CHAPTER 1

ACHIEVING HIGH DRY-MATTER INTAKE FROM PASTURE WITH GRAZING DAIRY COWS

P. DILLON

Dairy Production Department, Teagasc, Dairy Production Research Centre, Moorepark, Fermoy, Co. Cork, Ireland

Abstract. Due to economic, environmental and animal-welfare constraints, it is envisaged that in the future a larger proportion of the milk produced in temperate regions will be produced from grazed pasture. However, with the selection of modern higher-production dairy cows, increased emphasis on product quality and issues associated with nitrogen leaching, soil compaction, greenhouse-gas emissions and animal welfare, pasture-based systems will also require higher per-animal productivity in the future. This will necessitate the development of grazing systems designed to maximize daily herbage intake per cow, while at the same time maintain a high-quality pasture over the entire grazing season. Daily grass DM intake will be maximized by adhering to important sward characteristics such as maintaining a high proportion of green leaf within the grazing horizon while allocating an adequate daily herbage allowance. Increasing the green-leaf proportion at the base of the sward through appropriate grazing management in early spring may play an important role in increasing herbage intake and making grazing management easier. This requires knowledge of the carryover effect of early-season grazing management on mid-season pasture quality and the implication for milk output per hectare. The present plant selection and evaluation systems target improved grass DM yields rather than parameters that influence animal performance. There is a clear requirement for an increased selection emphasis on characteristics that influence animal performance, i.e., herbage intake. This can be best achieved by adopting an interdisciplinary approach with plant physiologists, nutritionists, breeders and evaluators sharing knowledge and resources. Likewise, in the future the cow genotype must be compatible with the system of milk production, and prediction of the phenotypic performance of dairy cattle must be based on knowledge of the cows' genotype as well as the environment in which they are managed. The development of reliable, easy to use decision support tools that facilitate increased reliance on grazed grass, to be used by farmers and extension services, will contribute to optimize animal performance from grazed pasture.
Keywords: herbage intake; grazing, herbage mass; allowance; sward height

INTRODUCTION

The recently rejuvenated interest in grazing systems of animal production in many temperate and subtropical regions of the world is a result of lower product prices, the continuing removal of subsidies and tariffs, rising labour, machinery and

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housing costs, and perceived environment and animal-welfare concerns associated with intensive systems. Grassland occupies some 150 million ha in Europe. This is used principally to provide feed for ruminant animals to produce milk, meat and fibre. Over the past 25 years, high product prices in the EU have encouraged systems with high inputs of concentrate feeds, machinery for forage conservation and inputs of fertilizer. However, limitations have appeared with these intensive production systems with the introduction of EU quotas, the necessity to account for environmental concerns and reduced product prices with the introduction of GATT reforms. This leads to an increased emphasis on production efficiency per unit of output.

Grazing dairy cows is common practice in many European countries, although dairying regions vary dramatically in climatic conditions. Grass grows more regularly from spring to autumn in Western Europe (e.g. UK, Ireland, Normandy in France), whereas in other regions grass does not grow in summer (Pays de Loire and Aquitaine in France) or the grazing season is quite short due to long cold winters (Northern countries). The grass-growing season varies from less than 150 days up to 365 days per year. In the most favourable regions, a potential grass DM yield of 15,000 kg per ha (Drennan et al. 2005) is achievable and can result in milk output of 1,200 kg of milk fat and protein per ha using a nitrogen input of 300 kg per ha and concentrate supplementation of 300 kg DM per cow (Horan et al. 2005). Such a system has been derived within an EU milk-quota scenario to maximize profitability (where total farm productivity is capped) by reducing costs through increased pasture utilization in dairy cow diets. Figure 1 shows the relationship between milk production costs and the proportion of grazed pasture in the dairy-cow ration (Dillon et al. 2005). The relationship shows that for every 10% increase in grazed grass in dairy-cow ration, milk production costs per litre are reduced by 2.5 cents.

However, in most European countries in recent years there has been a shift away from pasture-based systems to greater use of conserved-forage-based systems, especially forage maize. Despite regional differences, utilization of grass by grazing should provide the basis of sustainable dairying systems as grazed grass is the cheapest source of nutrients for dairy cows, thus enhancing the competitiveness of pasture-based systems of production, preserving the rural landscape and promoting a clean, animal-welfare-friendly, image for dairy production.

In the past, high performance from pasture-based systems was based on high stocking rates accompanied by high herbage utilization, where individual animal performance was compromised. However, with the selection of modern higher-productive dairy cows, increased emphasis on product quality and issues associated with nitrogen leaching, soil compaction, greenhouse-gas emissions and animal welfare, pasture-based systems in the future will require higher per-animal productivity. Therefore, the efficient exploitation of grazed grass will require the development of grazing systems designed to maximize daily herbage intake per cow, while maintaining a greater quantity of higher-quality herbage over the grazing season.

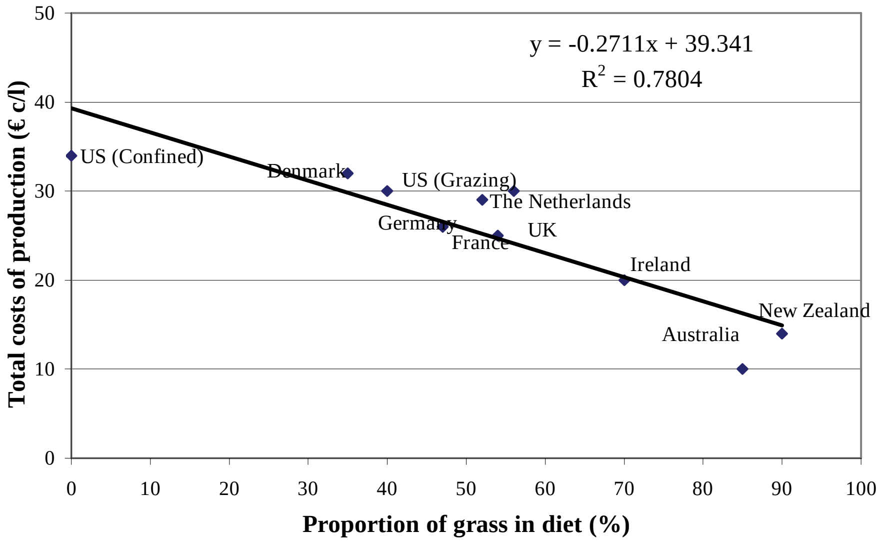

Figure 1*. Relationship between total costs of production and proportion of grazed pasture in cows ration (Dillon et al. in press)*

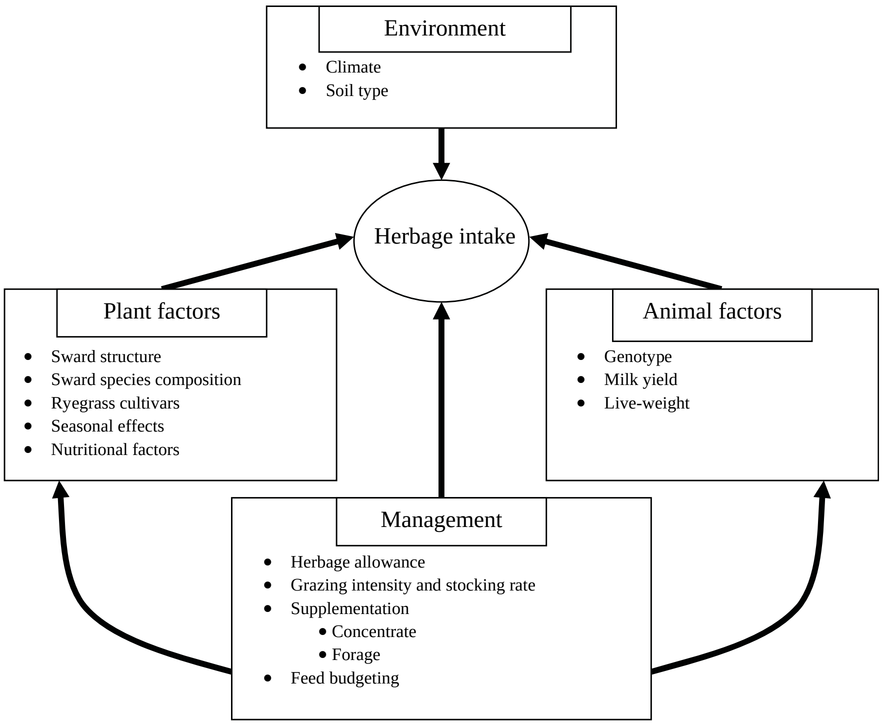

Figure 2*. Factors influencing herbage intake by ruminants*

Milk production from pasture is largely dependent upon the factors controlling herbage intake and ruminal digestion. The factors influencing herbage intake (Figure 2) are numerous, but can be broadly described in terms of four areas: environmental, plant, animal and management factors. The aim of this paper is to review recent advances in our understanding of the effect of these sources of variation, with particular emphasis on opportunities to increase herbage intake with lactating dairy cows, plus some recent developments in the measurement of herbage intake.

ENVIRONMENTAL FACTORS

Among the main factors influencing the ability of ruminant animals to consume high intakes of herbage in pasture-based systems are climatic and soil conditions. The effect of temperature on feed intake of ruminants has been reviewed by Webster (1976). Food intake decreases at high temperatures and increases at low temperatures (Ragsdale et al. 1950). Milk yield may decrease at temperatures above 18°C and food intake above 26°C (Head et al. 1976). However, in practice the effects on intake and performance are less than predicted from controlled-temperature studies, because lactating cows compensate lower daytime intake by night-time grazing.

PLANT FACTORS

Sward structure

Herbage availability can be defined as the relative ease or difficulty with which herbage can be harvested by the grazing animal. Herbage availability is a complex parameter that takes into account the qualitative and quantitative aspects of the sward and interactions with daily herbage allowance. To maximize intake, animals need to consume plants that have characteristics that allow rapid consumption and lead to fast rates of passage through the rumen. Rook (2000) defined intake of herbage as the product of bite mass and bite rate, and time spent grazing as the product of meal duration and number of meals per day:

Daily intake = (bite mass x bite rate) x (meal duration x number of meals)

Grazing ruminants vary bite dimensions, bite rate and grazing time in response to changes in sward conditions (Hodgson 1981; Gibb et al. 1997). Numerous studies have focused upon the relationship between sward structure and intake per bite, assuming an overriding importance of intake per bite in driving overall herbage intake. Surprisingly, there are few data to quantify the effect of sward structural characteristics known to influence the bite weight upon daily intake of dairy cows. Also, by the nature of the studies they are more relevant to continuous rather than rotational stocking situations.

In continuous stocking, herbage intake increases asymptotically with herbage mass/or sward height (Le Du 1980), with maximum intake being achieved at a sward height of 8 to 9 cm. In rotationally grazed pastures, herbage intake is maximized at a sward height of 9 to 13 cm (Stakelum et al. 1997). Cows grazing very short swards are unable to eat sufficient quantities of DM, even if the area of pasture offered is very large, whereas on tall, rotationally grazed swards other factors may carry a negative effect on daily intake.

On rotationally grazed swards, the herbage availability may be partly determined by the proportion of green leaf in the grazed horizon. Wade et al. (1989; 1995) first concluded that herbage availability increased with an increasing proportion of green leaf in the bottom of sward when animals cease grazing. This was further demonstrated by Parga et al. (2000), comparing two swards differing in the proportion of green leaf material below 15 cm, but with the same proportion above 15 cm. At high herbage allowance, herbage intake was similar for both swards, but when herbage allowance was reduced from 17 to 12 kg OM per day, herbage intake was reduced less in the sward with the higher proportion of green leaf material below 15 cm. Peyraud et al. (2004) showed that daily allowance of green leaf was a better predictor of DM intake than daily herbage allowance. This not only takes into account the effect of herbage allowance but also the effect of sward structure for a given allowance. Appropriate grazing management and/or selection of the appropriate herbage varieties may play an important role in increasing the proportion of green leaf at the bottom of the sward.

Sward species composition

In general, legumes have characteristics that lead to a higher animal performance compared to grasses. Herbage intake and milk production have been shown to be higher in mixed perennial-ryegrass – white-clover swards compared to pure perennial-ryegrass swards (Wilkins et al. 1994; 1995; Ribeiro-Filho et al. 2003). Rogers et al. (1982) showed that cows consuming white-clover pasture produced more milk and gained more live-weight (85 vs. 80 kg) due to a 30 % higher intake. Harris et al. (1997) showed that in mixed swards with perennial ryegrass, milk yield was increased by 20% when dairy cows consumed a diet with 55 – 65 % clover in the DM, compared to a diet with only 20 % clover. No further advantage in animal performance was achieved by offering diets with 80 % clover. Clovers contain less structural carbohydrate, leading to more rapid rates of breakdown of OM, nitrogen (N) and cell walls (Beever and Siddons 1986; Aitchison et al. 1986; Beever et al. 1986b) and the retention time is less compared with ryegrass (Ulyatt 1973). Despite the clear advantages in the intake of white clover over ryegrass, there are issues that need to be considered such as the cost of increased prevalence of bloat and the additional costs of maintaining swards high in white-clover content.

Ryegrass cultivars

In Europe, grass breeders have increased DM yield by 0.5 % per year as tested in cutting trials in the Netherlands from 1965 to 1990 (Van Wijk and Reheul 1991). However, there is little evidence that new grass cultivars have made a significant contribution to increased dairy production. The expense of animal production experiments has often been cited as the reason for using cutting trials in variety evaluations. Gately (1984) compared an early perennial (Cropper) with a late perennial ryegrass (Vigour) for milk production at two stocking rates. At a low stocking rate, the improved digestibility of the Vigour gave 8.8 % more milk yield than Cropper. However, at high stocking rate, Cropper gave 6.6 % more milk than Vigour, because of the greater pasture production in early spring at the time of peak milk yield. Hageman et al. (1993) obtained higher performance from tetraploid compared to diploid cultivars of perennial ryegrass with grazing dairy cows. Gowen et al. (2003) obtained higher DM intake and milk production from late heading compared to early heading perennial-ryegrass cultivars when cows were stocked to allow adequate feed allowance. The higher performance with the late heading perennial-ryegrass cultivars was associated with a higher proportion of green leaf in the grazed horizon. Tas et al. (2005) found no differences in DM intake and milk production when comparing eight diploid perennial-ryegrass cultivars differing in water-soluble carbohydrates content, and with inconsistent differences in crude protein and NDF content.

Seasonal effects

Lactating cows grazing temperate pasture consumed 10% less herbage in autumn than in spring for the same digestibility (Corbett et al. 1963). The higher intake in spring compared to autumn is attributed to a greater intake rate (Phillips and Leaver 1985) and a faster breakdown in the rumen (Corbett et al. 1966). The lower rate of intake in autumn may be attributed to the lower DM content (Leaver 1985), the greater proportion of dead material (Le Du et al. 1981) and the increased area due to rejection with excreta (Greenhalgh and Reid 1969). The slower breakdown of autumn herbage in the rumen may be attributed to the lower net energy value (Beever et al. 1986a). This is attributed to the higher concentrations of non-protein nitrogen, lower concentrations of water-soluble carbohydrates and higher cell-wall lignifications in the sward during autumn (Beever et al. 1986a).

Nutritional factors

It has been suggested that an ideal sward would have a nutrient profile similar to a total mixed ration (TMR) formulated to provide nutrients in relation to requirements while having the physical characteristics necessary to stimulate rumen function and rumination (Wales et al. 2005). A TMR diet offers control over the nutritive characteristics of the diet, when offered in sufficient quantities, it allows animals to approach their potential intake, and can provide the nutrient requirements for high animal performance. Kolver and Muller (1998) compared the nutritive characteristics and animal performance of a pasture diet based on a mixed grass/clover sward and a TMR consumed by dairy cows in early lactation. Despite both diets having a similar digestibility, there were obvious differences in the concentrations of essential nutrients, as well as pasture having lower DM and nonstructural carbohydrate concentrations and higher NDF concentrations. In comparison with TMR, cows consuming grazed pasture, even when supplemented with grain, had lower DM intake, milk production, milk protein and fat concentrations, lost more body condition and had lower live-weight. However, there is now strong evidence to show that the dairy cattle that are genetically best suited to high concentrate input systems are not best suited to grazing systems, indicating an interaction between genotype and feeding system (Dillon et al. in press).

The nutritive value of herbage gives an indication of its potential value to grazing animals, but its feeding value (nutritive value x intake) is of most importance. It has been well established that, with fibrous diets, intake is limited by rumen capacity and by the rate of passage of digesta through the rumen (Minson 1982). At high levels of digestibility, it has been postulated that voluntary intake is controlled more by the energy requirement of the animal and less by the above physical factors, and that intake stabilizes at digestibilities above 67 % (Conrad et al. 1964). However, these results were obtained with mixed roughage/concentrate diets and these findings do not apply to herbage diets, where linear responses have been shown up to 83 % digestibility (Hodgson 1977). However, digestibility differences in swards are most commonly associated with changes in sward structure, such as sward height, and content and distribution of leaf material, sheath, stem or dead material. These differences lead to difficulty in isolating the digestibility effect *per se* from other differences.

The DM content of the herbage can have a large effect on herbage intake. Studies with housed cows have shown below a critical value of 180 g DM per kg (Vérité et al. 1970), that intake is reduced with 1 kg DM, for a reduction in DM content of 40 g per kg. When water was added to the rumen *per fistulum*, there were no detrimental effects on the intake of forages by sheep (Lloyd Davies 1962), indicating the effects of water content on herbage intake may be associated with palatability or the large volumes of fresh herbage that need to be processed during ingestion. In cattle, Cabrera Estrada et al. (2004) showed that intake and eating rate were restricted by internal water of grass, but not by external water.

The crude-protein content of herbage varies considerably between species, with legumes being higher than grasses. The nitrogen content of herbage is dependent on the level of fertilizer N applied and soil OM content. Peyraud and Astigarraga (1998) reviewed the effect of fertilizer N on dairy-cow performance. In France, they showed that in deep and rich soils (10 % OM) reducing N fertilizer from 320 kg to almost zero N did not affect milk yield, while crude-protein content of unfertilized swards remained greater than 15 %. In contrast, in soil with low N supply capacity (2% OM) reducing N fertilization led a reduction in milk yield of 2.5 kg per day and in herbage intake of 2 kg DM, while protein content in the herbage fell below 12 %. Therefore, reduced herbage intake was mostly mediated through reduced protein content of the herbage, while herbage mass and height may also be of influence. Peyraud and Astigarraga (1998) calculated that, to maintain a daily milk production of 0.80 to 0.85 kg of milk protein, a daily intake of 3 kg of crude protein is required.

Improved grazing efficiency through grass breeding

Animal production from grazed pasture could be improved through increased use of herbage species or varieties with increased intake and digestibility potential. Traditionally, plant-breeding objectives were mostly focused on increasing DM yield and pest and disease resistance, with little emphasis on factors that affect animal performance and the characteristics of animal produce. Digestibility is a heritable characteristic and some improvement has resulted from conventional breeding, with further increases likely to result from biotechnological modification.

Wales et al. (2005) suggested that the use of techniques to genetically modify plants will enable the development of plants with elevated concentration of ruminal undegradable dietary protein and high energy-yielding compounds, such as starch or triacylglycerides. Grazing studies have shown that animals have a strong preference for herbage with high concentrations of soluble carbohydrates (Ciavarella et al. 2000). In zero-grazing studies, dairy cows offered pasture with high water-soluble carbohydrate concentrations consumed more DM and produced more milk than cows fed grasses with lower concentrations (Moorby et al. 2001). However Tas et al. (2005) found no difference in intake, milk production or milk composition in cultivars of perennial ryegrass differing in water-soluble carbohydrate. Another major objective of grass breeding should be to increase the length of the grass-growing season. The collection of ryegrasses from the Swiss uplands provides evidence that early spring growth and winter hardiness could evolve together (Tyler 1988). This has been exploited in present-day conventional breeding programmes, with new varieties such as Navan, having early spring growth some 10% higher than Portstewart, the previous leading late-flowering diploid perennial ryegrass. There are also other opportunities by including other species such as Italian ryegrass, or incorporating characteristics from these species into hybrids.

ANIMAL FACTORS

Strong evidence exists that milk yield, feed intake and energy balance are heritable traits, and that selection for a higher yield alone increases feed intake, in addition to a simultaneous widening of the energy gap between yield and intake (for review see Veerkamp 1998). Estimated genetic correlations between milk yield and dry-matter intake range from 0.44 to 0.65 when animals are not fed according to production (Veerkamp et al. 2003). Veerkamp et al. (2003) reported that the correlated response in feed intake under normal conditions is therefore only half of the extra energy required for the increased milk yield. Hence, the other half of milk-yield-driven energy requirement progressively decreases the energy balance with increasing genetic selection for yield; this energy gap is most likely filled by greater mobilization of the animal’s fat reserves.

Milk yield

The intake of herbage by lactating dairy cows is 20 to 50 % higher than by non-lactating dairy cows (Jones et al. 1965). Higher milk-producing dairy cows have a greater nutrient demand and this is reflected in increased grass intake. Since milk yield is an output variable, Peyraud et al. (1996) proposed to use potential milk yield for predicting herbage intake. Potential milk yield is expressed as milk yield at peak corrected for time elapsed from peak (assuming peak to occur on the sixth week of lactation), assuming a weekly persistence of 0.985. In the analysis of French data from a series of experiments carried out in May and June with autumn-calving dairy cows (Peyraud et al. 2004), the incremental increase in daily DM intake averaged 180 g per kg of peak milk yield and 250 g per kg of expected milk yield. An analysis of Irish data (Kennedy et al. 2003) showed that the coefficient of the regression between daily herbage intake and peak milk yield was 190 and 120 g per kg in the fourth and eighth month of lactation, respectively. Stakelum and Connelly (1987) estimated that daily herbage intake increased by 400 to 500 g per kg increase in actual milk yield, indicating that the limitation to cow productivity at grazing is low voluntary herbage intake. Using data from a number of grazing studies, Peyraud et al. (2004) showed that cows grazing in April to early July were able to produce 60 % of each kg of expected milk yield above 15 kg on a grass-only diet, which is in reasonable agreement with the marginal increase of 250 g of daily herbage intake with expected milk yield.

Live-weight

Herbage intake increases by 1 to 1.5 kg OM per 100 kg of live-weight (Peyraud et al. 1996). With increasing size and age, grazing time and biting rate decrease. Higher intake rate is related to an increase in bite weight (Zoby and Holmes 1982). Grazing time declined by 23 to 35 min per 100 kg of bodyweight in the studies by Zoby and Holmes (1982). Based on data from Brumby (1959), Demment et al. (1995) calculated a decrease of 30 min per 100 kg live-weight between adult cows. The increase in bite weight in relation to increase in live-weight may be partly explained by the morphology of the mouth (Demment et al. 1995).

Genotype

The influence of animal genotype on DM intake not only occurs through the animals' ability to consume greater quantities of herbage, but also through the capacity of the animal to calve each year at a time that facilitates the maximum amount of herbage to be incorporated in that animal's diet. Worldwide, dairy cattle are managed under a wide range of environments and production systems. Even within temperate conditions, these can range from grazing on lush temperate pastures with very low levels of supplementation to totally non-grazing or confinement systems, feeding concentrates and conserved roughages. Only about 10% of the world's milk comes from grazing systems (Steinfeld and Mäki-Hokkonen 1995), consequently the majority of dairy cattle have not been selected under grazing. Cattle on grazing systems must be able to graze effectively, survive fluctuations in feed supply and to walk long distances, abilities that are not required in confinement systems, plus conceive and calve at the right time every year.

There is now strong evidence to show that the cattle that are genetically best suited to non-grazing systems are not best suited to grazing systems, an interaction between genotype and feeding system (Dillon et al. in press). Successful grazing systems require dairy cows that are capable of achieving large intakes of forage relative to their genetic potential for milk production, so that they are able to meet their requirements almost entirely from grazing. Until recently, in the world of dairy cattle breeding, the term 'high genetic merit' was synonymous with high milk production potential. Now it is acknowledged that the complete index for high genetic merit should reflect as many characteristics as are required to reflect total economic profitability. In particular, due to the decline in reproductive efficiency within the Holstein, many countries have diversified their breeding goals to include measures of survivability or functionality (Philipsson et al. 1994; Veerkamp et al. 2002).

This should also increase the likelihood of survival in the seasonal grazing systems, for which the maintenance of a 365-day calving interval and good fertility are essential to optimize financial performance (Lopez-Villalobos et al. 2000). This limit to intake when grazing also suggests that cows most suited to grazing environments are likely to have lower genetic potentials for milk production and live-weight than cows best suited to more intensive diets. DM intake estimates differed by only 0.4 kg DM/day between the high-production North American Holstein Friesian selected solely on milk production and New Zealand Holstein Friesian selected from a seasonal pasture-based system (17.9 v. 17.5 kg DM) on a grass-only diet grazed to a post-grazing height 6 to 7 cm (Horan et al. in press) despite a large differential in milk production potential and live-weight. A greater differential in total DM intake (1.9 kg/day) was observed when both genotypes were offered a daily allowance of 3.7 kg concentrate DM (20.8 v. 18.9 kg DM/day) while grazing. This is in agreement with the results of Kolver et al. (2002), who reported values for DM intake of 16.6 and 20.4 kg/day for grazed pasture and 17.3 and 24.0 kg/day on TMR, for New Zealand Holstein Friesian cows or North American Holstein Friesian cows, respectively. For both strains, intakes were lower on pasture than on TMR, but on TMR the North American Holstein Friesian cows showed a much bigger increase in intake (3.6 kg/day) than the New Zealand Holstein Friesian cows (0.7 kg/day). The higher grass-concentrate substitution rate (resulting in a low response to concentrate supplementation) with the New Zealand Holstein Friesian cows suggests that they achieve a greater proportion of their potential milk production on grass alone than the high production potential North American Holstein Friesian cows. Linnane et al. (2004) concluded that the grazing appetite of the New Zealand Holstein Friesian is compromised by the provision of supplementary food. Horan et al. (in press) found that the lighter New Zealand Holstein Friesian had a higher grass DM intake per kg live-weight.

MANAGEMENT FACTORS

Numerous management factors exist that are conducive to the achievement of high herbage intakes and have the potential to enhance greatly the efficiency of pasture-based systems. In practice, management factors interact with the environmental, plant and animal factors discussed previously. Management factors, such as farm infrastructure (farm roadways, paddock access, water points) are also critical in achieving high grass DM intake under various climatic conditions. The management factors considered here are those with the greatest influence on grazing dairy cows' ability to achieve high DM intakes.

Herbage allowance

On rotationally grazed pastures, grass allocation is commonly described in terms of daily herbage allowance, which is the weight of herbage cut above a sampling height (i.e. kg of herbage DM per cow per day) (Greenhalgh et al. 1966). Daily herbage allowance is more often estimated to ground level or at a cutting height of 4 or 5 cm, assuming that the material below the cutting height is not available for grazing. Herbage allowance is one of the primary factors influencing herbage intake. A number of studies have shown a curvilinear relationship between herbage allowance and herbage intake (Greenhalgh et al. 1966; Peyraud et al. 1996; Maher et al. 2003). On vegetative perennial ryegrass swards, Peyraud and González-Rodríguez (2000) showed that herbage intake increased by 0.25 kg OM per day, per kg increase in herbage allowance ranging between 11 and 16 kg OM per day (above 4 to 5 cm). When herbage allowance increased above 20 kg OM per day, a much smaller increase of 0.05 kg of OM intake was achieved. Delagarde and O'Donovan (2005), comparing seven published relationships between herbage allowance to ground level and herbage intake of grazing dairy cows, showed an average increase of 0.20, 0.15 and 0.11 kg DM per kg DM increase in herbage allowance in the ranges of 20 to 30, 30 to 40 and 40 to 50 kg DM herbage allowance to ground level, respectively. Intake predictions are quite similar between models for medium herbage allowances, but predicted intake differences are greatest at low (< 30 kg DM/day) and high (> 50 kg DM/day) herbage allowances. Table 1 shows the results from an Irish study comparing three different DM allowances for dairy cows in early to mid lactation (Maher et al. 2003). Daily herbage allowances of 15.9, 19.8 and 24 kg DM per cow per day (> 3.5 mm) resulted in post grazing sward surface heights of 45, 55 and 66 mm, respectively, with corresponding daily milk productions of 20.8, 22.3 and 23.0 kg per cow. Increasing daily herbage allowance from 15.9 to 19.8 kg DM per cow increased herbage DM intake by 0.33 [16.7-14.7]/[19.8-15.9] kg DM per kg increase in allowance, while increasing daily allowance to 24 kg DM only increased DM intake by 0.12 [16.5-16.0]/[24-19.8] kg per day. The small increase in grass DM intake with increased daily herbage allowance above 20 kg DM (> 35 mm) indicates only a limited opportunity to increase DM intake from grass for cows yielding 23 to 25 kg per day.

Table 1. *The effect of daily herbage allowance on the performance of spring-calving dairy cows (Maher et al. 2003)*

	Herbage allowance (kg DM/ cow)[†]		
	15.9	19.8	24.0
Daily milk yield (kg)	20.8	22.3	23.0
Daily grass DM intake (kg) [*]	14.7	16.0	16.5
Post-grazing height (mm)	45	55	66
Herbage utilization[**] (%)	87	82	78

[*] Intakes are based on n-alkane measurements
[**] Herbage allowance and utilization are based on pre- and post-sward measurements above a sward height of >35 mm

Grazing intensity and stocking rate

Stocking rate or grazing intensity is a major determinant of the production per cow and per ha from grassland (McMeekan and Walshe 1963; Le Du et al. 1979; Journet and Demarquilly 1979). Grass growth rates in temperate pastures are highly seasonal with little or no growth in winter and very high growth in May and June. Late spring/early summer pasture growth rates are generally about twice the daily cow requirement at recommended stocking rates (Dillon et al. 1995). This surplus pasture can be harvested as silage or hay, or can remain as surplus herbage for summer grazing. Low rates of pasture utilization will result in wastage and may also reduce animal production in summer. Thomson (1985) has shown that grazing at a low intensity at one point may reduce animal production at a later stage, through a decline in feed quality. Low grazing intensity in spring has resulted in reduced growth rates of beef cattle (Dawson et al. 1981), reduced wool growth of sheep (Birrell and Bishop 1980) and reduced milk production of dairy cows (Holmes and Hoogendoorn 1983; Hoogendoorn et al. 1985) in the following summer. Stakelum and Dillon (1990) showed that pastures with high grazing pressure in spring/early summer produced swards of lower herbage mass, lower post-grazing height, higher proportion of green leaf and lower proportion of grass stem and dead material compared to swards with low grazing pressure. Increasing post-grazing sward surface height above 5 to 6 cm has been shown to result in a deterioration of sward quality in mid and late grazing season (Mayne et al. 1987; Stakelum and Dillon 1990).

Milk production results showed that pastures grazed to a post-grazing sward surface height in the May to June period of 5.5 to 6.5 cm compared to 8 to 8.5 cm achieved a higher DM intake (+0.8 kg per day) and higher milk production (+1.2 kg per day) in the July to September period (Stakelum and Dillon 1990). Additionally, in the May to June period, there was no difference in milk production per cow from both swards, with the lower post-grazing swards achieving greater grass utilization through higher stocking rates.

Alternative strategies to achieve high DM intakes while maintaining low post-grazing residuals may include mechanically topping pastures post-grazing (Stakelum and Dillon 1990), adopting a leader–follower grazing system with lower producing after high-producing animals (Mayne et al. 1988), the provision of supplementary concentrate with intensive grazing, or, in the longer term, the development of swards that would allow higher DM intakes while at the same time allow the sward to be grazed to a low residual height (Peyraud and González-Rodrígez 2000).

Supplementary feeding

Concentrate supplementation. Concentrate supplements are offered to grazing dairy cows either because of a shortfall in grass supply or to increase overall intake and milk production. The efficiency of the supplement is expressed by the increase (kg) in milk output per kg increase in concentrate DM intake. The substitution rate is the reduction in herbage DM intake per kg increase in concentrate DM intake. The interaction between level of concentrate supplementation and herbage allowance on milk production response can be substantial. Substitution rate increases with increasing pasture availability, from 0 for high grazing pressure to 0.6 - 0.8 for low grazing pressure (Stakelum et al. 1988; Stockdale 2000; Peyraud and Delaby 2001). The efficiency, and thereby the substitution rate, is influenced by a large range of factors such as herbage allowance, herbage composition, concentrate feeding level, concentrate composition and milk yield production of the cows being evaluated (genotype) (Bargo et al. 2002). Delaby and Peyraud (1999) estimated that milk production response reached a plateau at 4 kg when herbage allowance was high; whereas when herbage was restricted there was a linear response up to 6 kg of concentrate.

From a review of the literature up until the early 1990s, average substitution rates published were around 0.6, resulting in an efficiency of approximately 0.4 to 0.6 kg of milk per kg of concentrate DM (Journet and Demarquilly 1979; Meijs 1981; Leaver 1985; Stakelum et al. 1988). However, most of these studies were carried out with low- to moderate-yielding cows in the region of 15 to 25 kg per cow per day. Table 2 shows that since the late 1990s, lower substitution rates and higher efficiencies have been observed than those published previously. From the nine studies published, the average substitution rate was 0.40, resulting in an efficiency of 0.92 kg of milk per kg of concentrate. The higher response to concentrate supplementation with higher-genetic-merit cows may be attributed to greater nutrient partition to milk production than with lower-genetic-merit cows (Dillon et al. in press).

Table 2. *Substitution rate (SR) and milk response (MR) of dairy cows supplemented with concentrate (modified from Bargo et al. 2003).*

Reference	Cows[1]		Pasture[2]	Supplement		PA[3]	SR[4]	MR[4]
	DIM	Milk		Type	DMI kg/d	Kg DM/cow/d	kg pasture / kg concentrate	kg milk / kg concentrate
Effect of PA								
Bargo et al. 2002	101	45.8	OG	Corn	7.9	25.0	0.26	1.36
						40.0	0.55	0.96
Robaina et al. 1998	180	20.5	RG/WC	Barley / Lupin	4.3	21.1	0.31	0.98
						42.3	0.57	0.54
Stockdale 1994	108	29.9	RG/WC/P	Barley / Wheat	4.6	30.0	0.43	0.43
	106	30.0			4.9	30.0	0.45	0.55
	112	25.7			4.9	30.0	0.29	1.18
	165	19.3			3.0	30.0	0.30	1.18
	128	30.6			4.7	40.0	0.43	0.49
	180	25.1			4.8	40.0	0.46	0.98
	229	21.6			4.9	40.0	0.31	0.94
Effect of amount of concentrate								
Horan et al. in press	102	24.5	RG	Corn / Beet pulp	3.7	…	0.24	0.93
		22.0			3.7	…	0.40	0.87
		20.0			3.7	…	0.61	0.45
	240	24.5	RG	Corn / Beet pulp	3.7	…	0.17	1.26
		22.0			3.7	…	0.46	0.86
		20.0			3.7	…	0.49	0.34
Kennedy et al. 2003	107	29.5	RG	Corn / Beet pulp	2.7	…	0.62	0.74
					5.4	…	0.56	1.10

Table 2 (cont.)

Table 2 (cont.)

Reference	Cows[1] DIM	Milk	Pasture[2]	Supplement Type	DMI kg/d	PA[3] Kg DM/cow/d	SR[4] kg pasture / kg concentrate	MR[4] kg milk / kg concentrate
	107	25.0	RG	Corn / Beet pulp	2.7	…	0.60	1.10
					5.4	…	0.58	1.00
	201	29.5	RG	Corn / Beet pulp	3.6	…	0.57	0.86
	201	25.0	RG	Corn / Beet pulp	3.6	…	0.36	0.72
Delaby et al. 2001	182	30.7	RG	Corn / Beet pulp	3.6	…	…	1.04
Reis and Combs 2000	84	41.6	A/RC/RG	Corn	5.0	…	0.24	1.00
					10.0	…	0.41	0.86
Robaina et al. 1998	180	21.4	RG/WC	Barley	1.8	…	0.44	1.56
					3.4	…	0.65	0.94
					6.7	…	0.58	0.82
Walker et al. 2001	167	22.3	P/RG	Barley / Wheat	3.0	…	0.02	1.07
					5.0	…	0.18	1.18
					7.0	…	0.21	1.07
					9.0	…	0.19	0.92
					10.4	…	0.28	0.91

[1]Pre-experimental DIM and milk production (kg/day). [2]A = alfalfa (*Medicago sativa*), OG = orchard grass (*Dactylis glomerata*), P = (*Paspalum dilatatum*), RC = red clover (*Trifolium pratense*), RG = perennial ryegrass (*Lolium perenne*), WC = white clover (*Trifolium repens*). [3]PA = pasture allowance. [4]Calculated relative to unsupplemented treatment. [5]Data from 7 experiments.

Faverdin et al. (1991) showed that substitution rate is lower with high-yielding cows when energy requirements are not being met. Delagarde et al. (unpublished) demonstrated that substitution rate is directly related to the net energy balance of the unsupplemented cows. In situations where grass only was far from being sufficient to meet energy requirements, substitution rates were low (0.1) and negative energy balances were strongly negative (-21 MJ per day), while cows in good grazing conditions had higher substitution rates (0.6) and higher energy balance (+28 MJ per day). In such situations, concentrate supplementation only slightly reduces herbage intake and appreciably increases animal performance. Horan et al. (in press) showed a strong relationship between substitution rate and milk production efficiency (Figure 3). At substitution rates of 0.6 kg, milk production efficiencies were 0.4, while at substitution rates of 0.2 kg, milk production efficiencies were 1.1.

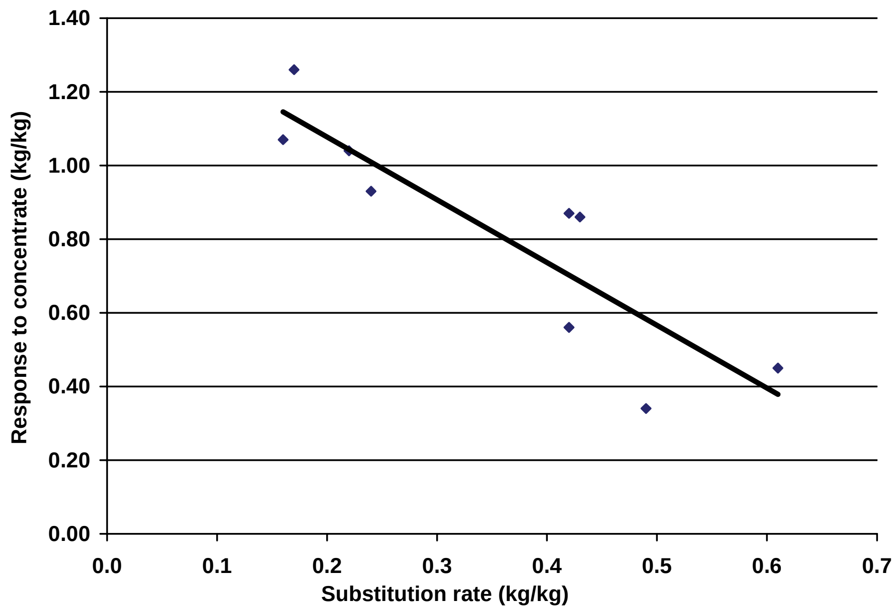

Figure 3. *The relationship between milk production response to concentrate supplementation and substitution rate of pasture for concentrate (Horan et al. in press)*

Concentrate supplement energy source (starch or fibre) has been shown to have only small effects on intake or milk production, especially when moderate levels are offered (1 to 6 kg per cow per day). On pasture, herbage intake was shown to be about 1 kg higher when cows were supplemented with 5 kg of a high-fibre concentrate compared with a 5 kg high-starch concentrate (Kibon and Holmes 1987). However, the effect of energy source becomes much more important at higher levels of supplementation (Sayers et al. 2003).

Fresh herbage would appear to supply adequate amounts of protein for intake and milk production up to a daily milk production of 35 kg (Journet and Demarquilly 1979). The response to supplementary protein is, however, dependent on the herbage intake and its protein content relative to cows requirement. Feeding concentrate with low levels of degradable protein increased herbage intake when cows grazed swards with a crude protein content less than 140 g per kg DM, while it had no effect when the crude protein of the herbage was greater than 160 g per kg DM (Delagarde et al. 1997).

Forage supplementation. In a review of the use of conserved forages as a supplement during the grazing season, Phillips (1988) concluded that under situations where ample herbage was available, supplementation with grass silage reduced both milk yield and protein yield with variable results on fat yield. Supplementation with grass silage under these conditions resulted in a large reduction in herbage intake (substitution rates of 0.84 to 1.02 kg OM/kg supplement OM intake. The large substitution effects obtained with the forage supplement appear to be the result from reduction in grazing time of approximately 43 minutes/day for each kg of silage DM consumed. In these situations, supplementary forage feeding could result in under-utilization of the grazed grass area and consequent deterioration in sward structure and composition. In a grass shortage situation, supplementary forage feeding will generally result in increase in DM intake and milk production. Maize silage has also been examined as a supplement for dairy cows. Corn silage supplementation had a positive effect on milk production when the amount of pasture offered was low (Stockdale 1994). However, where pasture allowance was adequate, supplementation with corn silage reduced pasture DM intake and resulted in similar total DM intake and similar milk production (Holden et al. 1995). Substitution rates are generally higher for forage than for concentrate supplementation due to higher forage fill value.

Feed budgeting

It was not until the 1970s that the knowledge of a relationship between milk yield and pasture allowance was identified (Hodgson 1976). To be useful to farmers this required simple and accurate methods of estimating short-term rationing at the paddock level. Sward height, especially after grazing, can be used for this purpose (Stakelum 1993; Mayne et al. 1987). O'Donovan (2000) established that including daily herbage allowance as well as post-grazing sward surface height greatly improved grass DM intake at farm level. Low post-grazing height will indicate an insufficient feed supply and imply that the average intake of grass by the herd was lower than it should be. High pre-grazing sward heights (>16 cm) will be difficult to graze down and grass DM intake will be reduced.

Clark and Jans (1995) referred to the concept of feed profiling, feed budgeting and grazing plan and to the development of decision support models for pasture management in New Zealand. Feed budgeting will be required at farm level for short-term rationing at paddock level, for medium-term budgeting on a weekly/biweekly basis and long-term on a yearly basis; which introduced the concept of farm grass cover (Stakelum 1993). O'Donovan (2000) developed targets for average pasture grass cover, expressed as either on per-hectare or per-cow basis. Pasture cover is important in a short-term basis, to allocate sufficient daily herbage allowance. For medium-term budgeting, grass growth can be highly variable, even under standard management conditions. For example, in Southern Ireland in a grass growth study managed to a strict and consistent protocol at one site, mean growth rate over 23 years between simulated grazing for the month of May was 95 kg DM/ha/day, but the range was from 72 to 123 kg DM/ha/day (Brereton 1995). If this level of variation can be expected under 'standard' management conditions, clearly variation of sward growth for a given time of year on-farm is likely to be even more pronounced, as sward age and grazing and fertilizer management vary. This variability in sward growth rate is one of the factors that result in poor or variable utilization of herbage produced on-farm, as farmers are unable to manage grazing with precision. By increasing predictability of grass growth and animal requirement, feed budgets can be drawn up with confidence. Taking this further, decision support systems can be designed, based on plant growth models and including the interaction between the herbage produced and the animals' intake, to be a grazing-management aid. Long-term feed budgeting will entail a yearly feed budget-taking cognisance of total herd feed demand and the grass production potential of the farm, and also the quantity of fertilizer and concentrate required to be purchased. The development of reliable, easy-to-use decision support tools will encourage greater reliance on grazed grass and greater connection between researchers, extension advisor and dairy farmers.

MEASUREMENT OF HERBAGE INTAKE

The development of reliable methods of measuring individual animal intake at pasture is essential for the development of efficient grazing-management systems. Various methods have been proposed to estimate daily intake of herbage during grazing, namely the faecal output/diet digestibility method (Langlands 1975), sward difference method (Walters and Evans 1979) and the grazing-behaviour method (Forbes and Hodgson 1985). For the majority of situations, methods based on the use of faecal output/diet digestibility appear to be the most reliable as they combine simplicity of sampling with a high degree of precision well above the other methods (Peyraud 1996). Sward difference techniques have many limitations in terms of individual animal-intake estimation because each animal has to be grazed separate, correcting for growth of herbage occurring while grazing, and differences in cutting height before and after grazing. This method may be extremely inaccurate on heterogeneous swards, while for short grazing periods with clean homogeneous swards it may be optimal. Methods based on grazing behaviour should be reserved to more analytical types of studies concerning relationship between animal and sward structure.

The characteristics of an ideal marker for use in the measurement of herbage intake have been reviewed previously (Langlands 1975). The characteristics of an ideal marker are that it should be chemically discrete, easily identified and analysed and that it should be indigestible in the digestive tract. Methods based on faecal output/diet digestibility are more suitable for intake estimates that span a number of days and give some indication of the animal-to-animal variability. The marker most commonly used to measure faecal output up until recently was chromium sesquioxide ether suspended in oil in gelatine capsule (Raymond and Minson 1955) or as shredded paper impregnated with Cr_2O_3 (Corbett et al. 1958). The main concern with this technique was the possibility of diurnal variation and its consequential error in estimation of faecal output. To overcome this source of error, controlled-released devices have been developed (Ellis et al. 1982).

The other component of the equation is herbage digestibility, which would be ideally estimated using an ingestible marker naturally occurring in the herbage providing an individual-animal estimate. Although many plant components have been evaluated as ‘internal marker’ digestibility markers (Kotb and Luckey 1972), none have proven satisfactory due mainly to difficulties with analysis as a chemically discrete entity. As a consequence herbage digestibility is usually estimated using *in vitro* procedures previously calibrated with *in vivo* measurements (Tilley and Terry 1963). Dove and Mayes (1991) identified three possible sources of error with *in vitro* procedures: (1) the relationship between *in vitro* and *in vivo* estimates may not apply to the test animal as estimates are frequently established with mature animals for near maintenance; (2) even if the relationship is applicable, only a single digestibility value is applied to all test animals, regardless of differences that may result due to level of intake or supplement intake; (3) individual test animals may select a diet that differs in digestibility to that used in chemical analysis. These factors can be large sources of error in the estimation of herbage intake, since a small error of digestibility (especially with highly digestible herbage) can lead to much larger errors in the estimate of intake (Langlands 1975).

In recent years plant wax components, namely n-alkanes, have been suggested as markers for the estimation of herbage intake (Mayes et al. 1986; Dillon and Stakelum 1989). Faecal recovery of long-chained n-alkanes was incomplete, but Mayes et al. (1986) argued that this incomplete recovery would not matter if the animal were dosed with a synthetic, even chained alkane as an external marker for the estimation of faecal output, provided the pair of natural (odd-chain) and synthetic (even-chain) alkanes had similar faecal recoveries. There is now a considerable body of information supporting the assumption that satisfactory results are obtained if intake is estimated using natural n-alkane C33 and dosed C32 n-alkane (Dove and Mayes 1991). The accuracy of the estimates of intake obtained using herbage and faecal alkane concentrations also depends on obtaining a representative sample of the consumed herbage, accurate administration of synthetic alkanes to grazing animals, dosing procedures and obtaining a representative sample of faeces plus sample preparation and extraction for alkane analysis. Therefore, the major advantage of the n-alkane technique is that the estimate of intake is on an individual-animal basis and also compatible with studies where grazing test animals are fed supplements. Additionally, in recent years n-alkanes have been successfully used to measure diet composition of grazing ruminant livestock (Mayes et al. 1995).

CONCLUSIONS

Due to economic, environmental and animal-welfare constraints, it can be envisaged in the future that a larger proportion of milk produced in temperate regions will be produced from grazed pasture. However, increased use of pasture-based systems poses many research and technology transfer challenges. Internationally, the balance of research resources is nevertheless strongly in favour of controlled indoor feeding of dairy cattle. Clark (2005) suggested that from an economic and environmental perspective pastoral research should develop plant and farm systems that allow high individual-animal intake. There is considerable scope to improve animal performance from grass-based systems given recent developments in our understanding of management factors that influence grass intake. Efficient exploitation of grass by grazing will require the development of grazing systems designed to maximize daily herbage intake per cow, while maintaining a large quantity of high-quality pasture over the grazing season. Grazing systems will not be limited by peak DM production during the peak two to three months of the grazing season, as high animal performance from pasture will supersede high animal performance per hectare. Daily grass intake will be maximized by adhering to important sward characteristics such as maintaining a high proportion of green leaf within the grazing horizon and allocating an adequate daily herbage allowance. The challenge for the future will be to develop swards through management and grass breeding that will maintain high DM intake while at the same time result in low residual sward height. Likewise, in the future the cow genotype must be compatible with the system of milk production, and prediction of the phenotypic performance of dairy cattle must be based on knowledge of the cow’s genotype as well as the environment in which they are managed. The development of reliable, easy-to-use decision support tools that facilitate increased reliance on grazed grass, to be used by farmers and extension services, will contribute to optimizing grazed-grass-based systems of milk production.

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