for crop improvement. *Crop Science* **49:** 1–12.

Hides, D.H., Lovatt, J.A. and Hayward, M.V. 1983. Influence of stage of maturity on the nutritive value of Italian ryegrass. *Grass and Forage Science* **38:** 33–38.

Hill, R.R., Jr. 1971. Effect of the number of parents on the mean and variance of synthetic varieties. *Crop Science* **11:** 283–286.

Humphreys, M., Feuerstein, U., Vandewalle, M. and Baert, J. 2010. Ryegrasses. In: "Fodder Crops and Amenity Grasses" (ed. B. Boller, U.K. Posselt and F. Veronesi), Springer, New York, pages 211–260.

Jafari, A. 1998. "Genetic Analysis of Yield and Quality in Perennial Ryegrass (*Lolium perenne* L.)", PhD thesis, University College Dublin, Ireland.

Jafari, A., Connolly, V. and Walsh, E.J. 2003. Genetic analysis of yield and quality in full-sib families of perennial ryegrass (*Lolium perenne* L.) under two cutting managements. *Irish Journal of Agricultural and Food Research* **42:** 275–292.

Jannink, J.L., Lorenz, A.J. and Iwata, H. 2010. Genomic selection in plant breeding: from theory to practice. *Briefings in Functional Genomics* **2:** 166–177.

Jones, E.L. and Roberts, J.E. 1986. Comparison of management techniques for evaluating Italian and hybrid ryegrass cultivars. *Grass and Forage Science* **41:** 9–15.

Kimbeng, C.A. 1999. Genetic basis of crown rust resistance in perennial ryegrass, breeding strategies, and genetic variation among pathogen populations: a review. Australian *Journal of Experimental Agriculture* **39:** 361–378.

Lam, A. 1983. A survey of ryegrass swards for the presence of fungal pathogens in relation to management. *Grass and Forage Science* **38:** 55–65.

Lande, R., and Thompson, R. 1990. Efficiency of marker-assisted selection in the improvement of quantitative traits. *Genetics* **124:** 743–756.

Meuwissen, T.H.E., Hayes, B.J. and Goddard, M.E. 2001. Prediction of total genetic value using genome-wide dense marker maps. *Genetics* **157:** 1819–1829.

Novy, E.M., Casler, M.D. and Hill, R.R., Jr. 1995. Selection for persistence of tetraploid ryegrasses and festulolium in mixture with perennial legumes. *Crop Science* **35:** 1046–1051.

O'Kiely, P. 1991. Effects of applying propiconazole to grass grown for silage. *Irish Journal of Agricultural Research* **30:** 74.

O'Rourke, 1976. "Disease of Grasses and Forage Legumes in Ireland". An Foras Talúntais, Dublin, 115 pages.

Posselt, U.K. 1994. Selection parameters of quality traits in perennial ryegrass. In: "Breeding for Quality" (ed. D. Reheul and A. Ghesquiere), *Proceedings of the EUCARPIA Fodder Crops and Amenity Grass Section*, EUCARPIA, Wageningen, The Netherlands, pages 129–135.

Posselt, U.K. 2010. Breeding methods in cross-pollinated species. In: "Fodder Crops and Amenity Grasses" (ed. B. Boller, U.K. Posselt and F. Veronesi), Springer, New York, pages 39–87.

Ravel, C. and Charmet, G. 1996. A comprehensive multisite recurrent selection strategy in perennial ryegrass. *Euphytica* **88:** 215–226.

Reheul, D. and Ghesquiere, A. 1996. Breeding perennial ryegrass with better crown rust resistance. *Plant Breeding* **115:** 465–69.

Roldán-Ruiz, I. and Kölliker, R. 2010. Marker-assisted Selection in Forage Crops and Turf: A Review. In: "Sustainable Use of Genetic Diversity in Forage and Turf Breeding" (ed. C. Huyghe), Springer, New York, pages 383–390.

Skøt, L., Humphreys, M.O., Armstead, I., Heywood, S., Skøt, K.P., Sanderson, R., Thomas, I.D., Chorlton, K.H., Sackville Hamilton, N.R. 2005. An association mapping approach to identify flowering time genes in natural populations of *Lolium perenne* (L.). *Molecular Breeding* **15:** 233–245

Smith, K.F., Dobrowolski, M.P., Cogan, N.O.I., Spangenberg, G.C. and Forster, J.W. 2009. Utilizing linkage disequilibrium and association mapping to implement candidate gene based markers in perennial ryegrass breeding. In: "Molecular Breeding of Forage and Turf" (ed. T. Yamada and G. Sprangenberg), Springer, New York, pages 259–274.

Smith, K.F., Reed, K.F.M. and Foot, J.Z. 1997. An assessment of the relative importance of specific traits for the genetic improvement of nutritive value in dairy pasture. *Grass and Forage Science* **52:** 167–175.

Talbot, M. 1984. Yield variability of crop varieties in the U.K. *Journal of Agricultural Science* **102:** 315–321.

van Eeuwijk, F.A. and Elgersma, A. 1993. Incorporating environmental information in an analysis of genotype by environment interaction for seed yield in perennial ryegrass. *Heredity* **70:** 447–457.

Vogel, K.P. and Pedersen, J.F. 1993. Breeding systems for cross-pollinated perennial grasses. *Plant Breeding Reviews* **11:** 251–274

Walsh, E.J. 1994. "Introduction to Crop Breeding". University College Dublin, Ireland, 122 pages.

Weyhrich, R.A., Lamkey, K.R. and Hallauer, A.R. 1998. Effective population size and response to S1-progeny selection in the BS11 maize population. *Crop Science* **38:** 1149–1158.

Wheeler, J.L. and Corbett, J.L. 1989. Criteria for breeding forages of improved feeding value: results of a Delphi survey. *Grass and Forage Science* **44:** 77–83.

Wilkins, P.W. 1989. Genotype/harvesting frequency and genotype/nitrogen level interactions for annual dry matter yield in *Lolium perenne* in relation to breeding. *Euphytica* **41:** 207–214.

Wilkins, P.W. 1991. Breeding perennial ryegrass for agriculture. *Euphytica* **52:** 201–214.

Wilkins, P.W. 1997. Useful variation in *in vitro* digestibility within perennial ryegrass. *Euphytica* **93:** 249–255.

Wilkins, P.W. and Humphreys, M.O. 2003. Progress in breeding perennial forage grasses for temperate agriculture. *Journal of Agricultural Science* **140:** 129–150.

A review of perennial ryegrass variety evaluation in Ireland

D. Grogan[1] and T. J. Gilliland[2]

[1]Crops Evaluation and Certification Division, Department of Agriculture, Fisheries and Food, Backweston Farm, Leixlip, Co. Kildare; [2]Agri-Food Biosciences Institute, Crossnacreevy, Co. Down BT6 9SH

Email: dermot.grogan@agriculture.gov.ie

Abstract

Official National List (NL) testing of perennial ryegrasses commenced in Ireland at the start of the 1970's with Northern Ireland (NI) having one site as part of the UK NL testing network and the Republic of Ireland (ROI) using five sites. The different testing strategies adopted to achieve sufficient precision for regional Recommended Listing (RL) in ROI from a multi-site system and from a single-site system in NI were considered, including the test protocols, use of sequential sowings, timeframes and 'merit scores'. The precision with which varieties can be discriminated for yield potential was shown to decline at lower trial plot yields. Furthermore, reducing the number of data sets used for decision testing was shown to increase the 'breeder's risk' of having an improved variety incorrectly rejected but not the 'tester's risk' of erroneously recommending a variety that was not a clear improvement, because statistical analysis expanded confidence limits. These variety lists initially assessed only yield and persistency, giving a progressive improvement in recommended varieties and despite high G×E responses was most clearly evident in spring productivity improvements. The lists have been highly influential in both jurisdictions as almost all agricultural grass seed sales were recommended in ROI or NI, but the over use of late maturing varieties in the ROI market and declining reseeding levels across Ireland indicated the current limits of this influence. This and increasing requirements from Irish farmers for improvement in the nutritive value of varieties to support greater dependence on grass for animal production, has lead to increased testing for digestibility and other quality parameters. While there is valid scientific evidence that shows that improvements in perennial ryegrass varieties has increased milk and meat production, more detailed information is required to satisfy the specific needs of local farmers. Consequently, a research initiative has been instigated to develop an index that will incorporate all the yield, persistence and quality performances of each recommended variety into a ranking score for a specific herd management system. This guidance should simplify recommendations and better quantify variety improvements in financial terms. It is envisaged that this will encourage an increase in renewal of Irish pastures, promote selection of varieties based on enterprise-specific value and will continue to enhance the profitability and sustainability of grass-dependent Irish farming as has been achieved since RLs were first introduced in Ireland.

Keywords: perennial ryegrass, variety evaluation, value for cultivation, Ireland

Introduction

Perennial ryegrass (*Lolium perenne* L.) is a widely used forage species in temperate regions of the world, and particularly in Western Europe where there is a valuable market for new varieties. There has been considerable breeding effort in this species to create improved grasses for Europe. Given the wide climatic range of growing conditions across the European market, selection criteria in grass breeding programmes need to focus on specific ecozones if breeding advances are to be achieved. The use of dormancy zones, based on Lucerne adaptation has been found to be a useful means of classifying such regions (Long and Gilliland, 2010). Ireland is within Zone six, which is a maritime region that includes Britain and the coastal regions of north west France and Spain. There is ample evidence that ryegrass breeding programmes focused on this agri-environmental zone have achieved notable success in the past (Van Wijk and Reheul, 1991; Wilkins and Humphreys, 2003).

The agri-environment of Ireland supports a predominately grassland dependent agri-business. Grassland covers approximately 85% of the arable area of the island of Ireland and is by far the most important agricultural land use. Within this total of 4.2m ha, 3.4m are in the Republic of Ireland (ROI) and the remaining 0.8m are in Northern Ireland (NI). A measure of the financial importance of grassland to these economies is that annual farm gate output from the ruminant sector was worth c. €4 billion to ROI (CSO, 2009) and c. €0.7 billion to NI (Department of Agriculture and Rural Development (DARD), 2010). A breakdown of these headline figures to separate enterprise sectors shows annual output values in ROI for beef at €1.5 billion, dairy at €1.1 billion and sheep at €0.2 billion. For NI these sector values are beef at € 0.3 billion, dairy at € 0.35 billion and sheep at €0.05 billion (DARD, 2010).

Given the dominant and valuable role of grassland based production in Irish agriculture, improvement in grass varieties has the potential to make a major contribution to the economies of both ROI and NI. There are two government funded grass breeding programmes on the island of Ireland; Teagasc, Oakpark, Co. Carlow in ROI and the Agri-Food and Biosciences Institute (AFBI) programme at Loughgall, Co. Armagh, NI. There are also a number of government funded institutes and private organisations providing research and development, tertiary education plus demonstration and extension services to the ruminant sector. Both jurisdictions also have specialist variety evaluation facilities and annually publish their national and regional Recommended Lists (RL) of perennial ryegrass varieties. These play a vital role in support of the ruminant industry by identifying and promoting the use of new varieties with improved performance characteristics. To this end, it is important to understand that for herbage, unlike cereals, assessment of variety value by farmers is virtually impossible, partly because most swards are sown as mixtures, but also because the end product is meat, milk or wool and many factors other than the grass can limit animal performance and mask the true contribution of the sward. This means that these specialist testing facilities are vital to indentifying new elite material and ensuring that the Irish farming businesses reap the benefits. This paper presents the procedures and impacts of these grass variety evaluation programmes in Ireland.

The history of grass variety evaluation in Ireland

Perennial ryegrass variety evaluation first started in NI in 1955 as an advisory function to local farmers. A formal variety testing programme did not commence until 1969 at Crossnacreevy, Co. Down, after the UK Plant Varieties and Seeds Act, 1965, made Value for Cultivation and Use (VCU) testing of agricultural species a statutory obligation. Agri-Food and Biosciences Institute, Crossnacreevy was one of the initial test centres in the UK National List (NL) of Perennial Ryegrass Varieties evaluation scheme (Weddell, Gilliland and McVittie, 1997), and trials are undertaken on behalf of the DARD, NI. Building upon these NL trial results, additional evaluation of the best performing varieties at the Crossnacreevy site is undertaken. The first DARD RL was published in 1972 (Stewart and Camlin, 1972) and the first list of perennial ryegrass varieties comprised 8 early, 6 intermediate and 8 late maturing varieties. These included varieties such as Gremie, Premo, Cropper, Abersytwyth S24, RvP Hay-Pasture, Barlenna, Perma, Melle and Aberystwyth S23, which would become market leading varieties.

In 1973 Ireland and the UK joined the EU, and statutory variety testing became a requirement under EU legislation (currently Council Directive 2002/53/EC; NI: S.I. 2001 No. 3510; ROI: S.I. No. 525/2002). Member States (MS) are obliged to set up, on the basis of official growing trials, a NL of agricultural varieties for marketing within the country. Information from the NL's of the MS is collected to form the EU Common Catalogue of varieties. The Common Catalogue implemented the 'common market' concept by making it legally permissible to sell a variety that has been listed on any MS NL, anywhere across the EU. While this conformed to the ethos of the EU, surpassing the minimum requirements in one MS gives no evidence of agronomic potential in another part of the EU where the climate is significantly different. For this reason, individual MS registration schemes have largely remained the driving force for variety use within their territories.

The first DAFF VCU trials in ROI were established in 1973 at 5 locations and the first DAFF RL was published in 1976. This included 10 early, four intermediate and nine late maturing varieties, including the varieties mentioned above, plus a number of Irish bred varieties such as Oakpark and Fingal that would later become market leaders. Varieties bred at Oak Park and Loughgall have continued to hold a significant proportion of the RL varieties, with almost half of the current ROI and NI recommended perennial ryegrass varieties from Irish breeders, about 20% from mainland UK, and the remainder from various EU breeders such as Netherlands, Germany, Denmark and France. This is a significant shift from 15 years ago when these lists would have been dominated by varieties from breeding programmes in Continental Europe.

Requirements for registration

To achieve NL status a candidate variety must show that it is Distinct, Uniform and Stable (DUS) and has VCU (Figure 1).

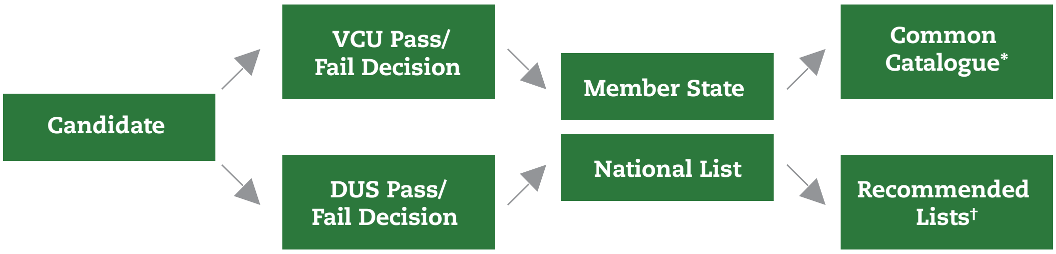


Figure 1: Schematic summary of variety testing phases in the EU
* entry to the Common Catalogue is automatic once registered by any MS
† recommended list scheme may be additional or integral to NL scheme

The DUS test is concerned with intellectual property rights and in essence ensures that when a breeder produces a superior variety, better than its competitors, it is protected from plagiarism. Distinct, Uniform and Stable tests of perennial ryegrass varieties submitted to the UK testing authority are carried out by AFBI at Crossnacreevy. As Crossnacreevy is an ‘Entrusted Centre’ of the EU Community Plant Varieties Office, Angers, France, for ryegrass DUS testing, submissions to ROI are normally also conducted at this centre through bilateral agreement. Unless a variety is proven to be distinct from all other varieties in common knowledge, plus uniform and stable in its essential morphological characteristics, it cannot be marketed, regardless of its VCU performance. This ensures that breeders of existing elite varieties are protected and can earn a fair remuneration that can fund further breeding for future improvements.

The VCU test involves assessment of the agronomic value of the varieties. In compliance with EU directives, MS are required to demonstrate that a new variety is a ‘clear improvement’ before it can be listed. Interpretation of ‘clear improvement’ differs from species to species and between different testing authorities. The minimum requirement for consideration on a NL is 2 years of field testing, but for long term species such as perennial ryegrasses, assessing value usually requires at least two sowings and 2-3 harvest years following a summer/autumn sowing.

Recommended List testing is regionally based and not under statutory or EU regulation and so test periods, procedures and entry standards vary greatly between MS and in some cases are integral to NL testing scheme. This allows them to be designed to assess the specific agronomic requirements and climatic conditions of the particular region. Typically they are run over a longer period than that required for National Listing. It is this more specific performance data that affects farmers' choice and breeders strategies in developing varieties for that market, though market size can also greatly influence breeders priorities (Long and Gilliland, 2010).

Ryegrass testing procedures in Ireland

As the two jurisdictions of ROI and NI are able to interpret the EU regulation to best suit their agri-environment and farming practices, there are both similarities and differences between the two schemes. Applications for DAFF combined NL/RL trials are invited from breeders and their agents in the year prior to sowing the trials. In NI, the UK wide NL system provides the preliminary screen of new perennial ryegrass varieties for the NI RL testing programme and so submissions are initially made to the coordinating offices of the Food and Environment Research Agency (FERA) of the Department for Environment, Food and Rural Affairs (DEFRA), in Cambridge, England (www.fera.defra.gov.uk/).

The DAFF, having a more diverse climatic region to assess have a multi-site system, similar to that used in the UK NL system. Initially in the 1970's this involved locations at Backweston, Co. Kildare, Ballyhaise, Co. Cavan, Clonakilty, Co. Cork, Mellowes College, Athenry, Co. Galway, and Oak Park, Carlow. The Oak Park site was discontinued during the 1980's, leaving 4 locations, and the Cork site was moved to Ballinacurra in 1996, and then to Ballyderown, Fermoy in 2003. In 2000 the Ballyhaise site was replaced with Tops Farm, Raphoe, Co. Donegal and a fifth location was established at Kildalton College, Piltown, Co. Kilkenny (Table 1). Candidate varieties are included in trials sown in two successive years and this produces a joint NL/RL recommendation after four years from when the variety was submitted for testing.

TABLE 1: Locations details of DAFF Cultivar Evaluation Trials for perennial ryegrass in Ireland 2010

Location	Northern Latitude	Western Longitude	Altitude (m)	Soil Type	Org. Matter %	pH
Athenry	53°18'	8°45'	35	Peaty loam	7.9	7.1
Backweston	53°22'	6°30'	50	Clay loam	6.3	7.2
Crossnacreevy	54°32'	5°52'	90	Med loam	6.5	6.5
Fermoy	52°08'	8°17'	53	Med loam	5.9	5.8
Kildalton	52°21'	7°20'	15	Clay loam	4.9	5.5
Raphoe	54°52'	7°36'	65	Med loam	6.2	5.6

The AFBI/DARD RL services a much less diverse ecozone than the DAFF programme and so utilizes a single site at Crossnacreevy, Co. Down (Table 1) but implements a sequential sowing system and a phased level of recommendation (Table 2). Varieties initially enter through the UK NL network which produces a multi-site informed UK listing decision four years after submission. The three additional RL sowings (only at Crossnacreevy) samples sufficient growing seasons to take account of variations in growing conditions and generate sufficient data over time to allow confident and reliable recommendations. Since the early 1980's these additional RL trials have been grazed with suckler cows in the first year to directly assess the response of the varieties to the pressures imposed by grazing animals. The first provisional recommendation for NI is a year after the UK NL decision, followed by an upgrading to 'Plain type' the following year. If the variety is sufficiently high performing it can be finally upgraded to the highest 'Bold Type' classification, almost eight years after the initial UK submission.

TABLE 2: Summary of Recommended List testing schedules undertaken by DAFF in ROI and AFBI in NI

Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
AFBI Sow I NL	(HY 1 C) Sow II NL	HY 2 SG (HY 1 C) Sow III RL	HY 3 C HY 2 SG Graze Sow IV RL	HY 3 C HY 2 SG Graze Sow IV RL **NL**	HY 3 C HY 2 SG Graze **RL (POV)**	HY 3 C HY 2 SG **RL (plain)**	HY 3 C **RL (bold)**
DAFF Sow I NL/RL	HY 1 GP Sow II NL/RL	HY 2 GP HY 1 GP	HY 2 GP	**NL/RL** (Subject to seed availability			

Key:

NL	National List
RL	Recommended List
HY	Harvest Year
C	Conversation management (5 cuts)
SG	Simulated Grazing (frequent cutting) management
GP	General Purpose Management (6 cuts, 2 silage + 4)

AFBI Recommendation Classes:

RL (prov)	Provisional Recommendation
RL (plain)	Plain Type Recommendation
RL (bold)	Bold Type Recommendation
(Hy 1 C)	Not used for Recommendation
Graze	Grazed with cattle
Sow I-V	Trail sowing series

Both DAFF and AFBI establish variety trials by broadcasting seed as this is common practice on farms. In ROI DAFF sow 11.4m^2 plots at seed rates of 30 kg/ha for diploids and 40 kg/ha for tetraploids and apply 350 kg N/ha/annum to their General Purpose management. During the establishment year, all trials are sprayed with appropriate broad-leaved herbicides, and where possible annual meadow grass is also controlled. In NI, AFBI sow 7.5m^2 plots at 25 or 37 kg/ha for diploid and tetraploid varieties and apply 360 kg Nitrogen (N)/ha/annum to their simulated grazing management trials and 375 kg N/ha/annum to the conservation management trials (Fera, 2010). Phosphate, potassium and sulphur are applied as indicated by annual soil analysis to meet growth requirements but to avoid contamination of waterways, as indicated by Tunney, Foy and Carton (1998). These fertilizer rates are intended to simulate intensive grassland use. For example, a cow with N consumption of 547 g N/cow/day will excrete 70% (383 g N/cow/day), and at a stocking rate of 4 cows/ha on a 24 day grazing cycle creates a total annual deposition potential over the grazing season of around 295 kg N excreted/ha/year. The remainder of the difference to the N-use levels on the trials is easily accounted for by inorganic fertilizer use on farm.

Herbage is harvested using a Haldrup plot harvester at cutting heights of between 5 and 8 cm for 'simulated grazing', 'general purpose' and 'conservation' managements. Plot weights are recorded and a sub-sample of 300 g - 400 g (depending on management system) is oven-dried at 80^{0}C for 16 hours to determine the total annual and seasonal dry matter (DM) yields (FERA, 2010; DAFF, 2010). Estimates of ground cover scores on a 0-9 scale are recorded by visual assessment at the end of each trial year and heading dates are recorded from single plants sown separately.

Changes in evaluation priorities

After World War II most available varieties such as Irish Commercial were low yielding, early heading, and lacking in persistence (Camlin, 1997). The main effort of grass breeders from then until the 1980's was, therefore, to improve the yield and persistence of varieties. As a consequence, evaluation procedures reflected this with the emphasis on yield, particularly under conservation management (i.e. 4-5 cuts per annum). Rapid progress was made in total yield potential and ground cover/persistency potential until the 1980's when the introduction of milk production quotas altered the farmer's requirements. From then on a wider seasonal distribution of yield, more spring and autumn growth, and improved animal digestibility became more important.

Values for spring growth were first published on the DAFF RL in 1995, followed by autumn growth in 1999 when DAFF protocols were changed to a six cut 'general purpose' management. A spring grazing cut was taken in early April followed by two silage cuts, and three late summer/autumn cuts. Similarly, for the NI RL, although there had always been a simulated grazing management that produced spring yields, it was not until 2001 that the full seasonal yield pattern of varieties was published.

Since 2003, all harvested samples from one location in ROI, Backweston, have been analysed by Near Infra-Red Spectrometry (NIRS). This technology potentially offers a rapid and cost effective means of measuring different nutritional parameters such as water soluble carbohydrates, crude proteins, digestibility, fatty acids (as conjugated lactic acids) and their precursors (α-linoleic acid and α-linolenic acid). While developing NIRS calibration equations to estimate these parameters is a substantial operation requiring sampling of many varieties, locations and years, it has the potential to help focus future breeding improvement to enhancing animal performance at grass, rather than simply increasing the amount of grass produced. This, however, brings both the advantage of specific nutritional assessment of varieties, but also a potential burden on breeders, if too many diverse requirements are demanded of new varieties. Initially priorities are focused on improving dry matter digestibility and water soluble carbohydrate content. To this end DAFF have already included these parameters in the RL's commencing in 2009.

Trial Precision

Results of the variety trials undergo analysis of variance (ANOVA) using the Agrobase software package (DAFF) or through a Fitted Constant Matrix and ANOVA (AFBI Biometrics Branch). Results are collated from all harvest years (and sites, DAFF), and candidate varieties compared to commercial control varieties of the appropriate ploidy level. The challenge of the testing system is to quantify differences between grass variety traits that tend to be small and difficult to detect.

The percentage coefficient of variation and mean yields for all DAFF experiments from 2007-2009 are presented in Figure 2. This shows that precision declines exponentially as plot yields fall below 2 t/ha DM. Even when the yields are higher there is a wide range in the accuracy between trials of similar productivity, such that only 40% of the scatter is explained by the curve. This clearly demonstrates the difficulty in measuring the merit and establishing the rank of grass genotypes due to this large genotype × environment (G×E) interaction on productivity (Talbot, 1984; Jafari, Connolly and Walsh, 2003). This was further confirmed in the case of the DAFF perennial ryegrass variety trials by Conaghan *et al.* (2008) who determined the nature and relative magnitudes of G×E interactions from six sites harvested from 2000 to 2004.

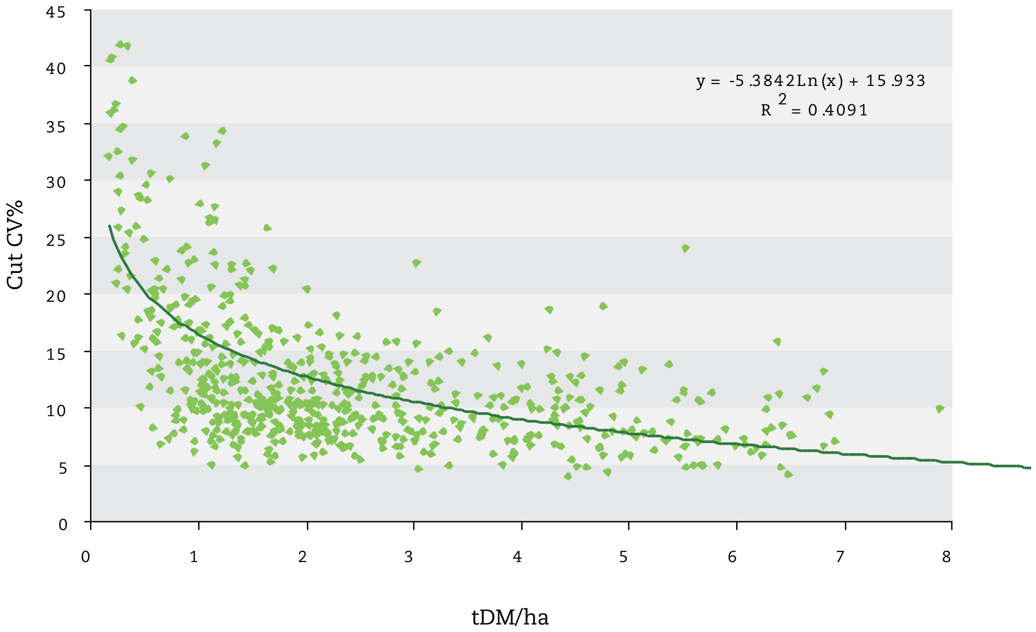


Figure 2: Relationship between DM yield (t DM/ha) and percentage coefficient of variation (CV) from 629 perennial ryegrass harvests in DAFF trials 2007-2009

The effects of microclimate, fertility, year of sowing, year of harvest and plot management (including cutting protocol) are all regarded as significant factors determining relative grass variety performance in evaluation trials. Figure 2 also shows how the precision of the trials would decline if lower rates of applied N were used.

In ROI DAFF use a ‘merit score’ where various traits are given relative weightings (for example spring growth is given a greater weighting than mid-season or autumn yield). An equivalent merit system is used in the UK and NI. Any candidate with a superior performance will achieve a positive VCU ‘merit score’ and will be included in the next RL, provided sufficient seed will be made available to farmers.

The current DAFF and AFBI trial arrangement of multiple locations or multiple sowings is designed to achieve the necessary levels of precision outlined by Talbot (1984). As these testing schemes apply a merit threshold that is dependent on trial precision, reduced accuracy due to fewer trials increases the ‘breeder’s risk’, not the ‘tester’s risk’. The principles of this are explained in Figure 3 which shows the relationship between the measured performance response and the pass/fail merit score. In this example a merit score of +2 is a ‘Clear Improvement’ sufficient to award listing and -2 is a ‘Clear Weakness’ that would normally result in a refusal for listing. Varieties falling between +2 and -2 would normally also fail unless additional evidence is available to show sufficient improvement in characteristics that would sufficiently improve the overall agronomic value of the variety to compensate for a merit score of less than +2. Typical characters would be pathogen or pest resistances, enhanced climate tolerances or increased nutritive value.

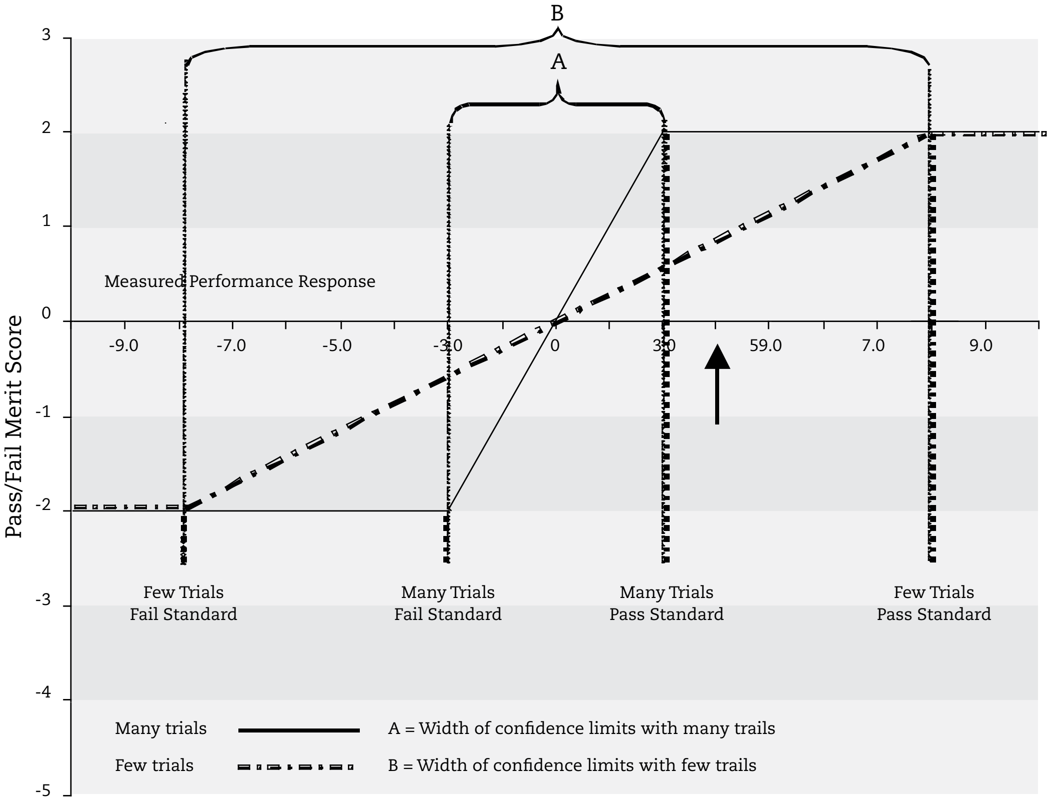
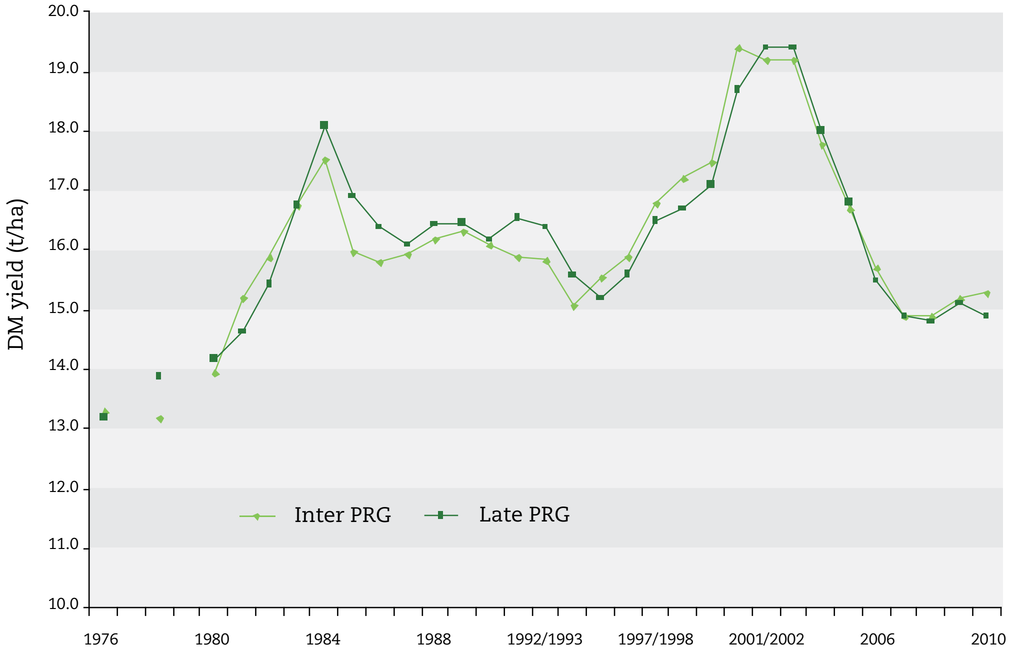


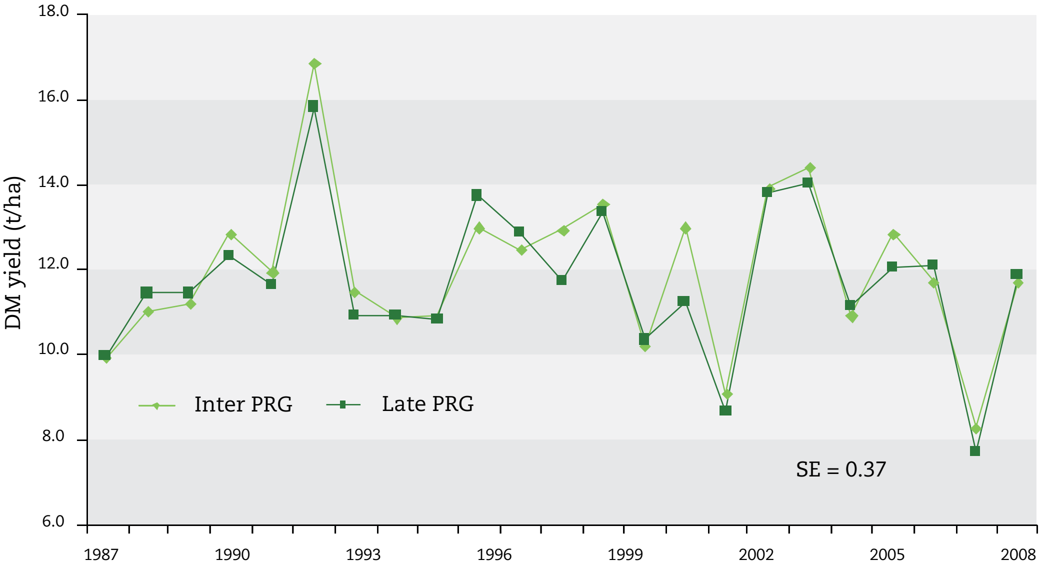
Figure 3: Consequence of reducing accuracy on pass/fail decisions in perennial ryegrass evaluation trials. The black arrow shows that a variety with measured response of '4.0' fails to reach the +2 pass standard when 'few trials' involved but is passed by a testing scheme with 'many trials'

Figure 3 shows that when there are many trials, and confidence limits, are small the slope of the graph is steep, but when there are few trials and confidence limits are wider, the slope is gradual. This means that to achieve the +2 pass with few trials requires a measured response of 9.0 (e.g. tonne (t) DM /ha), but only 3.0 (e.g. t DM/ha) when there are many trials. The black arrow in Figure 3 shows that a variety with a measured response of 4.0 fails to reach the +2 pass standard when 'few trials' are involved but is passed by a testing scheme with 'many trials'. The same response occurs for a clear weakness, so giving fewer clear failures (<-2). This means that with less trial data varieties have to achieve much higher performances to be listed and more varieties fall into the grey area of +2 to -2 and are failed. So the breeder's risk of having an improved variety refused increases, but the tester's risk of recommending a variety that is not an improvement remains unchanged.

In specific terms, Talbot (1984) showed that for the UK NL testing system the conservation management had a higher variance than the simulated grazing. In calculating the resulting increase in LSD (10%) due to the reduced precision of fewer results, he showed that a perennial ryegrass variety with a true yield of 105% of the pass standard had a 1:25 chance of failing to achieve the NL pass standard if a 6 trial series was used, but a 1:10 chance of failing with half the number of trials. This means that without sufficient precision, provided by an appropriate number of trial results, varieties with clear improvements could be falsely rejected for failing to show a clear improvement. These valuable varieties would be lost to Irish agriculture and an unfair rejection of a breeder's achievements would likely occur.



4a: DAFF Recommended List control variety values 1976-2010



4b: AFBI trials 1987-2009. Control varieties: Aubisque, Bastion, Condesa, Fantoom, Fennema, Magella, Lasso, Liprior, Parcour, Spira and Talbot

Figure 4: Average annual variation in the intermediate and late perennial ryegrass control variety yields (t DM/ha) from recommended list trials

Genetic gain and rate of introduction of new varieties

It is evident from the preceding section that the logistics of the current testing in ROI must be maintained if breeding progress is to be fairly rewarded. The G×E variation that makes trial precision so vital also masks an easy measure of genetic gain over time. Examples of this are given in Figure 4. The annual control yields from the DAFF RL (Figure 4a) appear to show an early rapid rise in yields during 1976-1984, followed by a period of decline to 1993. The rapid rise again to 2002 appears to have been followed by another acute decline to the present day. A similar annual fluctuation is also evident at the NI site (Figure 4b). Given that the same varieties were used in many of these years, combined with the standard setting procedure and trial precision of the testing system described above, this pattern cannot be due to fluctuating productivity potential of new varieties. Much of this fluctuation is in fact due to climate, changes to cutting managements, sites and fertilizer regimes and not simply to variety performance. For example, in recent years compliance with the Nitrates Directive has resulted in reduced applied N levels in DAFF trials and brought second harvest year yields down to an average of 14-15 t/ha DM. In addition, site to site variation in the same year has ranged from 17 t/ha in Fermoy to 13.0 t/ha in Donegal (Figure 5). Even when there have been no management or site changes and the control varieties are constant over time, background G×E variability in variety yields is still substantial.

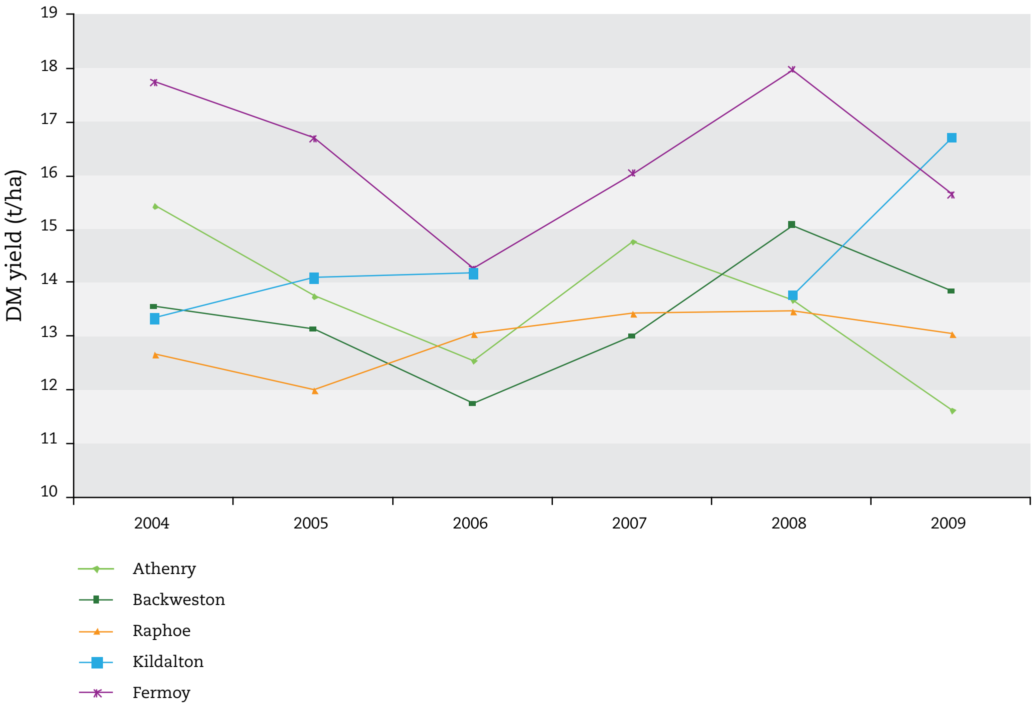


Figure 5: Comparison of ROI trial sites for total DM yield (t DM/ha) variation 2004–09. Data comprises year-2 average annual DM yields from late maturing perennial ryegrass trials

Despite this, several workers have been able to make statistically sound estimates of genetic gain in perennial ryegrass varieties. Current estimates for total DM yield increases due to the recommendation of improved variety genotypes are in the order of 0.5% per annum (Chaves *et al*., 2009; Smit, Metzger and Ewart, 2008; Gilliland and Gensollen, 2010). This compares well with the generally accepted genetic gain of 1-1.5% per annum for cereals (Peltonen-Sainio and Karjalainen, 1991; Silvey, 1986; Öfversten, Jauhiainen and Kangas, 2004). Furthermore, there have also been improvements in grass nutritive value, be that digestibility, reduced secondary heading, increased water soluble carbohydrate, or greater spring and autumn distribution of yield. Analysis of the DAFF spring yield data, exemplified by again examining the yield changes as the control varieties are changed over time for newer improved ones, shows a clear rising trend (Figure 6). If these improvements are included in the estimate of gain, then that gap between ryegrasses and cereals is further reduced. Grass farmers are much less able to judge variety improvement on farm and make informed choices than cereal growers, who annually get a measure of performance in their grain yields. It is a valid conclusion, therefore, that the role of RL for perennial ryegrasses has played a critical role in facilitating this gain over years.

Market impact of Irish recommended lists

Almost all varieties marketed to farmers in Ireland are on either the DAFF or AFBI/DARD RLs, with half the varieties present on both lists. Gilliland, Johnston and Connolly (2007) showed in their survey of the NI seed market that variety choice was made primarily on agronomic value with the top varieties on the RL being used predominantly, with only minor amounts of untested varieties in the market. Culleton and Cullen (1992) provided similar evidence for ROI. These lists are, therefore, widely used and respected by farmers, breeders, advisory services and seed merchants. While this is undoubtedly an impressive success story, there are still significant issues of concern.

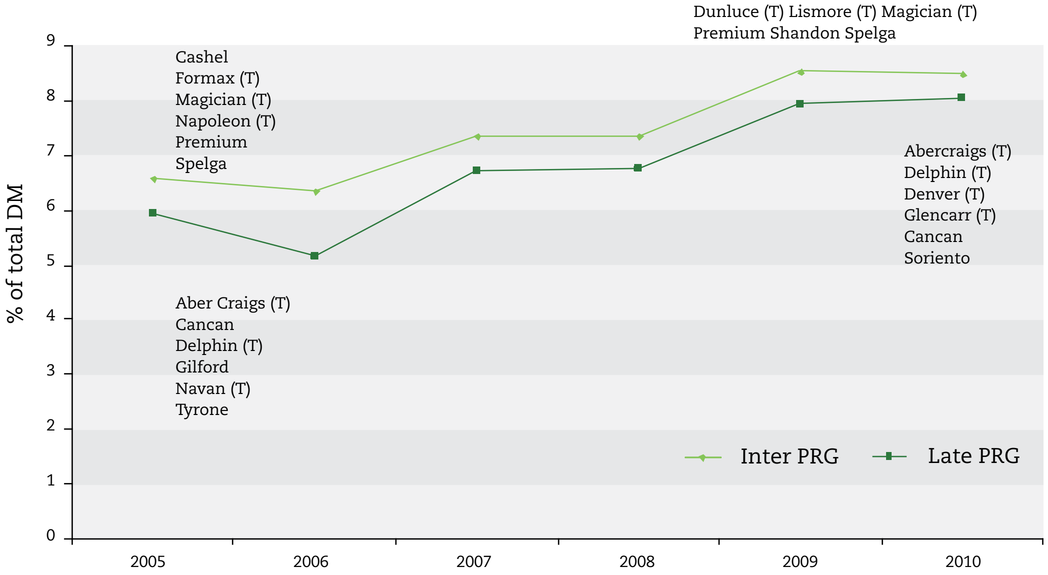
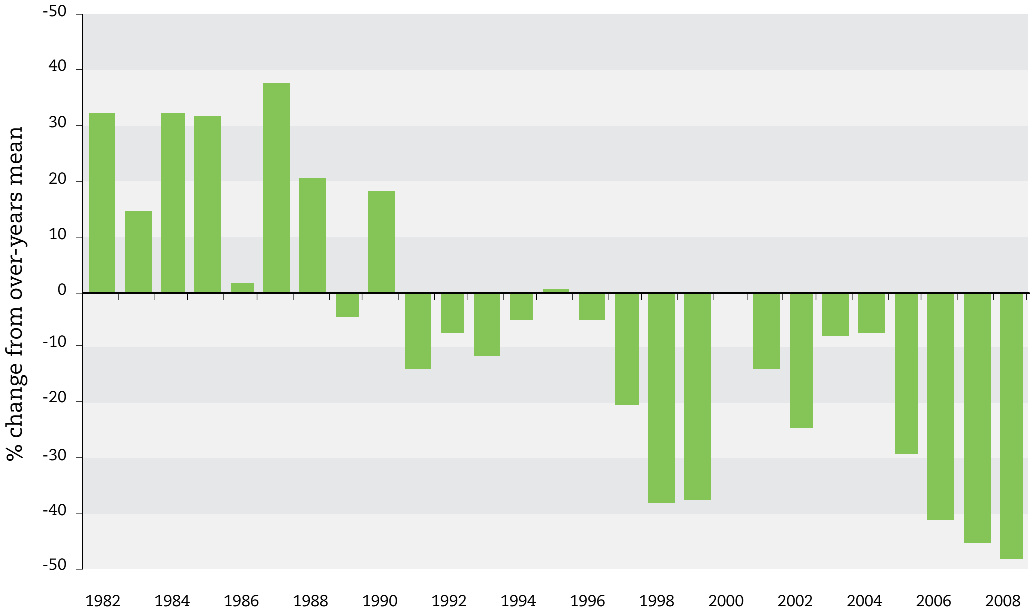


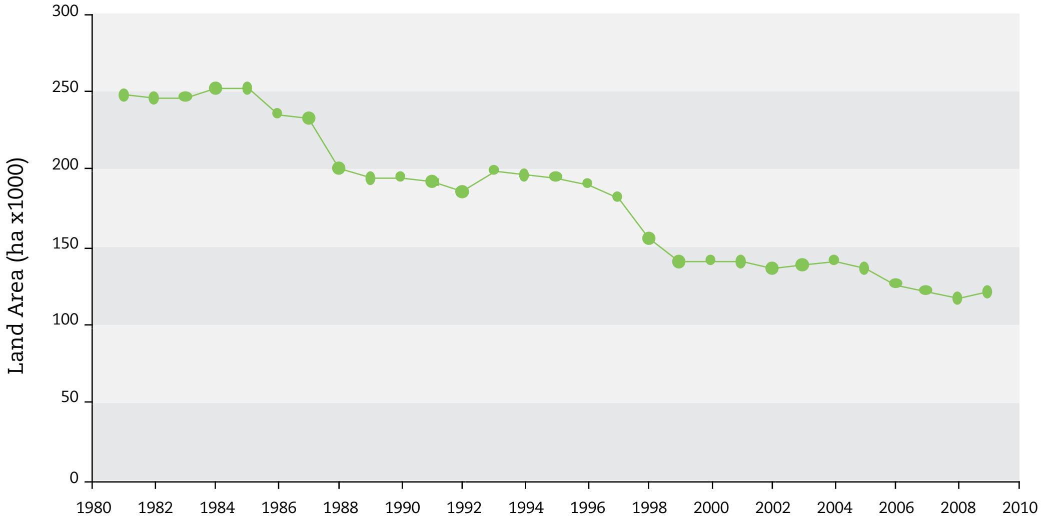
Figure 6: Spring growth of DAFF RL control varieties as a percentage of total annual DM yield 2005-2010

The key issue is the reduction in grassland reseeding activity in Ireland in recent decades. This is clearly demonstrated by the AFBI annual seed survey, compiled at Crossnacreevy, which shows a substantial decline in reseeding since the 1980's (Figure 7a). This is also clearly reflected in the decline in the area of grass under five years old in NI (Figure 7b), though the annual fluctuations appear smaller as these data are effectively five year rolling averages, whereas Figure 7a shows individual year data.

Based on the certified seed import and usage statistics from DAFF (Figure 8), the level of grassland reseeding has also fallen in ROI since EU entry in 1973, and is now at approximately 2.4% of the total pasture, hay and silage area. Perennial ryegrass accounts for 95% of grass seed usage, and there is no longer any native production of seed (Culleton, Cullen and McCarthy, 1992).



7a. Annual percentage change in Northern Ireland herbage seed sales volume



7b. Area of grassland under five years old in Northern Ireland

Figure 7: Change in reseeding activity in Northern Ireland

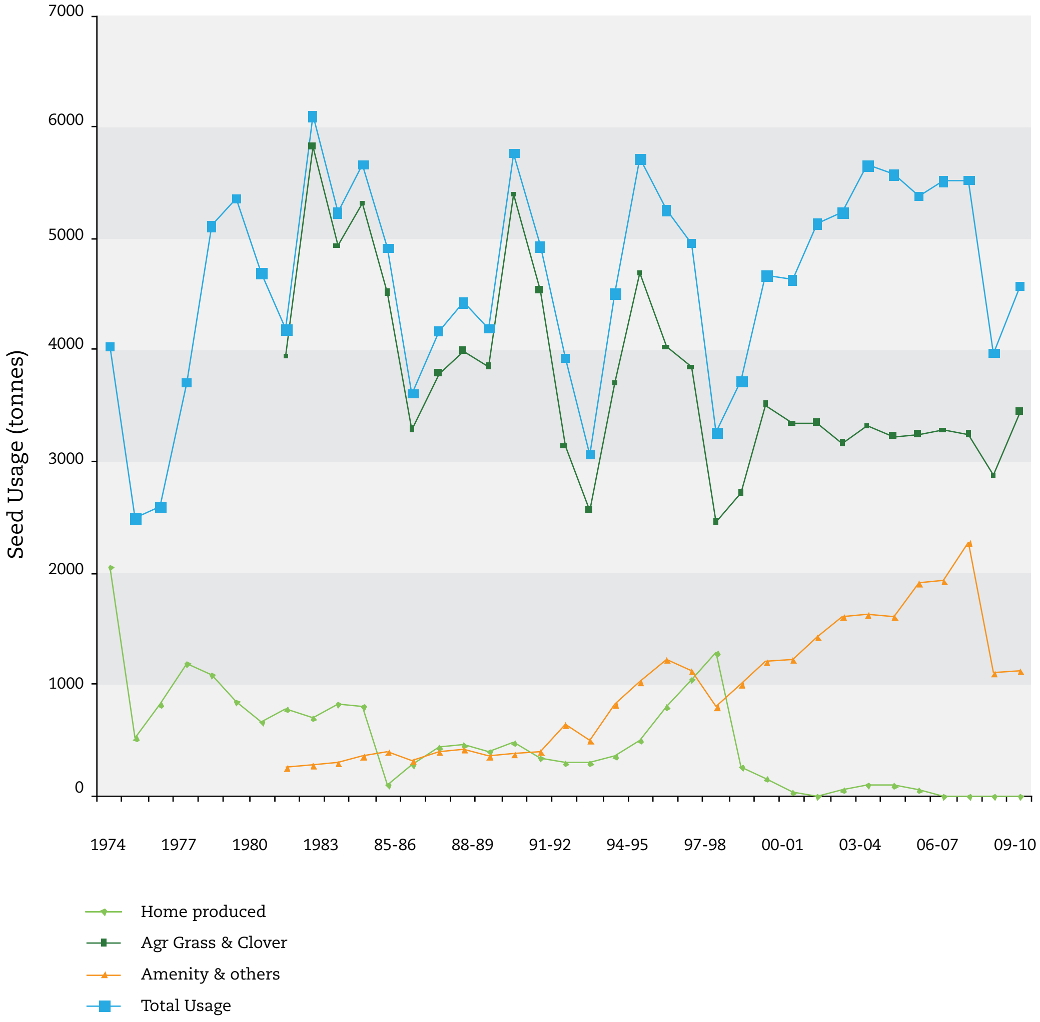
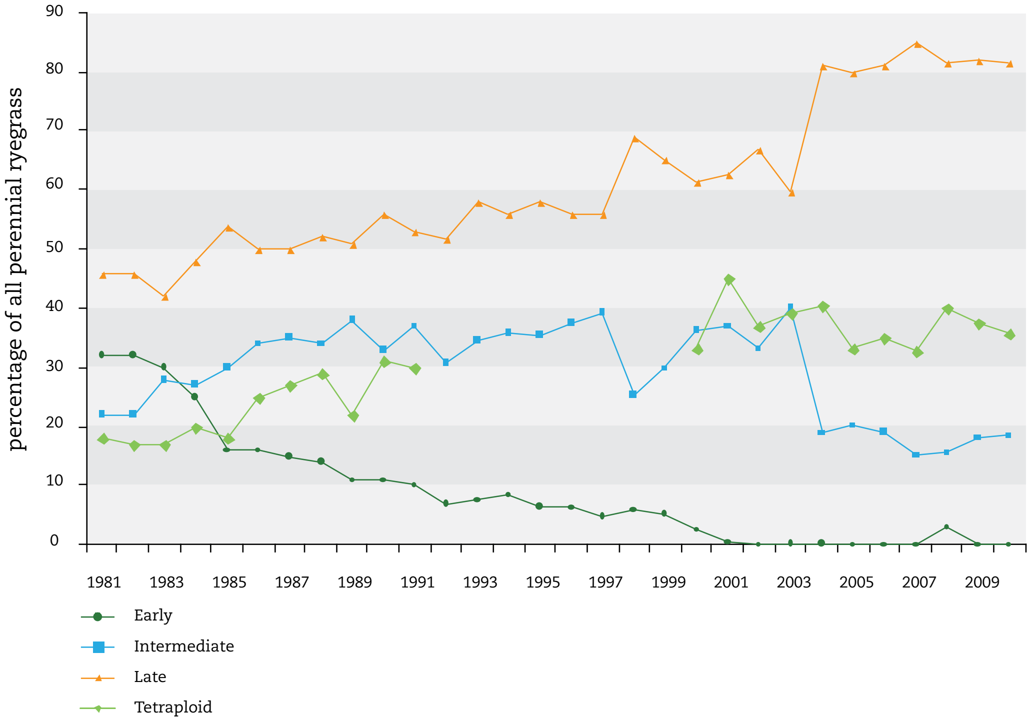


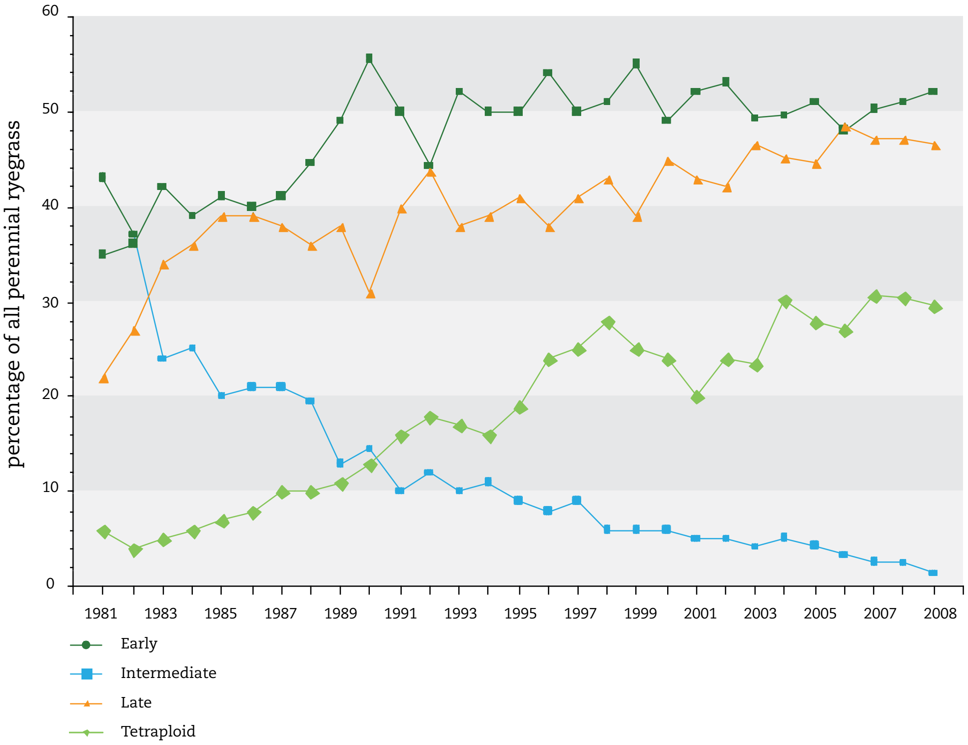
Figure 8: Republic of Ireland annual certified grass seed usage (tonnes) and imports 1973 to 2010

In the last 10 years overall imports of grass seed to ROI increased to over 5,000 tonnes, due mainly to a doubling of amenity grass seed imports. In the same period, however, agricultural varieties showed a continuing decline, falling below 3,000 tonnes for the first time since the 1980's. Total Irish seed demand is less than 1% of total world grass seed production, or about 2.5% of EU seed production (ISF, 2006). This common Irish profile shows a declining usage, which is partly driven by the removal of UK Government subsidies for reseeding in the 1980's, as well as a consequence of falling incomes in the past two decades.

The changes in the perennial ryegrass market, in the proportion of the different maturity and ploidy groups used by farmers in Ireland are shown in Figure 9. The use of tetraploid varieties has risen steadily since 1981 from less than 20% in ROI to 35-40% (Figure 9a) and from less than 10% in NI to around 30% (Figure 9b). Although the use of early maturing perennial ryegrasses was greater in NI than the ROI in 1981, the pattern of decline in this category is again very similar and has now largely disappeared from commercial use in both ROI and NI markets.



9a. Republic of Ireland 1981-2010



9b. Northern Ireland 1981-2008

Figure 9: Change in the proportion of perennial ryegrass maturity and ploidy types in Ireland. Data presented as % of total perennial ryegrass use each year. The maturity classes include both diploid and tetraploid use and 'Tetraploid' includes all three maturities

This has been attributed to a decline in the price of later maturing varieties due to increased seed yields and an awareness on-farm of problems with stemy regrowth from these early maturing varieties (Gilliland *et al.*, 2007). This decline has been replaced in NI by intermediate, or mid-season maturing (15-31 May) and late maturing (after 1 June) in broadly similar amounts. In contrast, however, the ROI market for late maturing perennial ryegrass varieties was the largest category in 1981, and has come to dominate the market, particularly in the past 10 years. This was not always the case as a survey in the mid 1960's reported that late maturing varieties accounted for 2% of the ROI market rising to 18% by 1975 (Connolly, 1975). It currently comprises 80% of the seed sown. Later heading varieties are regarded as more suitable for mid-season grazing management, and more persistent under intensive grazing (Gately, 1984; Gowen *et al.,* 2003). This carries through to such an extent that if a variety is categorized as an intermediate, then its market share is massively depressed. This is despite the fact that the 'Early', 'Intermediate' and 'Late' categories are not truly different types. As Figure 10 shows, this is an artificial classification based on whether a variety heads before or after a delineating variety. The only purpose of this demarcation is to separate varieties into similar heading date range groups so that they can be easily managed in NL/RL evaluation trials. It is, therefore, an artificial segregation of a continuum such that a variety close to a delineating border could be only a few hours different in heading date from another variety classified as a different maturity class.

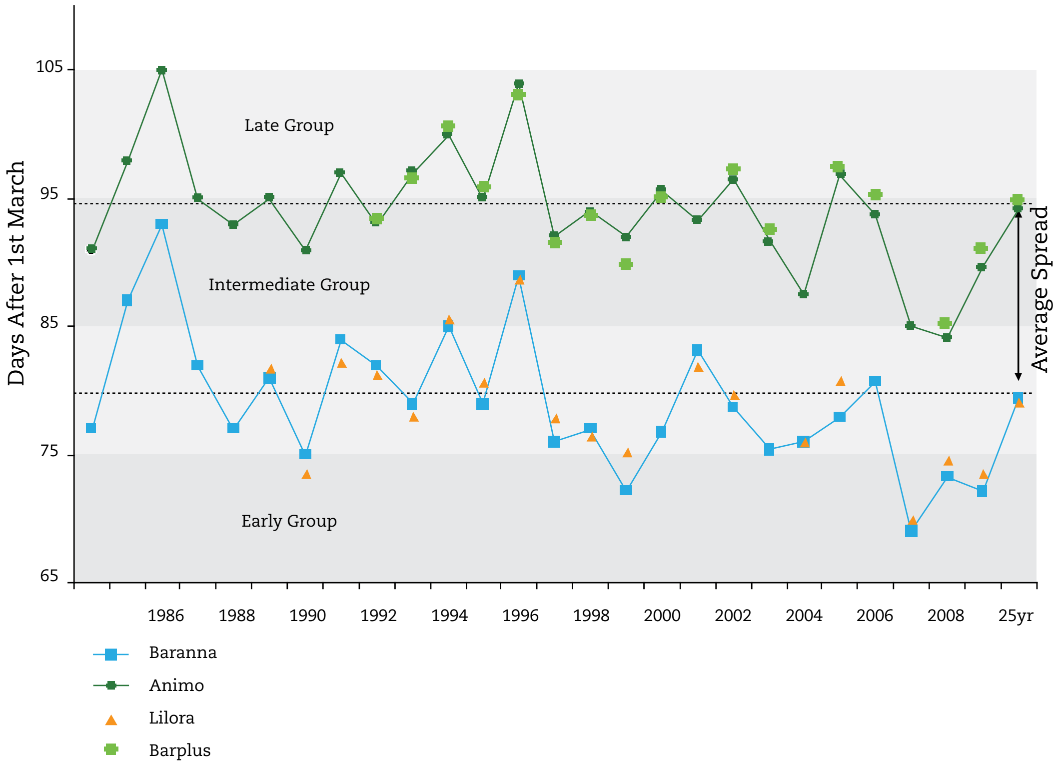


Figure 10: Annual flux in perennial ryegrass delineating varieties ear emergence dates. The 25 year average is shown as the final data set

The declining reseeding activity and market resistance to certain varieties based purely on their maturity classification are two issues that must be addressed by the testing authorities in the future, if grassland agriculture in Ireland is to fully benefit from the innovations of current perennial ryegrass breeding progress.

Future Developments and Conclusions

By the early 2000's, a demand for varieties more suited to high output intensive grazing became evident in Ireland. An increasing number of early spring calving herds of high genetic merit cows has led to increased demand for early spring production of highly digestible grasses, with less emphasis on silage production. Evidence of re-ranking of variety performance under frequent cutting (simulated grazing) compared to conservation protocols, and compared to animal grazing, has been widely reported (Reed, 1994; Smit *et al*., 2005; O'Donovan and Delaby, 2005).

In response DAFF, AFBI and Teagasc began a four year study in 2007 to compare various cutting and animal grazing protocols. The objective is to develop a means of bringing all the attributes of grass varieties into a unified assessment of animal value. The ultimate objective is to develop an index ranking for each recommended variety that is tailored to a specified herd management. This is a complex task, requiring expertise of a multidisciplinary team of scientists, and must account for both the unavoidable G×E sensitivity of perennial ryegrass and the diversity in ruminant management practices across Ireland. Nonetheless, the potential rewards of such an index to grassland agriculture in Ireland are immense, both financially for farmers and also for legislators in implementing EU policies on environmental issues such as reducing the carbon footprint of ruminant farming. This index will also quantify more precisely the financial benefits of individual varieties in terms of animal product, than previously. It is envisaged that this will encourage greater renewal of Irish pastures and promote the selection of varieties based on their value to the ruminant animal, rather than less relevant criteria such as maturity class or gross production.

To-date, NL and RL testing authorities in ROI and NI have successfully promoted adoption of perennial ryegrasses with improved yield and persistence and are now publishing results on nutritional value, mainly in terms of digestibility. This annual turnover in varieties on the RL's has provided a progressive improvement in the capability of Ireland's managed grasslands. This has been largely because the size and design of the testing programmes have given sufficient precision to reliably identify the few elite genotypes from among the many candidate varieties that are tested. There is also evidence from recent years that breeding and selecting varieties under Irish climatic conditions has helped create varieties that are among the highest performers in these trials. As input costs to the ruminant sector has risen, so the value of home grown herbage to the farm business has increased. As a consequence, leading grassland farmers in Ireland are seeking grasses that supply a greater proportion of the total nutritional requirements of their herds and flocks throughout the growing season. The current developments of the testing authorities in examining grass quality factors such as novel nutritive value parameters and low secondary stem development, plus the work on developing a grass index system, all seek to better service these increasing demands. The official testing authorities will, however, find it difficult to expand their testing programmes to include new or more detailed nutritional parameter testing within capped and/or contracting public funding. Nonetheless, this work is an essential link in the delivery of ever better perennial ryegrasses from breeder to farmer and will ensure that the ongoing support from RL's since the 1970's, continues to enhance the sustainability and profitability of grass-dependent Irish farming.

References

Camlin, M.S. 1997. Plant Breeding – Achievements and Prospects, Grasses. In: “Seeds of Progress”. (ed. J.R. Weddell) *British Grassland Society Occasional Symposium* **31**: pages 2-14.

Chaves, B., De Vliegher, A., Van Waes, J., Carlier, L. and Marynissen, B. 2009. Change in agronomic performance of *Lolium perenne* and *Lolium multiflorum* varieties in the past 40 years based on data from Belgian VCU trials. *Plant Breeding* **128**: 680-690.

Conaghan, P., Casler, M.D., McGilloway, D.A., O’Kiely, P. and Dowley, L.J. 2008. Genotype x environment interactions for herbage yield of perennial ryegrass swards in Ireland. *Grass and Forage Science* **63:** 107-120.

Connolly, V. 1975. New grass and legume varieties. *Proceedings of the Irish Society of Agronomy and Land Use*. May 15th 1975.

Culleton, N., Cullen, T. and McCarthy, V. 1992. The Decline of the Herbage Seed Production Industry in Ireland. *Irish Geography* **25:** 98–101.

DAFF. 2010. Department of Agriculture, Fisheries and Food, Grass and Clover Recommended List Varieties for Ireland 2010. http://www.agriculture.gov.ie/farmingsectors/crops/cropvarietyevaluationcve/cvepublicationsinformation/ (accessed 20 Aug 2010).

DARD. 2010. Department of Agriculture and Rural Development, Statistical Review of Northern Ireland Agriculture 2009, pages 11 and 37 http://www.dardni.gov.uk/statistical_review_of_northern_ireland_agriculture_-_2009.pdf (accessed 20 Aug 2010).

Fera. 2010. The Food and Environment Research Agency web site – VCU Procedures for Grasses (Perennial, Italian and Hybrid Ryegrass, Timothy and *Festulolium*). www.fera.defra.gov.uk/plants/plantVarieties/nationalListing/documents/protocolGrasses.pdf. (accessed 20 Aug 2010).

Gately, T.F. 1984. Early versus late perennial ryegrass (*Lolium perenne*) for milk production. *Irish Journal Agricultural Research* **23**: 1-9.

Gilliland, T.J., Barrett, P.D., Mann, R.L., Agnew, R.E. and Fearon, A.M. 2002. Canopy morphology and nutritional quality traits as potential grazing value indicators for Lolium perenne varieties. *Journal of Agricultural Science* **139:** 257–273.

Gilliland, T.J. Johnston, J. and Connolly, C. 2007. A review of forage grass and clover seed use in Northern Ireland, UK between 1980 and 2004. *Grass & Forage Science* **62**: 239-254.

Gilliland, T. J. 2010. Control of cultivar release and distribution. In: “Handbook of Plant Breeding, Volume 5: Fodder Crops and Amenity Grasses” (eds. B., Boller, U.K. Posselt, and F. Veronesi), Springer Science & Business Media B.V. pages 175-199.

Gilliland, T.J. and Gensollen, V. 2010. Review of the protocols used for assessment of DUS and VCU in Europe – Perspectives. In: Sustainable Use of Genetic Diversity in Forage and Turf Breeding” (ed. C. Huyghe), Springer Science & Business Media B.V. 2010. Chapter 37, pages 261-275.

Gowen, N., O’Donovan, M., Casey, I., Rath, M., Delaby, L., and Stakelum, G. 2003. The effect of grass cultivar differing in heading date and ploidy on the performance and dry matter intake of spring calving dairy cows at pasture. *Animal Research* **52:** 321-336.

ISF: International Seed Federation. 2006. Forage & Turf Crop Seed Statistics, http://www.worldseed.org/cms/medias/file/ResourceCenter/SeedStatistics/ForageandTurfSeedMarket/Seed_Production_of_Selected_Species_2006.pdf (accessed 18 Aug 2010).

Jafari A., Connolly V. and Walsh E.J. 2003. Genetic analysis of yield and quality in full-sib families of perennial ryegrass (*Lolium perenne* L.) under two cutting managements. *Irish Journal of Agricultural and Food Research* **42**: 275-292.

Long, D. and Gilliland, T.J. 2010. A review of the procedures and priorities for marketing of improved ryegrass varieties. *Irish Journal of Agricultural and Food Research* (in press).

O’ Donovan, M. and Delaby, L. 2005. A comparison of perennial ryegrass cultivars differing in heading date and grass ploidy for grazing dairy cows at two different stocking rates. *Animal Research* **54:** 1-11.

Öfversten, J., Jauhiainen, L. and Kangas, A. 2004. Contribution of new varieties to cereal yields in Finland between 1973 and 2003. *Journal of Agricultural Science* **142:** 281-287.

Peltonen-Sainio, P. and Karjalainen, R. 1991. Genetic Yield Improvement of Cereal Varieties in Northern Agriculture since 1920. *Acta Agriculturae Scandinavica* **41:** 267-273.

Reed, K.F.M. 1994. Improved grass cultivars increase milk and meat production – a review. *New Zealand Journal of Agricultural Research* **37:** 277-286.

Silvey, V. 1986. The contribution of new varieties to cereal yields in England and Wales between 1947 and 1983. *Journal of the National Institute of Agricultural Botany* **17**: 155-168.

Smit, H.J., Metzger, M.J. and Ewert, F. 2008. Spatial distribution of grassland productivity and land use in Europe. *Agricultural Systems* **98**: 208-219.

Smit, H.J., Tas, B.M., Taweel, H.Z., Tamminga, S. and Elgersma A. 2005. Effects of perennial ryegrass (*Lolium perenne* L.) cultivars on herbage production, nutritional quality and herbage intake of grazing dairy cows. *Grass and Forage Science* **60**: 297-309.

Stewart, R.H. and Camlin, M.S. 1972. Italian Ryegrass – Recommended Varieties. *Agriculture in Northern Ireland* **47**: 410-413.

Talbot, M. 1984. Yield variability of crop varieties in the UK. *Journal of Agricultural Science, Cambridge* **102**: 315-321.

Tunney, H., Foy, R.H. and Carton, O.T. 1998. Phosphorus inputs to water from diffuse agricultural sources. In: “Eutrophication in Irish Waters” (ed. J.G. Wilson), Royal Irish Academy, Dublin, pages 25-39.

Van Wijk, A.J.P. and Reheul, D. 1991. Achievements in fodder crops breeding in maritime Europe. In: “Fodder crops breeding: achievements, novel strategies and biotechnology” Proceedings of the 16th meeting of the Fodder Crops Section of Eucarpia, (eds. A.P.M. Den Nijs, and A.Elgersma,), Wageningen, Netherlands, pages 13-18.

Weddell, J.R., Gilliland, T.J. and McVittie, J. 1997. Evaluation Procedures: Past, Present and Future. In: Seeds of Progress, (ed. J.R. Weddell), British Grassland Society Occasional Symposium **31**: pages 202-225.

Wilkins, P.W. and Humphreys, M.O. 2003. Progress in breeding perennial forage grasses for temperate agriculture. *Journal of Agricultural Science* **140:** 129-150.

Capturing the economic benefit of Lolium perenne cultivar performance

M. Mc Evoy, M. O'Donovan and L. Shalloo
Animal & Grassland Research and Innovation Centre, Teagasc, Moorepark, Fermoy, Co. Cork, Ireland

Email: mary.mcevoy@teagasc.ie

Abstract

Economic values, in euros per hectare (ha) per year (€/ha/year), were calculated for traits of economic importance in Irish grass-based ruminant production systems. Traits were identified which had the greatest potential to influence the profitability of a grazing system. The traits selected were: spring, mid-season and autumn grass dry matter (DM) yield (€/kg DM/ha), grass quality (€/DMD/kg DM), first and second cut silage DM yield (€/kg/ha) and sward persistency (€/% change in persistency/year). The Moorepark Dairy Systems Model (MDSM) was used to simulate a model dairy farm. The effect of a unit change in each trait was calculated by simulating a unit change in the trait of interest while holding all other traits constant. The base scenario had fixed cow numbers and fixed land area (40 ha) and assumed an annual DM yield of 13 t DM/ha. The economic values generated on a per ha per year basis for the base scenario were: €0.152/kg DM spring yield, €0.030/kg DM mid-season yield, €0.103/kg DM autumn yield, the quality value was €0.001, €0.008, €0.010, €0.009, €0.008 and €0.006 per unit change in DMD/kg DM yield for the months of April, May, June, July, August and September, respectively, €0.033/kg DM 1st cut silage, €0.023/kg DM 2nd cut silage and -€4.961/1% decrease in persistency/ha. Subsequently, alternative scenarios were examined to determine the effect of a change in total DM yield (11 t DM/ha), a change in the utilisation of the herbage or the effect of a silage-only system. The economic values were applied to experimental production data collected across three years from perennial ryegrass varieties in a plot study. The total economic merit of each cultivar was then calculated. Spearman's rank correlation was used to determine the correlation between the base and the alternative scenarios for each of the 20 varieties. Rank correlations between the base scenario and a reduction in herbage utilisation resulted in an r_s= 1.0, indicating no reranking of varieties if herbage utilisation decreased. The scenario investigating a decrease in annual herbage DM yield to 11 t DM/ha resulted in an r_s= 0.94 compared to the base scenario. This indicates the total merit index can be used to identify the varieties that can generate the greatest economic contribution to a grass-based production system, regardless of intensity.

Introduction

Perennial ryegrass (*Lolium Perenne* L.) is considered one of the most important forage grass species for ruminant animal production in temperate regions. Eighty percent of the world's bovine milk and 70% of the worlds beef and veal are produced from temperate grassland systems (Wilkins and Humphreys, 2003). Recent increases in production costs and lower product prices as well as the perceived environmental and animal welfare concerns associated with intensive indoor production systems (Dillon *et al*., 2005) have rejuvenated the interest in agricultural grazing systems in many temperate and subtropical regions of the world (especially Europe and the USA). Gains in forage breeding in terms of dry matter (DM) yield of the important species of 4-5% per decade have been achieved over the last 50 years, while improvements in DMD in perennial ryegrass of 10 g/kg per decade have been achieved (Wilkins and Humphreys, 2003). The level of improvement in terms of animal performance as a result of this increase in DMD is not clearly defined, as differences in DM production and quality between varieties can be exaggerated by factors including climate, soil and farming system (DAFF, 2008). Genotype × environment (G × E) interactions which include the effects of management and year are widely observed in the evaluation of perennial ryegrass varieties (Jafari, Connolly and Walsh, 2003). These interactions indicate a change in the rank order of genotypes (crossover interactions), the magnitude of differences among genotypes (non crossover interactions), or both, between different environments (Conaghan *et al*., 2008). The occurrence of crossover interactions, results in genotypes which are superior in one environment not maintaining their superiority in other environments (Conaghan *et al*., 2008), hence the need for national variety evaluation trials and within these, multiple site testing, to identify suitable varieties for the end user.

Many countries are involved in the independent assessment and evaluation of grass varieties to identify the most suitable varieties for growing conditions within the country. The objective of National and Recommended List trials is to identify the superior performing varieties within a country. Dry matter yield is the most common trait reported internationally within Recommended Lists. Within some countries the Recommended List also publishes data on other traits which may include seasonal yield, sward quality, persistency and disease resistance within the environment where they were tested. Other characteristics such as heading date, winter hardiness and disease resistance may also be reported. The significance of a Recommended List is its ability to influence the market, thereby resulting in the rapid uptake of new varieties (Bentley, 2003).

In cattle breeding, the development of a total merit index to assist farmers in identifying the most profitable breeding bulls (Veerkamp *et al*., 2002) has been successfully adopted and accepted in many countries including New Zealand (Breeding Worth; NZAEL, 2009), USA (AIPL, 2010), Canada (CDN, 2010) and the Republic of Ireland (Economic Breeding Index; ICBF, 2008). The development of a similar approach to rank grass varieties would be a significant advancement in grass selection to guide grass breeders, research scientists, advisors and farmers in identifying grass varieties that would deliver the highest increases in profitability at farm level. Such an index would be used to present the ranking of grass varieties based on their total economic merit and to provide the industry with information on the optimum varieties for a system.

There are three objectives in this paper. The first is to describe an economic index for grass varieties; the second objective is to evaluate the performance of 20 varieties under three different management protocols and the final objective is to apply the economic values to the performance of grass varieties thus demonstrating the application of the total economic merit index.

Material and Methods

Economic Analysis

The Moorepark Dairy Systems Model (MDSM) is a stochastic budgetary simulation model, which provides a comprehensive simulation framework integrating biological, physical and economic processes in a model of a dairy farm (Shalloo *et al*., 2004). The MDSM was used to simulate a model farm, while integrating the effect of increased spring, mid-season and autumn DM yield, quality during April to September (inclusive), persistency and increased 1st and 2nd cut silage yields. The resulting change in the economic performance of the farm compared to the default, and hence the economic cost or benefit associated with a physical change in each of the traits of interest, was calculated. The MDSM was used to simulate herd parameters, nutritional requirements, land use and total inputs and outputs across the calendar year. A full description of the model is reported by Shalloo *et al*. (2004). The major revenues in the MDSM are milk and livestock sales. Land area is treated as an opportunity cost; all land was rented into the model as necessary, depending on the requirements for on-farm feeding of animals. Variable costs (fertiliser, concentrate, vet, medicine, artificial insemination, silage, reseeding and contractor charges), fixed costs (car, electricity, labour, machinery operation and repair, phone, insurance, etc.) and receipts (livestock, milk and calf) were based on current prices (Teagasc, 2008). The levels of feed offered were determined by the energy requirements of the animals for maintenance, milk production and body weight change (Jarrige, 1989). This information was used to generate the base scenario for the model dairy farm.

The key assumptions used in the MDSM are shown in Table 1. The gross milk price received was 27 c/L (Binfield *et al.*, 2008). The ratio of fat to protein price was 1:2 with a fat price of €3.42/kg and a protein price of €6.84/kg. The land was rented at an opportunity cost of €296.50/ha.

The model assumed a total annual grass DM production of 13 t DM/ha. The herd was spring calving, with cows turned out to grass immediately post-calving. Mean calving date was 24th February, with a calving interval of 365 days and 70, 20 and 10% of the cows calving in February, March and April, respectively. The base scenario used in this study had fixed cow numbers and a land area of 40 ha. Cow numbers were fixed to isolate the herbage effects from the animal effects in the model. A fixed land area of 40 ha was selected as most Irish dairy farms have a fixed land base to meet their production requirements (McEvoy *et al.*, 2010).

TABLE 1: Default parameters used for variables in the Moorepark Dairy Systems Model (MDSM)

Variable	Default value (€)
Farm size (ha)	40
Gross milk price (€/L)	0.27
Fat price (€/kg)	3.13
Protein price (€/kg)	6.27
Price ratio of protein: fat	2:1
Opportunity cost of land (€/ha)	297
Concentrate costs (€/tonne)	220
Fertiliser costs (€/tonne)	
CAN	280
Urea	360
0-7-30	340
1st Cut Grass silage contracting (€/ha)	284
2nd Cut Grass silage contracting (€/ha)	235
Reseeding costs (€/ha)	496

Source: (Shalloo *et al.*, 2004)

Trait Definition and Methodology to Calculate Economic Values

To derive each economic value a physical change was independently simulated for each trait of interest. The effect of changing a trait had on the model output compared to the output from the base scenario was then calculated to determine the economic value for the trait (Veerkamp *et al.*, 2002).

The economic value of a trait can be described as follows:

$$\text{Economic Value} = \frac{\text{net margin/ha}}{\Delta \text{ in trait of interest}}$$

The traits of importance for grass based systems were identified as follows:

1. *Dry Matter Yield*

i) Spring

The economic value for an increase in spring DM yield was calculated based on the assumption that each additional kg DM grass in the diet in spring will displace silage or concentrate on an equal energy basis.

$$\text{€/kg increase in spring DM yield} = \frac{\Delta \text{ net margin/ha}}{\Delta \text{ grass intake/ha}} \quad \text{x utilisation}$$

ii) Mid season

Mid-season DM yield is calculated on the assumption that each additional kg DM grass produced across the main grazing season will allow an increase in the carrying capacity of the farm, therefore allowing a higher stocking rate (SR) to be maintained on the same area.

$$\text{€/kg increase in midseason DM yield} = \frac{\Delta \text{ net margin/ha}}{\Delta \text{ grass intake/ha}} \quad \text{x utilisation}$$

iii) Autumn

The economic value for an increase in autumn DM yield is calculated based on the assumption that each additional kilogram of grass produced in the autumn will displace silage or concentrate on an equal energy basis. Therefore

$$\text{€/kg increase in autumn DM yield} = \frac{\Delta \text{ net margin/ha}}{\Delta \text{ grass intake/ha}} \quad \text{x utilisation}$$

It was assumed that grass utilisation for spring, mid-season and autumn DM production would be 90%, 85% and 80%, respectively (O'Donovan and Kennedy, 2007).

2. *Quality*

The voluntary DM intake (VDMI) of forages in lactating dairy cows is transformed into fill value (FV) and expressed as fill units (FU) for lactating dairy cows (LFU; Jarrige, 1989). If the forage is fed *ad libitum* as the sole feed, the VDMI of forage is obtained by dividing the feed intake capacity (IC) of the animal by the FV expressed in the same FU of the forage (Jarrige, 1989). A negative relationship exists between VDMI and LFU. The IC of a lactating dairy cow is calculated as:

$$IC = [13.9 + (0.015(BW - 600)) + (0.15 x MY_{pot}) + 91.5 x (3 - BCS))] \text{ x } L \text{ x } P \text{ x } M$$

Where, BW=bodyweight; MY_{Pot} = potential milk yield; BCS= body condition score; IL= indices of lactation = $a + (1-a) \times (1-e^{-0.16 \times \text{week of lactation}})$, where a = 0.6 for primiparous and 0.7 for multiparous cows, IL= 1 for dry cows; IP= indices of pregnancy=$0.8+0.2 \times (1-e^{-0.25 \times (40- \text{ week of pregnancy})})$; IM= indices of maturity= $-01 + 1.1 \times (1-e^{-0.08 \times \text{age in months}})$, (Faverdin *et al.*, 2007)

High fill values indicate forages with lower rates of digestibility. In the model the quantity of feed offered was adjusted to meet the net energy requirement of the system when forage quality changed. Within the MSDM, when the LFU of the sward was greater than the calculated intake requirement, then the energy intake requirement of the animal could not be satisfied and the performance of the animal was subsequently reduced, therefore resulting in a negative effect on production. For each month from April to September inclusive, the economic effect of a 1% increase in sward DMD on DM intake (DMI) corrected for LFU, was calculated as follows:

$$\text{€/unit increase in DMD value} = \frac{(\Delta\ \text{net margin/ha x utilisation})}{\%\ \text{unit}\ \Delta\ \text{DMD}}$$

3. Silage

Within Irish grass based production systems silage is generally harvested in two periods. As a result two economic values are available for silage – one for both 1st cut and 2nd cut silage. Total yield for both first and second cut was calculated on the assumption that 75% of the DM harvested was utilised. It was assumed that losses of 25% occur during the harvesting, conservation, ensiling and feeding processes (Gordan, 1999).

i) First cut

The economic value of an increase in DM yield above the base DM yield for first cut silage was calculated based on:

$$\text{€/kg increase 1}^{\text{st}}\text{ cut silage yield} = \frac{\Delta\ \text{net margin/ha}}{\Delta\ 1^{\text{st}}\ \text{cut silage yield/ha}} \quad \text{x utilisation}$$

ii) Second cut

The economic value of an increase in DM yield above the base DM yield for second cut silage was calculated based on:

$$\text{€/kg increase 2}^{\text{nd}}\text{ cut silage yield} = \frac{\Delta\ \text{net margin/ha}}{\Delta\ 2^{\text{nd}}\ \text{cut silage yield/ha}} \quad \text{x utilisation}$$

4. Persistency

The economic value for persistency was derived by assuming a 10-year period as the standard sward longevity, based on current recommendations. The economic value for persistency was calculated based on a 1% change in the lifetime of the sward relative to the base scenario set at 10 years, and was calculated as follows:

$$\text{€/\% change in persistency/ha} = \frac{\Delta\ \text{net margin/ha}}{\%\ \text{change in persistency relative to a 10 year base}}$$

Alternative scenarios

A number of alternative scenarios were also simulated with the purpose of testing the robustness of the cultivar ranking across a range of farming intensities and systems of production.

1. Changes to utilisation values or DM yield
    a. S1- herbage DM utilisation reduced to 80% (spring), 75% (mid-season) and 70% (autumn), this represents medium utilisation levels at farm level.
    a. S2- herbage DM utilisation reduced to 75% (spring), 70% (mid-season) and 65% (autumn), representing low utilisation levels at farm level.
    a. S3- on farm herbage production of 11 t DM/ha per year.
2. Silage-only scenario. In this scenario (S4) silage was the only trait of importance. This is comparable to an area that is identified as the silage area of the farm.

Production study details

A plot study was carried out at the Teagasc, Animal and Grassland Research and Innovation, Centre, Moorepark, Co. Cork, Ireland (50° 07'N; 8°16'W) to determine the effect of management protocol on cultivar performance. One-hundred and eighty plots (1.5 × 5m) were established in August 2006 on a free-draining, acid brown earth soil with a sandy loam texture. The experimental design was a randomized complete block. Twenty varieties of perennial ryegrass were sown. Three managements were applied to assess the effect of evaluation protocol on cultivar performance and economic ranking. Each management was replicated three times. The experiment was undertaken for three consecutive years: 2007 (Y1), 2008 (Y2) and 2009 (Y3). Management one (RG) represented a 10-harvest continuous rotational grazing system (simulated grazing), incorporating 10 simulated grazing harvests (using a mechanical mower) during the March to November period. A total of 315 kg nitrogen (N)/ha was applied annually. Management two (2C) incorporated a 2-cut silage harvest system, with four simulated grazing rotations from early April to October; the two silage harvests were in May and late June. The final management (3C) incorporated a 3-cut silage harvest with three silage harvests in late May, early July and mid-August, followed by two simulated grazings. The fertiliser N application to both managements 2C and 3C was 350 kg N/ha/year. Nitrogen was applied in the form of calcium ammonia nitrate (CAN) within two days of defoliation. No N fertilizer was applied after the final cut each year. In November 2006 all plots were harvested to a post height of 4cm. The experiment began in spring 2007. Plots were harvested with an Etesia mechanical mower (Etesia, UK Ltd, Warwick, UK) to a height of 4 cm. Dry matter yield was determined for three years (2007 to 2009 inclusive) and sward quality was measured for two years (2007 and 2008) on all harvests. Table 2 presents the harvest dates (± 3 days) and N fertiliser application levels following each harvest for each management.

Dry matter yield was measured on each plot at every cutting date for the appropriate protocol. The full length of the plot was harvested (mower width was 1.2 m). All mown herbage from each plot was collected and weighed and sub-sampled (0.1 kg) removed. The sub-sample was dried for 48 hours at 40°C in a drying oven to determine DM content. In 2007 and 2008, the dried sample was milled through a 1-mm screen. Dry matter digestibility (DMD) of the milled sample was determined using Near-Infra Red Spectrometry (NIRS).

TABLE 2: Cutting interval for the three evaluation protocols

	Rotational Grazing		2-cut silage		3-cut silage	
	Harvest	Kg N/ha	Harvest	Kg N/ha	Harvest	**Kg N/ha**
Fertiliser*	20 February	70	20 February	40	20 March	**100**
Cut 1	20 March	35	30 March	100	22 May	**90**
Cut 2	+ 3 weeks	35	+ 7 weeks[2]	90	+ 6 weeks[2]	**90**
Cut 3	+ 3 weeks	35	+ 6 weeks[2]	50	+ 6 weeks[2]	**25**
Cut 4	+ 3 weeks	35	+ 4 weeks	40	+ 5 weeks[2]	**35**
Cut 5	+ 3 weeks	35	+ 5 weeks	30	+ 4 weeks	
Cut 6	+ 3 weeks	35	+ 6 weeks			
Cut 7	+ 4 weeks	35				
Cut 8	+ 4 weeks	35				
Cut 9	+ 4 weeks	35				
Cut 10	+ 4 weeks					

*Indicates fertiliser application only. No managements were harvested on this date. Initial harvest date for each management is indicated by Cut 1. All other fertiliser applications occurred after harvesting. No fertiliser was applied after the final harvest for each management; [2]Indicates a silage harvest

The cuts were divided into seasonal periods as follows: spring (autumn closing until April 10), summer (April 11 to August 6) and autumn (August 7 until final harvest). Silage harvests dates are indicated in Table 2. Data from the simulated grazing harvests were used to generate data for the spring, mid-season and autumn periods, with the silage harvests used to generate the data for the 1st and 2nd silage yields for the appropriate protocol, where applicable. Data was analyzed using analysis of variance (ANOVA) in SAS (SAS, 2006). Protocol, cultivar and their interactions were included in the model.

$$V_{ij} = \mu + Y_i + M_j + Y_i \times M_j + e_{ijk}$$

Where, V_{ijk} = the response of cultivar V, to year *i*, management *j*; μ= mean; Y_i = year effect (*i*=1 to 3); M_j = management effect (*j* = 1 to 3); $Y_i \times M_j$ = the interaction between year and management; and e_{ijk} = the residual error term

.

Application of economic values to production data

In order to create the data necessary to meet the requirements of the economic index, the spring, mid-season and autumn DM yield values and the monthly quality values of the RG protocol combined with the silage data from the two silage cuts of the 2C protocol (RG2C) were used to calculate the total economic merit of a cultivar. Additionally, the 1st and 2nd cut silage DM yield recorded from the 3C protocol was used to assess the total economic merit within the intensive silage index.

Within each scenario, the average performance of the 20 varieties for a trait was subtracted from the actual performance of an individual cultivar. This difference was then multiplied by the economic value for the trait to generate the actual economic value for each trait within each cultivar across each scenario. The sum total of all the traits (yield, quality, silage and persistency) was then used to quantify the total economic merit of a cultivar. Spearman's rank correlations were used to determine the degree of re-ranking of varieties when the economic values of the different scenarios were applied to the production data. Spearman's rank correlation coefficients (r_s) were calculated using the following equation:

$$r_s = 1 - \left(\frac{6 \Sigma d^{21}}{n(n^2-1)} \right)$$

where, Σd^2 is the difference in rank change in economic performance squared and summed for all 20 varieties and n is the number of varieties. The Spearman's rank correlation coefficient returns a value between minus one and one, with one implying the exact same ranking and zero implying no correlation between varieties across scenarios.

Results

Bio-Economic Model

Table 3 presents the default herd parameters in the model for a 365 day period (Jan. to Dec.), including the number of animals present, feed requirements and land use for the base scenario. Total annual DMI (kg/cow) was 3,947, 1,114 and 366 kg DM of grazed grass, grass silage and concentrate, respectively; on a proportional basis these correspond to 0.71, 0.21 and 0.08 of the total diet, respectively. Total milk sales were 510,776 kg with fat and protein sales of 18,907 and 17,114 kg/cow, respectively.

The feed budget in the model was influenced by the calving date (Table 3). Cows were turned out to grass immediately post calving. Calving began in February with 59, 17 and eight cows calving in February, March and April, respectively. The corresponding proportion of grass in the feed budget of the total herd for these months was 0.2, 0.5 and 0.8, respectively, with silage decreasing from February (0.6) to March (0.2) and being removed from the diet thereafter until November (0.1).

TABLE 3: Default herd parameters for 12 months of a year

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Animals present													
Total cows	71	80	82	82	81	79	78	77	77	76	75	74	-
Cows milking	22	66	75	82	81	79	78	77	77	76	75	74	-
Cows dry	49	14	7	-	-	-	-	-	-	-	-	-	-
Cows calving	-	59	17	8	-	-	-	-	-	-	-	-	84
Replacements calving	-	12	3	2	-	-	-	-	-	-	-	-	-
Milk (%)	0.99	3.59	10.86	13.08	13.84	12.11	11.13	9.90	8.38	6.99	5.69	3.44	-
Fat concentration (%)	4.43	3.96	3.68	3.50	3.44	3.47	3.56	3.69	3.88	4.09	4.26	4.39	-
Protein concentration (%)	3.73	3.15	3.12	3.18	3.24	3.27	3.29	3.37	3.53	3.67	3.74	3.78	-
Feed Requirements													
Demand grass (kg DM/cow/day)	0.0	2.3	7.6	11.9	16.3	17.3	17.3	16.4	15.6	13.7	10.7	0.1	-
Demand silage (kg DM/cow/day)	10.9	7.4	3.6	0.5	-	-	-	-	-	-	1.4	13.0	-
Demand concentrate (kg DM/cow/day)	0.3	2.1	4.2	2.9	0.2	-	-	-	-	1.0	1.0	0.5	-
Total demand (kg DM/cow/day)	11.1	11.7	15.4	15.3	16.6	17.3	17.3	16.4	15.6	14.7	13.1	13.5	-
Proportion of different feeds in diet													
Grazed grass	-	0.2	0.5	0.8	1.0	1.0	1.0	1.0	1.0	0.9	0.8	-	-
Grass silage	1.0	0.6	0.2	-	-	-	-	--	-	-	0.1	1.0	-
Concentrate	-	0.2	0.3	0.2	-	-	-	-	-	0.1	0.1	-	-
Land use													
Area closed for silage (ha)	-	0.0	14.7	14.7	14.7	9.8	9.8	9.8	0.0	0.0	0.0	0.0	-
Area available for grazing (ha)	40.0	40.0	25.3	25.3	25.3	30.2	30.2	30.2	40.0	40.0	40.0	40.0	-
Area cut for silage (ha)	-	-	-	-	14.7	-	-	9.8	-	-	-	-	-
Grass growth utilised (kg/DM/ha)	-	48.3	481.0	1393.3	1990.3	1741.6	1876.5	1587.0	1166.3	644.2	127.1	0.0	11,056

TABLE 4: Key herd parameters when a unit change in trait of interest is incurred relative to the default scenario at a milk price of 27c/l

	DM yield				Quality							Silage	
Herd parameters	**default**	**Mid-season**	**Spring**	**Autumn**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Persistency**	**1st Cut**	**2nd Cut**
Herbage grown (t/ha)	13.0	14.3	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0
Herbage utilized (t/ha)	11.1	12.2	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1
Grass kg DM/cow	3,947	3,947	3,990	3,994	3,977	3,956	3,949	3,955	3,957	3,967	3,947	3947	3947
Silage kg DM/cow	1,114	1,114	1,088	1,087	1,114	1,114	1,114	1,114	1,114	1,114	1,114	1114	1114
Concentrate kg DM/cow	366	366	342	344	366	366	366	366	366	366	366	366	366
Farm size (ha)	40.0	37.2	40.1	40.1	40.2	40.0	40.0	40.0	40.1	40.1	40.0	39.4	39.7
Area used for silage (ha)	24.5	24.5	24.0	24.0	24.5	24.5	24.5	24.5	24.5	24.5	24.5	23.0	23.7
Farm stocking rate (LU/ha)	2.3	2.5	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.4	2.4
Milk sales	510,776	510,776	510,776	510,776	510,776	504,220	502,492	503,746	504,522	506,809	510,776	510,776	510,776
Fat sales	18,907	18,907	18,907	18,907	18,907	18,682	18,620	18,657	18,676	18,753	18,907	18,907	18,907
Protein sales	17,114	17,114	17,114	17,114	17,114	16,902	16,843	16,882	16,903	16,974	17,114	17,114	17,114
Silage yield 1st cut (kg/ha)	4,435	4,435	4,435	4,435	4,435	4,435	4,435	4,435	4,435	4,435	4,435	4,880	4,435
Silage yield 2nd cut (kg/ha)	3,558	3,558	3,558	3,558	3,558	3,558	3,558	3,558	3,558	3,558	3,558	3,558	3,914
Milk returns (€)	142,847	142,847	142,847	142,847	142,847	141,120	140,641	140,941	141,090	141,667	142,847	142,847	142,847
Livestock sales (€)	36,978	36,978	36,978	36,978	36,978	36,978	36,978	36,978	36,978	36,978	36,978	36,978	36,978
Total costs (€)	152,692	150,828	152,136	152,226	152,843	152,729	152,690	152,719	152,727	152,778	152,912	151,902	152,257
Total profit (€)	27,134	28,998	27,690	27,600	26,982	25,369	24,929	25,201	25,342	25,868	26,914	27,924	27,569
Profit per hectare (€/ha)	678	725	692	690	674	634	623	630	633	646	673	698	689

TABLE 5: Economic values (€ per ha/year) for DM yield, quality, persistency and silage yield performance

	Production (per kg DM/ha)			Quality (per unit decrease in DMD)						Persistency	Silage	
	Spring	Mid Season	Autumn	April	May	June	July	Aug	Sep		1st Cut	2nd Cut
Base scenario	0.152	0.030	0.103	-0.001	-0.008	-0.010	-0.009	-0.008	-0.006	-4.961	0.033	0.023

Economic Values

Table 4 presents the key herd parameters when a unit change in each trait was simulated compared to the default scenario. Table 5 presents the calculated economic value for each trait.

DM Yield

Simulating an increase in spring DM yield resulted in an additional 42 kg DM/ha grass in the system (Table 4), when corrected for energy this displaced 26 kg DM silage and 24 kg DM concentrate from the diet during the spring period. Total costs were reduced compared to the base scenario and the resultant farm profit increased by €13.90/ha. The economic value for an increase in spring DM yield is therefore calculated at €0.15/kg DM at 90% utilization (Table 5). Simulating an increase in mid-season herbage production resulted in an increase of 1.3 t DM/ha herbage grown, of which 1.1 t DM/ha was utilized. The resultant increase in farm profit was €46.60/ha, which corresponded to €0.03/kg DM at 85% utilization. Simulating an increase in autumn DM yield resulted in an additional 47 kg DM/ha grass available which, when corrected for energy, displaced 27 kg DM silage and 23 kg DM concentrate from the diet. The resultant increase in farm profit was €11.60/ha, which corresponds to €0.10/kg DM, at 80% utilization.

Quality

Simulating a one unit decrease in sward DMD resulted in a negative effect on milk production in the months of May to September, inclusive. The economic value for quality expressed as €/unit decrease in DMD/kg DM was -€0.001 for the month of April. During April, the required intake was satisfied and did not affect animal performance, hence there was no effect of grass quality on milk production. During the months of May to September, the FV of the grass restricted the DMI of the animal. As a result of this restriction on intake, milk yield decreased. The resulting economic values for these months expressed as €/unit decrease in DMD/kg DM was as follows: -€0.008 in May, -€0.010 in June, -€0.009 in July, -€0.008 in August and -€0.006 in September.

First cut silage DM yield

Simulating an increase in silage DM yield required less total area to be used for silage harvesting. Increased DM yield of 1st cut silage resulted in an additional 442 kg DM/ha conserved. This resulted in a total of 4,880 kg DM/ha harvested as 1st cut silage. The resulting total farm profit increased by €19.70/ha. The economic value for each additional kg DM of 1st cut silage conserved, assuming 75% utilisation, was €0.03/ha.

Second cut silage DM yield

Simulating an increase in the DM yield of 2nd cut silage resulted in an increase in 356 kg DM/ha conserved, therefore reducing the total area required for silage by 0.8 ha, compared to the base value. The resulting farm profit achieved from an increase in harvest yield of 2nd cut silage was €10.90/ha. The economic value for each additional kg DM of second cut silage was €0.02/ha.

Persistency

Simulating a decrease in persistency per year will result in a reduction in net margin of €4.96/% decrease in persistency/ha/year. The cost of reseeding is incorporated into the calculation of the economic value at €496.00/ha.

Cultivar performance

The production data of the 20 cultivars are shown in Table 6. The average DM production of the 20 cultivars for spring, mid-season, autumn of the RG management was 1704.6, 7106.5 and 3359.6 kg DM/ha for spring, mid-season and autumn, respectively. The average 1st and 2nd cut silage DM yields were 5175.9 and 3127 kg DM/ha for the 2C management, respectively, and 7089.8 and 3102.0 kg DM/ha for the 3C management, respectively, for the 20 cultivars. The economic value for each trait was applied to the production data for each protocol (Table 7). No persistency data was available on the 20 varieties so this has been omitted from the calculation of the total merit index.

Scenario analysis

Spearman's rank correlation was used to identify the level of correlation between the base scenario compared to medium (S1) and low (S2) herbage utilisation rates and an annual DM yield of 11 t DM/ha (S3). Despite a change in the total economic merit of a cultivar as the utilisation values changed, there was no reranking of varieties between a high, medium or low utilisation rate ($r_s = 1.0$). The effect of changes in the total herbage production from 13 t DM/ha to 11 t DM/ha, resulted in a change to the economic values of a cultivar, however the correlation between the base and S3 for cultivar ranking was high ($r_s = 0.94$). The comparison between the base scenario and the silage only index resulted in a very low correlation ($r_s = 0.13$).

TABLE 6: Biological data (seasonal DM production, silage production and quality) showing the individual performance of 20 perennial ryegrass cultivars for yield, silage production and quality

	DM yield (kg DM/ha)			Silage yield (kg DM/ha)		Quality DMD (g/kg DM)					
Cultivar	Spring	Summer	Autumn	1st cut	2nd cut	April	May	June	July	August	September
1	1430	7686	3642	5323	2960	851	825	796	829	816	807
2	1662	7355	3531	5349	2701	849	813	803	834	809	790
3	2126	6835	3277	4994	3090	849	829	779	798	793	775
4	2283	7047	3176	5214	3334	832	830	782	789	801	791
5	2158	7342	3512	4727	3039	852	835	796	807	808	807
6	1213	6811	3177	4944	3004	847	811	790	812	797	780
7	1680	6950	3528	4702	3308	852	843	795	815	813	813
8	1891	7227	3245	5278	3637	856	838	793	794	805	825
9	1546	7125	3432	5964	2470	845	816	794	818	808	798
10	1374	7355	3445	5606	3240	845	815	801	819	803	806
11	1797	7025	3207	5027	3516	852	832	788	797	805	805
12	1827	6823	3334	5228	3527	857	841	803	812	803	813
13	1703	6966	3127	5795	3243	847	833	787	814	805	811
14	1857	6828	3233	5375	3032	845	830	783	810	803	799
15	1392	6912	3453	5181	3017	840	815	791	817	797	790
16	1453	7637	3474	4521	2873	844	816	793	814	797	789
17	1691	6939	3307	5002	3356	852	841	792	812	816	856
18	1667	6861	3190	4921	3192	844	834	784	807	762	801
19	1371	7066	3407	5235	2942	845	809	794	813	797	786
20	1971	7339	3495	5131	3057	854	839	779	804	797	771

TABLE 7: Application of the base economic value to the biological data

Cultivar	Spring € value	Mid season € value	Autumn € value	Quality € value	Silage € value	Total € Value
Cultivar 1	-41.72	17.37	29.13	42.0	1.0	**47.83**
Cultivar 2	-6.53	7.47	17.68	25.3	-4.1	**39.85**
Cultivar 3	64.10	-8.15	-8.53	-54.0	-6.9	**-13.43**
Cultivar 4	87.95	-1.78	-18.88	-41.0	6.0	**32.32**
Cultivar 5	68.96	7.06	15.67	20.7	-16.8	**95.60**
Cultivar 6	-74.78	-8.87	-18.84	-35.7	-10.5	**-148.63**
Cultivar 7	-3.74	-4.70	17.36	44.5	-11.5	**41.94**
Cultivar 8	28.35	3.62	-11.82	16.5	15.1	**51.71**
Cultivar 9	-24.14	0.56	7.44	4.1	10.9	**-1.20**
Cultivar 10	-50.25	7.47	8.81	13.2	16.8	**-3.96**
Cultivar 11	14.09	-2.43	-15.75	-5.6	4.0	**-5.70**
Cultivar 12	18.57	-8.51	-2.68	39.0	10.9	**57.30**
Cultivar 13	-0.20	-4.22	-23.94	15.1	23.1	**9.91**
Cultivar 14	23.21	-8.35	-13.01	-8.3	4.4	**-2.04**
Cultivar 15	-47.50	-5.84	9.62	-18.0	-2.4	**-64.08**
Cultivar 16	-38.30	15.92	11.76	-19.5	-27.5	**-57.61**
Cultivar 17	-2.12	-5.03	-5.37	69.0	-0.5	**55.98**
Cultivar 18	-5.65	-7.37	-17.45	-44.5	-6.9	**-81.87**
Cultivar 19	-50.78	-1.22	4.87	-26.0	-2.3	**-75.43**
Cultivar 20	40.47	6.98	13.93	-36.8	-3.1	**21.52**

Discussion

The important traits for the grass total economic merit index were identified as those which have the largest effect on the economic performance of a system. A number of studies were reviewed (Dillon *et al*., 1995; Drennan and McGee, 2009; Keady, Hanrahan and Flanagan, 2009) to identify the most valuable traits affecting grass based production systems and are similar to those reported by others (DAFF, 2009; Casler, 2000; Wilkins and Humphreys, 2003). Additionally, it was considered of critical importance that the traits selected must be easily measured (Wilkins and Humphreys, 2003) and improvement in each trait must be achievable through plant breeding.

Total DM yield is considered one of the most important traits of forage plants, acting as the single unifying trait that is measured in nearly every cultivar evaluation trial, regardless of the environment or agricultural context (Casler and van Santen, 2010). High total DM yield is desirable as it may allow an increase in the carrying capacity on the farm, a reduction in the requirement for alternative feeds or a reduction in the land required for grazing. As the grazing season progresses both the supply of grass and the demand for it fluctuate, resulting in changes to the economic value of grass, which agrees with McEvoy *et al.* (2010) and Doyle and Elliott (1983). Improving the seasonal distribution of DM yield has long been a goal of forage breeders and agronomists through the extension of the growing season, either by early-spring growth or late autumn growth, or more uniform production throughout the growing season (Casler and van Santen, 2010).

Grass silage is the principal source of winter feed for livestock in Ireland (Drennan, Carson and Crosse, 2005). In Ireland, 87% of farms harvest silage annually, across one million hectares of land (Teagasc, 2002). The average proportions of this total area harvested for first, second and subsequent cuts of silage are 78, 21 and 1%, respectively. This emphasises the importance of 1st cut silage and 2nd cut silage within Irish production systems. There is a growing tendency within Irish dairy farms to conserve silage from a block separate to the main grazing platform, this practice is likely to become more common as stocking densities increase. This creates the requirement for an economic value solely focussed on the effect of high silage DM yields, with no emphasis on other traits such as seasonal DM yield or quality. As silage is the only important trait in such areas there is a much higher economic value applied to an increase in the DM yield of silage in this situation.

Casler (2000) reported *in vitro* DMD as the best single criterion of the nutritional value of a wide range of forage species and varieties for ruminants. Differences in morphological and nutritive composition between varieties can have a significant effect on animal production performance (Vipond *et al.*, 1997; Gowen *et al.*, 2003; O'Donovan and Delaby, 2005). The nutritive value of perennial ryegrass varies throughout the growing season (Johnston, Singh and Clarke, 1993; Walsh and Birrell, 1987). Increases in stem content as the plant growth changes from vegetative to reproductive is associated with a decline in plant digestibility (May to June period). Differences in DMD amongst varieties and cultivars of temperate grasses tend to be greatest in the mid to late summer periods, when the digestibility of fibre is at its lowest (Wilkins, 1997).

High persistency is desirable as full cultivation and reseeding of pasture is expensive (Wilkins and Humphreys, 2003). Additionally, poor persistency may have an environmental cost as less persistent varieties must be replaced more frequently. Ground cover score is the main estimator of persistency currently used in cultivar evaluation programmes; this however, is a subjective point in-time measurement. There is a requirement to measure the lifetime performance of varieties under animal grazing and relate this to ground score. Further research in this area is necessary to develop a more concise and rapid estimate of persistency.

Economic Performance

The economic values are calculated for a grass based intensive spring calving dairy system. In animal selection Beard (1987) reported that genetic progress could be maximized in economic terms if selection was based on the method of index selection. Such a method of selection should be directed towards a breeding objective comprising the sum of the breeding values for traits of economic importance weighted according to their relative economic value (Beard, 1987).

The total merit index for grass selection, identifies the key traits of importance for grass based ruminant production systems, and hence breeders can apply a weighting within their breeding programmes to each trait as appropriate. The change in the economic value of DM yield is dependant on the grass supply and herd demand. The higher value of an additional kg of DM in the spring and autumn compared to the mid-season period (€0.15, €0.10 and €0.03/ha/yr, respectively) will result in breeders selecting varieties which provide a greater proportion of their total DM yield in the spring and autumn periods. Currently, an objective within many breeding programmes is to provide a more even distribution of yield across the year (Casler and van Santen, 2010), success in this objective would benefit a cultivar within the total merit index due to the greater value of seasonal DM yield, compared to mid-summer DM yield.

The change in economic value for DMD across the months of April to September, reflects the effect of a change in UFL and FV on the intake potential of grass as the season advances. The difference in the total economic value for quality between the best and worst grass cultivar was €149.29/ha/year (range -€77.33 (Cultivar 6) to +€71.96 (Cultivar 7)). The difference in DMD (g/kg DM) between these two varieties for the 6 recorded months was: 21 (April), 39 (May), 21 (June), 22 (July), 31 (August) and 38 (September) g/kg DM, and 39 g/kg DM across the six months. This variation in DMD between varieties emphasises the requirement for frequent sampling of DMD within evaluation protocols to ensure the differences between varieties are being recognised. Infrequent sampling of these varieties for quality may result in a poor indication of the actual differences between them.

The application of the economic values to the evaluation protocol provides the opportunity to demonstrate the differences in the total economic merit between varieties. The calculation of the total economic merit of a cultivar is dependant on ensuring the traits within the index are captured within the evaluation process. Regardless of the utilisation rate of the herbage, Spearmans rank correlation indicated no reranking of the varieties (r_s=1.0). This indicates that if the utilisation of herbage fluctuates between farms there will be no change in the optimum cultivar, and hence, the index is a reliable tool to identify the best varieties across changes to farming intensity. Brereton (1995) reported that average annual DM yield in Ireland ranges from 11 to 15 t DM/ha. The rank correlation between the base scenario yielding 13 t DM/ha and S3 yielding 11 t DM/ha was high (r_s= 0.94). The high correlation in the ranking of varieties between these two levels of DM yield indicate that in regions where annual DM yields are lower and where farms are being operated less intensively the same varieties are relevant.

The silage only index applies the economic value to 1st and 2nd cut silage and is applicable for an intensive silage system. As there is significant reranking of varieties under silage compared to the base, varieties selected for silage only will not be suitable in a grazing system and vice versa. The poor correlation occurs as a result of the increased economic value of silage in this system, compared to the base and the removal of other traits from the index as silage is the only trait of interest. Additionally, the increased value of both 1st and 2nd cut silage (€0.093 and €0.096/kg DM silage yield, respectively) compared to the base silage values (€0.033 and €0.023/kg DM silage yield, respectively). This low rank correlation highlights the requirement for separate evaluation protocols where both intensive grazing and intensive silage conservation systems are in place to identify the most suitable varieties to the requirements of both systems. The use of two separate evaluation protocols to capture the performance of a cultivar will ensure the true performance of a cultivar is identified, and hence the optimum varieties are being selected to meet the requirements of the system.

Protocol

In countries where national and recommended lists are in place the major characteristics which are rewarded are yield, persistency, quality and disease resistance. The interaction between management and cultivar and subsequent ranking of varieties reported in the current study, agrees with others (Wilkins and Humphreys, 2003; Gilliland and Mann, 2000). Perennial ryegrass has two distinct phases of growth, the reproductive and vegetative phases. Growth rate during the two phases is to a large extent genetically independent (Wilkins, 1989). Reproductive growth forms a much larger proportion of the total annual DM yield under infrequent cutting (used for conservation based systems) than it does under frequent cutting managements (typical of simulated grazing systems); this can lead to genotype × cutting frequency interactions affecting total annual DM yield (Wilkins, 1989). Results of the current study indicate that varieties can be well adapted to either silage or grazing management, or both. Cultivars and breeding populations can rank differently in annual DM yield when managed for silage than when cut frequently to simulate actual grazing. This interaction creates a requirement to ensure that the evaluation protocol is representing the most common grazing practices within a particular country which will then result in the best cultivars being identified for the grazing system. Gilliland and Mann (2000) have found that alternating an evaluation protocol between intensive silage and intensive grazing does not create unfair advantage or disadvantage for any cultivar. This provides an economical method to evaluate the performance of a cultivar under two separate management systems without requiring extra plot numbers, sample numbers or resources. Ultimately, the choice of evaluation protocol to be implemented is the one which will identify the best varieties to support the grassland system practiced in a country/region.

Conclusions

The total economic merit index identifies the economic value of a cultivar within a grass based system of production. It enables the identification of varieties which will provide the greatest economic contribution to a grazing system. The high correlation between the base scenario and reductions in herbage utilisation indicate that, regardless of intensity, the ranking of varieties remains stable. The total economic merit index clearly identifies the strengths and weaknesses of individual varieties, thus enabling a farmer to select the most suitable cultivar to meet their individual requirements. The total economic merit index allows varieties to be ranked based on their ability to contribute economically to the system. The evaluation protocol in place must capture the traits of importance to ensure the accuracy of the index is maximised. The silage only index will enable varieties to be identified based on their suitability to the requirements of the system and hence depending on the needs of the grower, a cultivar can be selected for a grazing system or a silage only system.

Acknowledgements

The authors wish to thank Mr. M Feeney, F. Flynn, J. Nash, Ms. C. Fleming and Ms. N. Galvin for their technical assistance provided within the plot study. We would also like to acknowledge the funding received from the Department of Agriculture, Fisheries and Food through the Stimulus Fund RSF 07 526.

References

AIPL - Animal Improvement Programs Laboratory AIPL. 2010. Available: http://aipl.arsusda.gov/Main/site_main.htm. Accessed March 19, 2010.

Beard, K.T. 1987. Efficiency of index selection for dairy cattle using economic weights for major milk constituents. *Australian Journal of Agricultural Research* **38**: 273-284.

Bentley, S. 2003. The role of national and recommended list forage trials in the development of sustainable varieties. *Aspects of Applied Biology* **70**: 25-29.

Binfield, J., Donnellan, T., Hanarahan, K. and Westhoff, P. 2008. FAPRI-Ireland Baseline 2008: Outlook for EU and Irish agriculture. FAPRI-Ireland Partnership Teagasc, Carlow, Ireland.

Brereton, A. J. 1995. Regional and year-to-year variation in production. In: D.W. Jeffery, M.B. Jones and J.H. McAdam (Eds.). *Irish Grassland – Their Biology and Management,* pp. 12-22. Dublin, Ireland: Royal Irish Academy.

CDN - Canadian Dairy Network. 2010. Available: http://www.cdn.ca/home.php Accessed March 19, 2010.

Casler, M.D., and van Santen, E. 2010. Breeding objectives in forages. In: Fodder crops and amenity grasses pp 115-136. B. Boller, U. Posselt and F Veronesi (Eds.). Springer , DOI 10.1007/978-1-4419-0760-8_5.

Casler, M.D. 2000. Breeding forage crops for increased nutritional value. *Advances in Agronomy* **71**: 51-107.

Conaghan, P., Casler, M. D., McGilloway, D. A., O'Kiely, P. and Dowley, L. J. 2008. Genotype x environment interactions for herbage yield of perennial ryegrass sward plots in Ireland. *Grass and Forage Science* **63**: 107-120.

DAFF - Department of Agriculture Fisheries and Food. 2009. Grass and Clover, Recommended List Varieties for Ireland 2009. Maynooth, Ireland: Department of Agriculture Fisheries and Food.

Dillon, P., Roche, J. R., Shalloo, L. and Horan, B. 2005. Optimising financial return from grazing in temperate pastures. Pps 131– 147 in XXth Int. Grassl. Congr., Cork, Ireland. Ed. J.J. Murphy. Wageningen Academic Publishers, Wageningen, the Netherlands.

Dillon, P., Crosse, S., Stakelum G. and Flynn, F. 1995. The effect of calving date and stocking rate on the performance of spring-calving dairy cows. *Grass and Forage Science* **50**:286-299.

Doyle, C. J. and Elliott, J. G. 1983. Putting an economic value on increases in grass production. *Grass and Forage Science* **38**: 169-177.

Drennan, M.J., and McGee, M. 2009. Performance of spring-calving beef suckler cows and their progeny to slaughter on intensive and extensive grassland management systems. *Livestock Science* **120**: 1-12.

Drennan, M.J., Carson, A.F. and Crosse, S. 2005. Overview of animal production from pastures in Ireland. Pages 19-35 in Proceedings of XXth Int. Grassl. Congr., Cork, Ireland. Ed. J.J. Murphy. Wageningen Academic Publishers, Wageningen, the Netherlands.

Faverdin, P., Delagarde, R., Delaby, L. and Meschy, F. 2007. Alimentation des vaches laitières, in Alimentation des bovins, ovins et caprins, QUAE Editions, INRA, Versailles, France, 149-180.

Gilliland, T. J. and Mann, R. L. 2000. Effect of sward cutting management on the relative performance of perennial ryegrass varieties. *Journal of Agricultural Science (Camb.)* **135**: 113-122.

Gordon, F.J., Dawson, L.E.R., Ferris, C.P., Steen, R.W.J. and Kilpatrick, D.J. 1999. The influence of wilting and forage additive type on the energy utilisation of grass silage by growing cattle. *Animal Feed Science Technology* **79**: 15-27.

Gowen, N., O'Donovan, M., Casey, I., Rath, M., Delaby, L. and Stakelum, G. 2003. The effect of grass cultivars differing in heading date and ploidy on the performance and dry matter intake of spring calving dairy cows at pasture. *Animal Research* **52**: 321-336.

ICBF - Irish Cattle Breeders Federation. 2008. Understanding the Economic Breeding Index (EBI). http://www.icbf.com/publications/files/Understanding_EBI_PTA_BV_Spring_2008.pdf. Accessed Nov. 4 2009.

Jafari, A., Connolly, V. and Walsh, E. J. 2003. Genetic analysis of yield and quality in full-sib families of perennial ryegrass (*Lolium perenne* L.) under two cutting managements. *Irish Journal of Agricultural and Food Research* **42**: 275-292.

Jarrige, R. E. 1989. Ruminant Nutrition - Recommended allowances & feed tables. INRA.

Johnston, J. E., Singh, A. and Clark, E. A. 1993. Sward height in grazing management: vertical profiles in sward quality. XVII International Grassland Congress, Rockhampton, Australia: pp. 890-891.

Keady, T.W.J., Hanrahan, J.P. and Flanagan, S. 2009. An evaluation of two grassland-based systems of mid-season prime lamb production using prolific ewes of two genotypes. *Irish Journal of Agriculture and Food Research* **48**: 87-101.

McEvoy, M. O'Donovan, M. and Shalloo, L. 2010 Submitted. Development and application of an economic ranking index for grass varieties. Submitted *Journal of Dairy Science*, July 2010.

NZAEL, 2009. New Zealand Animal Evaluations Limited. Your index, Your Animal Evaluation System. 2nd Edition. http://www.aeu.org.nz/data/usr/Your% 20Index%20Your%20AE%20 System%2Epdf. Accessed Feb. 15, 2010.

O'Donovan, M. and Kennedy, E. 2007. Using grass to reduce feed costs. In Exploiting the freedom to milk, Teagasc National Dairy Conference, 2007, Ireland. Teagasc pp 63-80.

O'Donovan, M. and Delaby, L. 2005. A comparison of perennial ryegrass cultivars differing in heading date and grass ploidy with spring calving dairy cows grazed at two different stocking rates. *Animal Research* **54**: 337-350.

SAS Institute. 2006. SAS User's Guide: Statistics. SAS Institute Inc., Cary, NC.

Shalloo, L., Dillon, P., Rath M. and Wallace, M. 2004. Description and Validation of the Moorepark Dairy System Model. *Journal of Dairy Science* **87**: 1945-1959.

Teagasc. 2008. Management data for farm planning. Teagasc, Oakpark.

Teagasc. 2002. National Farm Survey Publication.

Veerkamp, R.F., Dillon, P. Kelly, E. Cromie, A.R. and Groen, A.F. 2002. Dairy cattle breeding objectives combining yield, survival and calving interval for pasture-based systems in Ireland under different milk quota scenarios. *Livestock Production Science* **76**: 137-151.

Vipond, J. E., Swift, G. Cleland, A.T., Fitzsimons, J. and Hunter, E.A. 1997. A comparison of diploid and tetraploid perennial ryegrass and tetraploid ryegrass/white clover swards under continuous sheep stocking at controlled sward heights. 3. Sward characteristics and animal output, years 4-8. *Grass and Forage Science* **52**: 99-109.

Walsh, G. L. and Birrell, H. A. 1987. Seasonal variations in the chemical composition and nutritive value of five pasture species in south-western Victoria. *Australian Journal of Experimental Agriculture* **27**: 807-816.

Wilkins, P.W. 1989. Genotype/harvesting frequency and genotype/nitrogen level interactions for annual dry matter yield in *Lolium perenne* in relation to breeding. *Euphytica* **41**: 207-214.

Wilkins, P.W. 1997. Useful variation in *in vitro* digestibility within perennial ryegrass. *Euphytica* **93**: 249-255.

Wilkins, P. W. and Humphreys, M. O. 2003. Progress in breeding perennial forage grasses for temperate agricluture. Journal of Agricultural Science **140:** 129-150.

Reseeding! A cost or an opportunity?

L. Shalloo, P. Creighton and M. O’Donovan
Animal & Grassland Research and Innovation Centre, Teagasc, Moorepark, Fermoy, Co. Cork, Ireland
Email: Laurence.Shalloo@teagasc.ie

Abstract

Herbage production and utilisation on dairy farms nationally is well below its potential. There a number of factors that are influencing this level of production not least the level of reseeding being carried out. The seasonal nature and total level of herbage production of old permanent pasture is substantially lower than the potential from perennial ryegrass. It is estimated that approximately 2% of the land area on commercial dairy farms is reseeded annually resulting in a low percentage of perennial ryegrass in the swards. The objective of this study was to quantify the economic benefits from reseeding different proportions of the farm on annual basis. Four levels of an annual reseeding program were evaluated with 1%, 5%, 10% and 15% of the farm reseeded annually across three milk prices, 20 c/L, 27 c/L and 33 c/L. Increasing the level of reseeding on farm resulted in increased total and seasonal herbage production, and when accompanied by increases in stocking rate resulted in increased herbage utilisation. At a milk price of 27 c/L farm profitability was €20,764, €24,794, €30,073 and €33,515 on a 40ha farm when 1%, 5%, 10% and 15%, respectively of the farm was reseeded annually. Irrespective of milk price increasing the level of reseeding had a positive effect on profitability with the highest gains achieved at the highest prices. Sensitivity analysis showed that sward persistency and to a lesser extent herbage utilisation had a significant effect on the benefits of reseeding.

Introduction

Irish dairy farmers are facing challenging times due to major changes in national and international policy. The continued reform of the European Union (EU) Common Agricultural Policy (CAP) is likely to change the production landscape dramatically for all EU producers (McCarthy *et al*., 2007). Recent agreements, such as the CAP Health Check, have centred on the removal of milk quotas by 2015. The policy reform between now and 2015 will create significant opportunities for Irish dairy farmers, facilitated by the allocation of additional quota paving the way for its removal by 2015. Under the CAP regime, milk price supports through import tariffs and export subsidies stabilized prices in the EU compared to those outside the EU (O’Donnell *et al*., 2008). A potential WTO agreement is likely to result in reduced EU milk prices through lower domestic support, tariff cuts and a reduction in export refunds (Dillon *et al*., 2008).

Business success in an environment of lower and more volatile milk prices requires producers to become even more focused on maximizing efficiency of milk production. Dairy producers can only maximize their levels of efficiency by producing the most output from the least levels of input. This can be achieved by more judicious use of inputs, innovation and increased productivity, therefore adopting the most efficient combination of inputs and outputs which will lead to the greatest return to the farm business.

Approximately 44% of the variation in total profit per hectare (ha) can be explained by grass utilised/ha (Shalloo, 2009); increasing grass utilisation/ha by 1 t dry matter (DM)/ha can increase profitability by €100/ha. Grazed grass is the cheapest feed available to all ruminant systems (Finneran *et al*., 2010), with a relative cost ratio of grazed grass to grass silage and concentrate of 1-1.8-2.4. A significant relationship between grazing season length and technical efficiency was reported by Kelly *et al*. (2010) using the Teagasc National Farm Survey (NFS, 2008).

Due to climatic conditions, Irish grass based system's have the potential to achieve a long grazing season at farm level. Dairy farmers are currently utilising 7.5 t DM/ha (calculations from NFS data) over a 210 day grazing season (Shalloo *et al.*, 2009), with the milking platform stocked at 1.8 livestock units (LU)/ha. In contrast, research and efficient commercial farms are utilising 12-14 t DM/ha, over a 280 day grazing season, with the farm stocked at over 3.0 LU/ha. Some reasons hypothesised for the poor performance centre around the type of grass, grassland management and overall farm stocking rate.

While perennial ryegrass is by far the most widely sown grass species in Ireland accounting for approximately 95% of forage grass seed sold (DAFF, 2010) its level in the national pastures is still low. As its name suggests perennial ryegrass has a perennial lifecycle, capable of surviving for many decades in pasture under suitable conditions. Perennial ryegrass establishes rapidly from seed, with a strong tillering ability to produce a dense sward, highly acceptable to stock, capable of withstanding intensive grazing, and responds well to fertile conditions and inputs of nitrogen (N). A recent grassland survey (Creighton *et al.*, 2010) confirmed the decline in grassland reseeding in Ireland. Twenty three percent of dairy farmers stated that they had not reseeded in the previous three years. Where reseeding occurred, farmers were more likely to reseed the grazing area rather than the silage area.

The objectives of this paper are to: i) determine the biological and economic benefit to reseeding pastures for grazing dairy livestock; ii) quantify the effect reseeding different proportions of the farm has on biological and economic performance; and iii) to determine the effect of persistency and utilisation of the reseeded sward on profitability.

Materials and methods

Dry matter production on dairy farms in Ireland

As previously mentioned grass utilised/ha is one of the main factors affecting profit/ha on a dairy farm. Grass utilised/ha is a consequence of grass grown/ha, stocking rate and grassland management. Nationally dairy farmers operate at a stocking rate of 1.78 LU/ha (O'Donnell *et al.*, 2008) on the grazing area. It is estimated that approximately 7.5 t DM/ha are utilised based on energy demand, concentrate fed, grazing season length and the feed value of grazed grass, grass silage and concentrate. Table 1 shows the total and range in herbage production for a group of 17 farms across a range of different soil types in 2009 in the Munster region (south of Ireland). The overall grazing platform stocking rate is high at 2.6 LU/ha. There was a large variation in grass DM production across the farms. Average herbage production was 11 t DM/ha and ranged from 9.2 to 14.4 t DM/ha, while individual paddock yields ranged from 6.3 to 17.0 t DM/ha within and across farms. A large proportion of farms were producing less than 12 t grass DM/ha annually.

TABLE 1: Mean and range in grass DM production on seventeen dairy farms in Ireland in 2009

Farm location and soil type	Average DM production	Top 20% of paddocks	Bottom 20% of paddocks	Stocking rate (Cows/ha)
Tipperary (Free draining)	14.4	17.0	9.5	3.0
Limerick (Heavy soil type)	13.4	14.5	11.4	3.1
Tipperary (Free draining)	12.8	14.3	10.1	2.5
North Cork (Free draining)	12.4	14.6	10.6	2.9
Tipperary (Heavy soil type)	11.9	15.0	8.0	2.2
North Cork (Free draining)	11.7	14.5	8.3	2.5
North Cork (Heavy soil type)	11.0	13.5	7.1	2.7
North Cork (Free draining)	11.0	13.2	8.5	2.1
North Cork (Free draining)	11.0	12.9	8.5	3.1
North Cork (Free draining)	10.9	13.2	8.4	2.6
Tipperary (Heavy soil type)	10.2	13.3	7.5	2.2
North Cork (Free draining)	9.9	13.3	6.3	2.7
Tipperary (Free draining)	9.6	11.7	7.5	2.5
North Cork (Free draining)	9.4	12.8	7.2	3.3
North Cork (Heavy soil type)	9.3	11.5	6.0	2.0
North Cork (Heavy soil type)	9.2	11.9	7.7	2.2
North Cork (50% Heavy; 50% Free draining)	9.2	11.0	6.3	2.7
Average Farm DM production	**11.0**	**13.4**	**8.2**	**2.60**

Moorepark Dairy Systems Model

The Moorepark Dairy Systems Model (MDSM) is a stochastic budgetary simulation model, which provides a comprehensive simulation framework integrating biological, physical and economic processes in a model of a dairy farm (Shalloo *et al.*, 2004a). The MDSM was used to simulate herd parameters, nutritional requirements, land use and total inputs and outputs across the calendar year. A full description of the model is reported by Shalloo *et al.* (2004a). The major revenues in the MDSM are milk sales and livestock sales. Within the model simulations, land area was treated as an opportunity cost with additional land rented in when required or leased out when not required for on-farm feeding of animals. Variable costs (fertilizer, concentrate, vet, medicine, artificial insemination, silage, reseeding and contractor charges), fixed costs (car, electricity, labor, machinery operation and repair, phone, insurance, etc.) and receipts (livestock, milk and calf) were based on current prices (Teagasc, 2008).

A spring-calving grass-based milk production system, which is similar to the production system of most Irish dairy farms (Dillon *et al.*, 2005) was simulated using the MDSM. Cows were turned out to grass immediately post-calving. Mean calving date was 24th February, with a calving interval of 365 days and 70, 20 and 10% of the cows calving in February, March and

April, respectively (Shalloo *et al*., 2004a). To achieve this, breeding started on a fixed calendar date in late April, with every cow detected in estrous served using AI, regardless of the number of days since calving, the breeding season was confined to a 13-wk period.

The system optimizes the use of grazed grass as a proportion of the total diet of the lactating dairy cow, allowing high cow performance, while minimizing the cost of milk production. The net energy (NE) system, described by Jarrige (1989), was used to determine the energy requirements of the system. The proportions of feeds offered (grass, grass silage and concentrate) were adjusted to meet the net energy requirements for milk production, maintenance and bodyweight change.

Analysis assumptions

Scenario 1 (S1)

Scenario 1 involved quantifying the effect of reseeding 1%, 5%, 10%, and 15% of the farm annually. In this Scenario (S1; base scenario), herbage production on the farm was 8,704 kg DM/ha with 7,402 kg DM/ha utilised (total annual DM utilised was assumed to be 7.4 t DM/ha nationally, based on calculations at Moorepark from NFS data). This production was made up of 8,400 kg DM/ha from old permanent pasture. It was then assumed that 1%, 5%, 10% and 15% of the farm was reseeded annually. Each reseeded paddock produced 15 t DM/ha in year 1, declining at a rate of 2% per year. The analysis was carried out at a milk price of 20 c/L, 27 c/L and 33 c/L.

TABLE 2: Key assumptions included in the reseeding costs

	€/Ha
Spraying	25.0
Glyphosate (Gallup 360) (Round-up (2 L/acre)	39.5
Ploughing (30)/ Till & sowing (one pass)(30)	148.0
Fertiliser (5 bags x 10:10:20)	116.0
Fertiliser Spreading	25.0
Levelling	25.0
Rolling	25.0
Grass seed	111.2
Post emergence herdicide sprays	
Duplosan - (1 L - €9/ac)	25.0
Costs (ex- post emergence sprays –depends on what farmers choose to use)	**540**

In general farmers estimate cost of reseeding at €200/acre (€500/ha), which is realistic as some of these costs outlined above are carried in the overall management of the farm.

Scenario 2 (S2)

Scenario 2 involved reseeding 10% of the farm annually and quantifying the effect of a reduction in grass utilisation, reduction in the persistency of the sward from a 2% decline annually to a 5% decline annually, and a 20% higher reseeding cost.

Model Assumptions

The key assumptions used in the MDSM are shown in Table 2. The base gross milk price received was 27 c/L (Binfield *et al*., 2008). The ratio of fat to protein price was 1:2 with a fat price of €3.42/kg and a protein price of €6.84/kg. There was an opportunity cost of €297/ha placed on all land in the system. Concentrate costs were included at €220/tonne (t). Silage contracting costs were included at €272 and €222/ha for both 1st and 2nd cut silage, respectively.

The reseeding cost included in the model was €540/ha (Table 3). In the analysis it was assumed that the sward was depreciated based on the whole farm being reseeded. Therefore, if 10% of the farm was reseeded annually, the whole farm would be reseeded over a 10 year period. Therefore, the reseeding was depreciated over a 10 year period. Both interest and depreciation were considered an expense. Interest was included at 5.0% over the term that the reseeding was carried out over, which depended on the reseeding program in place. It was assumed that the net yield in the year of reseeding would not change, as the period of time where the paddock would not be growing would be compensated for by increased production subsequently within the year. The performance of the paddock is based on the average performance expected over the 10 year period that the sward is in place.

TABLE 3: Key assumptions included in the model

Land area (ha)	40
Fertiliser costs	
Urea (€/t)	400
CAN (€/t)	280
Concentrate costs (€/t)	220
Replacement costs (€)	1,550
Replacement rate (%)	18
Housing costs (€)	2,500

Results

Perennial ryegrass is a high quality feed and is more nutrient responsive than other grass species. Recent research at Moorepark has shown old permanent pasture to produce on average 3 t DM/ha less than reseeded perennial ryegrass swards. Figure 1 shows the DM contribution across the grazing season of a 15% perennial ryegrass sward compared to 100% perennial ryegrass sward. The majority of the difference in DM yield between the two swards is accounted for between February and mid-May. Swards with low levels of perennial ryegrass are less nutrient efficient by approximately 25% than swards with high levels of perennial ryegrass.

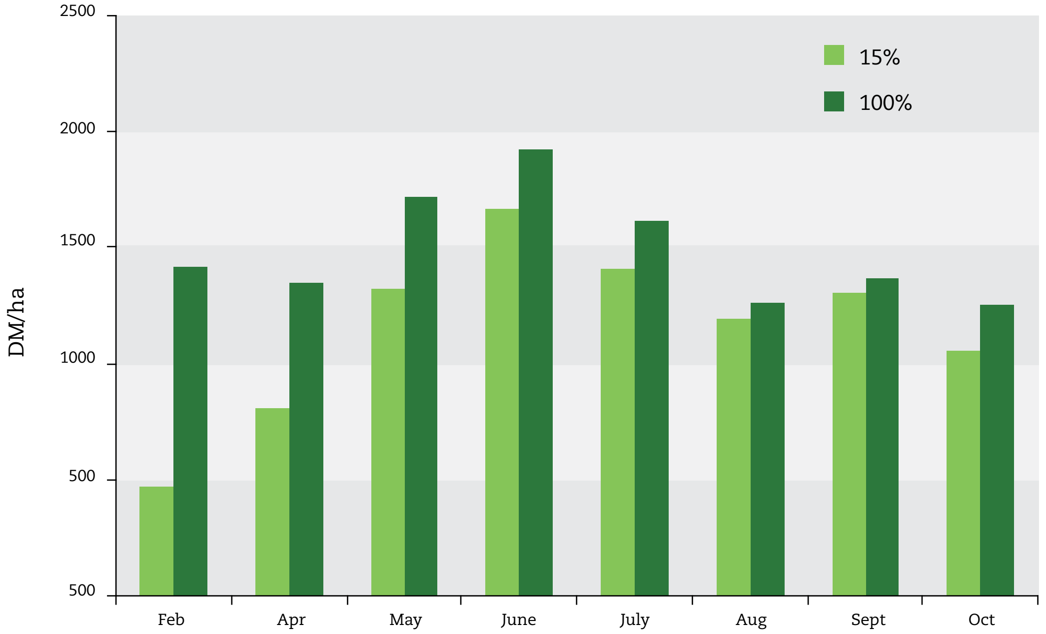


Figure 1: Dry matter distribution of a 15 and 100% perennial ryegrass sward

Effect of reseeding on performance

From the scenarios modelled, the level of reseeding carried out on a farm had a direct effect on the performance of the farm. In S1, when the level of reseeding is increased on the farm from the National Farm average of 1% to 5%, 10% and 15% there is a subsequent substantial increase in herbage production, with farm herbage production increasing to 9,856 kg DM/ha, 11,323 kg DM/ha and 12,254 kgDM/ha, respectively (Table 4). This increase in herbage production is based on the reseeded pastures producing 15,000 kg DM/ha in year 1 after reseeding and declining at a rate of 2% per year to simulate reductions in persistency, and permanent pastures producing 8400 kg DM/ha. As herbage production increased it was assumed that grass utilisation rate would remain constant, and, therefore cow numbers would increase to match the supply of feed from pasture on the farm. Grazed grass utilisation increased by 13%, 30% and 41% and cow numbers increased by 7%, 15% and 20%, respectively when 5%, 10% and 15% of the farm was reseeded annually. The level of reseeding on farm increased from 0.4 ha to 2 ha, 4 ha and 6 ha/annum where 1%, 5%, 10% and 15%, respectively, of the farm reseeded annually. Due to the expected seasonal change in herbage production with higher proportions of perennial ryegrass in the sward, the level of grazed grass, grass silage and concentrate in the diet of the dairy cow was simulated to change. In the base scenario the diet consisted of 56%, 30% and 14% grazed grass, grass silage and concentrate, respectively, in comparison to 60%, 28% and 12%, respectively, when 5% was reseeded, 65%, 26% and 9%, respectively, when 10% was reseeded and 69%, 24% and 7%, respectively, when 15% of the farm was reseeded annually. Milk production and total sales increased as the swards became more productive and cow numbers increased. It was assumed that more N fertiliser would be applied to the reseeded swards and that a greater herbage response to fertiliser N would occur than when it is applied to old permanent pasture.

TABLE 4: The effect of level of reseeding on farm physical performance

Level of reseeding	National reseeding Program 1% of area	5% of farm area	10% of farm area	15% of farm area
Grass Grown (kg DM/ha)	8,704	9,856	11,323	12,254
Grass Utilised (kg DM/ha)	7,402	8,382	9,629	10,421
No. of Cows Calving	71	76	82	85
Land area (ha)	40	40	40	40
Land area reseeded annually (ha)	0.4	2	4	6
Grazed grass (kg DM/cow)	3,003	3,195	3,414	3,641
Grass Silage (kg DM/cow)	1,605	1,495	1,383	1,248
Concentrate (kg DM/cow)	730	614	479	351
Milk Produced (kg)	443,600	473,702	510,636	530,143
Milk Sales (kg)	430,521	459,736	495,581	514,513
Fat Sales (kg)	15,936	17,018	18,344	19,045
Protein Sales (kg)	14,425	15,404	16,605	17,239
Nitrogen fertiliser (kg/ha)	166	189	213	236

*Performance from established systems with 1%, 5%, 10% and 15% of the farm reseeded annually

Effect of reseeding on profit

In S1 the effect of the level of reseeding on the economic performance of the farm was analysed at three different milk prices (20 c/L, 27 c/L and 33 c/L). The reseeding costs increased dramatically across the four reseeding regimes with costs of €229, €1,147, €2,295 and €3,442 for 1%, 5%, 10% and 15%, respectively, reseeded annually. As cow numbers increased so too did labour costs and fertiliser costs, while concentrate costs declined due to a longer grazing season.

The effect of different levels of reseeding on profitability was analysed across three milk prices, 20 c/L, 27 c/L and 33 c/L. Milk returns were increased by 6.8%, 15.1% and 19.5% at all three milk prices when a reseeding program based on 5%, 10% and 15% respectively, of the farm being reseeded was compared to only 1% of the farm being reseeded annually (Table 5). The effect level of reseeding had on farm profitability was different at different milk prices. At 20 c/L profitability increased by €1,886, €4,533 and €6,585 for the three reseeding levels, while the corresponding figure at 33 c/L was €5,866, €13,397 and €18,029. Margin per cow and per litre increased by the same magnitude as farm profit, across the three milk prices. While increased reseeding levels did not fully insulate against the effects of a low milk price, it did reduce the exposure, while the greatest benefits from reseeding were achieved at higher milk prices.

TABLE 5: The effect of level of reseeding on farm profitability

Level of reseeding	1% of farm area	5% of farm area	10% of farm area	15% of farm area
Reseeding costs (€)	229	1,147	2,295	3,442
Labour Costs (€)	31,605	32,489	33,573	34,146
Concentrate Costs (€)	12,409	11,461	10,127	8,264
Fertiliser costs (€)	9,540	10,478	11,421	12,294
Total farm Costs (€)	130,898	137,190	144,578	147,837
Milk Price at 27 c/L				
Milk returns (€)	120,403	128,573	138,598	143,893
Margin per cow (€)	292	327	367	394
Margin per kg milk (c)	4.68	5.23	5.89	6.32
Total profit/farm (€)	20,764	24,794	30,073	33,515
Milk Price at 20 c/L				
Milk returns (€)	88,993	95,032	102,441	106,355
Margin per cow (€)	-152	-118	-77	-50
Margin per kg milk (c)	-2.44	-1.89	-1.24	-0.80
Total profit/farm (€)	-10,844	-8,958	-6,311	-4,259
Milk Price at 33 c/L				
Milk returns (€)	147,286	157,281	169,544	176,021
Margin per cow (€)	672	707	748	775
Margin per kg milk (c)	10.78	11.33	11.99	12.42
Total profit/farm (€)	47,817	53,683	61,214	65,846

Scenario 2 shows the effect that variation in grass utilisation, sward persistency and reseeding costs had on the overall merits of reseeding when 10% of the farm was reseeded annually (Table 6). Reductions in grass utilisation reduced the benefits of reseeding. Total farm milk output reduced by 4.3% compared to the system where 10% was reseeded and there was no reduction in utilisation. While profitability was still substantially higher than when 1% of the farm was reseeded annually there, was still a substantial negative effect on overall profitability, especially at lower milk prices, when utilisation reduced.

The persistency of the reseeded sward has a significant effect on the benefits of reseeding. In the analysis it was assumed that sward persistency declined at 2% per year. When that level of decline was increased to 5% there was a substantial reduction in the benefits of reseeding. The total herbage utilised reduced from 9,629 kg DM/ha to 8,843 kg DM/ha and total milk output declined by 3.6% when compared to 10% reseeded with reseeded sward persistency declining at 2% annually. While profitability levels at the three milk prices were higher when compared to only reseeding 1% of the farm annually, they were 17.0%, 60.4% and 10.2% lower than when persistency declined by 2% per annum. When milk price was at its lowest there was little benefit from reseeding when persistency declined by 5% annually. A 20% increase in the unit cost of reseeding had only a marginal effect on the economic consequences of reseeding.

TABLE 6: Sensitivity analysis around grass utilisation and persistency of the sward

	Base		**Grass utilisation reduced by 5%**	**Persistency of sward dropping at 5% compared to 2%**	**Reseeding costs increased from €540/Ha to €650**
Level of reseeding	**1% of farm area**	**10% of farm area**	**10% of farm area**	**10% of farm area**	**10% of farm area**
Grass Grown (kg DM/ha)	8,704	11,323	11,323	10,399	11,323
Grass Utilised (kg DM/ha)	7,402	9,629	9,057	8,843	9,630
Cow's calving	71	82	78	79	82
Milk Produced (kg)	443,600	510,636	488,182	492,394	510,636
Milk Sales (kg)	430,521	495,581	473,789	477,877	495,581
Fat Sales (kg)	15,936	18,344	17,538	17,689	18,344
Protein Sales (kg)	14,425	16,605	15,875	16,012	16,605
Reseeding costs (€)	229	2,295	2,295	2,295	2,762
Labour Costs (€)	31,605	33,573	32,914	33,038	33,573
Concentrate Costs (€)	12,409	10,127	9,682	11,913	10,127
Fertiliser costs (€)	9,540	11,421	11,355	11,474	11,421
Total farm Costs (€)	130,898	144,578	139,735	143,413	145,046
Milk Price at 27 c/L					
Milk returns (€)	120,403	138,598	132,503	133,647	138,599
Margin per cow (€)	292	367	348	316	362
Margin per kg milk (c)	4.68	5.89	5.58	5.07	5.80
Total profit/farm (€)	20,764	30,073	27,223	24,965	29,606
Milk Price at 20 c/L					
Milk returns (€)	88,993	102,441	97,937	98,782	102,441
Margin per cow (€)	-152	-77	-97	-128	-83
Margin per kg milk (c)	-2.44	-1.24	-1.55	-2.06	-1.33
Total profit/farm (€)	-10,844	-6,311	-7,562	-10,120	-6,779
Milk Price at 33 c/L					
Milk returns (€)	147,286	169,544	162,089	163,487	169,544
Margin per cow (€)	672	748	728	697	742
Margin per kg milk (c)	10.78	11.99	11.67	11.17	11.90
Total profit/farm (€)	47,817	61,214	56,994	54,993	60,747

Discussion

Currently, regardless of system or enterprise, on a proportional basis grazed grass is the largest constituent of the ruminant feed budget (O'Donovan and Kennedy, 2007; Drennan and McGee, 2009; Keady, Hanrahan and Flanagan, 2009) and grass silage is the principal winter feed for livestock in Ireland (Drennan, Carson and Crosse, 2005).

Milk production systems in Ireland have a competitive advantage when compared to most other milk production systems throughout the world; with New Zealand being the only country that consistently produces milk at a significantly lower cost than Ireland (Shalloo, 2009). Ireland's competitive advantage centres on the conversion of grazed grass into milk at the lowest cost possible (Dillon *et al*., 2005; Shalloo *et al*., 2004a). However, analysis of the National Farm Survey data (NFS, 2008) shows that there is significant variation in production costs and profitability and that substantial scope to improve production system efficiency exists (Shalloo, 2009). When an analysis of the relationship between profit and grass utilisation was undertaken, 44% of the variation in profit/ha could be explained by differences in grass utilized/ha; each additional tonne of herbage utilised increased profit/ha by €100/ha. Dillon *et al*. (2005) showed that a 10% increase in the proportion of grazed grass in the feeding system reduced the cost of milk production by €0.025/l. The benefit of increasing the total herbage harvested at farm level will be magnified with the removal of milk quotas.

The objective of grass based systems of milk production is to match the availability of feed supply with the demand for feed, at the lowest cost possible. This ensures the system will be dynamic in the face of both input and output price volatility. Increasing the period of time during which grass can be harvested by the grazing animal, and therefore extending the grazing season has been shown in a number of studies to reduce the costs of milk production while at the same time increasing output (Shalloo *et al*., 2004b). The economic influence of grass DM yield fluctuates across the season and is influenced by feed supply and herd demand (Doyle and Elliott, 1983). In spring and autumn, feed demand generally exceeds supply for grass-based ruminant production systems. In the main grazing season, grass supply generally exceeds herd feed demand, the extent of which is dependant on stocking rate. Each additional kg of herbage produced in spring and autumn has a greater economic impact on a grazing system than a similar increase in the mid-season DM yield (McEvoy *et al*., 2010).

Increasing the quantity of herbage produced in the period of the year when demand exceeds supply will result in a reduced dependence on purchased feed. The purchase of this feed, which is subject to substantial price volatility such as has occurred in 2008 and in 2010, exposes the farm business to risk. Reducing exposure to this type of volatility in input price through focusing on increased grazing season length and reducing concentrate feed requirement will increase the sustainability of the dairy business especially with the expected increased volatility in milk price.

Milk quotas have limited milk production in Ireland since their imposition in 1985. Since then dairy farm numbers have declined from over 70,000 to under 20,000, dairy cow numbers have declined from over 1.5 million to just over 1.1 million and milk output nationally has declined by 8%. With the recent relaxation of the milk quota regime (9.3% increase between 2008 and 2013) and the stated objective of milk quota removal by 2015, the potential for expansion has substantially increased. In the analysis reported in this paper it has been shown that in order to realize the full potential from reseeding, herbage utilization should not reduce as a result. Therefore, the farm stocking rate should be increased as the farm is being reseeded to reflect the increased production potential from the sward. Increasing stocking rate and milk output from the farm will increase grass utilization, with a positive effect on profit (Shalloo, O'Donnell and Horan, 2007). This will be in part as a result of higher producing grass varieties with increased N fertilizer utilization returning a higher response to each additional unit of N. Milk output increases will only be achieved profitably in a post quota environment if the expansion is fueled through increased grass utilization.

The level of persistency of a sward will affect herbage production and the requirements for reseeding. High persistency is desirable as full cultivation and reseeding of pasture is expensive (Wilkins and Humphreys, 2003). This study has shown that the level of persistency has a substantial effect on the farm performance. The assumption of a 5% reduction in persistency versus a 2% reduction resulted in a reseeded sward producing 8,250 kg DM/ha versus 12,300 kg DM/ha by year 10. While the affect will be less in a more frequent reseeding program there is an overall substantial effect on the economics of reseeding. Additionally, this may have an environmental cost as less persistent varieties must be replaced more frequently. Measurement of persistency is difficult. Currently the most widely used method in grass cultivar evaluation programmes is ground cover score. Ground cover score is the main predictor of persistency; this is a subjective point in-time measurement. There is a requirement to measure the lifetime performance of varieties under animal grazing and relate this to ground score. Further research in this area would be beneficial to develop a more concise and rapid estimate of persistency.

In the analysis carried out in this study it was assumed that the reseeding was undertaken as part of the system, whether 1%, 5%, 10% or 15% of the sward was reseeded annually. The speed at which the herbage production on the farm can be increased will be dependent on the rate of reseeding. For example, after reseeding 5% of the farm over a three year period total herbage production would have increased from 8,730 kg DM/ha to 9,315 kg DM/ha, while reseeding 15% of the farm annually would result in an increase from 8,730 kg DM/ha to 11,145 kg DM/ha. While there is a higher upfront cost, this level of reseeding results in the farm becoming more productive and hence more profitable, faster.

Reseeding levels on farms that are currently productive will have to remain high in order to maintain performance. The identification and availability of productive perennial ryegrass varieties suitable to increase farm DM performance will be a continuous challenge. Grass varieties that not alone increase average performance but that also increase the performance of the best farms are required if reseeding can be justified, on highly stocked farms. In the future varieties that deliver much higher seasonal herbage yield, total herbage yield and that are persistent will be required if animal output from grassland is going to reach its potential.

Conclusions

Herbage production and utilisation on dairy farms nationally is well below its potential. There are a number of factors that are influencing this level of production not least the level of reseeding being carried out. It is estimated that approximately 2% of the land area on commercial dairy farms is reseeded annually resulting in a low percentage of perennial ryegrass in the swards. The seasonal and total herbage production of old permanent pasture is substantially lower than the potential from perennial ryegrass swards. Increasing the level of reseeding on farm will increase grass production and will result in increased milk sales if accompanied by increases in stocking rate. The profitability levels of the farm will be increased irrespective of milk price with the greatest gains achieved at the highest milk prices. The gains that are achieved from reseeding can be quickly lost if the increased herbage production is not captured through higher stocking rates and if the grazing season length is not increased.

References

Binfield, J., T. Donnellan, K. Hanarahan, and P. Westhoff. 2008. FAPRI-Ireland Baseline 2008: Outlook for EU and Irish agriculture. FAPRI-Ireland Partnership Teagasc, Carlow, Ireland.

Creighton P, Kennedy E, Shalloo L, Boland T.M., and O' Donovan M. 2010. A survey analysis of grassland dairy farming in Ireland, investigating grassland management, technology adoption and sward renewal. *Grass and Forage Science* (Submitted).

DAFF - Department of Agriculture Fisheries and Food, 2009. Grass and Clover, Recommended List Varieties for Ireland 2009. Maynooth, Ireland: Department of Agriculture Fisheries and Food.

Dillon, P., J. R. Roche, L. Shalloo, and B. Horan. 2005. Optimising financial return from grazing in temperate pastures. Pages 131– 147 in XXth Int. Grassl. Congr., Cork, Ireland. Ed. J.J. Murphy. Wageningen Academic Publishers, Wageningen, the Netherlands.

Dillon, P., T. Hennessy, L. Shalloo, F. Thorne and B. Horan. 2008. Future outlook for the Irish dairy industry: a study of international competitiveness, influence of international trade reform and requirement for change. *Int. J. Dairy Tech*. **61**: 16-29.

Doyle, C. J. and J. G. Elliott. 1983. Putting an economic value on increases in grass production. *Grass and Forage Science* **38**: 169-177.

Drennan, M.J., and M. McGee. 2009. Performance of spring-calving beef suckler cows and their progeny to slaughter on intensive and extensive grassland management systems. *Livestock Sci*. **120**: 1-12.

Drennan, M.J., A.F. Carson and S. Crosse. 2005. Overview of animal production from pastures in Ireland. Pages 19-35 in Proceedings of XXth Int. Grassl. Congr., Cork, Ireland. Ed. J.J. Murphy. Wageningen Academic Publishers, Wageningen, the Netherlands.

Finneran E., Crosson, P., Shalloo L., Foristal D., O' Kiely P. and Wallace M. 2010. Simulation modelling of the cost of producing and utilising feeds for ruminants on Irish Farms. *Journal of Farm Management* (Accepted).

Jarrige, R. E. 1989. Ruminant Nutrition - Recommended allowances & feed tables. INRA.

Keady, T.W.J., J.P. Hanrahan and S. Flanagan. 2009. An evaluation of two grassland-based systems of mid-season prime lamb production using prolific ewes of two genotypes. *Irish J. Agric and Food Res*. **48**: 87-101.

Kelly E., Shalloo L., Geary U., Kinsella A. and Wallace M. 2010. An application of DEA to measure technical efficiency on a sample of Irish Dairy Farms. *Journal of Dairy Science* (Submitted).

McCarthy S., Horan, B., Dillon, P., Berry, D.P., O'Connor, P., Rath, M., L. Shalloo. 2007. Economic Comparison of Divergent Strains of Holstein-Friesian Dairy Cows in Various Pasture-based Production Systems. *Journal of Dairy Science* **90**: 1493-1505.

McEvoy M., O' Donovan M., and Shalloo L., 2010. The development and application of a economic ranking index for grass varieties. *Journal of Dairy Science* (Submitted)

NFS. 2010. National Farm Survey. Rural Economy Research Centre. Teagasc, Athenry.

O'Donovan, M. and E. Kennedy. 2007. Using grass to reduce feed costs. In Exploiting the freedom to milk, Teagasc National Dairy Conference, 2007, Ireland. Teagasc pp 63-80.

O'Donnell S., Shalloo L., Butler A.M. and Horan B. 2008. Opportunities, challenges and limitations on Irish Dairy farms. *International Journal of Farm Management*. **13**: 419-434.

Shalloo, L., P. Dillon, M. Rath, and M. Wallace. 2004a. Description and Validation of the Moorepark Dairy System Model. *Journal of Dairy Science* **87**: 1945-1959.

Shalloo, L., P. Dillon, J. O'Loughlin, M. Rath, and M. Wallace. 2004b. Comparison of a pasture-based system of milk production on a high rainfall, heavy-clay soil with that on a lower rainfall, free-draining soil. *Grass and Forage Science* **59**: 157-168.

Shalloo, L., S. O'Donnell, and B. Horan. 2007. Profitable dairying in an increased EU milk quota scenario. National Dairy Conference, Kilkenny 20-44.

Shalloo L. 2009. Pushing the barriers on milk production Costs/Outputs. National Dairy Conference 2009. Wednesday and Thursday 18th & 19th November, Mullingar and Killarney. Page 19-38.

Teagasc. 2008. Management data for farm planning. Teagasc, Oakpark.

Wilkins, P.W., and M.O. Humphreys. 2003. Progress in breeding perennial forage grasses for temperate agriculture. *Journal of Agricultural Science* **140**: 129-150.

Studies into the dynamics of perennial ryegrass (*Lolium perenne L.*) seed mixtures

T. J. Gilliland[1], D. Hennessy[2] and V. Griffith[2,3]
[1]Agri-Food Biosciences Institute, Plant Testing Station, Crossnacreevy, Belfast, BT5 7QJ, UK; [2]Animal & Grassland Research and Innovation Centre, Teagasc, Moorepark, Fermoy, Co. Cork, Ireland; [3]Queens University Belfast, Belfast, UK
Email: trevor.gilliland@afbini.gov.uk

Abstract

This study examined the dynamic interactions under simulated grazing and conservation managements of four perennial ryegrass seeds mixtures sold in Northern Ireland. Mixture composition was determined by phosphglucoisomerase isozyme frequency changes. Productivity was compared over four growing seasons with the component yields estimated from their yields in monoculture weighted for their proportion in the mixture. No significant differences were found between mixtures and these theoretical yields, but when regressed against the heading date span in each mixture, a significant relationship was observed. A wide range of heading dates between the components of the mixtures was associated with increased yield stability over years and with a declining yield advantage for the mixture over the weighted average yields of its component grown as monocultures. In this aspect, the mixtures showed a more rapid decline under conservation than simulated grazing. Mixtures also had a flatter seasonal yield production profile than their components. Tetraploid components were more aggressive than diploids, though a more open growing diploid maintained its proportion in the sward better than a dense growing type and manipulating the sowing ratios could be used to influence the final sward composition after two years. It was concluded that the differences in heading date range within mixtures had a significant impact on mixture dynamics, with the tetraploid component being the most aggressive.

Keywords: Perennial ryegrass, mixtures, yield, aggressiveness

Introduction

In the UK and Ireland, where perennial ryegrass (*Lolium perenne* L.) is the dominant grass used in reseeded pastures, most seed is sold as variety mixtures (Culleton and Cullen, 1992; Gilliland, Johnston and Connolly, 2007). Initially this practice was driven by the pragmatic logic that reproducing the botanical composition of the most productive natural pastures would deliver the highest grass yields. The earliest science-backed mixture recommendations came from Robert H. Elliot of Clifton Park, who first published his work under the title of 'Agricultural Changes' in 1898. This was subsequently reprinted several times with the fifth and final edition in 1943 (Elliot, 1943). This promoted complex compilations of grasses, legumes and deep rooted herbs. Furthermore, prior to the formation of the International Seed Testing Association in 1924 (Steiner Kruse and Leist, 2008; Gilliland, 2010), which formalised reliable standardised tests for seed quality in support of national statutory controls, sowing a mixture of several seed lots provided a degree of insurance against total seed failure.

Today, the primary driving factors to the continued predominance of seeds mixture use have been largely commercial. Compiling seeds mixtures affords merchants better price control and helps balance low supply and high demand for the newest varieties. Mixtures also facilitate the sale of residual seed of varieties that are becoming outclassed. They are more multi-customer suitable, with potentially a greater market size than for any single variety and create 'merchant brands' that attract customer loyalty. In harmony with this is the perception of farmers of an often loosely defined 'added value' in mixtures, including a belief that mixtures provide greater yield and adaptability under differing farm enterprises and environments (Ingram, 1997) than do mono-cultures. Some research has reported that mixtures never yield less than the means of the monocultures, and frequently mixture yields exceed those of the monoculture components (Simonds, 1962; England, 1968). However, other research (Donald, 1963; Woodford, 1966; McBratney, 1978; Culleton, Murphy and O'Keeffe, 1986) has reported that mixtures did not yield greater than the highest yielding component grown in monoculture and that most mixtures yield at a level between the monoculture components. Little evidence of 'under yielding' has been reported. Trenbath (1974) and Culleton *et al.* (1986) found that mixtures did not yield significantly lower than the monoculture components of the mixtures. Recently, grass and legume mixtures have been reported to result in transgressive overyielding, whereby the mixtures yielded greater than any of the individual components (Kirwin *et al.*, 2007; Connolly *et al.*, 2009; Nyfeler *et al.* 2009).

Research and development into the compilation and performance of grassland mixtures began as early as 1898 with the multi-species mixtures of Clifton Park and Cockle Park (Elliot, 1943). These proved to be well adapted to dry conditions (Greenaway and Budden, 1958; 1959), but in more moist soils and with breeding efforts in the 1950's focusing on the more palatable and higher yielding ryegrasses (*Lolium* spp.), mixtures formulas became dominated by perennial ryegrass (*Lolium perenne*). These often also included white clover (*Trifolium repens*) and for colder or heavy soil areas may include Timothy (*Phleum pratense*). Despite their wide spread use, peer reviewed studies into mixtures of perennial ryegrass varieties are surprisingly rare and very few are recent. While there is extensive published research into all aspects of perennial ryegrass/white clover mixtures (eg. Anon, 2009), even review books intended as definitive resources on all aspects of grassland science, frequently omit the topic of grass seed mixtures, for example those of Pearson and Ison (1997) and Barnes *et al.* (2007). Even when grass seed mixtures are considered, the content has been limited to reporting current practice supplemented by some general observations on productivity of different compilations. The overview by Ingram (1997) and the study by McBratney (1978) are typical examples. This has been because most previous investigations of perennial ryegrass mixtures have not examined the competitive ability of the components, but has restricted study to comparing the overall performance of mixed swards, such as those by Humphreys and O'Kiely (2006, 2007). The problem is that there is no simple morphological method of identifying the component varieties once mixed. Camlin (1981), attempted to resolve this by complex and arduous taxonomic examination of excised tillers from mixed swards, but it was not until techniques based on isozyme frequencies were developed (Kennedy *et al.*, 1985; Gilliland and Watson, 1987), was it possible to accurately ascertain the composition of a perennial ryegrass mixture in the growing sward. Since then a number of useful studies have been conducted using this approach (Quaite and Camlin, 1986; Gilliland, 1995; Hazard and Ghesquière, 1995), but these still comprise a relatively limited body of work. The current paper presents new data on perennial ryegrass mixture dynamics derived from commercial-in-confidence examinations of mixtures sold in Northern Ireland. The paper also reanalyzes some previously published data to elucidate aspects of the aggressivity relationships between certain variety types.

Materials and Methods

Examination of allozyme frequencies

Starch gel electrophoresis by the standardised method of Gilliland (1983) was performed on individual leaves of perennial ryegrass to determine the genotype frequencies of phosphoglucoisomerase, locus PGI/2. Sampling sizes for each mixture was calculated using the formula published by Kennedy *et al.* (1985), whereby the chi-squared differences between the mixture components determined the sample size necessary to achieve the same levels of accuracy as Kennedy *et al*. Mixture compositions were determined using maximum likelihood analysis as described by Gilliland and Watson (1987) to relate the genotype frequencies of the sampled mixture to those of the components in monoculture.

The heading date or mean date of ear emergence of perennial ryegrasses has been defined by Green, Carroll and Terry (1971) as being when 50% of the tillers show ear emergence. The heading dates used in the current study were those published on the DARD Recommended List (e.g. Gilliland, 2009).

Mixture studies

The results presented in this study are a compilation of two different mixture experiments. Unless otherwise indicated, all experiments were conducted at the Plant Testing Station, Crossnacreevy, Belfast, Northern Ireland (54° 33’ N, 5° 52’ W) on a medium loam soil, pH 6.0. Swards were established by broadcasting seed into 6.5 m plot areas at 22 or 33 kg/ha^{-1} for diploid and tetraploid varieties and mixtures, respectively and at 27.5 kg/ha^{-1} for diploid/ tetraploid mixtures. Plots were sown in July and experimentation commenced the following spring. Harvesting was by Haldrup plot harvester at a cutting height of 5 or 8 cm for simulated grazing or conservation managements, respectively. A compound fertilizer was applied to deliver 360 or 370 kg nitrogen (N)/ha for simulated grazing or conservation managements, respectively, plus adequate phosphate and potassium. The grazing and conservation managements were the standard UK National List procedures as described by Weddell, Gilliland and McVittie (1997) and Fera (2010). All component varieties were fully recommended on the recommended list for Northern Ireland (e.g. Gilliland, 2009).

Examination of productivity

This study involved a comparison between four commercial seeds mixtures sold in Northern Ireland, which contained different combinations of maturities and ploidies (Table 1) and their component monocultures. In all mixtures the diploid and tetraploid components were present as both intermediate and late varieties, so eliminating any maturity effect in comparisons between ploidies. The ploidy compositions of the mixtures were determined each year by the isozyme frequency method.

TABLE 1: Classification of components in four commercial seeds mixtures

Mixture Code	Maturity Groups	Ploidy Groups	No. Varieties Mixed	Heading Date Range	Heading Span (days)
Commercial 1	Intermediate: 50% Late: 50%	Diploid: 52% Tetraploid: 48%	4	18 May - 8 June	20
Commercial 2	Intermediate: 50% Late: 50%	Diploid: 3% Tetraploid: 37%	2	24 May - 6 June	13
Commercial 3	Early: 50% Intermediate 50%	Diploid: 71% Tetraploid: 29%	3	12 May - 19 May	7
Commercial 4	Intermediate: 100%	Diploid: 61% Tetraploid: 39%	2	24 May - 27 May	2

Note: mixture and variety names not provided due to confidentiality restriction

The four mixtures were yielded along with their components in monoculture plots, under both the simulated grazing and conservation management systems over four growing seasons. The simulated grazing yields were presented as total annual yields and also in the four seasonal periods of spring, early summer, late summer and autumn, as used on the DARD recommended list (Gilliland, 2009). Similarly for the conservation management, the yields were presented as the total annual yield and as the total 3-cut yields, which are the three silage making cuts in the management protocol (Weddell *et al.*, 1997). Both trials were a randomised block design of three replicates. Samples for electrophoresis were taken by point quadrant of the cut herbage, used on a first-hit basis, to reproduce the contribution of each component to the canopy, as performed by Kennedy *et al.* (1985). These proportions were used to calculate the theoretical yield for each mixture based on the yield of each component in monoculture times its proportion in the harvested herbage.

Examination of ploidy and density effects on composition

This study involved two parallel experiments, in which mixture reconstructions similar to Commercial 1 were compiled to examine the effects of the density of the diploid component and the effects of changing the sown proportions of the components on sward composition. The first experiment involved a comparison between a tetraploid variety and either an open growing or a dense growing diploid variety, all with the same maturity date (Table 2a). Density was defined as percentage ground cover of the sown species, converted to a 0-9 scale as described by Weddell *et al.* (1997) and Fera (2010). In this classification a value of 1.0 represents a very dense, usually prostrate growth habit and 6.0 is an open erect growth habit (tetraploids are all open and erect growing and a value of 5.0 is typical of varieties in commerce; Gilliland, 2009). Three different proportions of tetraploid to each diploid were constructed on the basis of seed weight, giving six different mixtures in a randomised block trial of four replicates under the simulated grazing management. The composition of the mixtures at each of four seasonal periods was determined during the second full growing season following sowing in July two years previously. Composition of the swards was determined on the basis of plants present, and not canopy content, in order to better examine effects of density on plant competition. This was achieved by sampling tillers, using a point quadrant to determine the nearest tiller to the point quadrant position on the ground and then examining the leaf of each selected tiller by the isozyme electrophoresis method. By sampling in the second year it was hoped that all the mixtures would have reached a stable end point. The second experiment involved establishing a five step replacement series between 90:10 and 10:90 proportions of the open diploid to the tetraploid in mixture (Table 2b). The experiment was again a three replicate randomised block design, managed under the simulated grazing regime and the final canopy proportions were sampled in the September harvest of the second full growing season (28 months after a July sowing).

Statistical analysis was carried out using one-way ANOVA for comparing between mixtures within treatments and two-way ANOVA for comparing mixtures across years and seasons (Genstat 8; VSN International Ltd., Hemel Hempstead, UK).

TABLE 2: Composition of reconstructed mixtures containing differ ploidy proportions

a) Comparing differences in diploid density

Mixture Code	Low Diploid Content	Medium Diploid Content	High Diploid Content	Sward Density (0-9 high)
Tetraploid	5%	10%	80%	5.2
Open Diploid	95%	90%	20%	6.0
Tetraploid	5%	10%	80%	5.2
Dense Diploid	95%	90%	20%	7.1

b) Comparing differences in sowing proportions

Tetraploid	10%	30%	50%	70%	90%
Open Diploid	90%	70%	50%	30%	10%

Results

The over-years mean yields of the four commercial mixtures are given in Table 3. They are compared with their theoretical yields, which were calculated from the monoculture yields combined in the proportions determined from the isozyme frequencies. Under the simulated grazing management (Table 3a) there were significant differences between the annual yields of the commercial mixtures, in both total annual and spring yields. Surprisingly, Commercial 3 was only significantly better than one of the other three mixtures, despite being the only one with early maturing components. If the theoretical yields were calculated on the basis of sowing frequency, there was an apparent small significant yield gain ($P<0.05$) for the mixtures in total annual yield, however, when the theoretical yields were corrected for the actual composition by isozyme frequencies, there were no significant differences.

A similar result was found for the conservation management when the over-years averages were compared (Table 3b). There were significant yield differences between the mixtures in both yield categories. Here again, however, while there was an apparent yield advantage for the mixtures when the yields of the monocultures were combined on a sown proportion basis, calculation of the actual proportions to give the theoretical yields showed no significant differences between each mixture and its theoretical equivalent.

TABLE 3: Four-year mean yields of commercial mixtures, including theoretical yields calculated from the component yields in monoculture plots

a) Simulated Grazing Management (spring yields include all growth to 30 April)

Mixture Code	Four-Year Mean Annual Yields (t/ha DM)	Theoretical Yield Comparison (%)	Four-Year Mean Spring Yields (t/ha DM)	Theoretical Yield Comparison (%)
Commercial 1	14.65	99	2.69	97
Commercial 2	14.13	101	2.72	103
Commercial 3	14.41	99	3.02	98
Commercial 4	14.27	100	2.78	100
Mean	14.37	99.5	2.80	99.5
s.e.	0.157		0.111	
Significance	*		*	

b) Simulated Conservation Management (spring yields include all growth to 30 April)

Mixture Code	Four-Year Mean Annual Yields (t/ha DM)	Theoretical Yield Comparison (%)	Four-Year Mean 3 Cut Silage Yields (t/ha DM)	Theoretical Yield Comparison (%)
Commercial 1	17.70	101	14.08	101
Commercial 2	18.41	103	14.67	103
Commercial 3	19.02	101	15.33	101
Commercial 4	17.75	95	14.06	94
Mean	18.83	100	14.54	99.5
s.e.	0.314		0.372	
Significance	***		*	

NS = non-significant; * = $P<0.05$; **= $P<0.01$; ***= $P<0.001$

Although the differences between the actual and theoretical yields for the individual mixtures were not significant, when the difference between the four-year mean simulated grazing yields of each mixture and its theoretical yield was regressed against heading date range, a clear relationship was observed. Figure 1 shows a clear and significant relationship, with very high correlation values of over 90% for both total and spring yields. The curvilinear relationship indicates that in this experiment there was a yield gain associated with a heading date span of up to 15 days, beyond which a deficit was recorded. A repeat of this analysis for the conservation management showed that a similarly strong and significant relationship existed with heading date range (Figure 2). In this case, however, differences in mixture yield compared to that expected of its components showed a much more rapid decline with increasing heading date range. In this experiment the break-even point appeared to fall between 5-10 days for both the total conservation yields and the 3-cut silage yields.

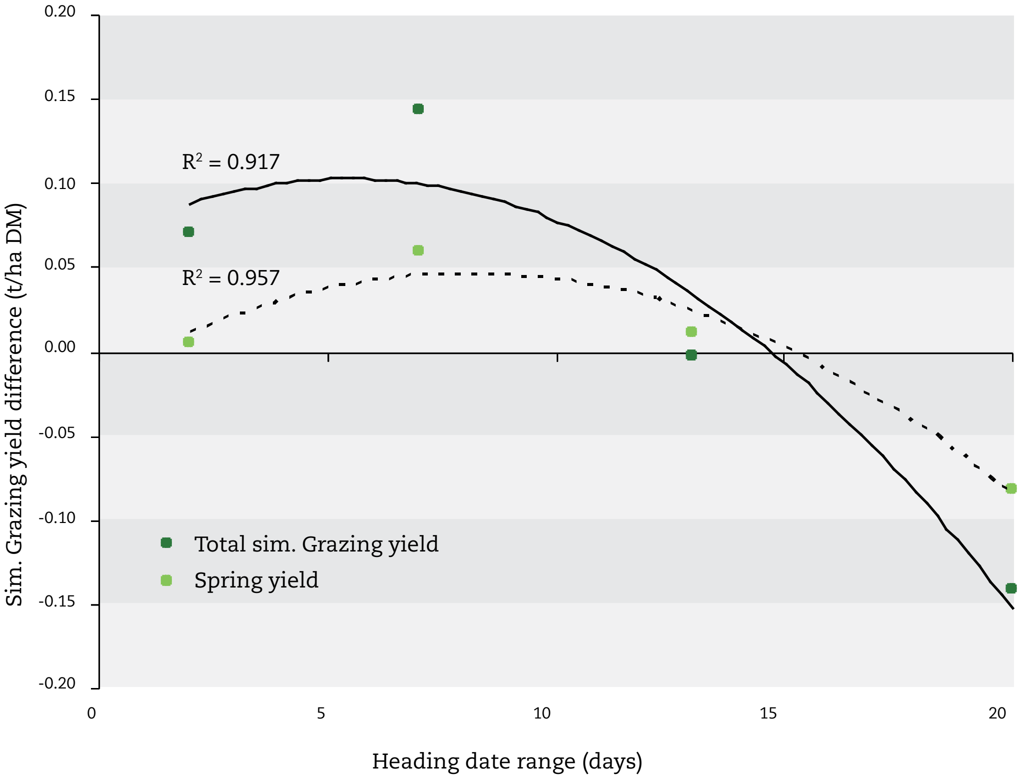


Figure 1: The difference in simulated grazing yields between mixtures with different heading date ranges and their components sown as monocultures

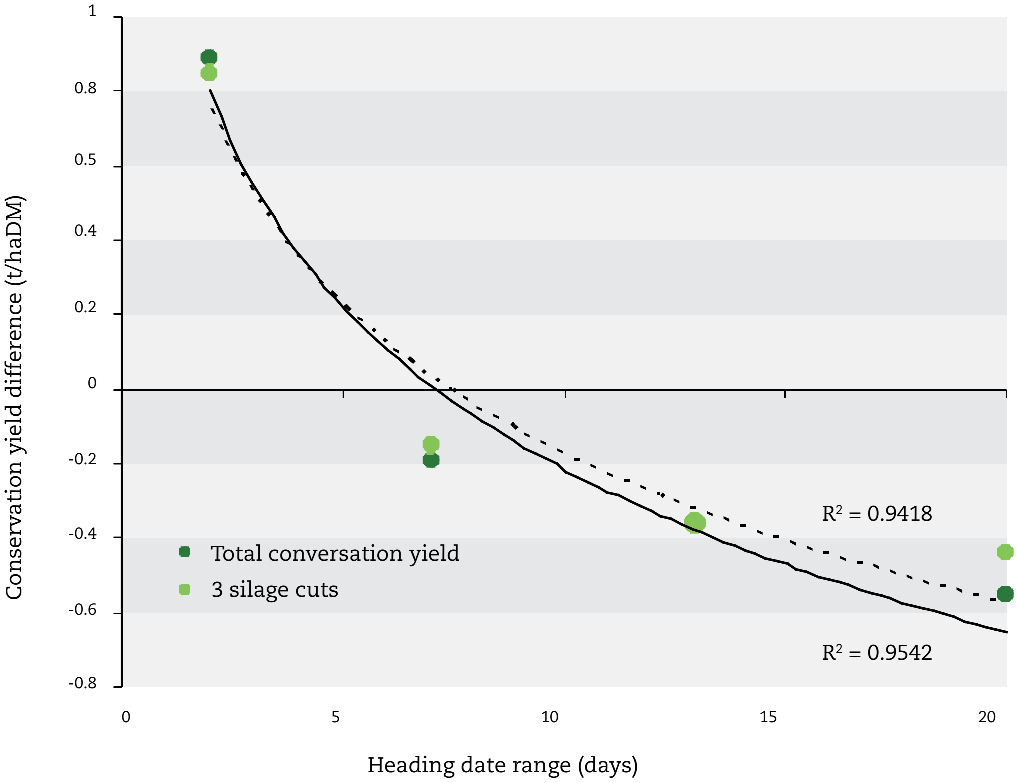


Figure 2: The difference in conservation yields between mixtures with different heading date ranges and their components sown as monocultures

When the annual variation in yield was examined under simulated grazing (Table 4), there were significant differences between years, and between mixtures within years. There was, however, relatively consistent ranking of the mixtures in each of the four years, with Commercial 1 generally highest and Commercial 2 lowest for total annual yields, and Commercial 3 again ranking highest for spring yields. It was not unexpected, therefore, that there was no correlation between heading date range and the variability of each mixture (calculated as the yield range across the four years as a percentage of the average yield). The R^2 values were only 0.0004 and 0.172 for total and spring yields, respectively, and these regression coefficients were non-significant. This was not an expected outcome of the experiment as the four mixtures had a large difference in their heading date range of between 2-20 days. The differences in the year-mean yields of the mixtures (Table 4a, 4b) represent an annual climatic variation that was over and above the variability between mixtures in any specific year. This was removed from the variability examination by standardising the yields in each year. This was achieved by adjusting the mean yield each year to match the 4 year mean yield across all four mixtures.

The same adjustment was then made to each mixture in each year. The variability for each mixture was, therefore, the range in yield across the four years, corrected for annual growth and expressed as a percentage of the four year mean yield. This removal of the climatic variation revealed a significant relationship between mixture yield variation and the range of heading dates in the mixture. Figure 3 shows that around 97% of the variation in total simulated grazing yield was associated with heading date, whereby the greater the range in heading the lower the annual variation in mixture yield. This relationship was curvilinear, with greatest response occurring below 10 days, with a much lower response thereafter. Spring yields were still not associated with the heading date range of the mixtures.

TABLE 4: Variability in simulated grazing yields of mixtures over four growing seasons

a) Total Annual Simulated Grazing Yields (t/ha DM)

Mixture	Harvest Years				Mean	Annual Variability (% of Mean)	Heading Range (days)
	First	Second	Third	Fourth			
Commercial 1	15.00	15.15	14.35	14.11	14.65	7.10	13
Commercial 2	14.60	14.86	13.57	13.47	14.13	9.84	20
Commercial 3	14.82	15.24	13.60	13.98	14.41	11.38	7
Commercial 4	14.03	15.13	13.88	14.04	14.27	8.76	2
Year Mean	14.61	15.10	13.85	13.90	14.37	9.27	
s.e.	0.218	0.182	0.237	0.354	0.175		
Significance	*	***	**	***	**		

b) Spring Yields (t/ha DM)

Mixture	Harvest Years				Mean	Annual Variability (% of Mean)	Heading Range (days)
	First	Second	Third	Fourth			
Commercial 1	2.61	3.05	3.40	2.94	3.00	26.3	13
Commercial 2	2.51	2.85	3.14	2.90	2.85	21.9	20
Commercial 3	2.89	3.28	3.33	2.91	3.10	14.2	7
Commercial 4	2.50	2.88	3.38	2.79	2.89	30.6	2
Year Mean	2.63	3.02	3.31	2.93	2.96	23.3	
s.e.	0.082	0.074	0.047	0.075			
Significance	*	***	**	***	**		

Variability for each mixture is its range in yield across the four years expressed as a percentage of its four year mean yield. NS = non-significant; * = $P<0.05$; **= $P<0.01$; *** = $P<0.001$

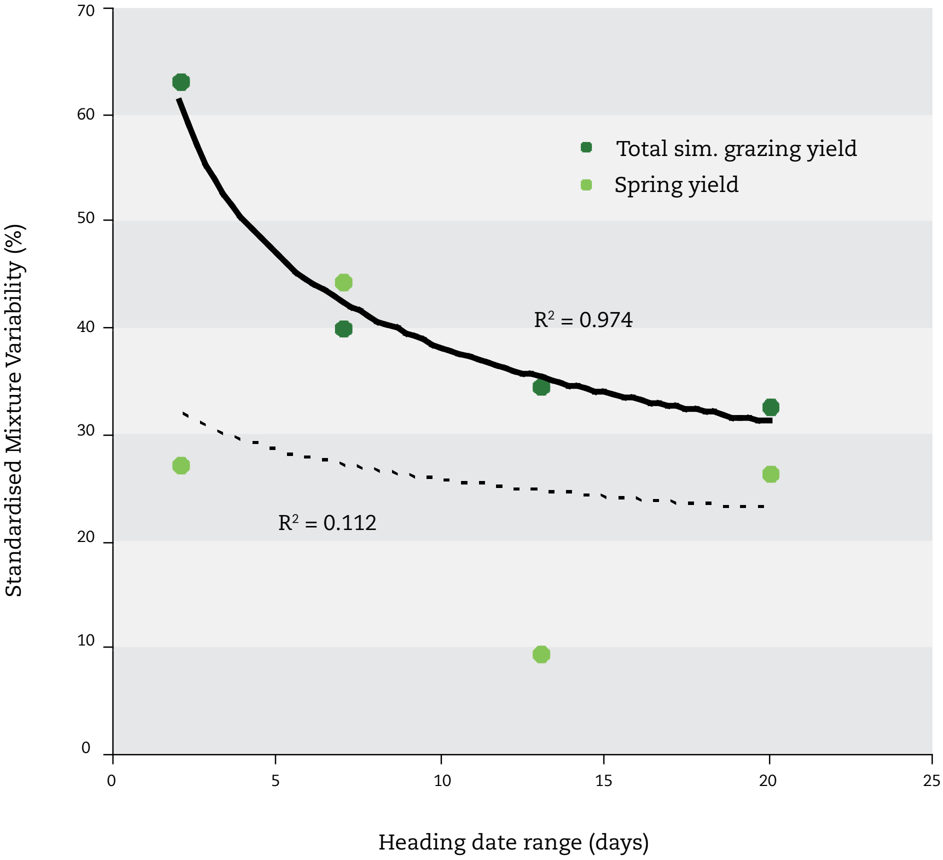


Figure 3: Relationship between the heading date range of commercial mixtures and their annual variation in yields, corrected for annual growing conditions, under a simulated grazing management

When the annual yield variability of the mixtures was examined under the conservation management, similar responses were found to that under the simulated grazing system (Table 5). Differences were again found between years and mixtures due to different growing year conditions, but again the ranking of mixtures was relatively consistent across the four years. In this case, Commercial 3 tended to be highest ranked in both categories with Commercial 1 and 4 being lowest for total annual yield and 3-cut yield, respectively. Examination of the relationship between mixture variability and heading range for the total annual conservation yield was greater than observed for the total grazing management, having an R^2 value of 0.261, but was again non-significant. When the 3-cut yields where regressed against the heading date range, however, an R^2 value of 0.625 was produced which indicated greater silage yield stability from year to year with wider heading date ranges. When these relationships were re-examined after standardisation for differences in annual growing conditions, as done for the simulated grazing results, a significant relationship was found to exist for both the total and 3-cut yields (Figure 4). For both these yield parameters, around 68% of the variation was associated with an increasing heading date range in the mixtures, and these two relationships showed less of a diminishing return at the wider heading ranges to that observed for the simulated grazing results.

TABLE 5: Variability in conservation yields of mixtures over four growing seasons

a) Total Annual Conservation Yields (t/ha DM)

Mixture	Harvest Years				Mean	Annual Variability (% of Mean)	Heading Range (days)
	First	Second	Third	Fourth			
Commercial 1	19.48	17.45	16.61	17.24	17.70	12.66	13
Commercial 2	19.97	18.51	17.81	17.35	18.41	14.23	20
Commercial 3	19.54	19.93	18.45	18.15	19.02	9.36	7
Commercial 4	19.29	17.97	17.81	15.91	17.75	19.05	2
Year Mean	19.57	18.47	17.67	17.16	18.22	13.83	
s.e.	0.517	0.456	0.417	0.404	0.410		
Significance	*	***	**	***	**		

b) Three-cut Silage Yields (t/ha DM)

Mixture	Harvest Years				Mean	Annual Variability (% of Mean)	Heading Range (days)
	First	Second	Third	Fourth			
Commercial 1	15.51	15.49	14.15	13.36	14.63	14.69	13
Commercial 2	15.82	15.24	14.13	13.50	14.67	15.75	20
Commercial 3	15.59	16.63	14.60	14.48	15.32	13.98	7
Commercial 4	15.33	14.69	13.93	12.29	14.06	21.59	2
Year Mean	15.56	15.51	14.20	13.41	14.67	16.50	
s.e.	0.344	0.350	0.245	0.194	0.410		
Significance	NS	***	*	***	***		

Variability for each mixture is its range in yield across the four years expressed as a percentage of its four year mean yield. NS = non-significant; * = $P<0.05$; **= $P<0.01$; *** = $P<0.001$

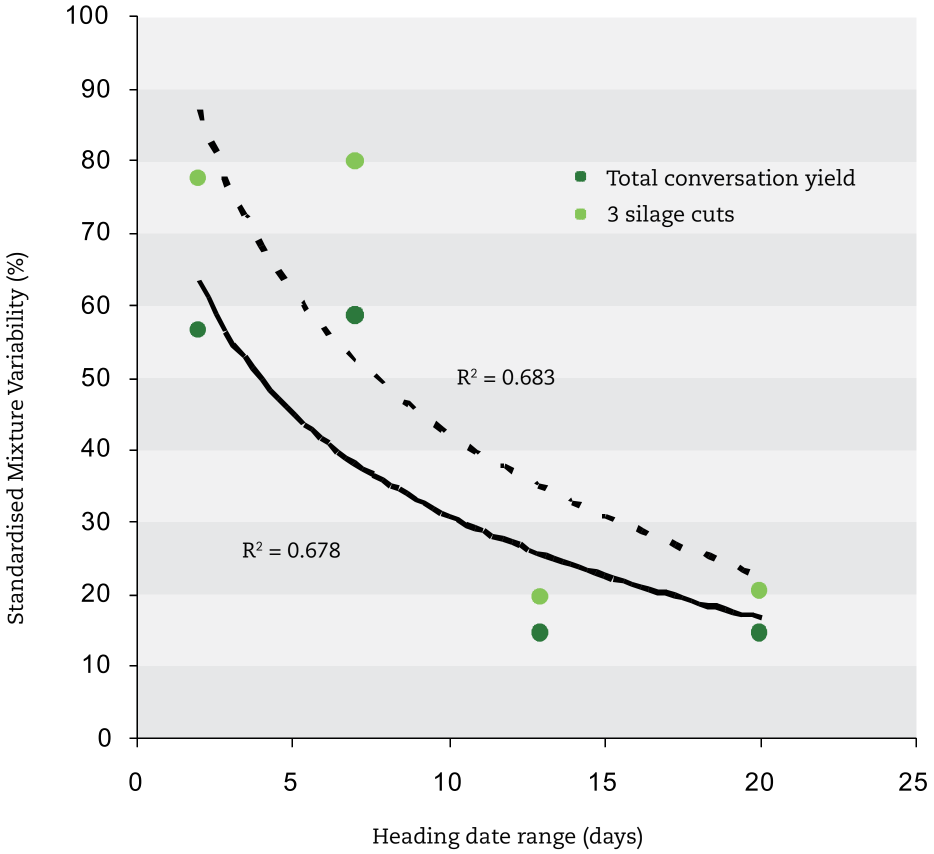


Figure 4: Relationship between the heading date range of commercial mixtures and their annual variation in yields, corrected for annual growing conditions, under a conservation management

A further aspect of mixture variability is summarised in Table 6, where the seasonal difference between each commercial mixture and its components are compared. The table shows the four-year mean difference between the highest and lowest yields produced by the components in the four seasonal growth periods of the simulated grazing management. This shows that over the four years, the components were more variable in seasonal distribution than the mixture that they formed. While there were some periods when the components were not significantly higher and/or lower than the mixtures, overall the mixtures had a flatter seasonal profile compared the maximum and minimum yields produced by the components grown in monoculture.

TABLE 6: Four-year mean seasonal yields of mixtures and the difference from the maximum and minimum yields of their components, under the simulated grazing management

Seasonal Periods	Spring	Early Summer	Early Summer	Autumn	4 Year Mean
Closure dates	30-Apr	30-Jun	31-Aug	31-Oct	
Commercial 1 yields (t/ha)	3.00	5.91	3.99	1.76	14.65
Component minimum	0.22	0.23	0.23	0.10	0.78
Component maximum	-0.27	-0.34	-0.25	-0.14	-1.00
Commercial 2 yields (t/ha)	2.85	5.85	3.77	1.65	14.13
Component minimum	0.32	0.37	0.79	0.21	1.69
Component maximum	-0.09	-0.34	0.11	0.04	-0.29
Commercial 3 yields (t/ha)	3.10	5.70	3.91	1.70	14.41
Component minimum	0.19	0.01	0.13	0.06	0.39
Component maximum	-0.08	-0.11	-0.14	-0.06	-0.39
Commercial 4 yields (t/ha)	2.89	5.78	3.91	1.70	14.27
Component minimum	0.07	0.11	0.16	0.00	0.33
Component maximum	-0.01	-0.12	-0.21	-0.04	-0.38
s.e.	0.049	0.073	0.075	0.052	0.175
Significance	**	*	*	NS	**

NS = non-significant; * = $P<0.05$; ** = $P<0.01$; *** = $P<0.001$

In the second study, which examined the effects of ploidy and density on composition, the results of the comparison between an open and dense growing diploid in mixture with a tetraploid are presented in Table 7. These results show that by the second full growing season, the tiller composition of both mixtures was relatively stable, with only small differences occurring between the seasonal periods. It was also clear that the tetraploid remained the dominant component and that the sowing densities of 2, 4 and 6 kg/ha had little or no influence on the final sward composition after two full growing seasons. There was, however, a significant difference between the open and dense diploids as there was around 10% more of the erect growing diploid in the mixtures than the dense type.

TABLE 7: Ground tiller proportions of diploid and tetraploid components in two mixtures

Diploid Sown (kg/ha)	Tetraploid Sown (kg/ha)	Tetraploid %	Tetraploid proportions in seasonal growth periods				Mean
			Spring	Early Summer	Late Summer	Autumn	
	Closure dates:		30-Apr	30-Jun	31-Aug	31-Oct	
Open Growing Diploid							
2	33	94.3	0.75	0.77	0.62	0.66	0.70
4	31	88.6	0.68	0.59	0.57	0.66	0.62
6	29	82.9	0.66	0.79	0.74	0.55	0.68
		Mean	0.70	0.72	0.64	0.62	0.67
Dense Growing Diploid							
2	33	94.3	0.75	0.96	0.74	0.79	0.81
4	31	88.6	0.83	0.77	0.89	0.77	0.81
6	29	82.9	0.78	0.91	0.76	0.74	0.80
		Mean	0.79	0.88	0.80	0.77	0.81
s.e.					0.062		
Significance					***		

*** = P<0.001

The second experiment involved establishing a replacement series of between 90:10 and 10:90 proportions of the open diploid to the tetraploid in mixture (Table 8). Here again the tetraploid was the dominant component, though in all cases there was a realignment of the mixtures to various extents towards a more equal composition of the two components. The only exception was the 50:50 sowing which drifted towards a more tetraploid dominant sward than sown. In contrast, the 70% diploid to 30% tetraploid mixture came closest to producing an even 50:50 composition after two years. Unlike the previous experiment there were still significant differences at the end of two years between the compositions of the mixtures in association with the sowing ratios. This was largely due to the wider range in ratios examined. In the previous experiment, while the diploid inclusion was increased in a doubling series, the content of the tetraploid was still between 80-95%. Comparing this to the replacement series study shows that for the most similar 90:10 tetraploid/diploid mixture the final composition of around 75% was in between the results for the open and dense mixture results.

TABLE 8: Effect of sowing ratios on the final sward composition after two full growing seasons

Diploid					
Sown %	90	70	50	30	10
Measured %	67.8	43.2	35.0	34.0	25.4
% Change	75	38	30	13	154
Tetraploid					
Sown %	10	30	50	70	90
Measured %	32.2	56.8	65.0	66.0	74.6
Percentage Change	322	89	30	6	17
s.e.			0.42		
Significance			***		

Discussion

It is a widely held belief in farming circles that mixtures express a synergism. This is not contrary to scientific principles, as it has long been purported that complex ecosystems should be more efficient in capturing and utilizing available environmental resources than less complex ones (Harper, 1967). More recently Kirwan *et al.* (2007) and Connolly *et al.* (2009) have reported increased biomass productivity with increased number of pasture species. This work, which included the important temperate grasses and legumes in Europe, reported mixture yields in excess of any of the components grown in monoculture. Similar to Culleton *et al.* (1986), the current study did not achieve this degree of yield enhancement. Although calculating the expected mixture yield from the monoculture yields of the components as a weighted average based on sowing proportion did show an apparent yield gain, this was incorrect. This was expected as several workers (Gilliland, 1995; Hazard and Ghesquière, 1995; Quaite and Camlin, 1986; Rhodes, 1970) have shown that the composition of ryegrass mixtures is not fixed at sowing and so these changes must be accounted for when calculating expected yields. The use of isozyme frequencies to determine the actual composition of components in the sward brought the expected and actual yield back into close agreement. So the mixtures did not out yield their components. Moreover, the mixtures were not even higher yielding than the expected mean of the components in monoculture. It is possible that as the mixtures in the current study were combinations of varieties from the same species they may not implement the degree of complexity present in the previous studies. It is notable that Nyfeler *et al.* (2009) observed that diversity effects needed to be sufficiently high for mixture performances to exceed that of the best monocultures present in that mixture. Furthermore Rhodes (1970) found over-yielding to occur in perennial ryegrass mixtures, but only under a conservation management, not under simulated grazing, and in only two of eleven mixtures studied. Moreover, it did not occur in the more complex mixtures with three or four components, but only in binary mixtures. McBratney (1978) also found no synergistic responses in a range of perennial ryegrass mixtures with differing combinations of maturities, compared to their monoculture yields. These studies would tend to support the supposition that increasing the number of perennial ryegrass varieties in a mixture did not introduce the degree of complexity necessary to create the over-yield responses recorded elsewhere.

The one characteristic of the perennial ryegrass cultivars that was associated with differential mixture performance was the heading date range in the mixtures. It was interesting to note the different responses of the mixtures under the two different managements. This was likely to have been driven by the key role of the large silage cuts in the conservation management. These are highly influenced by the interaction between heading date and timing of cut, whereby the earlier heading component is most aggressive at the first cut and weakest at the second cut, with a decline in overall aggressivity at the third cut (Gilliland, 1995). This publication reported that the greater the range in heading date the greater the competitive interactions between the mixture components. This would explain why the association between the total and 3-cut silage yields were so similar. These changing competitive hierarchies that increase with greater heading date range, could also explain the tendency for mixture yields to fall below the theoretical prediction if the heading span of the mixture was greater than around seven days. In contrast, the relationship between simulated grazing yield differences and heading date range showed a tendency to remain or rise slightly until the heading span was around 15 days. This different response pattern can be interpreted as a consequence of the management imposed. The simulated grazing management does not involve the accumulation of such large yields in the May-June period, when reproductive growth is predominant, as occurring with the conservation management. Therefore, there must be a lower level of competitive pressures between components, which is interrupted more frequently by defoliation.

The wider the heading date range between the components was also found to be associated with increased yield stability over years and the mixtures were also less reactive to growing conditions at the different seasonal growth periods. Greater annual stability would be advantageous for grassland management and may also indicate a wider climatic tolerance, which supports the popular belief that ryegrass mixtures have a wider geographical range for peak performance than monocultures (Ingram, 1997). The lower response to seasonal growing conditions compared to the best monoculture component is clearly advantageous. Dillon *et al.* (2002) have demonstrated clear advantages for increased grazed grass in the diet of cows in spring, making productivity in spring potentially the most valuable of the year. The current study indicates that any perennial ryegrass mixture will have a diluting effect, failing to achieve the biological potential of the most spring productive component.

The competitive interactions in the two diploid/tetraploid sowing rate studies were generally in good agreement. In both studies, the tetraploid component was the more aggressive, both when plants were sampled on the basis of tiller presence and on canopy composition. As Charles (1961) showed that competition between grass plants can result in as little as 20% seedling survival two months after sowing and as few as 10% after twelve months, it is likely that competition for space was entirely completed after two years. So these mostly tetraploid dominant mixture compositions should now be stable, at least in terms of plant to plant competition. The competitive advantage for the tetraploid was not maturity influenced as the components all had the same heading date, but could be related to canopy structure. For example, tetraploid perennial ryegrasses have longer leaves and it is notable that Hazzard and Ghesquière (1995) found that this gave a competitive advantage in ryegrass mixtures cut to a similar frequency as the current study. This would also explain the competitive advantage of the more open growing diploid compared to the dense growing one, because the open growing diploid was an erect growing type with longer leaves.

The overall conclusion from these mixture studies is that while component interactions can be complex and not easily observed, the use of isozyme frequencies to determine the actual compositions at the time of examination is a valuable asset which assists in exposing the influence of specific parameters on the competitive interactions. As the current study only involved examination of four mixtures, it is possible that the results may express some degree of specificity to these compilations, and this should not be ignored. Nonetheless, the productivity responses and hierarchies identified are likely to operate in other ryegrass mixtures, and even if this is at different magnitudes, this study provides a valuable basis for further and more detailed experimentation.

References

Anon. 2009. Forage legumes in temperate pasture-based systems. *Irish Journal of Agricultural and Food Research*, **48**: 115-281.

Barnes, R. F., Nelson, C. J., Moore, K. J. and Collins, M. 2007. Forages: The Science of Grassland Agriculture, 6th Edition, Vol II, Wiley-Blackwell, 2007 – pp: 791.

Camlin, M. S. 1981. Competitive ability of cultivars of perennial ryegrass (Lolium perenne L.). In Plant Physiology and Herbage Production (ed. C. E. Wright). *Occasional Symposium No. 13, British Grassland Society*, Pp. 137-142.

Charles, A. H. 1961. Differential survival of cultivars of *Lolium*, *Dactylis* and *Phleum*. *Journal of the British Grassland Society*, **16**: 69-75.

Connolly, J., Finn, J. A., Black, A. D., Kirwan, L., Brophy, C. and Luscher, A. 2009. Effects of multi-species swards on dry matter production and the incidence of unsown species at three Irish sites. *Irish Journal of Agricultural and Food Research*, **48**: 243-260.

Culleton, N, Murphy, W.E. and O'Keeffe, W.F. 1986. The role of mixtures and seeding rates in regrass productivity. *Irish journal of Agricultural Research*, **25**:229-306.

Culleton, N. and Cullen, T. 1992. Trends in herbage seed use in Ireland. *Plant Varieties and Seeds,* **5**: 63-69.

Dillon, P., Crosse, S., O'Brein, B. and Mayes, R. W. 2002. The effect of forage type and level of concentrate supplementation on the performance of spring-calving dairy cows in early lactation. *Grass and Forage Science*, **57**: 212-223.

Donald, C.M. 1963. Competition among crop and pasture plants. *Advances in Agronomy*, **15**: 1-18.

Elloit, R. H. 1943. The Clifton Park system of farming and laying down land to grass. Fifth edition published by Faber and Faber Limited, London.

England, F. 1968. Competition in mixtures of herbage grasses. *Journal of Applied Ecology*, **5**: 227-242.

Fera. 2010. The Food and Environment Research Agency web site – VCU Procedures for Grasses (Perennial, Italian and Hybrid Ryegrass, Timothy and Festulolium) (200 KB) www.fera.defra.gov.uk/plants/plantVarieties/nationalListing/documents/protocolGrasses.pdf. Accessed 25 July 2010.

Gilliland, T.J. 1983. Identification of ryegrass cultivars by classification of PGI allozymes/genotypes. *Proceedings of an International Seed Testing Association Symposium on biochemical tests for Cultivar Identification*, NIAB Cambridge, p 85-95.

Gilliland, T.J. and Watson, S. 1987. Study of complex Lolium cultivar seed mixtures by maximum likelihood analysis of isozyme frequencies. *Proceedings of the II International Seed Testing Association Symposium on Biochemical Identification of Varieties*, Leningrad, p 1-8.

Gilliland T. J., Johnston J. and Connolly C. P. 2007. A review of forage grass and clover seed use in Northern Ireland. *Grass and Forage Science,* **62**: 1-8.

Gilliland, T. J. 1995. Effect of Harvest Date and Cultivar Maturity on the Composition of Perennial Ryegrass (*Lolium perenne* L) Mixtures. *Irish Journal of Agricultural Research*, **34**: 143-150.

Gilliland, T. J. 2009. Department of Agriculture and Rural Development, Recommended Grass and Clover Varieties for Northern Ireland 2009/10, ISBN 978-1-84807-120-9 pp: 33.

Gilliland, T. J. 2010. Control of cultivar release and distribution. In: Handbook of Plant Breeding, Volume 5: Fodder Crops and Amenity Grasses. Boller, B., Posselt, U. K. and Veronesi, F. (eds.), Springer Science & Business Media B.V. 2010, XI, 523 p., ISBN: 978-1-4419-0759-2.

Green, J. O., Corrall, A. J. and Terry, R. A. 1971. Grass species and varieties: relationships between the stage of growth, yield and forage quality. GRI Technical Report, No. 8. Hurley, UK, The Grassland Research Institute.

Greenaway, T. E. and Budden M. 1958. A Discussion on the Influence of Relative Moisture Availability on the Swards Resulting from Standard Grass Seeds Mixtures, I. Mixture of the cockle park type. *Grass and Forage Science,* **13**: 222 - 228.

Greenaway, T. E. and Budden M. 1959. A Discussion on the Influence of Relative Moisture Availability on the Swards Resulting from Standard Grass Seeds Mixtures, 2. Swards produced from a cocksfoot/timothy/meadow-fescue mixture. *Grass and Forage Science,* **14**: 117 - 123.

Harper, J. L. 1967. A Darwinian approach to plant ecology. *Journal of Ecology*, **55**: 247-250.

Hazard, L. and Ghesquière, M. 1995. Evidence from the use of isozyme markers of competition in swards between short-lived and long-leaved perennial ryegrass. *Grass and Forage Science*, **50**: 241-248.

Humphreys J. and O'Kiely P. 2006. Amount and quality of grass harvested for first-cut silage for differing spring-grazing frequencies of two mixtures of perennial ryegrass cultivars with contrasting heading date. *Grass and Forage Science*, **61**: 77-88.

Humphreys J. and O'Kiely P. 2007. Effects of two mixtures of perennial ryegrass cultivars with contrasting heading dates, and differing in spring-grazing frequency and silage harvest date, on characteristics of silage from first-cut swards. *Grass and Forage Science*, **62**: 389-404.

Ingram, J. 1997. Some theoretical aspects of mixtures. p: 176-188. In: Seeds of Progress, (Ed. Weddell, J.R.), British Grassland Society Occasional Symposium No. 31, 1997, ISBN 0905944496, pp237.

Kennedy, S. J., Gardiner, S. J., Gilliland, T. J. and Camlin M. S. 1985. The use of electrophoretic techniques to distinguish perennial ryegrass cultivars when sown in mixtures. *Journal of Agricultural Science*, **104**: 1-9.

Kirwan, L., Luscher, A., Sebastia, M. T., Finn, J. A., Collins, R. P., Porqueddu, C., Helgadottir, A., Baadshaug, O. H., Brophy, C., Coran, C., Dalmannsdottir, S., Delgado, I., Elgersma, A., Fothergill, M., Frankow-Lindberg, Golinski, B. E., Grieu, P., P., Gustavsson, A. M., Hoglind, M., Huguenin-Elie, O., Iliadis, C., Jorgensen, M., Kadziuliene, Z., Karyotis, T., Lunnan, T., Malengier, M., Maltoni, S., Meyer, V., Nyfeler, D., Nykanen-Kurki, P., Parente, J., Smit, H. J., Thumm, U., and Connolly, J. 2007. Evenness drives consistent diversity effects in intensive grassland systems across 28 European sites. *Journal of Ecology* **95**: 530-539.

Nyfeler, D., Huguenin-Elie, O., Suter, M., Frossard, E., Connolly J. and Luscher, A. 2009. Strong mixture effects among four species in fertilized agricultural grassland led to persistent and consistent transgressive overyielding. *Journal of Applied Ecology*, **46**: 683-691.

McBratney, J. M. 1978. Production of perennial ryegrass cultivars of different maturity types when grown as pure swards and in certain combinations. *Grass and Forage Science*, **33**: 283-288.

Pearson, C. J. and Ison, R. L. 1997. *Agronomy of Grassland Systems. (Second Edition)*. Cambridge: Cambridge University Press 1997, ISBN 1-57808-005-3, pp. 222.

Quaite, E. and Camlin, M. S. 1986. The use of electrophoretically labelled populations for intra-specific competition studies in perennial ryegrass (*Lolium perenne* L.) swards. *Journal of Agricultural Science*, **106**: 99-106.

Rhodes, I. 1970. The production of contrasting genotypes of perennial ryegrass (*Lolium perenne* L.) in monocultures and mixed cultures of varying complexity. *Journal of the British Grassland Society*, **25**: 285-288.

Simmonds, N. W. 1962. Variability in crop plants, its use and conservation. *Biological Review of the Cambridge Philosophical Society*, **37**: 442-465.

Steiner M.A., Kruse M. and Leist N. 2008. ISTA method validation 2007: a historical retrospect. *Seed Testing Internal*, **136**: 30-33.

Trenbath, B. R. 1974. Biomass productivity of mixtures. *Advances in Agronomy* **26**: 177-210.

Weddell, J.R., Gilliland, T.J. and McVittie, J. 1997. Evaluation Procedures: Past, Present and Future. p: 202-225. In: Seeds of Progress, (Ed. Weddell, J.R.), British Grassland Society Occasional Symposium No. 31, pp2371997, ISBN 0905944496.

Woodford, E. K. 1966. The need for a fresh approach to the place and purpose of ley. Journal of the British Grassland Society 21: 109-115.

A Review of the Procedures and Priorities for Marketing of Improved Ryegrass Varieties

D. Long[1] and T. J. Gilliland[2]
[1]*Barenbrug UK Ltd, 33, Perkins Road, Rougham Ind.Est., Bury St Edmunds IP30 9ND;*
[2]*Agri-Food Biosciences Institute, Plant Testing Station, Crossnacreevy, Belfast, BT5 7QJ, UK*
Email: DLong@baruk.co.uk

Abstract

This paper describes the commercially orientated logistics for creating, evaluating and marketing a new perennial ryegrass variety by a modern grass breeding company. Details are provided of how a successful grass breeding business involves expertise in all the processes from devising market-aware breeding goals capable of addressing future requirements of the ruminant farming sectors for grass based diets, to delivering certified seed on-farm. The processes and commercial strategies necessary in recouping the costs of developing a new variety were estimated to be in the order of €600,000 and can take 16 years from initial cross to the first seed being released for sale. The source of these costs and timeframe were shown to result from the requirements for extensive regional testing of large numbers of early generation material by the breeder, plus the costs of the obligatory official national and advisory recommended list testing programmes, followed by several generations of seed multiplication and final marketing investments. Additionally, much less than one percent of the material bred successfully passes the breeders initial screening and selection processes, plus all the national and regional recommended list requirements necessary to enter the market place. The accumulative effect of all these factors was that commercial priorities were influential at all stages of the breeding process such that breeding an elite performing variety was not a success unless the market it supplied could support a annual minimum sale in the order of 50 tonnes of seed.

Introduction

Plant breeding is unquestionably a highly specialist scientific discipline, requiring scientists with expertise in plant genetics, physiology, ecology and also agronomy, for agricultural crops (Boller *et al.*, 2010). With recent developments in plant genomics, expertise in molecular biological techniques has also become increasingly important. While amateur breeders do exist, mostly in niche ornamental or vegetable species, the costs of maintaining a breeding programme in any important agricultural or amenity species is such that only specialist breeding companies of a significant size can successfully maintain a profitable business. Public sector breeding programmes do also exist, but most governments only support the early development phases of the breeding with the 'near-market' phases transferred to the private sector. There are currently three such public/private partnerships in the UK and Ireland for perennial ryegrass breeding. These are the Agri-Food and Biosciences Institute (AFBI) programme at Loughgall, Northern Ireland, the Institute of Biological, Environmental and Rural Sciences (IBERS, Aberystwyth University) programme at Aberystwyth, Wales and the Teagasc programme at Carlow, Ireland. They each have private sector partners; Teagasc with DLF Trifolium of Denmark and AFBI with Barenbrug BV from the Netherlands. The IBERS programme is partnered with Germinal Holdings Ltd in the UK.

Similar to any business survival and growth in a competitive market place depends as much on the commercial planning and controls as the quality of the product produced. One will not succeed without the other. This is particularly true of breeding grass varieties as the margins over costs are reputably smaller than for virtually any other major agricultural species. This paper details the logistics in the processes from initial breeders crosses to the eventual provision of seed for sale. In doing so it demonstrated that commercial expertise in all phases of the breeding, multiplication and distribution of new grass varieties is an essential business process.

Commercial goals for grass breeding programmes

Any modern grass breeding programme must be profitable to survive and so cannot be solely driven by a breeder's skill in creating novel genetics. While the cost of developing a new perennial ryegrass variety will vary depending on the size and objectives of the breeding programme, a total cost in the order of €600,000, would not be unusual. Breeding programmes must, therefore, be totally focused on the requirements of the market place. It also means that a large market volume is required to cover such a high investment. While thresholds may differ between companies an annual sales volume of around 50 tonnes is typically the minimum required to justify developing and maintaining a variety. This normally means that the variety must satisfy a diversity of differing enterprises and farmer requirements, or perform the same role in a range of different environments. Unless a variety captures a dominant position in a large national market this frequently means being successful in more than one country. This is not restricted to only the European markets, but increasingly commercial teams are seeking to develop sales on a global scale and for perennial ryegrasses this means temperate zone markets such as those in New Zealand and the American continent, north and south. So the annual review and planning of breeding strategies is based on a partnership between the breeder, the local and international marketing teams and various other company specialists dealing with the submission of varieties to official testing programmes in different countries, multiplication of seed and control of financial matters

The breeding and developing of new grass varieties is also a long and intricate process. From the initial cross, through all the evaluation and seed multiplication processes, to finally having a product to supply to the end user takes around 16 years (Figure 1). The major challenge in developing commercial targets is, therefore, to forecast what will be required in 16 years time. This involves taking account of many often unrelated factors such as predicting

- How national and international government policies may develop. Currently, these are concentrated on reversing the effects of Climate Change and protecting the environment from damage through nutrient management initiatives. In response to this, breeding companies are making foresight decisions based on factors such as whether governments will promote greater use of pasture land for biofuels, bio-energy and biorefining, or will they prioritise control of methane emissions as a key environmental improvement target for grassland based production within the food supply chain?

- How might the ruminant industry evolve in the future? Will sufficient farmers in the dairy, beef and sheep sectors of different countries want to progress to low input systems or organic systems or extended grazing or zero-grazed systems, or any other novel enterprise requiring the breeding of specialist varieties?

- What standards and attributes will variety testing authorities require of new varieties in the future to achieve listing? Currently there are increasing requirements for improved digestibility, but will other nutritional parameters such as water soluble carbohydrate, protein profile, fatty acid composition or any other novel characteristic become essential in the future?

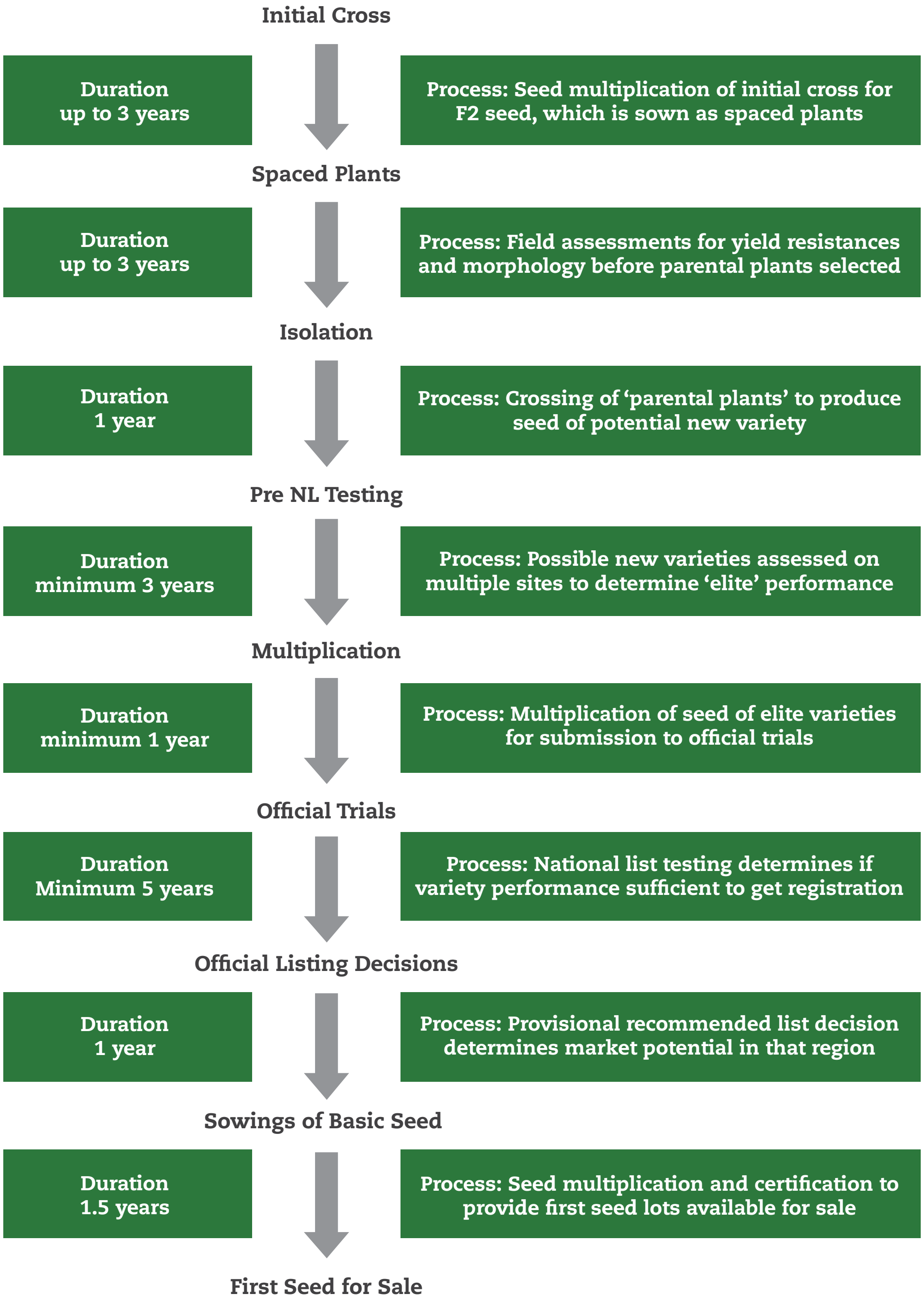


Figure 1: Example timeframe and stages in the creation of a variety from the initial cross to the offered for sale

- How might Climate Change affect how the current varieties perform in the future? Will breeding for enhanced resistance to drought, salt tolerance, winter kill, diseases and pests become more important, and in what regions/countries within Europe and globally?
- What will be the consumers and governments' attitude to GM varieties in the future?
- What are the gaps and deficiencies in the current portfolio of grass varieties that are failing to fully satisfy current market requirements?
- How long are the varieties that the company is currently selling expected to remain on the various recommended lists of different countries? What level of performance will be required to get replacement varieties listed in the future?
- What are the competitive pressures from other breeders likely to be?

Typical of any forecasting process this is a highly inaccurate discipline and so it is necessary to maintain as responsive a breeding programme as possible. For example the breeding of early perennial ryegrasses has largely stopped as a primary goal. This is not because breeders are unable to further improve early maturing varieties, but is totally driven by market forces. The market for early perennial ryegrasses is currently very small, probably no more than a few percent of seed usage across Europe and has been declining for many years, as recorded by Gilliland *et al*. (2007) for Northern Ireland (Figure 2) and for the Republic of Ireland by Culleton and Cullen (1992). With such low usage the commercial decision has been taken in virtually every grass breeding company to prioritise the creation of intermediate and late varieties. This is despite Dillon *et al*. (2002) having demonstrated clear advantages for increased grazed grass in the diet of cows in spring, and studies such as that of Marsh (1975) showing a clear advantage for spring grass to beef production compared to autumn grass. Consistent with this is that many farmers regard early spring grass as very valuable but reject early maturing varieties, which are the best way of producing herbage in the early season, due to perceived problems with mid-summer steminess. Although a number of scientific studies have demonstrated methods for offsetting this problem (Holmes *et al*., 1983; Kennedy *et al*., 2006), sales remain low. The marketing dilemma is what to do if an early maturing variety of high quality and low secondary stem regrowth does come from the breeding programme. Should the breeding company commit substantial funds for National List (NL) testing and then investing in multiplying seed in the hope of creating market interest? Failing to get a sufficient market volume could result in significant financial losses, but to discard the variety could deny farmers an important advantage for their grass-based enterprise and a potential niche market for the company. Despite scientific evidence that productivity in spring is potentially the most valuable of the year (Dillon *et al*., 2002; O'Donovan and Delaby, 2005), market forces would probably prohibit the development of such an early variety by most breeding companies, purely on an economics basis.

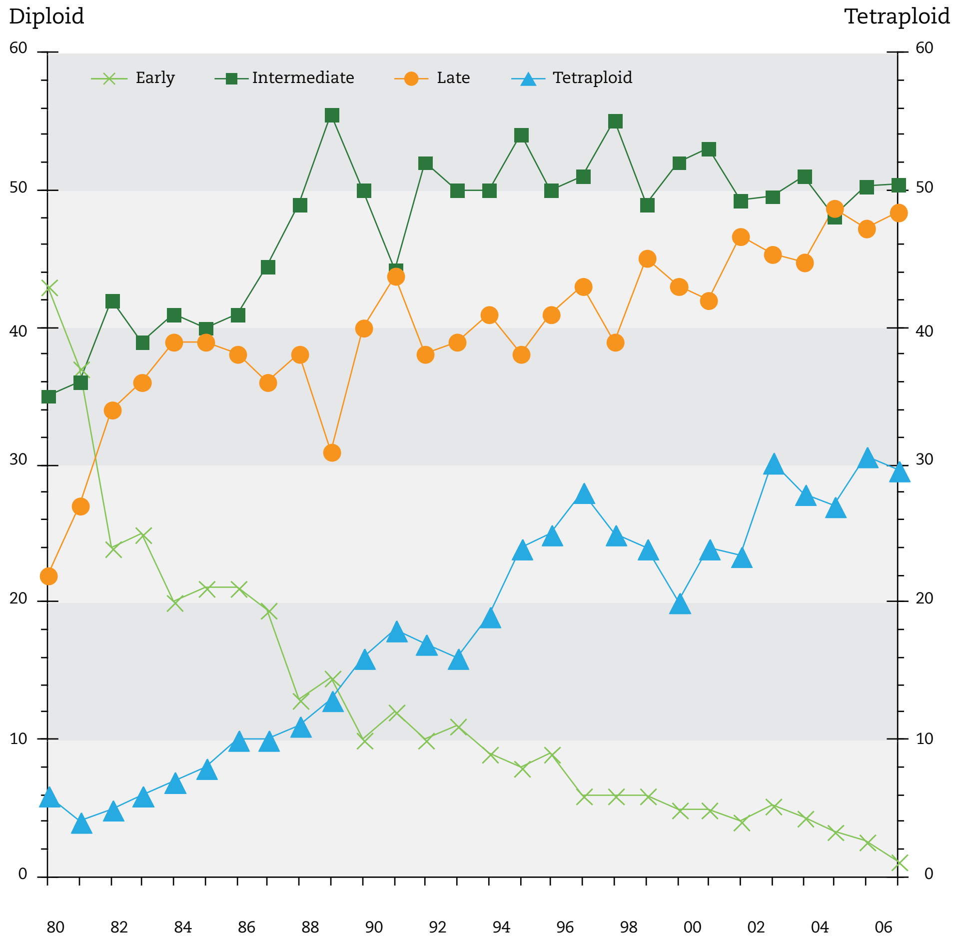


Figure 2: Change in sales of perennial ryegrass ploidy and maturity groups in Northern Ireland

Finding varieties with commercial potential

While a company might have very clear and precise commercial objectives, it is an unavoidable fact that the breeding process has a fairly high degree of uncertainty. High quality parent lines do not guarantee elite progeny, but normally produce a lot of plants that are broadly similar or poorer than the original parents and only a precious few that are significantly better. The challenge is to find those rare special plants that, when combined, create seed of a new variety with an exception performance profile. What makes this more difficult is that performances will differ in different growing seasons and locations. So where the breeding is carried out can be very important. There is grass breeding activity in most European countries, either commercially or government funded, or a combination of both, with the primary aim of breeding varieties that are adapted to local conditions for use by their farmers. As already discussed, given the high development cost a local market may not be sufficient and while it is valuable to conduct the breeding close to the market, commercial pressures require the possibility of success in other markets to be evaluated.

There is no certainly that a successful variety in one location will perform well in different climatic conditions, as reviewed by Talbot (1984). This is particularly the case where severe frost or low rainfall or disease pressure differences depress the growth potential of some genotypes but not others. Unfortunately, this means that performances derived at the breeding site in one location cannot be used to predict potential in another region, as these adaptations to various climatic and disease pressures can be complex and region specific. For this reason conducting trials on early generation material is one of the processes that adds greatly to the high investment cost of the breeding programme. So strategies are employed to optimise the chances of success. Barenbrug uses the Lucerne dormancy zones, which splits the world into nine zones; these are a combination of annual minimum and maximum temperatures, and rainfall. There are seven zones within Europe (Table 1). Within a zone, varieties have sufficient possibility of being sufficiently adapted that testing of breeding lines is a good investment of resources. Committing funds to test varieties bred in an adjacent zone is less likely to be successful, but may be justified, depending on the source of the breeding material. To move breeding lines more than one zone difference is very likely to either incur such a considerable loss in potential yield or a very high susceptibility to disease or climatic stress, that it is seldom justified.

The Temperate Maritime, Zone six, comprises the UK, Ireland and the coastal regions of North West France and North West Spain. There has been much success in breeding for this ecozone in the past (Van Wijk and Reheul, 1991; Wilkins and Humphreys, 2004). Some varieties from Denmark, Holland and Germany in Zone five have been found to perform well within Zone six, particularly in colder areas, like Scotland. Similarly, some varieties from New Zealand, Zone seven, have also been successful in Zone six, particularly in milder areas like Cork in the south of Ireland. Locally bred varieties are now also being tested in Zones five and seven as the logic of shared climatic conditions works in both directions. Interestingly the conditions defining Zone six are also found in certain parts of Argentina and Chile plus the coastal strip of Washington and Oregon in the USA and this can justify speculative testing of specialist locally bred lines.

TABLE 1: Lucerne dormancy zones, as an example of a climatic classification scheme, used to segment Europe into agri-environmental zones and prioritise the testing of early generation breeding material

Dormancy Zone Number	European Region	Zone Descriptor
Zone 2	Northern Europe	Sub Arctic
Zone 3	Eastern Europe	Steppe
Zone 4	Central Europe	Very hot summers and cold winters
Zone 5	Europe Maritime	Hot summers & cold winters
Zone 6	Temperate Maritime	Cool damp summers, mild winters
Zone 7	Southern Europe	Hot dry summers
Zone 8	Mediterranean	Early summer drought stress

Without investment in local testing facilities, the only option is to submit newly bred varieties into local official trials, but given the very large number of potential varieties needing testing at this stage in the breeding this would be prohibitively expensive. So many breeding companies either own their own testing sites in different regions or pay to have their material assessed at local variety test centres. Barenbrug UK use three sites, the AFBI breeding station at Loughgall, near Armagh, the Scottish Agricultural College (SAC) site near Aberdeen and a site near Evesham in the English Midlands. At the same time Barenbrug also runs parallel assessments in Zone six regions of France or Spain and for specifically selected lines in the adjoining Zones five and seven, such as those in Germany and the Netherlands. Some very specific lines will even be assessed at more distant locations with Zone six type climates, such as in

New Zealand. Similarly, the IBERS programme also uses a SAC site and submits material for evaluation in Europe, South America and New Zealand. The Teagasc programme also benefits from test sites across Europe through its Danish partner, DLF Trifolium. Conversely, European breeders targeting the UK and Irish market utilize test sites on these islands. For example, Eurograss of Germany has a breeding and evaluation site in Banbury, plus a NIAB test site in England. DLF and its subsidiary breeding companies have several sites in the UK including AFBI (Crossnacreevy), SAC, NIAB, plus the Teagasc breeding site in Ireland. The R2n plant breeding subsidiary of the French company Rouergue Auvergne Gévaudan Tarnais (RAGT) have sites at AFBI (Crossnacreevy) and SAC.

Hundreds of potential new varieties from different breeders, and controls, are sown across these sites every year with the aim of performing low cost tests to expose those few very exceptionally high performers. Conducting detailed assessments capable of accurately ranking the good, the average and the weak material is of no commercial value, as only the highest yielding varieties will be entered into NL testing. So breeders testing procedures can adopt compromises, such as not recording dry matter (DM) content (during at least some periods of the year), reduced or no replication and minimal test years, to provide a rapid cost effective screen to quickly discard all but those of highest potential. These ‘elite’ varieties can then be considered for further testing or submission to the official testing schemes for precise evaluation. Nonetheless, the assessments need to be extensive and cover all the physical, production and nutritional characteristics that can be evaluated in official trials in various countries (Table 2).

Entering varieties into official government NL testing is an expensive exercise that will take five or more years to complete. As breeding progress is constantly raising the pass standards in official trials (Camlin, 1997; Chaves, *et al.*, 2009), this timescale means that pass standards will be higher at NL decision time than when the varieties were first submitted. So before a variety is entered, it has got to have performed sufficiently better than current varieties to have a chance of still being a performance leader by the end of the NL trial period. The final decision on which varieties from the breeders trials should be submitted for testing is shared, however, between the breeders and the marketing team. While a new variety that is exceptionally better than any existing variety in any one region is clearly a great breeding success. If, however, there is insufficient market potential in that region and the variety is not suited to any other markets, it is not a commercial success. So investment in expensive official trials would not be commercially justifiable. The variety may be recycled into the breeding programme to acquire greater flexibility, but without the potential to attract a wide enough market, it is not a viable option. So again market forces play a major part in the breeding programme.

TABLE 2: Example of characteristics assessed in breeders own trials network, prior to submission to official government testing programmes

Type of Characteristic	Parameters Assessed
Physical characteristics	Resistance to and tolerance of Diseases (Rusts, Mildew, Dreshlera)
	Winter Hardiness
	Drought Tolerance
	General Persistency
Productivity Potential	Total Annual Grazing Dry Matter Yield
	Total Annual Conservation Dry Matter Yield
	Seasonal Growth
	Digestible Yield
	Seed yield
Nutritional characteristics	Water Soluble Carbohydrate Content
	Protein Content
	Polyunsaturated Fatty Acid Content
	Palatability
	Absence of Re-Heading (indicates grazing quality)

The main markets for perennial ryegrass are meat and milk production, but there are significant minor markets for horses and professional hay/haylage production. Geographically the market in the UK and Ireland splits approximately 44% in England and Wales, 12% in Northern Ireland, with Scotland and Ireland each comprising 22%. Each market is big enough to support the minimum sales of 50 tonnes required to commercialise a variety, but only if it is the clear market leader. The ideal from a marketing perspective would be to have varieties than capture significant proportions of the pan-European perennial ryegrass seed market, which in 2009 required the 68,000 hectares producing 84,000 tonnes of grass seed, approximately, including amenity varieties (EU Statistics). This was possibly more achievable in the past when perennial ryegrass varieties such as Francis, Talbot and Melle once held EU wide market dominations. With increased sophistication and influence of regional, national and recommended lists, however, regional diversity in variety listing has reduced the occurrence of varieties with wide geographical market success. Evidence of this comes from the increasing size of the EU Common Catalogue of perennial ryegrass varieties permitted to be sold in the EU (Anon, 2010; Figure 3, reproduced from Gilliland, 2010). An implication of this is that once the breeding and testing costs of a variety have been paid and it has had market success, a breeding company may decide to continue with the costs of maintaining and multiplying that variety for a small market volume. This is normally only if they do not have a higher sales volume variety to replace it or there is a very strong customer loyalty to a specific variety. A current example of this is Tyrone, a late diploid perennial ryegrass favoured by the Irish market.

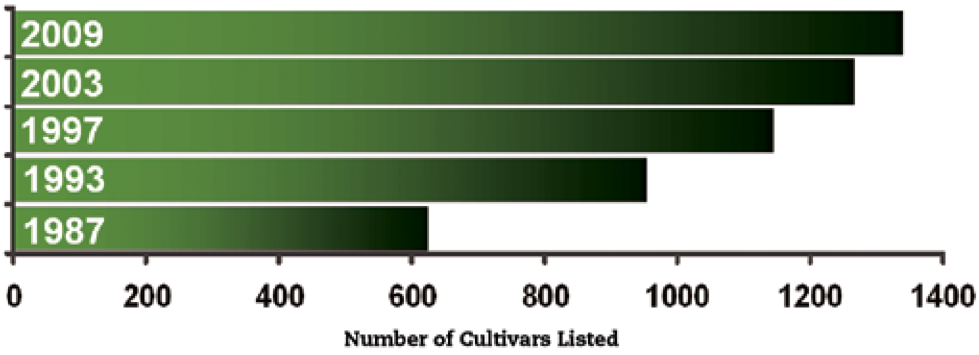


Figure 3: Numbers of grass and clover cultivars on EU Common Catalogue

The importance of recommended lists in marketing seed

The UK system is a two stage process. Following at least five years of NL testing, when up to 80% of the candidate varieties may fail to meet the necessary standards, the successful varieties still need to be good enough for the second stage of Recommended Listing (RL), (Weddell *et al.*, 1997). This is much more commercially orientated than the NL system and it is effectively impossible to sell large volumes of a variety without it being on the regional RL's in Scotland, Northern Ireland, England or Wales. The RL provides quality control and independent proof of the value of the variety, both to the merchant buyer, who usually assembles the mixture and the end user, the farmer. There are three separate testing systems in the UK. These are conducted by NIAB in England and Wales, SAC in Scotland and AFBI in Northern Ireland, and with the DAFF system in Ireland, making four independent lists for these islands. From a commercial viewpoint this can be regarded as four more hurdles blocking the way to market, or four separate opportunities. Unless a variety is exceptionally elite performing in one region it will need to be successful on several of these lists to gain that desired 50 tonne seed volume to justify further marketing investment.

The RL system, however, is a powerful and independent marketing tool supported by all the major breeding companies as it effectively removes the risk of unsuitable ryegrasses being sold with the consequent danger of crop failure. Not only does this protect farmers, but it also benefits the breeding companies who want to ensure that their breeding advances fully benefit their farmer customers, as the business success of the breeder depends on a similar success for the farmer. There is ample scientific evidence that improved grass varieties are helping to increase outputs of milk and meat on-farm (Reed, 1994).

There are currently 120 perennial ryegrass varieties on at least one of the RL's in the UK and Ireland, but only 10% are on all four, and only 25% on three of the four lists (Table 3). This demonstrates the importance of local testing and trialling, and the stringency of these RL systems. Varieties that perform well in Aberdeen, by being dormant enough to survive winter, will be very low yielding in Cork where grass can grow virtually all year and prolonged periods of frost are extremely uncommon. Conversely a variety that performs well in Cork, by trying to grow all year, will suffer severe winter damage in Aberdeen. For this reason farmers should treat any varieties that have not been listed on their local RL with considerable degrees of scepticism, no matter what claims are made for them.

TABLE 3: Recommend Perennail ryegrasses	
Total number of recommended varieties	120
Recommended by NIAB	85
Recommended by SAC	66
Recommended by DAFF	29
Recommended by AFBI	57
Recommended by 4 testing authorities	12
Recommended by 3 testing authorities	30
Recommended by 2 testing authorities	26
Recommended by 1 testing authority	52

Seed Multiplication - The last stage of the long road to market

Having bred a variety that has successfully passed the NL trials and got an RL listing, the next step is multiplying seed from breeding to commercial quantities. This is a sequential process for controlling the quality and purity of the seed of the new variety from the initial small volumes of Breeders Seed through four generations of multiplication to the tonnages required for marketing (Figure 4).

This seed multiplication scheme is designed to ensure that the seed of the new variety is reproduced accurately and with high germination and purity through generations of bulking up. The system is monitored by government officials at key stages in the process to validate that the growing seed crop is free from noxious weeds, diseases and is isolated from other sources of potentially contaminating pollen. The seed is then tested for germination and purity and successful completion of this is confirmed when the official certification labels and lot numbers are produced.

This system allows the breeder the freedom to repeatedly multiply small areas of seed of the Pre-Basic generation. By reseeding some of this harvested seed again and again, it is possible to build up the massive tonnages of seed needed to meet market demands, from the small quantity of Breeder's Seed. Once larger areas are sown to produce basic seed this can only be further multiplied once more to produce the final certified 1st Generation seed (Figure 4).

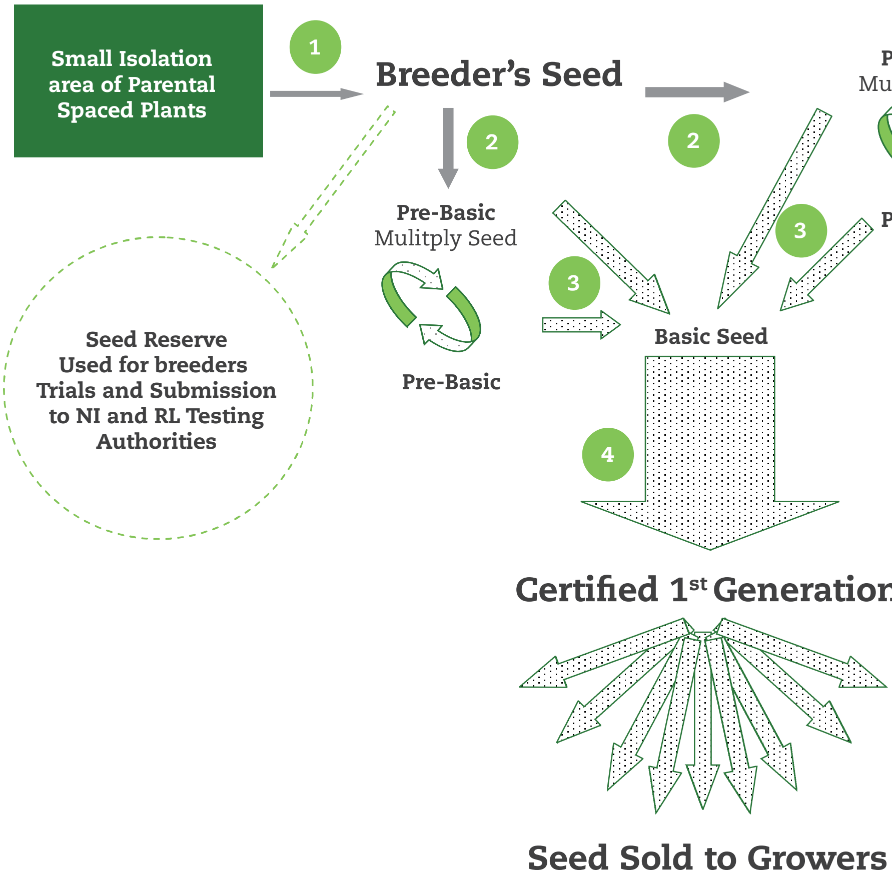


Figure 4: Seed multiplication flow diagram showing the four generations (1-4), of bulking up of seed volume from initial breeders 'Parental Spaced Plants' to the certified '1ST Generation' that is sold commercially (arrow sizes indicate increasing seed bulk). Also shown are the repeated cycles of Pre-Basic seed multiplication and the reserve seed used for variety evaluation purposes

Seed yields vary substantially between seed production areas and from year to year, but there are also very large differences in the seed production potential of different varieties. The commercially desired target seed yields are just over 1 t/ha for diploid perennial ryegrasses, with tetraploids approaching 2 t/ha. This is only a target, however, and yields can vary greatly. For example, even among forage varieties that have been marketed successfully, seed yields can be as low as 0.5 t/ha for a diploid variety in a poor growing year, or as high as 2.5 t/ha for a tetraploid variety in a good growing year. This is a critical factor in the marketing potential of a variety, not just in terms of the cost of seed production but also in the possibility of getting enough seed growers to accept a new variety for seed multiplication. Seed growers have the alternative of cereal seed crop production, which is a much higher yielding and less risky enterprise, in so much as a failed arable seed crop can be sold as grain, but a failed grass crop can only be discarded. So grass seed growers expect a premium of around 30% on the tonnage value of their grass seed crops compared to a cereal seed grower. This is also why the marketing wing of breeding companies ensure that seed yield potential is high on the breeders selection criteria and is assessed as early in the breeding programme as possible. If a variety has sufficient seed yield potential plus all the other agronomic attributes in the official trials that indicate a market potential for the variety, the decision will be taken to invest in seed production and begin marketing the variety to seed merchants and then to farmers. The typical quantities of seed at each stage in the multiplication process is as follows:

- 100 kg of Breeder’s Seed is produced by growing around 4000 spaced plants in isolation plots (often formed by sowing in the middle of a cereal field). Some of the seed from this is used to enter NL/RL trials, the remainder is held in cold storage while the variety is tested (Figure 4, stage 1).

- 10 kg of Breeder’s Seed is used to sow 2 ha, which is harvested for two years to produce around 4 tonne of Pre-Basic seed. This seed is held in long term, climate controlled storage and for most varieties this will be the only pre-basic seed ever produced, but can be further multiplied in small areas if necessary (Figure 4, stage 2).

- 30 kg of pre-basic seed is used to sow six ha and produce around 12 tonne of basic seed over 2 harvest years, which will then be used for the production of certified seed over several years (Figure 4, stage 3).

- Basic seed is sown at 10 kg/ha to give an average yield of around 1.4 t/ha (Figure 4, stage 4).

For a leading variety with a large market potential, several hundred hectares of seed production will be sown. For a smaller variety the amount of seed production may only be tens of hectares. It is only at this point, some 16 years following the initial crosses that there is something to sell and begin recouping the €600,000 cost of the investment in the variety.

Seed multiplication stages 2 to 4 (Figure 4) are usually undertaken by the commercial plant breeders and wholesalers who take the risk to multiply and produce seed of the variety to supply the market. Although there are large seed requirements, there are relatively few wholesalers and most breeders have long term relationships and agreements for marketing their varieties. Within the British Isles, the main wholesale companies for ryegrasses are DLF Trifolium, that markets in partnership with Limagrain along with their own and Teagasc (Republic of Ireland) varieties, Germinal Holdings Ltd that markets mainly IBERS (Wales) varieties, and Barenbrug UK who market mainly their own and AFBI varieties. In addition other commercial breeders, such as Eurograss and RAGT will market varieties on individual agreements with wholesalers or end users. These breeder or breeder’s agent companies may not sell any or all of their seed directly to the farmers. This is a financial decision of the company and depends on what sales team and market share they can maintain in a regional market. If it proves to be more efficient to do so, companies will also sell seed to independent merchants, either as pre-packed mixtures or as individual variety lots to allow them to assemble mixtures, based on local knowledge, tailored to meet the needs of the end user, the farmer. The overall aim is to recoup the extensive investment in bringing the improved perennial ryegrass variety to market and then to make a profit. This will help establish a secure financial basis for the company and ensure it can continue to invest in creating ever greater improvements in grass varieties for the future needs of the ruminant industry.

Summary

It is only after some 16 years following the initial crosses and all the private breeders trials, official NL and advisory RL testing programmes, plus the eventual seed multiplication and marketing processes that a return on the estimated €600,000 can begin, as summarised in Figure 4.

The source of these costs and timeframes involve much more than the specific cost of those initial crosses. It is clear that there are substantial financial outlays required in evaluating the new breeding lines under the growing conditions of different market regions. This is followed by paying for further evaluations in official national and regional recommended list testing systems. Further investment is necessary for seed production and seed quality certification plus the warehouse processing, marketing and delivery costs, before any financial return can be expected from a new variety. In addition only a small number of the varieties bred ever achieve market success and sell at least the target base level of 50 t/annum. Given these massive and unavoidable commitments, it can be strongly argued that expertise in the commerce of the seed industry is as essential as the actual breeding process in maintaining the viability of a grass breeding company.

References

Anon, 2010. EU common Catalogue at http://ec.europa.eu/food/plant/propagation/catalogues/comcat_agri_2008/index_en.htm accessed 28 July 2010.

Boller, B., Posselt, U. K. and Veronesi, F. 2010. Handbook of Plant Breeding, Volume 5: *Fodder Crops and Amenity Grasses*. (eds.), Springer Science & Business Media B.V. 2010, XI, 523 p., ISBN: 978-1-4419-0759-2.

Camlin, M. S. 1997. Plant Breeding – Achievements and Prospects – Grasses. In Weddell J.R. (ed.) *British Grassland Society Occasional Symposium* **31**: 2-14.

Chaves, B., De Vliegher, A., Van Waes, J., Carlier, L. and Marynissen, B. 2009. Change in agronomic performance of *Lolium perenne* and *Lolium multiflorum* varieties in the past 40 years based on data from Belgian VCU trials. *Plant Breeding* **128**: 680-690.

Culleton, N. and Cullen, T. 1992. Trends in herbage seed use in Ireland. *Plant Varieties & Seeds* **5**: 63-69.

Dillon, P., Crosse, S., O'Brein, B. and Mayes, R. W. 2002. The effect of forage type and level of concentrate supplementation on the performance of spring-calving dairy cows in early lactation. *Grass and forage Science* **57**: 212-223.

Gilliland, T. J., Johnston, J. and Connolly, C. P. 2007. A Review of Forage Grass and Clover Seed Use in Northern Ireland. *Grass and Forage Science* **62**: p 239-254.

Gilliland, T. J. 2010. Control of cultivar release and distribution. In: *Handbook of Plant Breeding*, Volume 5: Fodder Crops and Amenity Grasses. Boller, B., Posselt, U. K. and Veronesi, F. (eds.), Springer Science & Business Media B.V. 2010, XI, 523 p., ISBN: 978-1-4419-0759-2.

Holmes, C. W. and Hoogendoorn, C. J. 1983. Some effects of grazing management in early lactation and topping on the growth and quality of pasture. In *Dairyfarming Annual*, Massey University, Palmerston North, NZ, pp. 36–43.

Kennedy, E., O'Donovan, M., Murphy, J. P., Delaby, L. and O'Mara, F. P. 2006. Effect of spring grazing date and stocking rate on sward characteristics and dairy cow production during mid-lactation. *Journal of Dairy Science* **90:** 2035–2046.

Marsh, R. 1975. A comparison between spring and autumn pasture for beef cattle at equal grazing pressures. *Grass and Forage Science* **30**: 165-170.

O'Donovan, M. and Delaby, L. 2005. A comparison of perennial ryegrass cultivars differing in heading date and grass ploidy with spring calving dairy cows grazed at two different stocking rates. *Animal Research* **54**: 337–350.

Reed, K. F. M. 1994. Improved grass cultivars increase milk and meat production – a review. *New Zealand Journal of Agricultural Research* **37**: 277-286.

Talbot, M. 1984. Yield variability of crop varieties in the U.K. *Journal of Agricultural Science, Cambridge* **102**: 315-321.

Van Wijk A. J ,P. Reheul D., 1991. Achievements in fodder crops breeding in maritime Europe. *Proceedings 16th Meeting of the Fodder Crops Section of Eucarpia*. Wageningen, the Netherlands.

Weddell, J. R. Gilliland, T. J. and McVittie, J., 1997. Evaluation Procedures: Past, Present and Future. p: 202-225. In: Seeds of Progress, (Editor. Weddell, J.R.), *British Grassland Society Occasional Publication*, 1997, pp237.

Wilkins, P. W. and Humphrey, M. O. 2004. Progress in breeding perennial forage grasses for temperate agriculture. *Grass and Forage Science* **59**: 531-535.

NOTES

NOTES

NOTES

NOTES

NOTES