Recent Developments in Feeding Beef Cattle on Grass Silage-Based Diets

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Shingfield, K.J. (2000). Estimation of microbial protein supply in ruminant animals based on renal and mammary purine metabolite excretion. A. Review. *Journal of Animal and Feed Sciences,* 9, 169-212.
Shingfield, K.J., S. Jaakkola & P. Huhtanen (2001). Effects of level of nitrogen fertilizer application and various nitrogenous supplements on milk production and nitogen utilization of dairy cows given grass silage-based diets. *Animal Science,* 73, 541-554.
Shingfield, K.J., A. Vanhatalo & P. Huhtanen (2003). Comparison of heat-treated rapeseed expeller and solvent-extracted soya-bean meal protein supplements for dairy cows given grass silage-based diets. *Animal Science*, 77, 305-317.
Schwab, C.G., P. Huhtanen, C.W. Hunt & T. Hvelplund (2005). Nitrogen Requirements of Cattle. In: E. Pfeffer & A.N Hristov (eds), Interactions between Cattle and the Environment. CABI publishing (In Press).
Tamminga, S. (1992). Nutrition management of dairy cows as a contribution to pollution control. *Journal of Dairy Science*, 75, 345-357
Vanhatalo, A., E. Pahkala, P. Salo-Väänänen, H. Korhonen, V. Piironen & P. Huhtanen (2003). Rapeseed and soyabean as protein supplements of dairy cows fed grass silage based diets. In: Hilmer Sorensen et al. (eds.) *Proceedings of the 11th International Rapeseed Congress. The Royal Veterinary and Agricultural University, Copenhagen,* 1238-1240.
Vanhatalo, A., P. Huhtanen, V. Toivonen & T. Varvikko (1999) Response of dairy cows fed grass silage diets to abomasal infusions of histidine alone or in combinations with methionine and lysine. *Journal of Dairy Science*, 82, 2674-2685
Vanhatalo, A., T. Varvikko & P. Huhtanen (2003a). Effects of casein and glucose on responses of cows fed diets based on restrictively fermented grass silage. *Journal of Dairy Science,* 86, 3260-3270.
Vanhatalo, A., T. Varvikko & P. Huhtanen (2003b). Effect of various glucogenic sources on production and metabolic responses in dairy cows fed grass silage-based diets. *Journal of Dairy Science*, 86, 3249-3259.
Van Bruchem, J., H. Schiere & H. Van Keulen (1999). Dairy farming in the Netherlands in transition towards more efficient use of nutrients. *Livestock Production Science*, 61, 145-153.
Van Vuuren, A.M., P. Huhtanen & J.P. Dulphy 1995. Improving the feeding and health value of ensiled forages. In: Journet, M. *et al*. (eds.). *Recent Developments in the Nutrition of Herbivores*. INRA, Paris. p. 297-307.
Verbic, J., E.R. Ørskov, J. Zgajnar, X.B. Chen & V. Znidarsic-Pongrac (1999). The effect of method of forage preservation on the protein degradability and microbial protein synthesis in the rumen. *Animal Feed Science and Technology,* 82, 195-212.
Volden, H., L.T. Mydland & V. Olaisen (2002). Apparent ruminal degradation and rumen escape of soluble nitrogen fractions in grass and grass silage administered intraruminally to lactating dairy cows. *Journal of Animal Science*, 80, 2704-2716.
Wahlroos, M.T. (2004). Modification of histidine content in transgenic *Brassica rapa* plants. Dissertation, 49 p. + encl. University of Turku.
Weiss, W.P., D.G. Chamberlain & C.W. Hunt (2003). Feeding silages. In: D.R Buxton, R.E. Muck & J.H. Harrison (eds.) Silage Science and Technilogy. *American Society of Agronomy,* Madison, USA, 469-504.

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Key points:

1. High digestibility grass silage with moderate concentrate supplementation can sustain a large proportion of the cattle performance achieved on high concentrate diets.
2. Increasing concentrate supplementation reduces the importance of grass silage nutritional value.
3. Subsequent compensatory growth diminishes the advantage of concentrate supplementation of young cattle.
4. Meat quality and fatty acid composition can be influenced by grass silage-based diets.

Keywords: grass silage, beef cattle, concentrate supplementation

Introduction

Grass silage is a basic component of many beef production systems worldwide, particularly in those countries with a temperate climate such as in Northern and Western Europe. In addition to providing forage, usually for the indoor period/winter feeding, grass silage is often an integral part of grassland management through the removal of seasonal surpluses associated with typical grass growth curves. Furthermore, the grass silage land area permits recycling of organic manure and is also a means of reducing internal parasite challenge to grazing cattle. As a ruminant feedstuff, grass silage can be less attractive than alternative forage crops or high concentrate diets due to constraints of often variable and unpredictable weather, the scarcity of silage-cutting contractors, coupled with ever-increasing costs of production and effluent management. In addition to unfavourable relative costs of nutrient supply, changing beef production systems and consumer market demands can necessitate higher levels of concentrate feeding for beef cattle.

Relative to the dairy cow, there is much less research carried out on the nutrition and feeding of beef cattle on grass silage-based diets and consequently the science and technology is much less developed.

Nutrient supply from grass silage

Nutrient supply to the ruminant from grass silage is primarily influenced by altering the cutting date of the grass crop (i.e. digestibility) and by modifying and restricting fermentation through wilting or the use of additives (Thomas & Thomas, 1985). The effects of wilting (Ingvartsen, 1992; Wright *et al.*, 2000) and silage additives (O'Kiely, 2001; Kung *et al.*, 2003) on the performance of cattle has been the subject of previous reviews. 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 (Rinne, 2000). It is well established that the performance of beef cattle increases with increasing grass silage digestibility (Flynn, 1981; Randby, 2001; Steen *et al.,* 2002). For example, Steen (1988) calculated from the literature that where silages were offered as the sole feed, carcass gain was increased by 33 g/d per 10 g/kg increase in silage digestibility. The corresponding value where silages were supplemented with concentrates at 0.20 to 0.37 of total dry matter (DM) intake was 28 g/d. The latter value is in good agreement with the value of 29 g per 0.01 increase in digestible organic matter (DOM) reported by Steen *et al.* (2002). As forage DM intake decreases with increasing levels of supplementary concentrates, the effect of forage digestibility diminishes (Van Vuuren *et al.*, 1995) to the extent that at high (0.80 of the diet) concentrate feeding levels silage digestibility had no effect on carcass gain (Steen *et al.*, 2002). Steen (1998) calculated a response in daily carcass gain of 26, 21, 12 and 1 g / 10 g/kg increase in silage digestibility when silages were supplemented with 2.25, 4.5, 6.75 and 9.0 kg concentrates/head daily (~0.20 to 0.80 of total DM intake), respectively. Clearly, this has implications for the cost of producing silage in that silage of lower digestibility may be produced at a lower cost per unit DM (higher yield) where high concentrate feeding levels are practiced.

Intake

It is widely believed that the intake potential of herbage is reduced as a result of ensiling although the variation in the magnitude of the reduction is large (Mayne & Cushnahan, 1995). Mayne & Cushnahan (1995) suggested that factors such as stage of maturity at harvest explained at least some of the reduced intake (and animal performance) with grass silage relative to grass at the stage it is grazed. They attributed the direct effect of ensilage to progressive changes in the nitrogenous components. However, when good ensiling techniques are used and conservation quality is excellent, ensilage *per se* has relatively little effect on the intake of cattle (Mayne & Cushnahan, 1995; Dulphy & Van Os, 1996). Keady & Murphy (1993) presented data from the literature showing that intake of growing heifers and finishing steers ranged from proportionately –0.08 to +0.06 for well preserved grass silage relative to the parent herbage.

Many attempts have been made to estimate the effect of silage composition, digestibility, and fermentation quality on grass silage intake by beef cattle. Steen *et al.* (1998) concluded that the intake of grass silage offered as the sole feed to beef steers is closely related to factors which influence the extent of digestion and rate of passage of material through the animal including *in vivo* apparent digestibility, rumen degradability and the concentrations of the fibre and nitrogen fractions. Intake was poorly related to more conventional factors such as pH, total acidity, buffering capacity and the concentrations of lactic, acetic and butyric acids. The use of Near Infra Red Spectrometry predicted intake with the highest degree of accuracy (R^2 of relationship = 0.90).

Substitution rate

The conventional method of overcoming the deficiencies in nutrient supply from grass silage is to supplement with concentrates. Increasing the level of supplementary concentrates in the diet of beef cattle reduces grass silage intake (Drennan & Keane, 1987a, b; Dawson *et al.*, 2002; Caplis, 2004) but increases total DM intake. The magnitude of the decrease in silage intake is usually greater with silage of higher digestibility (Drennan & Keane, 1987a; Steen, 1998). Similarly, there is also evidence that the substitution rate (SR) is much greater with silage of restricted fermentation (Dawson *et al.*, 2002) although this is not always so (Agnew & Carson, 2000). The effect of silage preservation on SR may be confounded with changes in digestibility (e.g. Shiels, 1998). Mayne *et al.* (1995) reported that SR in growing cattle was positively correlated to intake characteristics of the silage when offered as the sole feed. 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 (Agnew & Carson, 2000; Steen & Kilpatrick, 2000; Patterson *et al.*, 2000; Dawson *et al.*, 2002; Caplis, 2004). Recent studies have reported a curvilinear increase in total DM intake with increasing concentrate level (Steen, 1998; Keane 2001; Caplis, 2004) implying a progressively decreasing intake of grass silage with increasing concentrate level. From a series of experiments with high digestibility grass silage, Steen (1998) calculated substitution rates of 0.33, 0.64, 0.90 and 1.15 kg silage DM/kg concentrate DM for successive increments of concentrates equating to 0.22, 0.42, 0.62 and 0.85 of total DM intake, respectively. Caplis (2004) found substitution rates for high digestibility silage of 0.29, 0.65 and 1.10 kg silage DM/kg concentrate DM for successive increments of concentrate equating to 0.31, 0.55 and 0.85 of total DM intake. Surprisingly, there are relatively few reports in the literature where a wide range of supplementary concentrate levels in the diet of beef cattle offered grass silage-based diets were examined.

The effect of energy supplement type on the intake of grass silage is unclear. Mayne *et al.* (1995) reported that starch or fibre supplements had no significant effect on mean SR in growing cattle when considered across a range of silage compositions but there were interactions between supplement type and silage type. With extensively fermented silages characterised by high lactic acid concentrations, SR were lower with high starch than with high fibre supplements. It was suggested that this difference may reflect better synchronisation of nitrogen and fermentable energy. Steen (1993a) reported that silage intake was higher for fibre than starch-base concentrates for growing cattle. Silage intake of finishing beef cattle was shown to be not differentially affected by starch, fibre or sugar-based concentrates (Moloney *et al.*, 1993), fibre or starch-based concentrates (Steen, 1995a; O'Kiely & Moloney, 1994) and higher for starch than fat-based concentrates (Steen, 1995a; Moloney, 1996) or fibre-based concentrates (Moloney, 1996).

The effect of protein supplementation on grass silage intake is equivocal. Moloney (1991) found no effect of increasing the crude protein concentration (110 to 515 g/kg DM) of the concentrate on grass silage intake in growing cattle while Mayne *et al.* (1995) reported reduced substitution rates from increasing the supplement crude protein concentration (120 to 260 g/kg fresh weight).

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 (Patterson *et al.*, 2000; Steen & Kilpatrick, 2000; Caplis, 2004), in particular where grass silage of higher digestibility is fed (Drennan & Keane, 1987a; Steen *et al.*, 2002). 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 such as barley-based (starch) concentrates (Huhtanen & Jaakkola, 1993) and sucrose (Khalili & Huhtanen, 1991) in grass silage-based diets. The decrease in the digestibility of cell wall constituents is related to a reduction in ruminal pH. Mulligan *et al.* (2002) concluded that for diets based on grass silage and high fibre concentrate supplements, the depressive effect of feeding level *per se* on diet digestibility was greater for high (0.85 dietary DM) than moderate (0.50 dietary DM) concentrate diets. For moderate concentrate diets the reduction in digestibility was attributed to an increased fractional rumen outflow rate for the concentrate component while for high concentrate diets, decreased rumen pH and a decreased rate of concentrate and forage digestion were deemed to be important components. Consequently, dietary energy intake often mirrors total DM intake with increasing concentrate feeding level.

Production response to supplementation

Growing cattle

Due to compensatory growth a close inverse relationship (quadratic) has been found between liveweight gain of weanling cattle in winter and subsequent gain at pasture (Keane, 2002). Consequently, there was a highly significant positive curvilinear relationship between supplementary concentrate (range 0-3 kg) feeding of young/weanling cattle offered grass silage *ad libitum* and liveweight gain during the winter and a significant negative curvilinear relationship with liveweight gain of these same animals when subsequently grazing grass during the following summer (Keane, 2002). There was no difference in compensation at pasture for additional winter gain achieved either by increasing grass silage quality or by concentrate feeding (Keane, 2002). A continuing effect of compensation during a subsequent finishing phase indoors after the grazing season (or common diet) is evident in some, but not all studies (Keane, 2002; Keady *et al.*, 2004a). Similarly, the optimum level of concentrate feeding for cattle in the second winter is higher if animals are to be slaughtered at the end of the winter than for animals ("store cattle") destined to spend the following (3^{rd}) summer at pasture (Keane & Drennan, 1994). Drouillard & Kuhl (1999) highlighted the lack of research pertaining to integrated production systems where a more thorough understanding of the interactions among grazing nutrition and management, finishing performance and carcass traits is needed to facilitate greater economic exploitation of these relationships.

Finishing cattle

Although Scollan *et al.* (2003) concluded that good quality silage will support high levels of performance without the need for supplementation, the time taken to achieve the same slaughter live weight was 277 d for silage only compared to 228 and 196 d for a diet containing 0.3 and 0.7 concentrate on a DM basis, respectively. The carcass growth response to concentrate supplementation is generally lower with higher digestibility (Drennan & Keane, 1987a; Steen, 1998; Randby, 2001) or higher intake/restricted fermentation (Agnew & Carson, 2000) grass silage. Drennan & Keane (1987b) feeding grass silage with an *in vitro* DMD of 725 g/kg to steers reported a linear increase in carcass gain of 52 g per kg concentrate DM fed within the range 2.9 to 10.9 kg/head/d. More recently, Caplis (2004) feeding grass silage with an *in vitro* DMD of 758 g/kg obtained a curvilinear increase in the daily liveweight gain of steers (decreasing from 130 to 13 g liveweight/kg additional concentrate DM) with increasing concentrate level over a comparable concentrate range. Steen (1998) calculated that the response in carcass growth rate to concentrate supplementation within the range 2 to 9 kg/head/d was curvilinear (decreasing from 93 to 4 g carcass/kg additional concentrate) and linear (58 g carcass/kg concentrate) for high (733 g DOM/kg DM) and medium (625 g DOM/kg DM) digestibility silage, respectively. Consequently, the optimum input of concentrates is higher with lower digestibility silage.

Due to a progressive decline in the response to concentrates, high digestibility grass silage plus moderate concentrate inputs can achieve a large proportion of the carcass and lean tissue gain achieved with high concentrate diets. In the study of Patterson *et al.* (2000), bulls offered a high digestibility (730 g DOM/kg DM) grass silage and concentrates at 0.52 of dietary DM intake produced proportionately 0.90 of the rate of carcass gain and 0.99 of the lean tissue gain produced by a diet containing 0.75 concentrates. Indeed, 0.95 of the lean tissue gain was achieved at a relatively low concentrate proportion of 0.39. Steen *et al.* (2002) concluded that a diet containing 0.80 of high digestibility (743 g DOM/kg DM) grass silage and 0.20 concentrate sustained proportionately 0.85 of the carcass gain produced by a diet containing 0.80 concentrate, whereas a diet containing 0.60 high digestibility grass silage and 0.40 concentrate sustained the same carcass gain as a diet containing 0.80 concentrate. At similar metabolisable energy (ME) intakes, indications were that the net energy value of high digestibility silage per MJ of ME can be close to that of a high concentrate diet.

Accordingly, in order to determine the optimum or breakeven level of concentrate supplementation *per se*, 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 (Keane, 2001).

Energy source

The feeding value of wheat is the same as barley as a supplement to grass silage for finishing cattle (Steen, 1993b; Drennan & Moloney, 1998). When compared with barley as a supplement to grass silage-fed steers, molasses was used more efficiently at 210 g/kg total DM intake, but its relative energy value declined as the level of inclusion increased above 330 g/kg DM (Drennan, 1985). Replacement of barley-based with molasses (0.18-0.21 of dietary DM intake)-based concentrates did not affect the performance of finishing cattle on grass silage-based diets (Moloney *et al.*, 1993; Chapple *et al.*, 1996). The decline in the relative nutritive value of molasses with increasing inclusion level may be attributed to a possible reduction in fibre digestion due to sub-optimal ammonia concentration in the rumen together with excessively high butyrate production and possible differences in the site of digestion of carbohydrate within the digestive tract (Moloney *et al.*, 1994). Drennan *et al.* (1994) found that as a supplement to finishing bulls offered grass silage, a low protein, starch-based, concentrate was superior to a low protein starch + sugar-based (0.18 of dietary DM molasses) concentrate but there was no difference between the energy sources at higher protein inclusions.

Replacing starch with digestible fibre in the concentrate increased the liveweight/carcass weight gain of cattle offered grass silage-based diets in some studies (Moloney *et al.*, 1993; O'Kiely & Moloney, 1994), but not in others (Steen, 1995a; Moloney, 1996; Moloney *et al.*, 2001a). 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. Further research is required in this area.

Fat-based concentrates are inferior to starch or fibre-based concentrates as supplements to grass silage which is attributed to a lower organic matter digestibility for the former (Steen, 1995a; Moloney, 1996). Dietary supplementation with fat, especially polyunsaturated fats (with the possible exception of fish oil), at greater than 50 g added fat/kg concentrates, has an increasingly adverse effect on ruminal digestion of fibre (Doreau & Chillard, 1997).

Protein source

Growing cattle fed grass silage alone respond to supplementation with ruminally undegraded protein with relatively large improvements in gains (Titgemeyer & Loest, 2001). Silage intake (scaled for bodyweight) was not affected by supplementation and responses to ruminally undegraded protein supplementation were observed across different qualities of silage and different levels of intake. Similarly, including rumen undegradable protein increased the liveweight gain of young steers offered grass silage plus low levels of concentrate (Moloney, 1991; 1993; Rouzbehan *et al.*, 1996). Titgemeyer & Loest (2001) suggested that diets based on grass silage are likely to provide inadequate supplies of amino acids for growing cattle due to low microbial protein production and low ruminally undegraded protein content in the silages. This deficit was corrected by the rumen undegraded protein supplement resulting in increased protein deposition in those cattle. However, Sanderson *et al.* (2001) concluded that although rumen undegradable protein was an effective means by which to enhance protein deposition in young cattle given silage diets, the composition of the carcass remained unaffected. Supplementation of grass silage alone with a rumen degradable source of protein has also increased the performance of growing steers (Veira *et al.*, 1995; Scollan *et al.*, 2001a). Where young growing cattle are offered grass silage *ad libitum* and a low level of barley-based concentrates the inclusion of rumen degradable protein has increased (Moloney, 1991) or had no significant effect (Keane, 2002) on growth rate. There are indications of interactions between grass silage digestibility and crude protein degradability. Scollan *et al.* (2001a) found that as the sole supplement, rumen undegradable protein seemed to be superior to rumen degradable protein with lower digestibility silage with little difference between the protein types with higher digestibility silage. In contrast, Moloney (1993) found that decreasing CP degradability in the concentrate increased liveweight gain with high digestibility silage but not with low digestibility silage. However, when taken in the context of production systems much of the advantage to protein supplementation of young cattle was often lost during a subsequent standard feeding phase (Moloney, 1993) or grazing season (Seoane *et al.*, 1993; Scollan *et al.*, 2001a; Keane, 2002) due to compensatory growth.

For finishing cattle offered high digestibility grass silage plus barley-based concentrates, increasing protein intake by using either a rumen undegradable (Drennan *et al.*, 1994) or degradable (Drennan *et al.*, 1994; Steen & Robson, 1995; Steen, 1996a) protein source did not significantly affect animal growth. Furthermore, feeding excess protein increased nitrogen excretion to the environment (Steen, 1996a). Calculations by Titmeyer and Loest (2001) showed that while amino acids were the limiting factor with lighter weight calves offered grass silage, energy availability was the limiting factor with heavier steers. This shift in the most limiting nutrients as the steers become larger is related to greater energy to protein requirement for growth by the heavier animals. However, there is evidence that finishing cattle are likely to respond to supplementary protein in barley-based concentrates when grass silage digestibility is moderate to low (Waterhouse *et al.*, 1985) and in situations where animals are of very high growth potential (Steen, 1996b). Steen (1996b) and (2000) concluded that in silage-fed finishing cattle, responses to protein in addition to that contained in barley (10%) are likely to be obtained in bulls given a wide range of silage types, but only in steers and heifers given silages that are badly preserved and/or with low digestibility and/or low protein contents.

Concentrate feeding strategies

Feeding frequency

Supplementary concentrates have traditionally been fed in two feeds daily in order to reduce the likelihood of digestive problems. Feeding 6 kg (0.52 of total DMI) of rolled barley (4 experiments) or wheat (2 experiments) (Drennan & Moloney, 1998) or 4.5 kg (0.54 of total DMI) of a cereal-based coarse ration (Keady *et al.*, 2004b) in one as opposed to two daily feeds to finishing cattle offered grass silage *ad libitum* had no significant effect on carcass gain or feed conversion efficiency. This has positive implications in terms of labour efficiency.

Complete diet feeding/total mixed ration (TMR)

There is a limited quantity of published information comparing separate and TMR feeding of beef cattle offered grass silage-based diets with concentrates. Recent studies show that finishing steers offered grass silage plus a barley-based concentrate (0.31 or 0.55 (Caplis, 2004) and 0.40 or 0.80 (Keane, 2003a) of the dietary DM intake) either fed separately in one feed daily (following gradual introduction) or mixed with the silage through a diet feeder had similar carcass growth rates, carcass traits and muscle and fat colour. Furthermore, feeding method had no significant effect on diet digestibility, ruminal pH, ammonia or total volatile fatty acids concentrations (Caplis, 2004). However, the molar proportions of propionate were higher for the mixed diets than the separate diets. While there are many purported benefits for TMR feeding, these results demonstrate no advantage of mixing *per se* of grass silage and barley-based concentrates on animal efficiency or performance.

Co-ensiling

Previous studies with molassed sugar beet pulp (MBP) used as a silage additive demonstrated improved fermentation, reduced effluent production and increased silage nutritive value under good silage management practices (O'Kiely, 1992). Intake, *in vivo* digestibility and performance of finishing steers were similar when offered comparable amounts of MBP either as MBP co-ensiled with grass or as untreated, well-preserved silage supplemented with MBP. An additional benefit is the convenient manner of concentrate supplementation. Recent results suggest that citrus pulp, and to a lesser extent, soya hulls have similar potential (O'Kiely, 2002). However, some feed ingredients seem less promising and where grass undergoes an extensive clostridial fermentation co-ensiling is considerably less attractive (Stacey *et al.*, 2002).

Concentrate distribution pattern

Feeding weanling cattle a fixed total concentrate allowance offered at a flat daily rate or at a higher rate over the first half of the winter gave a better growth response than when offered at a higher rate over the second half of the winter (Keane, 2002; 2003b). Steen & Kilpatrick (2000) reported that finishing cattle given grass silage plus concentrates at 0.12 of dietary DM intake had similar average liveweight and carcass gains and a lower carcass fat score and fat trim than animals that initially received silage only followed by silage plus concentrates at 0.36 of dietary DM intake. Keane (1998) showed that finishing steers offered grass silage plus a fixed total quantity of supplementary concentrates at (i) a flat rate (5 kg), (ii) a stepped increased rate (2.5, 5.0 and 7.5 kg for each consecutive one-third of the 126-d finishing period) or (iii) silage for the first 42 d followed by *ad libitum* concentrate had similar carcass gains and feed energy efficiency over the same length of finishing period. Combining two experiments it was concluded that there were no significant differences in carcass gains, on efficiency of feed energy utilisation between the flat and *ad libitum* feeding treatments but the latter had a significantly lower carcass fat score and weight and proportion of kidney and channel fat.

Restricted feeding

Restricting the feed allowance to cattle under feed-lot or high concentrate feeding situations has been shown to reduce liveweight gain but to improve the efficiency of conversion of dietary dry matter to carcass weight when compared to *ad libitum* feeding of high cereal-based diets (Hicks *et al.*, 1990) and by-product based diets (French & Moloney, 2001). This improved feed conversion is largely attributed to higher rates of fat deposition in animals offered *ad libitum* concentrates but partly due to a lower digestibility at the higher feeding level (French & Moloney, 2001). Increasing the level of feeding of concentrate ingredients to cattle (offered at 0.85 of dietary DM) decreases the nutrient digestibility (Woods *et al.*, 1999). These findings contrast with studies examining the effect of restricting dry matter intake (~0.8 of *ad libitum*) on the efficiency of carcass gain of cattle finished on grass silage-based diets where results have shown reduced (Steen & Kilpatrick, 2000) and no effect (Keane & Drennan, 1980; Moore *et al.*, 1991; Steen *et al.*, 2002) on efficiency. Steen (1995b) found that restricting the intake of a grass silage-based diet significantly reduced the efficiency of conversion of ME to carcass gain in bulls but had little effect in steers or heifers. The differences in efficiency between restricted and *ad libitum* high concentrate versus forage-based diets are partly attributed to effects of compensatory growth, plane of nutrition and carcass fat content (Steen, 1995b). Furthermore, there was no significant effect on digestibility from restricting the DM intake of grass silage-based diets containing low to moderate proportions of concentrates (Steen, 1995b; Steen & Kilpatrick, 2000; Steen *et al.*, 2002). Restricted feeding must also be considered in relation to the delay in time to slaughter whereby the improvement in feed efficiency must offset the increased days on feed.

Carcass composition

There is considerable evidence that grass silage diets may predispose animals to depositing more fat in the gain than dried grass and wilted silages (e.g. McCarrick, 1966). However, most of those studies involved young animals and the results may not apply to animals slaughtered at commercial weights. Recent studies suggest that cattle fed on grass silage are not fatter. Scollan *et al.* (2003) found that from 350 kg empty body weight upwards the carcasses of animals given supplementary concentrate contained more fat than those offered good quality silage alone. Kim *et al.* (2003) feeding high quality grass silage compared with grass silage and concentrates at similar levels of ME intake per kg metabolic live weight found that concentrate supplementation increased the rate of tissue accretion but nutrient partitioning between fat and protein deposition was similar between 250 and 500 kg live weight. Increasing the protein content of grass silage-based finishing diets by inclusion of soyabean meal with barley increased carcass fatness in a number of studies (Steen & Robson, 1995; Steen, 1996a).

Increasing slaughter weight increases carcass weight and all measures of fatness. For cattle finished on grass silage and concentrates, Steen & Kilpatrick (2000) concluded that reducing slaughter weight is likely to be a more effective strategy to controlling carcass fat content than reducing energy intake either by diet restriction or reducing concentrate proportion.

Meat quality

The perception of healthiness and/or safety, tenderness, juiciness and aroma and flavour are important quality criteria that influence the decision of a consumer to purchase beef (Moloney *et al.*, 2001b). Furthermore, the colour or visual appearance of beef (lean meat and carcass fat) is often a key purchasing factor (Moloney *et al.*, 2004).

Many studies comparing the effects of forage and concentrates on meat quality have been confounded with plane of nutrition effects, such that cattle fed the higher energy concentrate diet have been heavier and fatter than those fed the forage-based diets (Muir *et al.*, 1998). Alternatively, the concentrate fed animals may be younger when grown to a specific bodyweight or back-fat thickness (French *et al.*, 2000). These are all factors which, can alter meat quality, and exist in commercial practice.

There are inconsistent effects of grass silage-based diets on subcutaneous fat colour. Moloney *et al.* (2003) reported that fat colour from steers offered grass was more yellow than fat from animals offered restricted fermentation grass silage-based diets and high concentrate starch or fibre-based diets, which were all similar. However, the fat colour from extensively fermented grass silage-based diets was not significantly different from the grass diet. Dunne *et al.* (2002) concluded that while concentrate feeding led to a time dependent decrease in subcutaneous fat yellowness relative to grass, substituting grass silage with concentrates did not lead to a consistent reduction in yellowness. Other studies have shown that at a similar carcass growth rate animals offered a grass silage/concentrate diet have yellower (Moloney *et al.*, 2000) or similar subcutaneous fat colour (French *et al.*, 2000) compared to non-silage high concentrate diets.

Substituting grass silage with concentrates generally has no effect on muscle redness, lightness and yellowness (Moloney *et al.*, 2000; French *et al.,* 2000; Lively *et al.*, 2004).

At similar carcass growth rates, a straw/concentrate-based diet resulted in beef with similar sensory attributes to a grass silage/concentrate diet (Moloney *et al.*, 2000). Equally, French *et al.* (2000) found that there was no difference in eating quality traits between diets of grass silage plus concentrates, high concentrates, grass plus concentrates and grass only. Moloney *et al.* (2003) comparing grass, restricted and extensive fermentation grass silage-based diets and high concentrate starch or fibre-based diets concluded that after ageing for 14 days, the only difference between the diets in eating quality traits was that beef from extensively fermented grass silage was more juicy than all treatments except the fibre-based concentrates. Similarly, Muir *et al.* (1998) concluded from their review that when compared at similar carcass weights or the same degree of fatness, grass-fed and grain-fed beef had no effect *per se* on tenderness, juiciness, lean meat colour, marbling or pH.

Ruminant meats are generally low in polyunsaturated fatty acids (PUFA) and rich in saturated fatty acids (SFA) due to the biohydrogenation action of rumen bacteria on fat consumed by the animal. Following human health guidelines many studies have aimed at increasing the PUFA content and in particular the *n*-3 long chain fatty acids, as well as the conjugated linoleic acid (CLA) content in intramuscular fat of beef (Raes *et al.*, 2004). One of the limitations of increasing PUFA in beef tissue through dietary supplements with oil or oilseed is the extent of rumen biohydrogenation as well as possible adverse effects on flavour, colour and shelf life of beef cuts with some oils (Mir *et al.*, 2003). In the latter case, high levels of dietary antioxidants are required to help stabilise the effects. This contrasts with grass and grass silage-based diets which contain natural anti-oxidants (Vitamin E) (Warren *et al.,* 2003; Scollan *et al.*, 2005). Protecting the lipid source from the hydrogenating action of the rumen micro-organisms results in reductions in SFA and increases in PUFA (Scollan *et al.*, 2002).

The lipid fraction of most grass-based forages contains alpha-linolenic acid as the main fatty acid and has a very low *n*-6:*n*-3 ratio (Givens *et al.*, 2000). Ensiling of forages generally results in fatty acid losses (Scollan & Wood, 2000). Dewhurst & King (1998) found that the effects of various silage additives and consequently fermentation had only a small effect on levels and proportions of fatty acids but shading and wilting had large negative effects on total fatty acids and on alpha-linolenic acid. However, Noci *et al.* (2004) reported that wilting did not impact negatively on the overall content of *n*-3 PUFA in muscle and increased the concentration of CLA. Diets with higher proportions of concentrates than grass silage have a higher *n*-6:*n*-3 PUFA ratio in intramuscular fat (Steen *et al.*, 2002; Warren *et al.,* 2003). Many studies have enhanced the fatty acid profile of beef muscle from grass silage-based diets by fortifying the supplementary concentrates with oils or oilseeds including sunflower oil, fish oil and linseed (Choi *et al.*, 2000; Scollan *et al.*, 2001b; Noci *et al.*, 2004, 2005). There is also evidence that longer term feeding of oils, rather than just in the finishing period, further enhances the intramuscular fatty acid composition (Raes *et al.*, 2004). Nevertheless, while dietary manipulation to enhance the fatty acid composition of meat has invariably resulted in highly significant changes the effects are generally small. The challenge is to increase the magnitude of these effects.

References

Agnew, R.E. & M.T. Carson (2000). The effect of a silage additive and level of concentrate supplementation on silage intake, animal performance and carcass characteristics of finishing beef cattle. *Grass and Forage Science*, 55, 114-124.

Caplis, J. (2004). *The effects of concentrate level and feeding a total mixed ration on intake and performance of finishing steers.* M.Agr.Sc. Thesis, National University of Ireland, 138 pp.

Chapple, D.G., H.F. Grundy, K.P.A. Wheeler & S.P. Marsh (1996). The effect of supplementing grass silage with molasses and/or a mineralised fish meal on performance and carcass characteristics of finishing beef cattle. *Animal Science*, 62, 653-654.

Choi, N.J., M. Enser, J.D. Wood & N.D. Scollan (2000). Effect of breed on the deposition in beef muscle and adipose tissue of dietary n-3 polyunsaturated fatty acids. *Animal Science*, 71, 509-519.

Dawson, L.E.R., R.M. Kirkland, C.P. Ferris, R.W.J. Steen, D.J. Kilpatrick & F.J. Gordon (2002). The effect of stage of perennial ryegrass maturity at harvesting, fermentation characteristics and concentrate supplementation, on the quality and intake of grass silage by beef cattle. *Grass and Forage Science*, 57, 255-267.

Dewhurst, R.J. & P.J. King (1998). Effects of extended wilting, shading, and chemical additives on the fatty acids in laboratory grass silages. *Grass and Forage Science*, 53, 219-224.

Doreau, M. & Y. Chilliard (1997). Digestion and metabolism of dietary fat in farm animals. *British Journal of Nutrition*, 78, Suppl. 1, S15-S35.

Drennan, M.J. (1985). Evaluation of molasses and ensiled pressed beet pulp for beef production. In: Ch. V. Boucque (Ed), *Feeding value of by-products and their use by beef cattle. Commission of the European Communities*, Luxembourg, pp. 171-183.

Drennan, M.J. & M.G. Keane (1987a). Responses to supplementary concentrates for finishing steers fed silage. *Irish Journal of Agricultural Research*, 26, 115-127.

Drennan, M.J. & M.G. Keane (1987b). Concentrate feeding levels for unimplanted and implanted finishing steers fed silage. *Irish Journal of Agricultural Research,* 26, 129-137.

Drennan, M.J. & A.P. Moloney (1998). Effect of concentrate type and feeding method on performance of cattle offered grass silage-based diets. *Irish Journal of Agricultural and Food Research,* 37, p.115.

Drennan, M.J., A.P. Moloney & M.G. Keane (1994). Effects of protein and energy supplements on performance of young bulls offered grass silage. *Irish Journal of Agricultural and Food Research,* 33, 1-10.

Drouillard, J.S. & G.L. Kuhl (1999). Effects of previous grazing nutrition and management on feedlot performance of cattle. *Journal of Animal Science,* 77, Suppl. 2, 136-146.

Dulphy, J.P. & M. Van Os (1996). Control of voluntary intake of precision-chopped silages by ruminants: a review. *Reproduction Nutrition Development*, 36, 113-135.

Dunne, P.G., A.P. Moloney, F.J. Monahan & F.P. O'Mara (2002). Subcutaneous adipose tissue colour of heifers fed grass, grass silage or concentrate-based diets. *Irish Journal of Agricultural & Food Research,* 41, 126.

Flynn, A.V. (1981). Factors affecting the feeding value of silage. In: W. Haresign & D.J.A. Cole (eds), *Recent Advances in Animal Nutrition - 1981*, 265-273.

French, P. & A.P. Moloney (2001). A note on diet digestibility, feed conversion efficiency and growth in steers offered *ad libitum* or restricted allowances of concentrates. *Irish Journal of Agricultural and Food Research,* 40, 271-275.

French, P., E.G. O'Riordan, F.J. Monahan, P.J. Caffrey, M. Vidal, M.T. Mooney, D.J. Troy & A.P. Moloney (2000). Meat quality of steers finished on autumn grass, grass silage or concentrate diets. *Meat Science*, 56, 173-180.

Givens, D.I., B.R. Cottrill, M. Davies, P.A. Lee, R.J. Mansbridge & A.R. Moss (2000). Sources of n-3 polyunsaturated fatty acids additional to fish oil for livestock diets- a review. *Nutritional Abstracts and Reviews*, Series B: Livestock Feeds and Feeding, 70, 1-19.

Hicks, R.B., F.N. Owens, D.R. Gill, J.J. Martin & C.A. Strasia (1990). Effects of controlled feed intake on performance and carcass characteristics of feedlot steers and heifers. *Journal of Animal Science*, 68, 233-244.

Huhtanen, P. S. & Jaakkola (1993). The effects of forage preservation method and proportion of concentrate on digestion of cell wall carbohydrates and rumen digesta pool size in cattle. *Grass and Forage Science,* 48, 155-165.

Ingvartsen, K.L. (1992). Effect of conservation and dry matter concentration of forage from grassland on feed intake, daily gain and feed conversion ratio of growing cattle: A review. *Report 711 National Institute of Animal Science, Foulum,* 44 pp.

Keady, T.W.J. & J.J. Murphy (1993). The effects of ensiling on dry matter intake and animal performance. *Irish Grassland and Animal Production Association Journal*, 27, 19-28.

Keady, T.W.J., A.F. Carson & D.J. Kilpatrick (2004b). The effects of two pure dairy breeds and their reciprocal crosses, and concentrate feeding management, on the performance of beef cattle. *Proceedings of the British Society of Animal Science*, p. 187.

Keady, T.W.J., R.M. Kirkland, D.C. Patterson, D.J. Kilpatrick & R.W.J. Steen (2004a). The effect of plane of nutrition during the growing and finishing phases, and gender, on the performance of beef cattle. *Proceedings of the British Society of Animal Science*, p. 188.

Keane, M.G. (1998). Effects of concentrate distribution pattern on the performance of finishing steers fed silage. Beef Production Series No. 3, Teagasc, Grange, Co. Meath, Ireland, 48 pp.

Keane, M.G. (2001). Response in beef cattle to concentrate feeding. Occasional Series No. 3, Teagasc, Grange Research Centre, Co. Meath, Ireland, 40 pp.

Keane, M.G. (2002). Response in weanlings to supplementary concentrates in winter and subsequent performance. Occasional Series No. 4, Teagasc, Grange Research Centre, Co. Meath, Ireland, 36 pp.

Keane, M.G. (2003a). Comparison of separate and mixed feeding of silage and concentrates for finishing cattle, Experiment 2. Beef Production Research Report, Teagasc, Grange Research Centre, Co. Meath, Ireland, 23-26.

Keane, M.G. (2003b). Response of weanlings to different winter feeding levels. Beef Production Research Report, Teagasc, Grange Research Centre, Co. Meath, Ireland, 29-30.

Keane, M.G. & M.J. Drennan (1980). Effects of diet type and feeding level on performance, carcass composition and efficiency of Friesian steers serially slaughtered. *Irish Journal of Agricultural Research,* 19, 53-66.

Keane, M.G. & M.J. Drennan (1994). Effects of winter supplementary concentrate level on the performance of steers slaughtered immediately or following a period at pasture. *Irish Journal of Agricultural and Food Research,* 33, 111-119.

Khalili, H. & P, Huhtanen (1991). Sucrose supplements in cattle given grass silage-based diet. 2. Digestion of cell wall carbohydrates. *Animal Feed Science and Technology*, 33, 263-273.

Kim, E.J., N.D. Scollan, M.S. Dhanoa & P.J. Buttery (2003). Effects of supplementary concentrates on growth and partitioning of nutrients between different body components in steers fed on grass silage at similar levels of metabolisable energy intake. *Journal of Agricultural Science*, 141, 103-112.

Kung, L., M.R. Stokes & C.J. Lin (2003). Silage additives. In: D.R. Buxton, *et al.* (eds.), Silage science and technology - Agronomy monograph No. 42. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, Wisconsin, USA, p. 305-360.

Lively, F.O., T.W.J. Keady, B.W. Moss, R.M. Kirkland, D.C. Patterson & D.J. Kilpatrick (2004). The effect of gender and the plane of nutrition during the growing and finishing phases, on carcass characteristics and meat quality. *Proceedings of the British Society of Animal Science,* p. 68.

Mayne, C.S. & A. Cushnahan (1995). The effects of ensilage on animal performance from the grass crop. In: *68th Annual Report, Agricultural Research Institute of Northern Ireland*, pp. 30-41.

Mayne, C.S., R. Agnew, D.C. Patterson, R.W.J. Steen, F.J. Gordon, D.J. Kilpatrick & E.F. Unsworth (1995). An examination of possible interactions between silage type and concentrate composition on the intake characteristics of grass silage offered to growing cattle and dairy cows. *Proceedings of the British Society of Animal Science*, Paper 21.

McCarrick, R.B. (1966) Effect of method of grass conservation and herbage maturity on performance and body composition of beef cattle. In: A.G.G. Hill *et al.* (eds) *Proceedings of the 10th International Grassland Congress*, Helsinki, 575-580.

Mir, P.S., M. Ivan, M.L. He, B. Pink, E. Okine, L. Goonewardene, T.A. McAllister, R. Weselake & Z. Mir (2003). Dietary manipulation to increase conjugated linoleic acids and other desirable fatty acids in beef: A review. *Canadian Journal of Animal Science*, 83, 673-685.

Moloney, A.P. (1991). Growth, digestibility and nitrogen retention in young Friesian steers offered grass silage and concentrates which differed in protein concentration and degradability. In: *Proceedings of the 6th International Symposium on Protein Metabolism and Nutrition*, 9-14 June, Herning, Denmark, EAAP publication No. 59, 342-344.

Moloney, A.P. (1993). The effects of grass silage digestibility and supplementary protein on growth, digestibility and nitrogen retention in young steers. In: P. O'Kiely *et al.* (eds.) *Proceedings of 10th International Silage Conference*, Dublin City University, Dublin, Ireland, p. 236-237.

Moloney, A.P. (1996). Digestion and growth in steers fed grass silage and starch, fibre or fat-based concentrates. *Irish Journal of Agricultural and Food Research,* 35, p. 65.

Moloney, A.P., A.A. Almiladi, M.J. Drennan & P.J. Caffrey (1994). Rumen and blood variables in steers fed grass silage and rolled barley or sugar cane molasses-based supplements. *Animal Feed Science and Technology*, 50, 37-54.

Moloney, A.P., D. McGilloway, M.T. Mooney, M. Vidal & D.J. Troy (2003). Influence of grass silage fermentation and concentrate composition on the appearance and sensory characteristics of bovine *M. longissimus dorsi*. *Proceedings of the British Society of Animal Science,* p. 201.

Moloney, A.P., T.V. McHugh & A. McArthur (1993). Growth and rumen fermentation in steers fed silage and concentrates differing in energy source. *Irish Journal of Agricultural and Food Research,* 32, p. 101.

Moloney, A.P., F.J. Monahan, F.P. O'Mara & P.D. Dunne (2004). Manipulation of beef fat and lean colour. Beef Production Series No. 58, Teagasc, Grange, Co. Meath, Ireland, 28 pp.

Moloney, A.P., M.T. Mooney, M.J. Drennan, B. O'Neill & D.J. Troy (2000). Fat colour and the quality of meat from beef cattle offered grass silage or concentrate-based diets. *Irish Journal of Agricultural and Food Research,* 39, p. 152.

Moloney, A.P., M.T. Mooney, J.P. Kerry & D.J. Troy (2001b). Producing tender and flavoursome beef with enhanced nutritional characteristics. *Proceedings of the Nutrition Society*, 60, 221-229.

Moloney, A.P., P. O'Kiely, M.C. Hickey & L.A. Adams (2001a). Optimisation of nutrient supply for beef cattle fed grass or silage. Beef Production Series No. 26, Teagasc, Grange, Co. Meath, Ireland, 48 pp.

Moore, C.A., K.J. McCracken, E.F. Unsworth, R.W.J. Steen, F.J. Gordon & D.J. Kilpatrick (1991). Effect of plane of nutrition and slaughter weight on growth and food efficiency of Friesian steers during the finishing period. *Animal Production*, 52, p. 572.

Muir, P.D., J.M. Deaker & M.D. Bown (1998). Effects of forage- and grain-based feeding systems on beef quality: A review. *New Zealand Journal of Agricultural Research*, 41, 623-635.

Mulligan, F.J., P.J. Caffrey, M. Rath, J.J. Callan, P.O. Brophy & F.P. O'Mara (2002). An investigation of feeding level effects on digestibility in cattle for diets based on grass silage and high fibre concentrates at two forage:concentrate ratios. *Livestock Production Science,* 77, 311-323.

Noci, F., A.P. Moloney & F.J. Monahan (2004). The effects of fish oil inclusion in the concentrate and method of silage preservation on fatty acid composition of muscle from steers. *Proceedings of the British Society of Animal Science,* p. 86.

Noci, F., P. O'Kiely, F.J. Monahan, C. Stanton & A.P. Moloney (2005). Conjugated linoleic acid concentration in *M. Longissimus dorsi* from heifers offered sunflower oil-based concentrates and conserved forages. *Meat Science*, 69, 509-518.

O'Kiely, P. (1992). The effect of ensiling sugarbeet pulp with grass on silage composition, effluent production and animal performance. *Irish Journal of Agricultural and Food Research*, 31, 115-128.

O'Kiely, P. (2001). Producing grass silage profitably in northern Europe. In: *Production and utilisation of silage, with emphasis on new techniques.* Nordic Association of Agricultural Scientists; Seminar #326 at Lillehammer, Norway, 27-28 Sept. 2001, 18 pp.

O'Kiely, P. (2002). Soya hulls or citrus pulp as alternatives to molassed beet pulp as silage additives. In: L.M. Gechie and C. Thomas (eds.) *Proceedings of XIII International Silage Conference*, Sept.11-13 (2002), SAC, Auchincruive, Scotland. p. 220-221.

O'Kiely, P. & A.P. Moloney (1994). Silage characteristics and performance of cattle offered grass silage made without an additive, with formic acid or with a partially neutralised blend of aliphatic organic acids. *Irish Journal of Agricultural and Food Research,* 33, 25-39.

Patterson, D.C., R.W.J. Steen, C.A. Moore & B.W. Moss (2000). Effects of the ratio of silage to concentrates in the diet on the performance and carcass composition of continental bulls. *Animal Science*, 70, 171-179.

Raes, K., S. De Smet & D. Demeyer (2004). Effect of dietary fatty acids on incorporation of long chain polyunsaturated fatty acids and conjugated linoleic acid in lamb, beef and pork meat: a review. *Animal Feed Science and Technology*, 113, 199-221.

Randby, A.T. (2001). Beef from forage: The potential of high quality grass silage. In: *Production and ùtilisation of silage, with emphasis on new techniques.* Nordic Association of Agricultural Scientists; Seminar #326 at Lillehammer, Norway, 27-28 Sept. 2001, 46-51.
Rinne, M. (2000). Influence of the timing of the harvest of primary grass growth on herbage quality and subsequent digestion and performance in the ruminant animal. Academic dissertation, University of Helsinki, Department of Animal Science. Publications 54, 42 p. +5 encl.
Rouzbehan, Y., H. Galbraith, J.H. Topps & J. Rooke (1996). Response of growing steers to diets containing big bale silage and supplements of molassed sugar beet pulp with and without white fish meal. *Animal Feed Science and Technology*, 62, 151-162.
Sanderson, R., M.S. Dhanoa, C. Thomas & A.B. McAllan (2001). Fish-meal supplementation of grass silage offered to young steers: Effects on growth, body composition and nutrient efficiency. *Journal of Agricultural Science*, *Cambridge*, 137, 85-96.
Scollan, N.D. & J.D. Wood (2000). Improving the nutritional value and eating quality of beef. In: D. Pullar (Ed.), Beef from Grass and Forage. *Occasional Symposium No. 35*, *Proceedings of the British Grassland Society*, 20 & 21 Nov. 2000, 29-42.
Scollan, N.D., N.J. Choi, E. Kurt, A.V. Fisher, M. Enser & J.D. Wood (2001b). Manipulating the fatty acid composition of muscle and adipose tissue in beef cattle. *British Journal of Nutrition*, 85, 115-124.
Scollan, N.D, M.S. Dhanoa, E.J. Kim, J.M. Dawson & P.J. Buttery (2003). Effects of diet and stage of development on partitioning of nutrients between fat and lean deposition in steers. *Animal Science*, 76, 237-249.
Scollan, N.D., S. Gulati, K.G. Hallett, J.D. Wood & M. Enser (2002). The effects of including ruminally protected lipid in the diet of Charolais steers on animal performance, carcass quality and the fatty acid composition of longissimus dorsi muscle. *Proceedings of the British Society of Animal Science,* p. 9.
Scollan, N.D, I. Richardson, S. De Smet, A.P. Moloney, M. Doreau, D. Bauchart & K. Nuernberg (2005). Enhancing the content of beneficial fatty acids in beef and consequences for meat quality. In: J.F. Hocquette & S. Gigli (eds), *Indicators of milk and beef quality*. EAAP publication No. 112, Wageningen Academic Publishers, 151-162.
Scollan, N.D., A. Sargeant, A.B. McAllan & M.S. Dhanoa (2001a). Protein supplementation of grass silages of differing digestibility for growing steers. *Journal of Agricultural Science*, *Cambridge*, 136, 89-98.
Seoane, J.R., A. Amyot, A-M. Christen & H.V. Petit (1993). Performance of growing steers fed either hay or silage supplemented with canola or fishmeal. *Canadian Journal of Animal Science*, 73, 57-65.
Shiels, P. (1998). *Defining the conditions under which benefits accrue from the use of bacterial inoculants as silage additives.* Ph.D. Thesis, National University of Ireland, 413 pp.
Stacey, P., P. O'Kiely & F.P. O'Mara (2002). Conservation characterisation of dry concentrates co-ensiled with grass. In: L.M. Gechie & C. Thomas (eds.) *Proceedings of XIII International Silage Conference*, Sept. 11-13, SAC, Auchincruive, Scotland. 222-223.
Steen, R.W.J. (1988). Factors affecting the utilisation of grass silage for beef production. In J. Frame (ed.). *Efficient beef production from grass, Occasional Symposium No. 22, British Grassland Society*, 129-139.
Steen, R.W.J. (1993a). A comparison of supplements to grass silage for growing beef cattle. In: P. O'Kiely *et al.* (eds.) *Proceedings of 10th International Silage Conference*, Dublin City University, Dublin, Ireland, 206-207.
Steen, R.W.J. (1993b). A comparison of wheat and barley as supplements to grass silage for finishing beef cattle. *Animal Production*, 56, 61-67.
Steen, R.W.J. (1995a). A comparison of supplements to grass silage for beef cattle. *Proceedings of the British Society of Animal Science*, Paper 166.
Steen, R.W.J. (1995b). The effect of plane of nutrition and slaughter weight on growth and food efficiency in bulls, steers and heifers of three breed crosses. *Livestock Production Science,* 42, 1-11.
Steen, R.W.J. (1996a). Effects of protein supplementation of grass silage on the performance and carcass quality of beef cattle. *Journal of Agricultural Science*, *Cambridge*, 127, 403-412.
Steen, R.W.J. (1996b). Factors affecting the optimum protein content of concentrates for beef cattle. Research on beef production. *Occasional Publication No. 22, Agricultural Research Institute of Northern Ireland.* 53-59.
Steen, R.W.J. (1998). A comparison of high-forage and high concentrate diets for beef cattle. In: *71st Annual Report, Agricultural Research Institute of Northern Ireland*, pp. 30-41.
Steen, R.W.J. (2000). Finishing systems based on conserved grass. In: D. Pullar (Ed.), Beef from Grass and Forage. *Occasional Symposium No. 35, Proceedings of the British Grassland Society*, 20 & 21 Nov. 2000, 55-64.
Steen, R.W.J. & D.J. Kilpatrick (2000). The effects of the ratio of grass silage to concentrates in the diet and restricted dry matter intake on the performance and carcass composition of beef cattle. *Livestock Production Science*, 62, 181-192.
Steen, R.W.J. & A.E. Robson (1995). Effects of forage to concentrate ratio in the diet and protein intake on the performance and carcass composition of beef heifers. *Journal of Agricultural Science*, *Cambridge*, 125, 125-135.

Steen, R.W.J., F.J. Gordon, L.E.R. Dawson, R.S. Park, C.S. Mayne, R.E. Agnew, D.J. Kilpatrick & M.G. Porter (1998). Factors affecting the intake of grass silage by cattle and prediction of silage intake. *Animal Science,* 66, 115-127.

Steen, R.W.J., D.J. Kilpatrick & M.G. Porter (2002). Effects of the proportions of high or medium digestibility grass silage and concentrates in the diet of beef cattle on liveweight gain, carcass composition and fatty acid composition of muscle. *Grass and Forage Science*, 57, 279-291.

Titgemeyer, E.C. & C.A. Loest (2001). Amino acid nutrition: Demand and supply in forage-fed ruminants. *Journal of Animal Science*, 79, E Suppl., E180-E189.

Thomas, C. & P.C. Thomas (1985). Factors affecting the nutritive value of grass silages. In: W. Haresign & D.J.A. Cole (eds) *Recent Advances in Animal Nutrition-1985*, 223-256.

Van Vuuren, A.M., P. Huhtanen & J.P. Dulphy (1995). Improving the feeding and health value of ensiled forages. In: M. Journet *et al.* (eds), *Recent Advances in the Nutrition of Herbivores, Proceedings of the IVth International Symposium on the Nutrition of Herbivores*, INRA Editions, Paris, 279-307.

Veira, D.M., H.V. Petit, J.G. Proulx, L. Laflamme & G. Butler (1995). A comparison of five protein sources as supplements for growing steers fed grass silage. *Canadian Journal of Animal Science*, 75, 567-574.

Warren, H.E., M. Enser, I. Richardson, J.D. Wood & N.D. Scollan (2003). Effect of breed and diet on total lipid and selected shelf-life parameters in beef muscle. *Proceedings of the British Society of Animal Science,* p. 43.

Waterhouse, A., R. Laird & D.P. Arnot (1985). Responses to protein supplements in silage-fed finishing steers: Effects of silage quality and supplement type. *Animal Production*, 40, 538.

Woods, V.B., A.P. Moloney, F.J. Mulligan, M.J. Kenny & F.P. O'Mara (1999). The effect of animal species (cattle or sheep) and level of intake by cattle on *in vivo* digestibility of concentrate ingredients. *Animal Feed Science and Technology*, 80, 135-150.

Wright, D.A., F.J. Gordon, R.W.J. Steen & D.C. Patterson (2000). Factors influencing the response in the intake of silage and animal performance after wilting of grass before ensiling: a review. *Grass and Forage Science,* 55, 1-13.