Introduction
Beef producers are in the business of converting feed into animal product as cost efficiently as possible. Feed provision accounts for over 75% of direct costs of beef production. Relative to concentrates or conserved forage diets, grazed grass is generally the cheapest feed source on grass-based farming systems (Finneran et al., 2012). Due to the considerably lower comparative cost of grazed grass as a feedstuff, beef production systems should aim to increase animal output from grazed grass. Nevertheless, primary feed costs on beef farms relate to indoor (winter) feeding periods and particularly, feeding of finishing cattle. For example, within grass-based, suckler calf-to-beef steer systems on research farms, about two-thirds of the feed consumed annually is comprised of grazed grass, with the remainder made up of grass silage (27%) and concentrates (7%). The latter are mainly fed to the finishing cattle. However, when this feed budget is expressed in terms of cost (land charge included), the outcome is very different, in that grazed grass makes up only 44% of total feed cost, whereas grass silage accounts for 39% and concentrates accounts for 17% of total feed costs. This means that even small improvements in feed (cost) efficiency at these times has a relatively large influence on farm profitability. Economic sustainability of beef production systems therefore depends on optimising the contribution of grazed grass to the lifetime intake of feed and on providing silage and concentrate as efficiently and at as low a cost as feasible (Crosson et al., 2014; O’Kiely, 2014).

Feed Efficiency
There are many different contexts, approaches and measurements of feed efficiency in beef cattle production ranging from the individual animal to the production system operated. In the context of the animal, traditionally, feed conversion ratio (FCR) (i.e. feed:gain) or its mathematical inverse, feed conversion efficiency (i.e. gain:feed), was the measurement of choice. However, the use of this ratio in cattle breeding programmes generally leads to selection of faster growing animals that have a larger mature size and thus, a higher feed requirement. This has particular negative ramifications for the cow component of suckler beef production systems because of the proportionately higher (overhead) costs associated with it. In essence if an increase in feed requirements of the breeding cow herd offsets the gains in growth efficiency, there will be no change in production system feed efficiency. An alternative measure of feed efficiency, that is genetically independent of growth and body size, is residual feed intake (RFI) – also known as net feed efficiency and net feed intake. Residual feed intake is defined as the difference between an animal’s actual feed intake and what its predicted feed intake should be based on bodyweight and level of performance. Therefore, efficient animals eat less than expected and have a negative or lower RFI value, whereas inefficient animals eat more than expected and have a positive or higher RFI value. Research at Teagasc and UCD has shown that in any population of cattle, within breed, there can be in excess of 20% difference between the most efficient compared to the least efficient animals for the same level of growth and performance (e.g. McGee, 2009; Kelly et al. 2010; Crowley et al., 2010; Lawrence et al., 2012; Fitzsimons et al., 2014 –Table 1). Furthermore, these feed efficient cattle produce less
methane (Fitzsimons et al., 2013) and consequently, have a lower environmental footprint. We have also demonstrated significant genetic variance in the trait (Crowley et al., 2010) and that, genetically, it is not antagonistically associated with desirable growth or carcass traits in growing beef cattle (Crowley et al., 2011).

Table 1: Intake and performance of beef cattle with high (Inefficient), medium and low (efficient) RFI

<table>
<thead>
<tr>
<th></th>
<th>RFI¹</th>
<th></th>
<th>RFI²</th>
<th></th>
<th>RFI³</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hig</td>
<td>Med</td>
<td>Lo</td>
<td>Sig.</td>
<td>Hig</td>
</tr>
<tr>
<td>DMI (kg/day)</td>
<td>6.3</td>
<td>5.9</td>
<td>5.5</td>
<td>***</td>
<td>10.2</td>
</tr>
<tr>
<td>Live weight (kg)</td>
<td>31</td>
<td>327</td>
<td>33</td>
<td>NS</td>
<td>522</td>
</tr>
<tr>
<td>ADG (kg)</td>
<td>0.6</td>
<td>0.61</td>
<td>0.6</td>
<td>NS</td>
<td>1.66</td>
</tr>
</tbody>
</table>

Source: ¹Lawrence et al., 2012; ²Fitzsimons et al., 2014; ³Kelly et al., 2010

The challenge is, therefore, to reliably and cost-effectively identify these feed efficient animals and proliferate their genetics through structured animal breeding programmes. A large research programme funded by DAFM has commenced at Grange to address this and to also determine if there are genotype x age or environment interactions for feed efficiency.

Factors affecting Feed Efficiency

Live weight and live weight gain

For finishing cattle, approximately two-thirds of feed consumed is used for body maintenance (i.e. to maintain physiological functions). As maintenance is largely a function of weight, a heavier animal requires more feed to maintain itself, and furthermore, for a fixed rate of live weight gain, the feed energy required is higher for heavier animals (e.g. Table 2). Consequently, feed efficiency is better with lighter, fast growing animals.

Table 2: Theoretical energy requirements of finishing bulls (UFV/day) at different weights and growth rates

<table>
<thead>
<tr>
<th>Average daily gain (kg)</th>
<th>450</th>
<th>500</th>
<th>550</th>
<th>600</th>
<th>650</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>4.4</td>
<td>4.8</td>
<td>5.1</td>
<td>5.5</td>
<td>5.8</td>
</tr>
<tr>
<td>1.0</td>
<td>6.0</td>
<td>6.5</td>
<td>6.9</td>
<td>7.4</td>
<td>7.9</td>
</tr>
<tr>
<td>1.2</td>
<td>6.5</td>
<td>7.0</td>
<td>7.5</td>
<td>8.0</td>
<td>8.6</td>
</tr>
<tr>
<td>1.4</td>
<td>7.0</td>
<td>7.6</td>
<td>8.1</td>
<td>8.7</td>
<td>9.4</td>
</tr>
<tr>
<td>1.2 vs. 1.4</td>
<td>0.5</td>
<td>0.6</td>
<td>0.6</td>
<td>0.7</td>
<td>0.8</td>
</tr>
</tbody>
</table>
Duration of Finishing period / Slaughter weight

Growth in animals is defined as accretion of protein, fat and bone. In cattle some parts, organs and tissues grow relatively more slowly than the animal overall, and so become decreasing proportions over time, while others grow relatively faster and become increasing proportions (Keane, 2011a). With increasing slaughter weight, the proportions of non-carcass parts, hind-quarter, bone, total muscle and higher value muscle decrease, while the proportions of non-carcass and carcass fats, fore-quarter and marbling fat all increase (Keane, 2011a). Energetically, efficiency of accretion of fat is approximately 1.7 times that of protein but because more water is stored with deposited protein than with deposited fat, lean tissue gain is four times as efficient as accretion of fat tissue (Owens et al., 1995). As carcass weight increases, the proportions of bone and muscle decrease and the proportion of fat increases, but the rates of these changes differ amongst breed types (Keane 2011b).

Daily live weight gain over the finishing period is not constant. In general, it is higher at the beginning and declines, often progressively, with increasing duration of finishing period. For example, in steers offered concentrates ad libitum over 132 days average daily live weight gain was 25% lower for the second half of the finishing period compared to the first half (Caplis et al., 2005). The decline in daily live weight gain can be attributed to an increase in gut fill at the initial stages, fixed or declining intake relative to increased weight (and maintenance requirements), and increased fat deposition. As fat deposition requires more energy than protein deposition, more feed is required to produce a kilogram of fat. The proportional fall in daily live weight gain over the finishing period is largely a function of the fatness of the animal and thus, is generally greater at high feeding levels and with more mature animals.

The practical implications of this are that feed efficiency deteriorates, and the feed cost per kg live weight and carcass gain increases, with increasing length of finishing period. Avoiding overly long finishing periods and ensuring that animals achieve minimum carcass fat score without impairing carcass value are ways to reduce feed requirements and costs.

Breed type / Genetics

There is broad agreement across countries on the ranking of beef breeds for production and carcass traits (Keane, 2011a). Differences between dairy and early-maturing beef breeds in growth and slaughter traits are small, but the latter have lower feed intake and better carcass conformation. Late-maturing beef breeds also have lower feed intake and better carcass conformation and in addition, have a higher growth rate, kill-out proportion and carcass muscle proportion (Keane, 2011a). Therefore, in general, beef breeds and beef crossbreds are more feed efficient than beef x dairy breeds, who in turn, are more efficient than Friesian and Holstein. Within the beef breeds, late-maturing breeds are more feed efficient than early-maturing breeds, especially in terms of muscle production.

For example, in terms of RFI (MJ/day), an analysis of performance data (offered a high concentrate diet) from the national bull performance centre in Tully, Co. Kildare showed that of the five main breeds used nationally, Aberdeen Angus and Hereford were the least efficient, Charolais and Limousin were the most efficient, with Simmental being intermediate (Crowley et al., 2010). The difference between the least and most efficient breeds was ca. 14%. There was also large variation in feed efficiency within breeds. A
study at Grange comparing Holstein/Friesian and suckler-bred beef cattle (slaughtered as bulls at 15 months of age or as steers at 24 months of age) showed that overall, the beef breeds gained about 23% more live weight during the finishing period per unit of energy consumed than dairy breeds (Clarke et al., 2009). However, because of the higher kill-out proportion and the greater proportion of meat in the carcass of beef compared to dairy breeds the percentage of meat produced per unit of energy consumed was on average 51% greater for the beef than dairy breeds. It is important to bear in mind that comparison of intake and efficiency data for cattle breed types must be interpreted in the context of the production system operated and animal age / slaughter end point of the comparisons, as the ranking could vary with changes in these factors (Keane, 2011a).

**Gender**

Bulls are inherently more “efficient” for beef production than steers, upon reaching puberty, due to naturally occurring male steroid hormones (O’Riordan et al., 2011). Published comparisons of steers versus bulls are predominantly based on dairy and dairy x beef animals. A review of studies carried out at Teagasc, Grange comparing bulls and steers of similar breed, reared under similar management on the same diet and slaughtered at the same age showed that, on average, live weight gain was 8.4% higher, carcass weight was 9.5 % heavier and lean meat yield was 20% greater for bulls than steers (Fallon et al., 2001). Similarly, data from Hillsborough, Northern Ireland, showed that compared to comparable steers reared in the same way, bulls produced 10% more live weight, 14% more carcass, 21% better carcass conformation, 20% more lean meat and 17% more saleable meat per kg feed consumed (Steen and Patterson, 1994). Likewise, a review of mainly North American data showed that mean growth was 17% higher, carcass fat was 35% lower and feed efficiency was 13% better for bulls than steers (Seideman et al., 1982). Equally, a review of data from mainly continental European countries, illustrated that, on average, intake of bulls was 1% higher, growth was 20% higher, carcass fatness was 27% lower and feed efficiency was 17% better than for steers (Boucque et al., 1992). Differences in favour of bulls are generally more pronounced at higher feeding/feed energy levels and with increasing slaughter weight. In practice, bulls and steers are generally reared in different production systems involving different levels of feeding, particularly in winter, different lifetime ratios of grazing to indoor feeding and different ages and weights at slaughter. This means that the effects of “gender” are confounded with production system factors. The combination of these factors largely determines differences in performance obtained between bulls and steers commercially.

**Compensatory growth potential**

Compensatory growth is the ability of an animal to undergo accelerated growth when offered unrestricted access to high quality feed after a period of restricted feeding or under-nutrition. Exploitation of this biological phenomenon is recommended for feeding weanlings (or ‘store’) cattle over the expensive indoor winter period following which they are turned out to pasture in the spring to graze cheaper produced grass (e.g. Keane, 2002; McGee et al., 2013). However, compensatory growth may also be expressed during the indoor finishing phase by cattle that experienced sub-optimal growth earlier. For animals previously grazing pasture this sub-optimal animal growth may be due to inadequate supplies or quality of grazed grass. Even where grass supply is adequate and nutritive value is high, compensatory growth indoors following a period
at pasture is clearly evident with some categories of cattle such those with high potential for growth.

Indoor finishing

Concentrate feeding level

Grass silage is the basal forage on most beef farms in Ireland. Most of the variation in net energy content of grass silage is associated with its digestibility, which in turn is mainly determined by the stage of growth of the grass plant at harvest. It is well established that the performance of beef cattle increases with increasing grass silage digestibility, with increases in carcass gain of ca. 33 g/day per 1% unit increase in silage digestibility where silages were offered as the sole feed and 21-29 g/day per 1% unit increase in silage digestibility when supplemented with concentrates at 0.20 to 0.40 of total dry matter (DM) intake (McGee, 2005). Similarly, in a more recent review of the literature Keady et al. (2013) concluded that overall, each 1% unit increase in grass silage digestibility increased carcass gain by 24 g/day. As forage DM intake decreases with increasing levels of supplementary concentrates, the effect of forage digestibility diminishes to the extent that at high (0.80 of the diet) concentrate feeding levels silage digestibility had no effect on carcass gain (McGee, 2005). Likewise, Keady et al. (2013) reported daily increases in carcass gain per 1% unit increase in silage digestibility of 35g, 26g 17g and 8g for silage:concentrate ratios of 100:0, 80:20, 60:40 and 40:60, respectively. Conversely, each 1 unit decline in digestibility of grass silage requires an additional ca. 0.4 kg concentrate daily to sustain performance in finishing cattle (Keady et al., 2013).

Substitution rate

Even high quality grass silage is incapable of sustaining adequate growth rates to exploit the growth potential of most cattle. The conventional method of overcoming the deficiencies in nutrient supply from grass silage is to supplement with concentrates. An important factor affecting nutrient intake of cattle when supplementing forage, is substitution rate i.e. the decrease in forage dry matter intake per unit of concentrate intake. Increasing the level of concentrates in the diet reduces forage intake but increases total DM intake with the magnitude of the decrease in forage intake usually greater with forage of higher digestibility (McGee, 2005). For diets containing low to moderate levels of concentrate (<0.47 of dietary DM intake) substitution rates range from 0.29 to 0.64 kg silage DM per kg concentrate DM with high digestibility grass silage (McGee, 2005). Studies where higher levels of supplementation were offered have reported a curvilinear increase in total DM intake implying a progressively decreasing intake of forage with increasing concentrate level (Caplis et al., 2005; Keane et al., 2006). At the higher levels of supplementation (0.55 to 0.85 of total DM intake) substitution rates between 0.55 and 1.15 kg silage DM / kg concentrate DM for successive increments of concentrates are found (McGee, 2005).

The effect of energy supplement type or protein supplementation on the intake of grass silage is unclear with conflicting reports across studies (McGee, 2005). In contrast to expectations from published feed table values, increasing the proportion of concentrate in the diet of beef cattle does not necessarily increase the digestible energy value of the total diet, in particular where grass silage of higher digestibility is fed (McGee, 2005). This negative associative effect is often attributed to a depression in fibre digestibility in the rumen and in the total digestive tract from the inclusion of
rapidly fermentable carbohydrates in grass silage-based diets. Consequently, dietary energy intake often mirrors total DM intake with increasing concentrate feeding level (McGee, 2005).

**Growth response**
The response in live weight and carcass growth rate to concentrate supplementation (increasing from ~2 kg to >9 kg/head daily) is generally curvilinear (e.g. Figure 1). This means that the incremental growth response generally declines as concentrate feed level increases (e.g. Table 3). Additionally the growth response is lower for high digestibility grass silage than for medium digestibility silage (McGee, 2005). Consequently, the economically optimum input of concentrates is higher with lower digestibility silage. For a fixed rate of gain less concentrates are required with high digestibility silage, and due to a progressive decline in the response to concentrates, high digestibility grass silage plus a moderate level of concentrates can achieve close to the same level of performance as achieved on high concentrate diets (McGee, 2005).

In general, the growth response to concentrate supplementation is higher in animals of high growth potential than those of lower growth potential (e.g. Figure 1).

![Fig. 1: Growth response to concentrate supplementation](image)

**Table 3:** Daily live weight and carcass weight response of steers fed grass silage to incremental increases in concentrate supplementation (expressed as dietary proportion)

<table>
<thead>
<tr>
<th>Response</th>
<th>Dietary concentrate&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Dietary concentrate&lt;sup&gt;2&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ad 0.30 0.55 Ad libitum</td>
<td>0.38 0.75 Ad libitum</td>
</tr>
<tr>
<td>Live weight (g/kg DM)</td>
<td>174 54 38</td>
<td>177 45 75</td>
</tr>
<tr>
<td>Carcass (g/kg DM)</td>
<td>110 41 42</td>
<td>102 31 68</td>
</tr>
</tbody>
</table>

**Source:** McGee 2014 (unpublished)

**Optimum level of concentrate feeding**
In order to determine the optimum or breakeven level of concentrate supplementation, for finishing cattle, estimates of carcass efficiency (kg concentrates per kg carcass), silage substituted (kg DM per kg carcass gain) and the true costs of grass silage and
concentrates are required. Table 4 provides guidelines on the cost per kg of carcass gain at various concentrate prices and feeding levels, assuming that the remainder of the diet is high quality grass silage. The results show that the cost per kg carcass increases with increasing concentrate feeding level. It is acknowledged that some minimum level of concentrates (~3 kg/day) is necessary otherwise the animals won’t finish. Assuming a breakeven point of 385 c/kg carcass, the optimum concentrate feeding level is between 5 and 6 kg when concentrates cost €300/t. This increases to ~7 kg when concentrate costs fall to €250/t, and continues to increase progressively as concentrate costs fall further.

Table 4: Cost (c/kg) of carcass gain for steers

<table>
<thead>
<tr>
<th>Feeding level (kg/day concentrate)</th>
<th>Concentrate costs (€/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>175</td>
</tr>
<tr>
<td>3</td>
<td>117</td>
</tr>
<tr>
<td>4</td>
<td>119</td>
</tr>
<tr>
<td>5</td>
<td>124</td>
</tr>
<tr>
<td>6</td>
<td>159</td>
</tr>
<tr>
<td>7</td>
<td>172</td>
</tr>
<tr>
<td>8</td>
<td>180</td>
</tr>
</tbody>
</table>

Silage substituted valued at 15.0 cents/kg DM

Where silage DMD is poor (e.g. 60%) and/or in short supply, and animal growth potential is high, feeding concentrates ad libitum should be considered. Of particular concern when feeding concentrates ad libitum, particularly cereals, is the rapid fermentation of high levels of starch to organic acids resulting in acidosis. Therefore, it is critical to ensure; (i) gradual adaptation to concentrates, (ii) minimum roughage inclusion (~10% of total DM intake) for rumen function, (iii) meal supply never runs out and, (iv) that a constant supply of fresh water is provided.

Concentrate type

Barley vs. Wheat vs. Oats

Although feed nutrition databases indicate that the feed energy value of wheat is 3-9 % superior to that of barley, in practice the difference is negligible for beef cattle. In experiments carried out in Teagasc Grange, carcass weight gains and feed conversion efficiency to carcass gain were not significantly different between rolled barley and rolled wheat (6 kg fresh weight - equivalent to 0.52 of total dry matter (DM) intake) offered with grass silage ad libitum (Drennan et al., 2006). It made no difference whether the concentrates were offered in one (6 kg) or two (3 kg each) feeds daily. Similarly, a review of feeding trials of cattle fed high concentrate diets primarily from North America found no significant difference in average daily gain, DM intake or feed to gain ratio between barley or wheat averaged across a range of processing methods. There is less information on the feeding value of oats relative to barley. The published feed energy value of oats is 85-94% that of barley. A study in Finland comparing rolled barley and rolled oats fed as a supplement to finishing bulls on a grass silage-based diet showed that the energy value of oats was 7% lower than barley (Huuskonen, 2009).

Native Cereals vs. Other Cereal and Non-cereal Feed Ingredients
The effect of replacing half the barley in a barley-based concentrate ration with maize meal (plus sufficient soyabean meal to ensure adequate dietary protein) on the performance of young bulls offered concentrates *ad libitum* was evaluated at Grange (Keane, 2008). Results showed that intake was higher for the maize-based ration but there was no difference in carcass weight or carcass traits between the two rations.

In addition to cereals, a wide variety of other feed ingredients are available and used extensively in beef rations in Ireland. In practice, this means that beef rations formulated to have similar energy and protein concentrations, can range from being high in starch (of varying rumen degradability) to being high in digestible fibre and consequently, providing a variable balance of nutrients for absorption. Replacing starch with digestible fibre in the concentrate increased the live weight/carcass weight gain of cattle offered grass silage-based diets in some studies but not in others (McGee, 2005). However, in these studies, concentrate feeding level and silage quality differed widely. Differences between concentrate energy sources should be more evident at higher concentrate feeding levels. A more recent study at Grange compared intake and performance of finishing cattle offered concentrates formulated to have similar energy and protein levels, but contrasting in ingredient composition, either as a 5 kg/day supplement to grass silage or *ad libitum* (plus 5 kg fresh weight grass silage) (McGee et al., 2006, 2009). Ingredients ranged from, rapidly fermented starch (barley-based), to slowly fermented starch (maize-based), to rapidly fermented starch + fibre or fibre only (pulps-based). Intake, production and carcass traits were unaffected by concentrate energy source, whereas increasing concentrate feeding level increased all production and carcass traits except kill-out proportion and carcass conformation. Concentrate energy source had no effect on rumen pH or fermentation parameters when offered as a supplement to grass silage but significantly altered the end products of rumen fermentation when offered *ad libitum*. Similarly, Cuveleir et al. (2006) found no significant difference in live and carcass weight gain between the starch- (barley) and fibre-based concentrates when offered *ad libitum* to bulls. Collectively, this implies that (net) energy (and protein) levels of beef rations are more important than ingredient content per se.

At present there are a number of DAFM-funded studies on-going at Teagasc Grange evaluating feed ingredients including, maize distillers, wheat distillers, soya hulls, palm kernel meal, maize meal, and flaked toasted maize, for inclusion in beef rations (Magee et al.; Lenehan et al. - unpublished).

**Protein supplementation**

For finishing steers or heifers offered well-preserved, high digestibility grass silage there is no response to additional protein with barley (McGee, 2005). Similarly, with young finishing bulls offered high digestibility grass silage, adding soyabean meal to a barley-based concentrate gave no improvement in intake, live weight gain, carcass gain or carcass fat score. The barley had 11.5 to 12.9% crude protein (CP)/kg DM. From review of the literature Huuskonen et al. (2014) reported that for cattle fed grass silage-based diets increasing dietary crude protein concentration increased live weight gain but the responses were quantitatively very small - 1.4g per 1g/kg DM increase in dietary crude protein concentration. Furthermore, the response in daily live weight gain was not significantly different for bulls vs. steers and heifers or for dairy vs. beef breeds. Additionally, the effect of crude protein concentration declined with increasing body weight. They concluded that there was generally no benefit from using protein supplementation for beef cattle fed grass silage-based diets providing the supply of...
rumen degradable protein is not limiting digestion. There is evidence that finishing cattle are likely to respond to supplementary protein in barley-based concentrates only when grass silage has moderate to low digestibility and/or low protein content (McGee, 2005).

Similarly, an experiment at Grange with young bulls of high growth potential offered a barley-based concentrate ad libitum without (11.6 % CP/kg DM) and with soya bean meal (concentrate = 14.3 % CP/kg DM) showed no differences in slaughter weight, carcass weight and carcass traits (Keane, 2005). There was an increase in live weight gain due to soya bean meal inclusion in the early part of the finishing period (related to a higher intake) but those not given soya bean meal compensated subsequently.

**Pasture-based finishing**

Due to the seasonality of grass growth, herd feed demand usually exceeds supply in the autumn. This is particularly so on beef farms because, due to accumulated animal growth, feed requirements increase as the grazing season progresses, whereas grass growth declines after mid-summer. Furthermore, all else being equal, when compared with spring grass, autumn grass often has a lower feeding value. Research at Grange has shown that even on well managed pasture with adequate supplies (daily dry matter allowance of 20 g/kg live weight) of high digestibility grass, live weight gain of finishing cattle in autumn was only ~0.75 kg/day. This contrasts with much higher gains (>1 kg/day) obtained earlier in the season. In practice, animal performance is often substantially less than this. Consequently, options for finishing of cattle in autumn generally involve concentrate supplementation at pasture or finishing indoors (e.g. Keane and Drennan, 2008; Keane and Moloney, 2009; 2010; McNamee et al., 2012).

As grazed grass is considerably cheaper than grass silage (or concentrates), early finishing of cattle at pasture in autumn, before housing becomes necessary, is less costly. In situations where complete finishing at pasture is not possible, short-term supplementation at pasture is often worthwhile as it still reduces the requirement of more costly conserved forage. For example, the build-up or adaptation period to concentrates may be implemented at pasture prior to indoor finishing. Diet aside, there are also the obvious substantial costs associated with feeding cattle indoors compared with grazing.

**Concentrate feeding level at pasture**

Animal response to concentrate supplementation while grazing will primarily depend on the availability and quality of pasture and level of supplemented concentrate. Research at Grange shows substitution rates for finishing cattle grazing autumn pasture supplemented with concentrates ranging from 0 to 0.81, with marginal values at higher levels of supplementation in excess of 1.0 in some studies. In other words, where grass supply was restricted, substitution rates were very low, but where grass supply was adequate, increasing the level of concentrates reduced grass intake but usually also increased total dry matter and energy intake. Consequently, carcass growth response to concentrate supplementation at pasture in autumn is higher where grass supply is low and where grass quality is poorer and, declines as concentrate supplementation level increases. Studies at Grange have shown that at adequate (~20 g/kg live weight) grass allowances in autumn, feeding ~0.50-0.75 kg of concentrate per 100 kg live weight resulted in carcass growth responses between 30 and 110 g carcass per kg concentrate (e.g. Keane and Drennan, 2008; McNamee et al.,
In practice, feeding this moderate level of concentrates will likely result in carcass growth responses at the upper end of this range. On-going research at Teagasc, Grange is evaluating the response to concentrate supplementation at pasture, in both bulls and steers, at different stages of the grazing season (O’Riordan et al.; Marren et al.; McMenamin et al.; Lenehan et al. - unpublished).

**Concentrate type at pasture**

In autumn the diet of grazing cattle is generally unbalanced, in terms of energy and protein, because there is usually excess degradable protein in autumn grass. Research at Grange has shown dietary energy rather than protein is the limiting factor and supplementation with concentrate energy sources is required. Three studies at Grange showed that animal performance was similar for starch-based (barley) or fibre-based (pulp) concentrates as supplements to autumn grass.

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