Maximizing Forage Intake from Grazed Grass

Grassland, Forage and Soils Research Partnership

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Executive summary

Fresh grass intake by dairy cows and the effects on milk production is a complex system that has been comprehensively studies over the last half century. Forage intake by grazing dairy cows is influenced by a range of factors, including the milk yield potential, live weight, age, reproductive stage and innate grazing behaviour of cattle, the quantity of herbage available to the animals, its quality (digestibility) which affects the rate of passage through the rumen, and also the uniformity and botanical composition of the herbage in the sward. A systematic review of the scientific literature relevant to grazing dairy cows in temperate grasslands has been conducted. Existing research has been categorised into the following themes:

1. Influence of sward botanical competition on cow preference and forage intake
2. Impact of sward fertilisation on forage intake
3. Influence of animal and pasture management on forage intake
4. Effect of feeding supplementary feeds on forage intake
5. Relationship between class of animal (breed, genetic potential, age and stage of lactation) and forage intake

From the research review the following conclusions have been drawn:

- Herbage legumes have a higher feed value than grasses, but their main benefit to livestock is from enhanced intake. Animal performance benefits reach a maximum when clover content is around 60% of the (Dry Matter) DM in the diet

- There is some evidence that cows show a preference for tetraploid over diploid perennial ryegrasses but variety maturity date had a greater effect on grass DMI and milk production. Later heading ryegrass varieties resulted in higher grass dry matter intake (DMI) and milk production compared with varieties with a difference in ploidy

- Application of sodium to pasture can improve herbage DMI and milk production, particularly in cows of low production potential

- Daily herbage allowance (DHA) per cow is a better metric than herbage height for determining herbage DMI and milk production. It should be the DHA of green leaf dry matter, not the DHA of total herbage DM that should be considered.

- Bite mass and biting rate tend to be highest in the afternoon. There is some evidence that providing a fresh paddock at this time of day increases grass DMI

- Slurry application to grass for grazing should be carried out by injection or trailing shoe rather than by surface spreading, since herbage DMI is reduced substantially (circa 30% nine weeks after application) after surface spreading.

- Herbage DMI is a function of average bite size, the number of bites per minute and the length of time available for grazing. The first two of these are related to herbage availability. Thus sward height, which can be equated with herbage mass, has a very major impact on herbage DMI, and is an essential tool for grassland planning, budgeting and dairy cow rationing.

- Extending the grazing season in autumn or early spring has considerable potential for reducing cost of production, through savings in silage consumption. Grazing for as little as two hours per day can increase yield of milk and milk constituents.

- Well-managed grazed herbage, unsupplemented, can support average milk yields per cow of 20-22kg/day over the whole season. With high yielding cows milk yields of up to 30kg/day are possible without supplementation, but only over a short period and by mobilising significant levels of energy reserves. With this type of cow, in order to achieve a satisfactory combination of high milk yield per cow, even with good sward utilisation and high levels of output per hectare, concentrate supplementation is required from turnout. Substitution rate of concentrate for grazed herbage is low at low levels of DHA (13 to 15 kg DM/cow), for example in early spring.

- There is no benefit in terms of animal performance to feeding a forage supplement (e.g. silage), unless grazing conditions are poor and silage quality is good as it can reduce grazing efficiency.

- The research shows consistently that cows with the highest genetic potential for milk production tend to exhibit the highest grass DMI (and milk yield). This is true within the Holstein-Friesian (HF) breed and in comparisons between HF and other breeds. However, there is clear evidence that this production advantage is associated with greater loss of live weight and body condition score, and poorer fertility performance. Jersey X HF crossbred cows produce lower milk yields but the same fat plus protein yield as HF cows and have significantly better fertility performance. These crossbred cows also had a higher herbage DMI per kg metabolic weight than HF, suggesting a higher overall efficiency.

- Variables which have a significant effect on grass DMI, total DMI and milk yield include body weight, body condition score, potential milk yield, days in milk, DHA (above 4cm), concentrate level and parity.

Contents

1. Introduction

As part of the SRUC led partnership with AHDB Dairy systematic literature review was commissioned to draw together research under the theme of 'Maximising Forage Intake from Grazed Grass'. This review was to consider the published literature from 1970 to 2011. The review has been split into five key themes:

1. Influence of sward botanical competition on cow preference and forage intake
2. Impact of sward fertilisation on forage intake
3. Influence of animal and pasture management on forage intake
4. Effect of feeding supplementary feeds on forage intake
5. Relationship between class of animal (breed, genetic potential, age and stage of lactation) and forage intake

An initial search of literature, using the Web of Knowledge data bases from 1970 to the end of 2011 was done using the following specific search terms: dairy and grass clover (542), dairy and reseeding (21), dairy cows and drinking water (278), dairy cows and water drinking (278), dairy grazing and climate change (66), dairy milk production and grazed grass (742), extra grazing allowance (15), grass intake and dairy cows (1786), grass yield and milk yield (1837), grazed grass and milk yield (504), grazing and reseeding (188). After screening for relevance from the article title this gave 831 papers from a total of 6257 papers.

The abstracts of the 831 papers were then extracted from the data bases or through online researches and a detailed review of these gave 300 papers of relevance. Once these papers' relevance had been confirmed with DairyCo they were incorporated into a draft document under the following headings: Animal Behaviour (25), Animal Breeding (24), Animal Performance (32), Climate Change (15), Diet Manipulation (5), Feeding at Grass (36), Grassland Systems (1), Herbage Genetics (8), Measuring Yield of Grass (1), Milk Production (32), Palatability (6), Pasture Management/Animal Management (78), Sward Fertilisation (35) and Water Supply Intake (2).

2. Influence of sward botanical composition on forage intake

The composition of the sward (herbage species and varieties) affects forage intake through the physical and chemical characteristics of each botanical component in the sward and through the preferences shown by grazing animals for these botanical components.

2.1 Preference of grazing animals for different grass species

A large selection of forage plants (14) was tested for cow preference in Australia by Horadagoda et al (2009) in eight seasons over two years, using Holstein Friesian cows. These included two perennial ryegrass varieties and red and white clover as well as a number of tropical and semi-tropical grasses. A prediction equation comprising water soluble carbohydrates (WSC%) and nitrate-nitrogen [NO_3-N (g/kg DM)] over all seasons and forage species accounted for more variation in cow preference than any other single or combination of variables measured. These two variables had a positive and negative effect, respectively, on cow preference. The authors concluded that the relative palatability of forages can be reasonably well predicted from percentage WSC and nitrate-N concentration. The predicted results were improved by the inclusion of a factor for percentage neutral detergent fibre, which also had a negative effect on cow preference.

2.2 Effect of herbage legumes on forage intake and animal performance

Of all the sources of variation in botanical composition of grazed swards, the content of clover probably has the greatest potential impact on dry matter intake (DMI) and animal performance. White clover is the main legume used in grazing pastures, but it is important to note that red clover, which is used primarily for silage rather than for grazing, has major effects on intake, animal performance and milk quality.

Herbage legumes have a higher feed value and higher intake characteristics than grass herbage (Peyraud et al, 2009; Thomson et al, 1985) and many studies have identified an increase in dry matter intakes in a number of studies. Ribeiro Filho et al (2003) showed that the average organic matter intake rate of Holstein cows was higher on perennial ryegrass/white clover swards than on fertilized pure stand perennial ryegrass swards. Duodenal non-ammonia N (NAN) flow and milk yields were also higher on the grass clover swards and lower on the older regrowth. The performance of the cows on mature grass/clover regrowth was the same as those on the younger pure grass regrowth. These authors concluded however that the nutritional advantage of introducing white clover into swards of perennial ryegrass was related to an increase in herbage intake and not to any improvement in the nutritive value of the sward.

In contrast, however, the same authors found that compared with pure ryegrass swards, grass/white clover swards (containing 27% clover in the dry matter (DM)) did not improve herbage intake or milk production when this was associated with a sharp decrease in sward height and herbage mass in the upper strata of the sward (i.e. herbage allowance). In this trial, therefore, herbage intake and milk yield was much more influenced by herbage allowance than by the presence of clover in the sward. Because of the lower quantity of herbage mass in the upper layers in the grass/clover swards, the cows had greater difficulty in harvesting herbage, limiting intake rate. More research is required to determine if the use of large-leaved varieties of white clover, which tend to have a taller growth habit than small or medium leaved varieties, for grazing mixtures would overcome this issue.

Dewhurst et al (2009) also reviewed the effect of inclusion of legumes, especially red clover in silage and white clover in grazed swards, in dairy cow diets. In their research they again noted an increase in dry matter impact with swards containing legumes. This was a reflection of the differences in cell structure between clovers and grasses, which led to a higher fermentation rate and a faster ruminal breakdown of the legumes. A further benefit of legumes was the reduced rate of decline in digestibility with advancing maturity, particularly in white clover. Whilst legumes had limited effects on gross milk composition or carcass characteristics, there were marked increases in levels of beneficial n-3 polyunsaturated fatty acids (PUFA). Legumes have often led to a reduction in methane production from the rumen and again, this related to both physical and chemical differences between forage species. In midsummer, when clover content in the sward is at its highest, a high concentration of rapidly degraded protein in legumes also leads to inefficient utilisation of dietary N and increased urinary N output.

Respiratory chamber experiments were carried out by van Dorland et al (2006) to compare metabolisable energy and protein utilisation in dairy cows fed either red or white clover with ryegrass. In general the study showed that the white and red clovers investigated were equivalent in energy and protein supply. However, the investigation could not ascertain whether the forage legumes, when supplemented to a moderate-protein ryegrass, could have contributed to the metabolisable protein supply or would have merely increased metabolic nitrogen load.

The ruminal breakdown and intestinal protein digestion in dairy cows of grass and grass/clover swards of different seasonal maturity and nitrogen fertiliser application were compared by Steg et al (1994). The results showed that there were seasonal effects on degradation rates between grass and clover. Effectively, rumen-degradable (g/kg DM) carbohydrates and CP, escaped protein and intestinal digestion of escaped protein were all higher in clover than in grasses. Inclusion of clover in swards could result in higher post-rumen protein supply. Supplementation of clover-based diets was suggested to compensate for an increased loss of nitrogen in the rumen.

Whilst there is good evidence for improvements in milk yield from cows fed pure legume silages or those with a high legume content, in the grazing situation the evidence for improvements in milk yield is much less strong. This is probably because of the difficulty of maintaining a sufficiently high clover content in the grazed sward through the grazing season and over a period of years. As with the agronomic benefits of legumes, the animal performance benefits also increase as the legume content in the diet increases relative to the grass content. Research evidence suggests that the animal performance benefits of legumes reach a maximum when clover content is around 60% of the DM in the diet (Harris et al, 1998), which is a relatively high level to maintain across a whole growing season, particularly for a grazed grass/white clover sward. In practice it may be difficult to achieve a white clover content of more than 30 to 40% in the dry matter in grazed herbage, averaged across the whole grazing season.

Nevertheless, a number of reviews have concluded that forage legumes, especially clover, have an important role to play in ruminant livestock systems, including modern dairy systems (Woodfield and Clark, 2009; Peyraud et al, 2009; Dewhurst et al, 2009). Woodfield and Clark (2009) suggested that changes in grazing management may need to be considered in order to optimise the potential of clover, such as considering growing clover and ryegrass in separate strips. Cosgrove et al (2006) examined such novel presentations of clover to dairy cows to enhance the legume content of their diet. They compared ryegrass and clover growing side by side as well as a system of feeding the grass only at night and the clover during the day. These systems were compared with the more standard mixed ryegrass/clover pasture and a ryegrass only pasture. When cows were offered the side by side system of grass-clover grazing and the day time feeding of clover, milk production increased. The spatial and temporal allocations of grass and clover affected the concentrations of indolic compounds in afternoon and morning milk, which suggested there was scope to improve the efficiency of protein utilisation in the rumen.

However, a number of dairy systems projects have shown that traditional intimate mixtures of grass/clover can support viable dairy systems in terms of milk output and therefore provide an opportunity to reduce the input of N fertiliser (Leach et al, 2000; Schils et al, 2000). Frankow-Lindberg and Danielsson (1997) also examined the animal performance, pasture output and clover content of grass/clover systems during the grazing season on commercial dairy, beef and sheep farms. A total of nine farms were included in the study with the clover content of the pastures generally high (around 20% in the Spring rising to a peak of 40-50% in July/August). The proportion of grass/clover pastures and clover content varied considerably among farms with dairy production. Output of utilised metabolised energy (between 39,000 and 57,000 MJ/ha) compared well with previous studies on commercial farms with grass and nitrogen pastures. The physical and economic viability of clover-based dairy systems is also confirmed by the considerable expansion throughout north-west Europe in the last 20 years of organic dairy farming, which is based on forage legumes.

In addition to the effect of the nutritive characteristics of herbage species on digestion processes and intake by grazing animals, intake may also be affected by active preferences for different herbage species shown by the animals. A historical and evolutionary review of ruminants by Rutter (2010) discussed the lack of diet choice which present-day swards offered compared with pre-domestication. The current evidence indicated that dairy cattle, along with sheep, have a preference for approximately 70% clover when offered alongside grass and showed a consistent diurnal pattern of preference (Rutter et al, 2004). A partial preference for grazing white clover swards, or swards containing a high proportion of white clover, was also described by Chapman et al (2007). The work showed that higher soluble protein was associated with satiety in cows. However, it was found that on a monoculture of white clover, cows did not eat more than if they had grazed perennial ryegrass (PRG). Hill et al (2009) also reviewed ruminants' forage choices when offered a mixed diet. The review focused on the 'satiety theory' and investigated changes in the physico-chemical make-up of forages on sheep and dairy cows' intake. It was suggested that the preference for clover and the 'satiety' of diet was related to the rate of release of ammonia from the soluble protein fraction of the forage and its subsequent up-take of ammonia in the blood. It was hypothesised that by mixing grass with the clover the animal was better able to increase the duration of the meal, potentially reflecting a "better" dietary balance of energy to soluble protein which controlled the rate of accumulation of ammonia in rumen fluid.

It seems, therefore, that a mixed species diet is optimum in terms of preference by grazing animals. When offered a free choice between different forage species in a heterogeneous sward, ruminants will choose a mixed diet, even when one dietary component could meet all of their nutritional needs (Hill et al, 2009).

Although not specifically linked to maximising forage intake, it should be noted that diets which contain a significant clover content, especially grazed rather than ensiled clovers, can enhance the content of omega-3 polyunsaturated fatty acids in milk compared with high-concentrate diets or forage-based diets with low clover content (Slots et al, 2008; Lee et al, 2009).

2.3 Effect of ploidy and heading date in perennial ryegrass varieties on intake and animal performance

Perennial ryegrass *(Lolium perenne)* is by far the most widely sown herbage species in the British Isles. Approximately 100 varieties are listed in recommended lists by NIAB, SAC and DARDNI. These are categorised by heading date (early heading varieties tend to have an upright growth habit and relatively low tiller density, whilst late heading varieties tend to have a prostrate growth habit and a high tiller density). Ryegrass varieties are also either diploid or tetraploid in their genetic make-up. Tetraploid varieties have a duplication of the chromosome content (n=28) compared with diploid varieties and have different morphological and physiological characteristics, such as an increased cell size (which increases the ratio of cell content to cell wall). This greater cell content increases the concentration of soluble carbohydrates, proteins and lipids resulting in potentially improved forage digestibility. However, tetraploid varieties have the disadvantage of a more open growth habit than diploids, with a lower tiller density.

Balocchi and Lopez (2009) studied the effect of the ploidy of perennial ryegrass in adapting to different soil and climatic conditions and their effect on herbage production, nutritive value, grazing preference and utilisation of the pasture produced. Four tetraploid cultivars and four diploid cultivars were studied. The results showed that the diploid cultivars had greater herbage mass accumulation (10856 compared to 9715 kg DM/ha), but there were no significant differences in annual average crude protein content. In two of the three years of the investigation the D value of the tetraploid cultivars was significantly higher than that of the diploids (D value of diploids was 75.1 and 72.9 in the first and second year respectively compared to 76.4 and 74.2 for the tetraploids). Overall, the cows showed a preference for grazing the tetraploid cultivars for a longer period of time, with a lower residual herbage mass after grazing, than for the diploid cultivars. The average pasture utilisation efficiency (the ratio between the apparent intake and pre-grazing herbage mass offered) over three years was 81.0% for tetraploids and 78.0% for diploids.

The above study did not measure animal performance, but other studies have found that the heading date of ryegrass varieties has a greater effect on animal performance than ploidy of the varieties. Gowen et al (2003) compared perennial ryegrass varieties with different ploidy and a range of heading dates for their effect on milk production and grass dry matter intake. They found that later heading cultivars had a beneficial effect on the milk production of spring calving dairy cows, with significant increases in milk yield and composition compared to early varieties. Averaged over two years, daily milk yield per cow was 1.1kg higher for late varieties compared with early varieties, solids corrected milk yield was 1.08kg higher, protein yield was 0.05kg higher and lactose yield was 0.06kg higher. Grass dry matter intake was also significantly higher for cows grazing the later heading cultivars. O'Donovan and Delaby (2005) compared a similar set of cultivars (Millennium, a late heading tetraploid; Portstewart, a late heading diploid; Napoleon, an intermediate heading tetraploid and Spelga, an intermediate heading diploid) at high and low stocking rates. Averaged over two seasons, the stocking rates were 5.0 and 4.3 cows/ha for the high and low stocked rates during April to early June and then 4.1 and 3.5 for the rest of season. It was found that the late heading cultivars produced swards with higher intake, better digestibility coefficients, sward characteristics and grass quality. These improvements in sward quality allowed the low stocking rate cows that grazed later heading cultivars to improve their milk production (5% higher milk production compared with intermediate heading varieties), because these late varieties maintained a better leaf to stem ratio and therefore better digestibility (O'Donovan et al 2005). Flores-Lesama et al (2006) also found higher milk production in cows grazing perennial ryegrass varieties which exhibited higher tiller density, lower biomass per tiller but higher bulk density and green leaf mass.

A number of other studies have compared perennial ryegrass cultivars in terms of their effect on milk production. Smit et al (2005) investigated the differences in herbage production, nutritive value and dry matter intake over a two year grazing period on high producing dairy cows (i.e. cows averaging 33.0 and 29.8 kg/d milk yield at the start of the grazing season in 2002 and 2003 respectively). The sward structures of pure sown cultivars of perennial ryegrass (two intermediate heading and two late heading) were monitored, as well as analysis of the grass for lignin, protein and water soluble sugars, over both years. The cultivars' susceptibility to crown rust was also noted. The cultivars varied for different aspects of chemical, physical and crown rust susceptibility over the two years. The conclusions were that the options for breeders to select for higher herbage intake was limited, but those cultivars that had greater resistance to crown rust were related to a higher herbage intake.

2.4 Effect of high sugar perennial ryegrass varieties on intake and animal performance

The claims of quality differences in cultivars of perennial ryegrass, particularly in sugar content, have been investigated by Tas et al, (2005) when the effect of only diploid cultivars of perennial ryegrass on digestibility, DMI, and milk yield were considered. The largest differences between the cultivars were found to be in water soluble carbohydrate and protein content of the herbage, whereas DMI and effects on milk yield were not affected by cultivar. A delayed heading date in the second year of the study increased differences in dry matter digestibility, but overall the cultivars studied did not provide enough variability for plant breeders to select for DMI, dry matter digestibility, and milk yield in breeding programs. Tas et al (2006) continued to investigate four diploid cultivars of perennial ryegrass that differed in concentrations of WSC on milk yield and nitrogen utilisation. This study showed that, at relatively high N grass concentrations and with only small differences between cultivars in neutral detergent fibre concentrations, those cultivars with an elevated WSC concentration did not increase N utilisation in grazing dairy cows.

Miller et al (2001) also examined the nitrogen use efficiency of high sugar grass compared to a control. In contrast to the results of Tas et al (2006), Miller et al (2001) showed that the partition of dietary nitrogen for milk protein biosynthesis was much higher ($P<0.01$) in animals consuming the high sugar grass and was reflected by the lower plasma urea concentrations. It was proposed that by providing grass varieties with a better match of readily available energy and protein, significant improvements in N use efficiency could be achieved.

The effect of high sugar varieties of perennial ryegrass on rumen function and performance of the dairy cow was also investigated by Taweel et al (2005). The results indicated that the high sugar varieties may have reduced milk urea concentration. However, all other aspects of the milk production and milk quality assessed showed that the hypothesis that high sugar grass increased DMI and therefore milk production was not proven.

Taweel et al (2006) also investigated the grazing behaviour of dairy cows (Holstein-Friesian) offered perennial ryegrass varieties that were morphologically and chemically similar apart from their WSC concentration. The results showed that, at the differences of WSC measured in the two varieties (32 g/kg), grazing and rumination behaviour was not affected by the high sugar pasture and was not therefore of any benefit in terms of improving dry matter intake, milk yield or in altering the composition of the milk produced. It was suggested that an increase in WSC content in grasses was only likely to improve production in situations where metabolisable protein was lacking, because of the consequent increase in microbial protein. This study showed no benefit to a higher WSC content, as there was sufficient protein in the diets fed and the additional sugar was not confounded with improved digestibility. In fact, O'Donovan et al (2011) suggested that the increase in WSC content needs to be large before any improvement in animal production is recorded, estimating that a 50 g/kg increase in WSC content is required to produce a 1% increase in DM digestibility.

The dietary preferences of dairy cows were investigated by Francis et al (2006) in a study to assess whether grasses bred for a high WSC content would be preferred by grazing cows to varieties with a lower WSC concentration. The results suggested there was no difference in the botanical composition of non-structural carbohydrates between the two grass varieties and so the cows were unable to express any preference. However, when the cows were offered a spatially separated mixed diet of perennial ryegrass and white clover they selected a mixed diet with a slight preference for clover. The authors also identified that cows which were offered only grass employed different grazing and rumination strategies compared to when they were offered grass and clover. The authors suggested that this may have been to help manage the slower digestion rates for grass. Cows may prefer to graze species that are easier to eat, having lower tensile strength, or taking less time to consume and thereby allowing the animal to feel full sooner.

Ellis et al (2011) used a dynamic model to assess the potential of high sugar grasses to reduce nitrogen excretion and increase milk yield. An attempt was made to explain the variation in response between simulated results and literature results. The model predicted the nitrogen content of urine, milk and excretion accurately and followed the observed patterns from each study. The simulation results indicated that the nitrogen utilisation ratio increased as the WSC content of the diet increased, but at different rates dependent on the grass scenario. It was concluded that, with high sugar grasses, the variation of the simulated results from those in the literature could have been a consequence of the WSC increase being linked to changes occurring within the crude protein and neutral detergent fibre fractions of the plant. Larger differences were predicted the lower the level of nutrition of the diet (low grain feeding and low N fertilisation levels). The results were generally in line with observed data, and explained at least some of the variation observed. The high WSC grasses may increase the efficiency of N utilization and milk yield, but results would depend on the composition of the grass and the diet under consideration.

3. Influence of sward fertilisation on forage intake

3.1 Nitrogen fertiliser and forage intake

Nitrogen (N) is the plant nutrient which has the greatest influence on herbage growth. Clover can fix atmospheric N and therefore can substitute for fertiliser N to a certain extent, but unless a deliberate, planned, clover-based grassland system is in place, an adequate supply of N fertiliser is essential to ensure the provision of sufficient herbage for grazing animals. The rate of N application should be linked to the intended stocking rate per hectare.

Although having a major impact on forage availability and therefore potential intake through its effect on herbage production, the literature suggests that application of N fertiliser *per se* has relatively little effect on forage intake. There is a widely recognised reduction in percentage dry matter content of herbage as N fertiliser application rate is increased. A cow offered lower DM pasture would have to eat more fresh herbage than a cow on drier pasture to consume the same DMI per day. Verite and Journet (1970) estimated that daily DMI would be depressed by 0.34 kg per 1% fall in DM content below 18% but the estimate by Cabrera Estrada et al (2004) was for a fall of 0.134kg DMI per 1% fall in DM content from 30% to 12%. Van Vuuren et al (1992) also found a strong positive correlation between DMI and grass DM% but, comparing the relatively high application rates of 275 and 500 kg N/ha/yr, they found no consistent effects of N fertiliser on DMI of cows.

Similarly, Valk et al (2000), who compared the effect of three relatively high N fertiliser rates (150, 300 and 450 kg N/ha/yr) on grass intake by cows in mid-lactation, also showed little effect of N fertiliser on DMI. They found that reducing fertiliser N decreased crude protein content and in-vitro digestibility, but increased sugar content in grass. Overall, in the spring experiments, a reduction in N fertilization from 450 to 150 kg/ha/yr did not affect grass intake per head, although in one experiment net energy intake of cows on the 150 kg N/ha treatment was lower, resulting in lower milk yields per cow. Again, in late summer, cows fed the 150 kg N/ha fertilised sward consumed less grass and produced lower yields of milk, fat and protein compared to the other treatments. The authors suggested, therefore, that a reduction of nitrogen fertiliser from 450 to 300 kg/ha per year did not affect intake or milk production.

In a New Zealand experiment at lower N levels, a high N treatment (100-150 kg N/ha/yr) resulted in a lower average DMI by Friesian and Jersey cows compared with a low N treatment (25 kg N/ha/yr) (Mackle et al, 1996). The difference (14.0 cf 14.6 kg DM/cow/day) was significant but did not translate to differences in milk yield and the authors concluded that the effect of N fertiliser application had only minor effects on DMI and milk composition.

While very high N fertiliser applications may reduce DM content of the herbage and may potentially reduce intake, low fertiliser N applications may also have an adverse effect on forage intake by reducing the crude protein content of the herbage. In vitro digestibility is also reduced while sugar content is increased (Valk et al, 2000). Delaby et al (1996) found that forage intake and milk yield was reduced when the crude protein content of the herbage fell below 120 g/kg DM. However, in maritime temperate regions this is only likely to occur in situations where soil N mineralisation is low (e.g. on low organic matter, light, sandy soils), no fertiliser N is applied, and no clover is present.

It appears therefore, that it is only in extreme circumstances that N fertiliser, or the lack of it, is likely to affect forage intake per head. In recent years, concerns about rising fertiliser costs and diffuse pollution have focussed attention on more efficient use of fertiliser N (and other fertilisers), animal manures and the adoption of clover-based systems, rather than on maximising N application rates. Animals excrete in faeces and urine a relatively high proportion of the nutrients they eat and retain a relatively small proportion for the production of milk, meat, etc (Whitehead, 2000). Deenen and Lantinga (1993) estimated that at a fertiliser level of 250 kgN/ha/yr, the average efficiency of use of ingested N was only 23%. As N application increases, efficiency of N use falls further and, as both stock carrying capacity and the N content of the herbage increase, the amount of N excreted per hectare rises.

This is illustrated in a paper by Humphreys et al (2008), who examined productivity and N flows in grassland-based dairy systems in Ireland over two years. Four levels of total N input, as fertilisers, concentrates and biological N fixation combined (205, 230, 300 and 400 kg N/ha) supported four different stocking rates (1·75, 2·10, 2·50 and 2·50 cows/ha/ann respectively). Milk output per hectare increased as N input and stocking rate increased, but there were no differences in annual milk yield per cow (6337 kg/cow), live weight or body condition score. Pre-grazing N concentrations in herbage increased with increasing N input while the proportion of N inputs recovered in products declined from 0·34 to 0·24, and annual N surpluses increased with increasing N inputs from 137 to 307 kg/ha. More efficient N use was associated with lower N inputs and in particular lower N concentrations in grazed herbage.

In fact average fertiliser N use on grassland in the UK, including dairy farms, is relatively modest compared to the levels quoted above and shows a long-term declining trend. Even in the 1990s, the average application rate of N fertiliser on grazed grass on dairy farms was reported to be approximately 170 kg N/ha/yr (Hemingway, 1999) and in 2011, the level was estimated to be 143 kg N/ha/ann (Anon, 2012).

In addition to decisions about total annual application rates of fertiliser N, the farmer also needs to make decisions about the seasonal pattern of N applications. This was investigated as a means of influencing the seasonal pattern of herbage production, in order to synchronise better the herbage supply with livestock feed demand through the season (Hennessy et al (2008). Daily grass growth rate tends to be very high in April and May but falls off in July and August. Strategies of applying either 20% (treatment IN) or 60% (treatment RN) of total annual N fertiliser inputs before June were compared. Herbage production was reduced in April and May and increased in the June-October period in treatment IN. Annual herbage production was not significantly affected by the treatments, except in the third year when treatment RN produced significantly greater annual herbage production. Crude protein (CP) concentration of herbage was lower in April and May on treatment IN than treatment RN, but CP concentration of herbage was rarely below 150 g/kg DM and so it is unlikely that livestock productivity would be compromised. Conversely, on treatment IN concentrations of CP in herbage were higher in the late summer than on treatment RN, which may increase livestock productivity during July and August when livestock productivity is often lower. However, whilst applying most of the annual fertiliser N in summer (IN) offers the prospect of increasing herbage and milk production during this period, such a policy conflicts with the objective of reducing winter feed costs through promoting early grass growth and early turnout of cows.

3.2 Fertilisers other than nitrogen

Although fertilisers such as potassium can have a significant effect on the mineral content of the herbage, the only major nutrient which has a significant effect on forage intake per se is sodium (Na). Chiy and Phillips (2000) examined the application of Na fertiliser to grazed perennial ryegrass pasture and the effects on high (mean figure of 27.8 l/d) and low (mean figure of 18.8 l/d) milk production cows. Application of sodium to the pasture increased the intake of herbage DM, the time that cows spent grazing and the biting rate. It also increased the concentration of Na, magnesium (Mg) and calcium (Ca) in herbage and decreased the concentration of potassium (K). Applying Na fertiliser had a greater effect on low-production potential cows. In this group, milk yield and milk fat concentration was increased and somatic cell count was reduced. In high production potential cows, applying Na increased persistency of milk production. The improved intake of nutrients would have a greater effect on the low production cows as there was greater potential for improvement, and although the increase in Na in the diet decreased the somatic cell count (SCC) in both groups, there were almost twice as many cows with a high level of SCC (over 200 000 cells/ml) in the low production group as in the high group. The concentration of lactose in both the high and low yielding cows was also seen to increase after the application of Na fertiliser.

This effect of Na on herbage intake is potentially significant. Apart from the effect on intake per se, Na can, to some extent, be used as a substitute for K as a plant nutrient without adversely affecting herbage yield. In areas where soil and herbage are naturally low in Na, applications of Na (salt) will reduce the ratio of K to Na in the herbage. This may confer benefits in animal health (lower risk of hypomagnesaemia and milk fever) as well as the performance benefits reported above (although the issue of K fertilisation relates more to grass for silage than on grass for grazing). The greatest benefits from Na application are likely to be obtained in eastern and inland areas of the UK, where Na content in soil and herbage is likely to be sub-optimal. In western coastal areas of the UK the Na content will probably be adequate as a result of salt spray from the sea (although the trials of Chiy and Phillips (2000) were conducted at Bangor in North Wales).

3.3 Effect of slurry application on forage intake

On dairy farms most of the organic manure, including slurry, is applied to grass for conservation, but it is also sometimes applied to grazed grass. Sporndly (1996) confirmed that herbage intake on clean pasture was higher than that on fouled pasture. Furthermore, topping of fouled pasture increased the fouled area considerably. Slurry injection and surface spreading were compared in terms of cow grazing behaviour by Pain and Broom (1978). Cattle on pasture where slurry had been surface spread approximately nine weeks pre-grazing, ate about 30% less herbage DM than where slurry had been injected, or where an inorganic N fertiliser had been used. Cows on surface spread paddocks also spent more time grazing, more walking was observed, they appeared to have a smaller bite mass, exhibited more competition behaviour and drank more often, compared to cows on injected paddocks. Laws and Pain (2002) also compared different slurry application methods, including application by injection, trailing shoe or splash plate, either at 32 days or 10 days before commencement of grazing. A control treatment (i.e. where no slurry was applied) was also included. Results showed that the adverse effects on grazing behaviour seen with surface spreading could be overcome by the use of slurry application techniques such as injection or trailing shoe. Recent research at AFBI-Hillsborough has demonstrated that slurry can be applied twice during the grazing season using a trailing-shoe system (31.5 and 19.1 m^3/ha applied) without any detrimental effects on animal performance, while reducing fertiliser N input by 80 kg/ha (Dale, 2011).

4. Influence of animal and pasture management on forage intake

4.1 Cattle grazing behaviour and forage intake (grazing time, bite size, biting rate)

The evolution of ruminant ecology was reviewed by Hackmann and Spain (2010) with the rationale of translating natural ecological observations to the domesticated environment. In both wild and domestic ruminant species voluntary feed intake is proportional to body weight, and this proportionality suggests that both physical and metabolic factors regulate intake simultaneously and are not mutually exclusive, as is often presumed. This section of the review focuses on the mechanics of grazing by cattle. Intake can be seen as a function of a number of factors including the average bite size, the rate of biting (number of bites per minute) and the overall length of time available for grazing. The first two of these are related to herbage availability and the extent to which the animals have to move over the sward to find new herbage which is acceptable to them.

The effect of sward height on the grazing behaviour of lactating cows was studied by Gibb et al (1997). The results showed that sward surface height could significantly influence intake rate. As sward height decreased the cow's only effective strategy was to compensate for any reduction in intake rate by an increase of grazing time, but this may be limited by the requirement for ruminating and non-grazing activities, which were influenced by qualitative and quantitative aspects of the herbage ingested. Tharmaraj et al (2003) also studied the defoliation patterns on swards of differing heights and daily herbage allowance and their resistance to prehension bites. These authors found that, in terms of the time and energy costs of prehension bites, larger bites are handled more efficiently than smaller bites. The volume of herbage defoliated and herbage intake increased with sward height and daily herbage allowance (DHA). Corresponding to an increase in DHA from 35 to 70 kg DM cow/day, there was a proportional increase in the total defoliation area (TDA) and intake. The increase in defoliation area was 24% in the short sward compared with 16% in the tall sward, whilst the increase in intake was 55% in the short sward and 32% in the tall sward. These results suggested that the volume of sward canopy defoliated is the major variable which affected herbage intake.

Orr et al (2004) observed the ingestive behaviour of yearling dairy heifers that were rotationally stocked on pasture following re-growth after cutting of perennial ryegrass and white clover. The average sward height was reduced from between 20 and 38cm down to 8 to 9cm. It was observed that most of the leaf was consumed and bite mass was considerably reduced as sward height was reduced. There was no change observed in eating time but ruminating time increased as the leaf:stem ratios declined. Total jaw movement rate during grazing also declined, the authors suggested that the heifers spent more time searching for leaves as sward height fell. Correlations between bite mass and plant factors suggested that total herbage mass was less useful for assessing likely levels of intake than green leaf mass or sward surface height, when managing grazed ryegrass swards, but total mass may have a place in the prediction of intake of white clover. More detailed plant measurements indicated that the lengths of the 2^{nd} and 3^{rd} oldest fully expanded live grass leaves were significantly correlated with bite mass and this, along with the role of sheath tube lengths, defined the grazed horizon in ryegrass swards.

Gibb et al (1999) examined the grazing behaviour of lactating or dry cows on continuously grazed swards maintained at three different sward surface heights (measured by sward stick) ; 5, 7 or 9cm. The results showed that both lactating and dry cows compensated for the reduction in intake rate at lower sward heights by increasing the total grazing time and total number of bites per day. The increased time spent grazing was associated with a reduction in the time spent ruminating, despite similar levels of daily intake being achieved across sward surface height treatments. Although dry cows had much lower daily intakes, they spent only about 30 minutes less each day ruminating than the lactating cows, allowing them 120 to 160 minutes more idling (i.e., non-grazing, non-ruminating) behaviour. The authors reported that there was no difference in milk yield between cows on the different sward heights (mean daily milk yield was 26.6 kg), nor between the milk protein, fat or lactose, which had respective mean contents of 30.4, 42.3 and 47.4 g/kg milk.

The grazing behaviour of high yielding (32.0 kg/day) and low yielding (24.8 kg/day) Friesian cows was studied by Bao and Giller (1992). They found that the relative level of movement by the cows while grazing was not related to the milk yield but related to lactation number, with the younger cows moving further in the paddock than the older cows. The distribution of the high yielding and low yielding cows was found to be similar over the paddock when grazing.

The question of where to graze within a field or paddock, or patch selection, was studied by Griffiths et al (2003a) with Friesian and Friesian x Jersey cows. In vegetative swards, cows preferentially selected the tallest swards, as measured by the number of bites per patch. When swards comprising reproductive stem were offered, cows selectively grazed short-stubble swards rather than tall-stubble swards but the depth of regrowth was the most important factor. There was no evidence that cows chose where to graze based on conditions in adjacent patches, suggesting that the cows assessed grazing opportunities on a patch-by-patch basis. Observations on bite depth mirrored those on patch selection (Griffiths et al, 2003b). There were also indications that bite depth was conditioned by the number of bites removed. This suggested that cows initially took a cautious approach to grazing, building up bite depth with feedback over the first 20–30 bites in a new patch.

A model to simulate optimal foraging theory was used (Woodward et al, 2008) to test the assumption that animals maximise their food intake by exploiting food patches. The results showed that both modelled rules of optimal patch selection, and optimal patch residence time, significantly increased intake rate in a grazed pasture environment, but differences that resulted from the use of different variations of the patch selection rules were small. The findings seemed to broadly support the optimal foraging theory, which can be used as a tool to predict the intake of grazed pasture. Animals grazing herbage that is easy to eat will more easily meet their optimal intake.

The effect of grazing behaviour on energy expenditure by the animals was investigated by Kaufmann et al (2011). Over a 14 day grazing trial using measurements of the CO_2 content of the dairy cows' blood assessed from an automatic blood sampling system, a comparison was made between pasture grazing and barn feeding. Eating pattern and physical activity were measured using a behaviour recorder and an activity meter with milk yield recorded daily. The measurement period was for 6 hours and showed that the energy expenditure of cows on pasture was higher than that of barn fed cows, as grazing cows spent more time walking and less time standing and lying than the barn fed cows. In addition, time spent eating was greater and time spent ruminating was lower for cows on pasture compared with indoor grass-fed cows. Positive correlations between energy expenditure and walking and eating time indicated that the higher energy requirements of dairy cows on pasture may be at least partly caused by the higher level of physical activity. However, daily feed intake and milk production were not affected by the feeding treatment. Further work needs to be done to determine whether these effects are applicable over 24 hours.

4.2 Relationship between forage intake and grass height (or herbage mass)

In making grassland management decisions, the dairy farmer must strike a balance between on the one hand maximising forage intake and milk yield per cow and, on the other, maximising stocking rate to maximise milk output per hectare. These decisions are complicated by the fact that grass growth rate varies considerably within and between seasons and exhibits a seasonal pattern of vegetative and reproductive development which has a major influence on feed value.

Stocking rate is the relationship between the number of animals and the total area of the farm over a specified time, usually a year. The potential overall stocking rate is determined by the annual herbage production potential on the farm, which in turn is dependent on weather, sward and soil conditions, including nutrient supply. Clearly decisions on overall stocking rate have an over-arching effect on day-to-day management issues but as far as the research literature is concerned, the focus of grassland and livestock experimentation tends to be on within-season grazing management challenges, employing concepts such as target sward heights and daily herbage allowance.

Systematic approaches, based on measurement of grass height as an estimate of the herbage mass, have been developed in order to facilitate grazing management decisions. Dillon (2010) confirms that grass measurement is the key to success in grassland management and planning ahead would allow shortages and surpluses to be identified and opportunities used. In continuous grazing situations regular monitoring of grass height provides a crude measure of whether, over a period of time, the herbage available is adequate for the grazing livestock, and can be manipulated by adjusting stock numbers or grazing area. In rotational grazing situations, grass height (usually expressed as pre- or post-grazing height) is also the basis for estimating the total herbage mass per hectare (or grass 'cover') in each field or paddock. This can be used to predict and manage herbage allowance for the grazing animals (and utilisation of surplus herbage). Grass height can be measured by ruler or stick (uncompressed height) or more commonly by rising plate meter (compressed height).

As indicated in Section 4.1 above, grass height or herbage mass has a major effect on forage intake (Gibb et al (1997, 1999); Thamaraj et al, 2003). Sudo et al (2002) also showed that herbage intake was determined primarily by herbage mass and decreased as intake of concentrate supplement increased. The influence of grass height on intake and performance is discussed further below, firstly in the context of rotational grazing situations and secondly in the context of continuous grazing.

4.2.1 Effect of grass height on forage intake under rotational grazing

The effect of pre-grazing sward height on herbage intake and milk production was investigated by Sprondly and Burstedt (1996). Herbage intake by strip-grazed dairy cows (average milk yield 15.6 kg/ha and live weight of 546 kg) was estimated over different parts of the grazing season, different sward heights and different years, whilst maintaining the same level of pasture allowance (30 kg DM/cow/day). Herbage mass, herbage composition, milk yield, live weight, lactation week and age of the experimental animals were also recorded with the intention of producing a model that assessed the influence of sward height and season on herbage intake. It was found that the sward height, season, milk yield, live weight and year, and the interaction between sward height and season, were significant in the statistical analysis and were thus included in the model. In the early part of the season, herbage intake increased by 0.8 kg organic matter for every one cm increase in sward height. In mid-season, intake was significantly reduced at pasture heights below 9 cm, while in late season there were no differences in intake at different sward heights. Late season intake was significantly lower ($P < 0.001$ and $P < 0.01$) compared with intake during early season and mid-season, respectively. The model showed the influence of milk yield and live weight on herbage OM intake was 0.2 kg OM per kg milk and 0.5 kg OM per 100 kg live weight, respectively.

McGilloway et al (1999) investigated the effects on cow performance of reducing sward height in a series of experiments on perennial ryegrass dominated swards. Intake of herbage was reduced as level of sward height reduction (SHR) increased. Herbage intake rates varied from 1·9 to 4·4 kg DM/h, whereas DM intake per bite ranged from 0·5 to 1·3 g. The level of SHR generally had no effect on biting rate but sward surface height (SSH) was identified as the principal determinant of DM intake/bite. The authors concluded that the principal factor controlling intake (g DM/bite or kg DM/h), as swards are progressively grazed down, is SSH, but at a high level of SHR, sward density also influences intake per bite.

Rotational grazing of dairy cows and the effect of pre-grazing grass height was the subject of a study of Yayota et al (2002). Two levels of pre-grazed grass height (low 20cm and high 30cm) were used for grazing cows, which were maintained through the grazing period. The low pre-grazed grass had higher crude protein and lower neutral detergent fibre content, whereas the high pre-grazed grass had higher herbage allowance and, therefore a higher herbage intake per animal. Milk yield was found to be slightly higher in the low pre-grazed grass but the difference between treatments was not significant. Nakatsuji et al (2006) also studied the effect of pre-grazing sward height on the herbage intake and milk production in a rotational grazing system (pre-grazing heights of 15cm and 20cm). In contrast to other work reported here, the conclusion drawn from this study was that the pre-grazing height of the sward had no obvious effect on the nutritive values of herbage, herbage intake per animal, and herbage intake and milk production per unit area.

Dillon (2010) suggested that the producer should focus on milk yield per ha, not on production per cow and that in order to achieve this, the optimum pre-grazing height should be 8-9cm.

In two experiments, Mayne et al (1987) compared a range of post-grazing residual sward heights, assessed by rising plate meter, on the performance of rotationally grazed British Friesian cows. In the first experiment, post-grazing sward heights of 42, 50 and 59mm resulted in daily milk yields of 11.8, 14.6 and 14.5 kg respectively, whilst in the second experiment, post-grazing sward heights of 50, 60 and 80mm gave milk yields of 13.7, 16.0 and 17.0 kg respectively. The authors conclude that a reasonable compromise between sward utilization and animal performance can be achieved by grazing January/February calved cows to a residual sward height of 60 mm as assessed by a rising-plate sward stick.

Delaby et al (2003) also highlighted the importance of making the best possible use of herbage produced by adapting the stocking rate to achieve a post grazing sward height of 5 to 6 cm during the grazing season. With high genetic potential cows, high individual cow performance at grazing could be attained by the use of concentrate supplementation.

The effect of different post-grazing heights on cow performance was investigated by Houssin et al (2005), over three years. Swards were grazed to post-grazing height of either 5.0 to 5.5 cm (low grazing height) or 6.5cm (high grazing height). The cows on the lower grazed swards had a lower grass DMI (between -0.8 and -2.4 kg DM/cow/day), which led to a lower milk production, an average of 1.5 kg/day lower over the time at pasture. However, milk production per ha was 25 to 38% higher in the lower grazed swards.

4.2.2 Effect of grass height on forage intake under continuous grazing

Phillips and James (1998) considered the effects of offering cows a choice between tall and short mixed perennial ryegrass/white clover swards. The results showed that the cows offered only the tall sward produced most milk (17.6 kg/day), and those offered only the short sward produced the least (15.2 kg/day). Milk fat content was reduced for cows offered only the tall sward (39.7 g/kg compared to 41.8 g/kg). Cows offered a choice of the tall or short swards spent longer grazing in total than the cows offered only tall or only short swards but there was no difference in the time spent grazing the tall and short swards.

In experiments carried out over six weeks with Holstein-Friesian cows, an increase in sward height (swards maintained at 3-5cm cf swards maintained at 7-9cm) led to greater milk yield persistency and a significant ($P<0.01$) increase in milk yield (20.6 kg/day to 24.4 kg/day), DMI, grazing time and rate of intake (Pulido and Leaver, 2001). Increasing levels of concentrate feeding led to significant increases in milk yield ($P<0.01$) and milk yield persistency ($P<0.001$), but decreased herbage dry matter intake, time spent grazing and rate of herbage intake.

Rook et al (1994) investigated the effect of sward height (measured by rising plate meter) and supplementation on the digestive behaviour of spring calving Holstein-Friesian cows grazing grass clover pasture at three different heights (40, 60 or 80mm). Grazing time was greater at 40 mm sward height than at 60 or 80 mm when unsupplemented, but was less when supplemented (4 kg). Proportionately, 0.88 of grazing time and 0.67 of ruminating time by dairy cows occurred during daylight, with a large grazed evening meal particularly evident. This was consistent with other ruminants where more feeding was concentrated in the evening period. On the 40mm sward, unsupplemented animals grazed for longer and had a higher biting rate but lower bite mass and less mastication and rumination. When supplement was offered at the 40mm sward height, animals appeared to 'give up' harvesting the sward more readily.

Leaver (1982) studied continuously stocked dairy cows which were offered supplementary concentrates according to the herbage height measured weekly with a rising plate meter. Grass heights were maintained at 9, 7 and 5 cm. Concentrates were offered at a rate of 1 kg/day for each 0·2 cm decline below these threshold levels. All the three grass heights had the same stocking rates of 5.6 for the early grazing period, and 3.6 for the mid and late grazing periods. For the maintenance of a 9cm grass height the concentrate dry matter intake was 3.3 kg/day (with an additional 0.8 kg/day of hay) and gave a mean daily milk yield of 17.7 kg, to maintain a grass height of 7cm resulted in a concentrate intake of 1.7 kg/day of dry matter and produced a mean daily milk yield of 16.0 kg and the 5cm grass height maintenance resulted in a concentrate intake of 1.3 kg/day and a mean daily milk production of 15.0 kg. The increased levels of supplementary feed also produced an increase in liveweight and body condition score, and a reduction in milk fat.

4.3 Relationship between forage intake and daily herbage allowance (DHA) per head

The limitation of grass height alone as a tool for grazing management is that it takes no account of the stocking density of grazing animals, i.e. the grazing area available to each cow. This can be overcome by translating grass height measurements to an estimate of herbage mass per hectare, or grass 'cover', using a standard conversion equation. From this, an estimate can be made of the daily herbage allowance available to each cow.

Where no concentrate supplementation is offered, increasing DHA has been shown to increase milk yield. For example, Dalley et al (1999), comparing a range of herbage allowances in spring, showed that DHA was an important factor in determining voluntary feed intake and milk production. To achieve higher milk production from herbage, without supplementation, meant that high DHA was required. Similarly, Stakelum (1986), comparing herbage allowances of 16 and 24 kg DM/cow/day with and without concentrates in spring, showed that grass DMI was influenced by herbage allowance, although he did not observe a significant effect on fat-corrected milk yield. O'Brien et al (1997), on the other hand, found with mid-lactation cows that increasing DHA from 16 to 24 kg DM resulted in significant increases in the yields of milk (average response of 1.6 kg milk per kg estimated DM intake), fat, protein, casein and lactose and the concentrations of total protein, casein and lactose. King and Stockdale (1984), working in Australia, compared pasture allowances of 6.9, 13.1 and 23.2 kg digestible dry matter per cow per day for late lactation Jersey and Friesian x Jersey dairy cows, found that increasing pasture allowance during late lactation improved milk yield and body condition. Pasture intake was shown to be positively related to pasture allowance. In this situation, each additional kilogram of dry matter eaten was shown to have produced 0.93 kg milk and 0.045 kg milk fat.

Increasing herbage allowance to very high levels may bring no response, however, as shown by Johansen and Hoglind (2007), although this may depend on the potential milk yield of the cows. They compared relatively high levels of DHA (18 kg and 36 kg DM/head/day) with Norwegian Red cows, and found no effect on either herbage intake or daily milk yield per cow. In other experiments, they compared DHA of 12, 18 and 24 kg DM. In these experiments there was a significant positive effect of herbage allowance on herbage intake, the average increase being 0.24 kg DM intake per extra kg DM on offer. Milk yield and composition was not affected by DHA, however, probably because in these experiments small amounts of concentrates were also fed (ranging from 0 to 6.8 kg/head/day depending on milk yield). The utilization of the sward (measured at 3 cm above ground level) decreased from 72% at the lowest herbage allowance to 51% at the highest herbage allowance.

Similarly, in terms of the utilization of the sward, Wade (1991) found that cows with a low herbage allowance harvested 65% of the total herbage mass compared with only 46% for cows on a high herbage allowance. A sward utilization rate, or sward height depletion, of greater than 50% was found to be limiting for intake, but the author also found that in ryegrass swards with a high pre-grazing height it is the presence of grass sheaths rather than the absolute height of the grazed horizon which limits intake. This issue of sward structure is discussed further in Section 4.4 below.

At the start of the growing season when grass growth may still be slow, herbage mass (or sward height) is restricted and it may not be possible to allocate the desired DHA without using a large grazed area, or in rotational grazing situations, moving cows quickly round the paddocks (i.e. shortening the grazing rotation). Strategic feeding of concentrates can mitigate this challenge. McEvoy et al (2008) compared two levels of DHA (13 and 17 kg DM) and three levels of concentrate (0, 3 and 6 kg/day) with spring-calving Holstein-Friesian cows turned out in mid-February. Cows offered the low DHA had significantly lower grass dry matter intake (13.3 kg) and total dry matter intake (16.3 kg) than the high-DHA cows during the experimental period. During the subsequent carryover period previous DHA continued to have a significant carryover effect on milk protein concentration, body-weight change, and end-point body condition score. The authors concluded that offering a medium level of DHA (17 kg of herbage DM) in early lactation will increase milk production. Offering concentrate results in a linear increase in milk production. In an early spring feed-budgeting scenario, when grass supply is in deficit, offering 3kg of dry matter concentrate with 17 kg of DHA has the additive effect of maintaining the grazing rotation at the target length as well as ensuring the herd is adequately fed.

Kennedy et al (2008) also examined the effect of DHA and concentrate supplementation in early spring on dry matter intake, milk production and energy balance of early lactation Holstein-Friesians, at approximately 40, 80 and 120 days in milk. From 21 February to 8 May they compared three levels of DHA (13, 16 and 19 kg DM/cow/day; > 4 cm) and two concentrate allowances (0 and 4 kg DM/day). Offering a low DHA resulted in a restricted grass dry matter intake (DMI) at 40 and 80 days. Daily herbage allowance had no effect on milk yield or composition at 40 days but a low DHA tended to reduce milk yield at 80 days. Concentrate supplementation significantly increased total DMI and milk yield. Cows offered a low DHA had a lower post-grazing sward height but increased sward utilisation (> 4 cm) up to 80 days in milk, but there was no difference during the carryover period. Concentrate supplementation increased post-grazing sward height by 11% from 40-80 days but had no effect in the initial period and in the carryover period. The authors concluded that during this early part of the growing season animals should have low DHA (13 kg DM/day) in early lactation, but that this should be supplemented with concentrate.

Curran et al (2010) compared two levels of DHA (15 and 20 kg DM/cow) and two levels of pre-grazing herbage mass (1600 and 2400 kg DM/ha) in a study in Ireland from early April until the end of October and came to the same conclusions. The higher DHA increased milk, protein and lactose yields. The milk response per kilogram of grass DMI was 1.13 kg for the low herbage mass cows compared to 0.65 kg for the high herbage mass cows. The low herbage mass treatment had a higher proportion of leaf and a lower proportion of dead material during the second part of the experimental period (July – October). The low HM groups completed 9.5 rotations of average 22 days length compared to 6.5 rotations of 32 days for the high HM groups. The results suggested that a low herbage mass sward (1600 kg DM/ha) and a DHA of 20 kg DM/cow/day had a positive effect on sward characteristics, which resulted in increased milk production and sward quality.

A trial with similar treatments was carried out by McEvoy et al (2010) with two levels of DHA (16 and 20 kg DM/cow/day >4cm) and two levels of herbage mass (1700 kg DM/ha and 2200kgDM/ha >4cm) compared with Holstein-Friesian cows between April and August. The results showed an increase in milk yield by offering 20kg DHA in the first grazing period (April and May) but not during the second (July and August). As with the work of Curran et al (2010), McEvoy et al (2010) found that maintaining the 1700 kg DM/ha mass sward across the season improved its nutritive value in the latter part of the grazing season compared with the high-mass swards, resulting in increased animal intakes and milk production throughout the latter part of the trial. The level of pre-grazing herbage mass was also important, as well as achieving high utilisation rates before the grass reached its reproductive phase. Overall, offering a medium mass sward (1700 kg DM/ha) and 20kg DHA resulted in increased DMI and milk production compared with the high mass sward, especially toward the end of the grazing season.

Wims et al (2010), working with Holstein-Friesians in June and July, also found that a low herbage mass sward (1000 kg DM/ha) compared with a high herbage mass sward (2200 kg DM/ha) had increased organic matter digestibility, increased herbage DMI in the first part but not the second part of the trial, but had no effect on milk yield per cow. Another major potential benefit of the high quality low herbage mass swards was lower methane production per cow per day, per kilogram of milk yield and per kilogram of milk solids.

4.4 Relationship between forage intake and sward structure

As indicated above in the work of Curran et al (2010) and Wims et al (2010), the sward structure (e.g. the ratio of leaf to stem and the ratio of live to dead leaf) and quality is influenced by management and can have a significant effect on intake and animal performance. The results of Holmes et al (1992) echo those of Curran et al (2010). Holmes et al (1992) examined the effects of differences in pre-grazing herbage mass and composition on milk production from cows grazing in early spring. They concluded that low DM mass swards contained lower concentrations of grass stem and senescent material, but higher concentrations of clover, than the high DM mass swards. Herbage from the low-mass swards was also more digestible. The cows grazing on the low DM mass swards (2.9 t DM/ha) produced significantly greater yields of milk, milk fat and milk protein indicating that the sward was of a higher feeding value for lactating cows in early lactation.

The effects of different grazing intensities in spring grazed pasture on the subsequent sward composition and milk production in summer was studied by Hoogendoorn et al (1992). Increased intensity of grazing imposed during spring (including the period of reproductive development in ryegrasses) produced swards in early summer with lower pre-grazing herbage masses, which contained higher concentrations of green leaf, clover and digestible nutrients, but lower concentrations of grass stem and senescent material. In two experiments where cows were given a common daily allowance of total herbage dry matter, the animals grazing on low-mass swards in early summer produced larger daily yields of milk, fat and protein than those grazing on the high-mass swards. In a third experiment, cows were given a common daily allowance of green leaf DM from three swards which differed in pre-grazing herbage mass and in herbage composition. The allowances of total DM required (to achieve the same allowance of green leaf DM) differed widely between the treatments. There were no significant differences in milk yield between the swards despite the large differences in herbage composition, indicating that it is the DHA of green leaf DM which is the most significant factor determining milk yield rather than the DHA of total herbage DM.

The same conclusion was reached by Brink and Soder (2011) in the United States, using a different range of temperate grass species (cocksfoot, meadow fescue, reed canary grass and couch) in a rotational grazing situation. Leaf bulk density and the leaf fraction mass within grazed sward layers were positively associated with herbage intake, while stem bulk density and stem fraction mass within grazed sward layers were negatively associated with intake. Thus it is the quantity of leaves in the canopy that has the greatest influence on grazing intake of vegetative grasses. The nutritive value of meadow fescue was generally greater than that of the other grasses. Similar conclusions were reached by Flores-Lesama et al (2006), comparing ryegrass cultivars of varying morphology at the same DHA. They found that the lowest level of milk production was with a cultivar with high biomass per tiller but low tiller density, bulk density and green leaf mass.

The effect of grazing pressure on subsequent sward composition was also investigated by Stakelum and Dillon (2007), who found that early season grazing pressure was important to create a leafy, highly digestible sward for the remainder of the growing season. High stocking rates (6.35 and 6.06 cows/ha) reduced the areas of the sward which were affected by dung patch long grass and led to lower post-grazing heights (6.6 and 5.9 cm for the two experiment conducted). This effect of increased stocking rate, or grazing pressure, on sward structure was also reported by (Roca-Fernandez et al, 2010), in maritime NW Spain. They found that an increased stocking rate improved sward characteristics, resulting in higher sward utilization, grass quality, milk yield and milk quality in both, spring and autumn calving cows.

Dillon et al (1998) reported results on the effects of grazing intensity in late summer/autumn on sward characteristics and milk production. A low stocking rate (3.45 cows/ha) in early summer resulted in lower milk yield (19.2 to18.2 kg/day), fat yield, protein yield, lactose yield, milk protein concentration and lactose. This lower performance was associated with significantly higher pre-grazing herbage mass, lower organic matter digestibility, a lower proportion of live leaf in herbage offered and longer rotation length. A further reduction in the stocking rate (to 2.45 cows /ha) during a second period of grazing had no effect on milk production but milk protein concentration was increased.

One of the consequences of increased grazing pressure on sward structure is a higher tiller density in the sward (Fisher et al, 1995). In this work, higher grazing pressure in the spring led to high live tiller density and live:dead tiller ratios compared with low spring grazing pressure and a silage aftermath. The high grazing pressure treatment also increased sward herbage mass and, to a limited extent, herbage metabolizable energy and crude protein contents. These sward effects led to increased herbage dry-matter intake and milk yield in one experiment. The authors concluded that acceptable milk yields can be obtained from grazing summer-calving cows, without offering forage buffers, by applying high stocking rates (low grass heights) in spring. However, the benefits of this manipulation could be lost by lax grazing in mid-season.

These effects were subsequently confirmed by the same authors (Fisher et al, 1996). Creating two swards of different tiller density (by imposing different sward heights in the spring), they found that herbage on the high-density (27,350 tillers/m^2) sward contained more metabolizable energy (11.9 vs. 10.4 MJ kg/ DM) and crude protein (232 vs. 205 g/kg DM), had fewer rejected areas (16.5 vs. 26.9%) and a higher live:dead tiller ratio (4.6 vs. 2.1) than that on the low density sward (13,300 tillers/m^2). Herbage intake, and on occasions milk yield, of cows grazing high-density swards were higher than on swards with low tiller density.

It could be speculated that one way to establish low herbage mass swards and the structural advantages which they bring is to shorten the rotational grazing interval in spring. Dale et al (2008) examined the effects of very short grazing intervals in the first 60 days of the growing season (8 - 12 days rotation compared with a 20 day rotation). This very short rotation length significantly reduced pre- and post-grazing heights and pre-grazing herbage mass in May and June. Total herbage production was significantly lower on the short than the normal rotation treatment as a result of a significant reduction in the growth rate of herbage in May and June. Stocking levels were not adjusted in order to maintain equal levels of daily herbage allowance per cow and so the short rotation treatment significantly reduced herbage intake, reflecting reductions in intake per bite, grazing time and total bites per day, and had a significantly lower milk output per cow. The authors concluded that a more modest reduction in grazing interval may control herbage production without any reduction in animal performance.

4.5 Extending the grazing season: late season and early season grazing

The cost of housing cattle and the associated costs of silage making and feeding are major components of the overall cost of dairy production, and extending the grazing season in late autumn or early spring is one way of improving profitability. Because of the restricted herbage mass and the increased risk of poaching during these periods, extended grazing normally involves cows grazing for a limited number of hours per day but in regions with free-draining soils and a mild climate, cows may be fully turned out much earlier than has been common practice. The aim is to reduce costs relative to a fully housed, silage fed system rather than to increase milk yield per cow, but several trials have shown that animal performance is also enhanced. For example, Dillon et al (2002), found that cows with access to pasture (5–6 h per day in 1993 and 11–12 h per day in 1994) in February, March and April had lower silage DMI and higher total forage DMI in both years than those kept indoors, resulting in significantly higher yields of milk, fat, protein and lactose. Sayers and Mayne (2001) also found that early turnout of dairy cows to pasture in March and April for as little as 2 hr/day reduced silage consumption significantly, and also increased milk and protein yield, relative to fully housed animals that were offered grass silage with a low level of concentrates. Mayne and Laidlaw (1995) have demonstrated similar benefits with extended grazing in November and December. These trials show that access to grazing for a limited period each day in February-March or in November–December allows an increase in milk yield of 2 – 3 kg/cow/day coupled with a reduction in concentrate use of 4 to 6 kg/day.

A comparison of early turnout (mid-February) Holstein-Friesian cows receiving a low level of concentrate (3 kg DM/cow) with housed cows on a silage and concentrate ration (10.9 kg DM/cow) was undertaken by Kennedy et al (2005). There was no difference between the two groups in total DMI or in milk yield per cow, but the grazed group, receiving a daily herbage allowance of 15.1 kg DM/cow plus concentrate, had a higher milk protein concentration and a higher milk protein yield. Milk fat concentration was higher in the indoor fed group. Although there was no difference between the treatments in total DMI, the digestibility of the grazed herbage was higher than that of the silage fed to the indoor cows. This may have been the reason for the slightly improved animal performance. In addition, of course, the grazed treatment resulted in a significant saving in silage and total feed costs.

Kennedy et al (2008) investigated the more precise management of early spring grazing, in terms of daily herbage allowance (DHA). This work was described above, in Section 4.3. Essentially, the authors conclude that, after a February turnout date, in the period February to May animals should be offered a low DHA (around 13 kg DM/cow/day) up to 80 days in milk after which DHA should be increased. However animals should also be supplemented with concentrate during the early post-partum period (in the trial, concentrates were offered at 0 or 4 kg/cow/day).

In the management of extended grazing, farmers also need to make decisions about the length of time cows spend on grazing swards and whether to supplement them with silage when they are housed during this extended grazing period. Kennedy et al (2011) undertook a trial to investigate the effect of restricting pasture access time of spring calving Holstein-Friesian cows in early lactation and to establish whether silage supplementation was required when cows return indoors after short grazing periods. The trial was carried out between 25 February and 26 March. The four treatments compared were: full-time access to pasture (22H; control); 4.5-h- pasture access after both milkings; 3-h pasture access after both milkings; 3-h pasture access after both milkings with silage supplementation by night (additional 4 kg DM/cow of grass silage). All treatments were offered 14.4 kg DM/cow per day herbage from swards, with a mean pre-grazing yield of 1739 kg DM/ha above 4 cm, and were supplemented with 3 kg DM/cow per day of concentrate. Restricting pasture access time had no effect on milk (28.3 kg/cow per day) and solids-corrected milk (27.2 kg/cow per day) yield when compared with the treatment grazing full time. Supplementing animals with grass silage did not increase milk production when compared with all other treatments. Animals grazing twice per day for 3h grazed for 98% of the time whereas animals grazing for the same length of time but supplemented with silage only grazed for 79% of the time. Restricting pasture access time did not affect end body weight or body condition score. The results indicate therefore that restricting pasture access time in early lactation does not affect milk production performance and that supplementing cows with grass silage does not increase milk production but reduces grazing efficiency.

Although Laidlaw and Mayne (2000) found that the date of defoliation up to December had no effect on spring herbage mass in the subsequent early spring (March and April), in contrast Roche et al (1996) found that a delayed final date of pasture grazing in the autumn significantly reduced the availability of herbage in the following spring. By the following May the effects of the late final date of grazing were still seen on the herbage growth. However, any effect of an early start to grazing was not apparent in May. There appeared to be no correlation between either late final grazing date or an early start to grazing on milk yield, milk composition or live weight change per head. O'Donovan et al (2002), who studied spring herbage mass and its relationship to closing herbage mass in the autumn on ten dairy farms over a two year period, also found that closing herbage mass (i.e. date of final utilisation) in the autumn had a large effect on the following spring herbage mass. Each 1-day delay in closing between 1st October and 11th December reduced spring herbage mass by 15 kg DM/ha.

The contradiction between the results of Laidlaw and Mayne (2000) and those of Roche et al (1996) and O'Donovan et al (2002) are likely to be caused by geographical and climatic differences between trial sites, as observed by Hennessy et al (2006), who found there was no significant effect of autumn-closing date in a site in the NE of Ireland whereas in the south, earlier autumn closing reduced the herbage mass in late March by up to 0·34 t DM/ha and delaying winter grazing reduced the herbage mass in late March by up to 0·85 t DM/ha. The effects of later grazing dates in winter on herbage mass continued into the summer at the southern site, reducing the herbage mass for the period from late March to July by up to 2 t DM/ha. It is now widely accepted that, in order to maximise the availability of herbage for early grazing in February, March and April, a series of autumn closing dates need to be established on the network of grazing paddocks, creating a 'wedge' of grass for spring grazing.

In addition to the effect of spring grazing pressure (stocking rate) on the subsequent sward morphology and intake characteristics as discussed in Section 4.4 above, the timing of the start of grazing in spring (turnout date) also has a significant residual effect. O'Donovan and Delaby (2008) showed that, compared with a mid-April turnout date (L), a March turnout date (E), although having a significantly lower herbage mass, led to higher herbage quality during the mid-April to mid-June measurement period - a significantly higher leaf proportion and less dead material in the grazing horizon (> 80 mm— extended tiller height). A lower herbage mass will potentially have a significant impact on daily herbage allowance of course, depending on the stocking rate. These authors also included two stocking rates of autumn calving Holstein cows in their trial: H (5.5 cows/ha) and M (4.5 cows/ha). The measured total daily herbage allowance (> 50 mm) was on average 12.7, 15.9, 18.2 and 21.9 kg DM/cow for EH, EM, LH and LM, respectively whilst the daily leaf allowance (> 80 mm) was 10.1, 12.3, 13.3 and 14.5 kg DM/cow for EH, EM, LH and LM, respectively. Dry Matter intake for the EH treatment was significantly lower than for the other three treatments, as was milk yield, but the EM treatment, although having a lower average daily herbage allowance than the two late turnout treatments, produced the same milk yield as the LM (23.9 kg/cow/day), and higher than the LH treatment (22.8 kg/cow/day). The authors concluded that swards grazed in early spring allowed higher grass utilisation and high milk production performance when grazed at a medium stocking rate.

Similar residual benefits from early spring grazing were observed by Kennedy et al (2006), who compared a February and April spring grazing date with spring-calving Holstein Friesian cows, at two stocking rates (4.5 and 5.5 cows/ha for the February date and 5.5 and 6.4 cows/ha for the April date) during the measurement period 12 April to 4 July. Commencing grazing in February had a positive effect on herbage quality in subsequent grazing- a greater proportion of leaf, less stem and dead material, higher OM digestibility and crude protein content. Total herbage yield was lower in the early grazed swards, but as a result of the higher herbage quality, milk and solids-corrected milk yields as well as grass DMI were greater, up to the fourth grazing rotation, for animals grazing the February-grazed sward. The February grazed swards, stocked at a stocking rate of 4.5 cows/ha resulted in the highest grass DMI and the highest milk production of all four treatments. By the time of the fourth grazing rotation, sward quality and structure were similar between swards.

4.6 Influence of time of day on grazing behaviour and intake

Over the period of a day, forage intake by grazing cows may be influenced by the innate grazing behavioural pattern of the animals and by sward characteristics such as botanical composition and, especially, by DM content and sugar content of the herbage.

Gibb et al (1998) showed that grazing jaw movement rates were the same at different times of day, (0700, 1100, 1600 and 1900h), but bite rate (discounting non-grazing jaw movements) decreased during the morning from 52.6 to 47.5 bites/min and increased again in the afternoon, with a maximum rate of 59.4 bites/min in the evening. Bite mass measured as fresh weight was greatest in early morning because the grass is wetter then, but this was a function of the DM of the grass and not of time of day. Bite mass measured as dry matter at these same times of day showed significant differences, being 332, 384, 481 and 402 mg DM/bite. Overall, therefore, bite rate and bite mass led to an increase in DMI and organic matter intake (OMI) as the day progressed.

Rutter et al (2004), Rook (2005) and van Dorland et al (2008) have all observed a diurnal feeding pattern in dairy cows, with cows showing a preference for clover in the morning and grass in the afternoon. Rook (2005) found that milk yield could be increased by 5%, when a new supply of grass was offered in the afternoon, after milking. This is a time when cows generally eat a large meal and coincides with time of day when bite mass, biting rate and intake rate are also high, as recorded by Gibb et al (1998). It is also probably linked to the fact that grass DM content and sugar content are generally at their highest in the afternoon (Orr et al, 2001).

Barrett et al (2001) studied the intake of cows grazing a paddock for 24 hours, compared with cows that were moved to fresh grass during the day. In the cows on 24-h paddocks, bite mass and intake rate decreased during the course of the day. In contrast, when offered a fresh paddock, the intake rate did not decline with advancing time of day and daily herbage intake was 4 kg DM/day higher (17.9 compared to 13.9 kg DM/day). On the other hand, Abrahamse et al (2009) found no benefit in herbage intake and milk yield from moving cows to a new sward in the afternoon, compared with moving them in the morning, although sugar intake was increased and milk fat content was increased following an afternoon move. Climatic factors such as rainfall, temperature, or the presence of dew will affect the characteristics of the herbage in the morning compared to the afternoon and may therefore, affect the response to different moving times – an afternoon move perhaps being more beneficial in cooler, wetter locations.

4.7 Automatic milking: influence of distance to pasture, access to water, etc on forage intake

In the UK, the adoption of automatic milking systems is usually associated with permanently housed cows, but field grazing is practised on some farms with automatic milking, and is a common management practice in many countries. In a review of the advantages and disadvantages of automatic milking, Svennersten-Sjaunja and Pettersson (2008) concluded that use of automatic milking and grazing systems together is possible as long as the distance from the milking parlour to pasture is short.

Bizeray-Filoche et al (2010) found that permanently housed animals, with no access to grazing, had a slightly higher milking frequency and milk yield compared to those with access to grazing. However, lameness problems were also slightly higher in the non-grazing animals. The cows allowed access to grazing pasture spent less time there during the later part of the season but grazed more when given access to young grass. These findings echo those of Sporndly and Wredle (2004) who compared the behaviour and performance of cows grazing either near (N) (50m) or distant (D) (260m) from the automatic milking shed. Both groups also received 3 kg DM grass silage. A third group also grazed the distant pasture but were offered an ad lib supply of grass silage in the shed (D+S). During the first measurement period (June 5 to July 13), cows in the N group had a higher milk yield (29.1 kg) than did cows in the D group (26.4 kg) and had a higher milking frequency compared with the other groups, 2.5 vs. 2.3 and 2.3 milkings/day, respectively. During the second measurement period (August), cows in group D+S had a lower milking frequency (2.1 milkings/day) compared with the two groups on lower supplementation (2.5 milkings/day). In Period 1, all groups spent approximately 20% of their time grazing, but after mid July groups D and D + S decreased the time they spent grazing to around 10%; cows in group N continued to graze as before. It was suggested that as the fresh grass content of the pasture decreased, the motivation to walk further decreased, since by day 7 the time that the near cows spent grazing was on average 21% compared to 7% for the distant pasture cows. It is clear, therefore, that while field grazing can be used with an automatic milking system, longer distances to pasture may lead to decreases in milk yield, milking frequency, and grazing time of cows, and so it is important to provide grazing as close to the shed as possible. Where distant pastures have to be used, grazing management must be planned carefully in order to maintain regular supplies of fresh pasture as the season progresses and thus maintain the motivation of cows to walk to the pasture. Increasing the level of silage supplementation does not appear to give a significantly higher milk yield compared with other cows also grazing more distant pastures. The same authors (Sporndly and Wredle, 2005), in a separate study, found no benefit, in terms of milk yield, milking frequency, or water intake from providing a water supply both in the shed and in the pasture, compared with providing a supply only in the shed.

5. Effect of feeding supplementary feeds on forage intake of grazing cows

The feeding of supplementary feeds to grazing dairy cows may be carried out for a number of reasons. Concentrate feeds, of various types, will help to maximise milk yield whilst maintaining energy balance and animal health, whilst supplementary forages may help to maintain intake and milk production during periods when herbage availability is limited e.g. in early spring. The optimum combination of grazed herbage, supplementary forage and concentrate supplement is a complex issue depending on many factors including herbage quality and availability, quality of conserved forage, type and cost of available concentrate and genetic potential of the cows.

Well-managed grazed herbage has a high potential feed value and can support moderate daily milk yields without concentrate supplementation. For example, Delaby et al (2003) have reported average milk yields of 22 to 24 kg/cow/day in the first half of the season and 20 to 22kg/cow/day averaged over the whole season, from Holstein and Normande cows receiving no concentrate supplementation. Wilkins et al (1994) recorded an average milk yield of 25.4 kg/cow/day without concentrate supplementation, on swards with a high clover content (20% clover in the DM at the start of the experiment). With high genetic merit Holsteins, even a milk yield of 30 kg/cow/day has been reported, without concentrate supplementation (Kennedy et al, 2003a). On the other hand, Kolver and Muller (1998) concluded that, with high producing Holstein cows, although they achieved a daily intake of 19 kg of grass DM on spring pasture, significant mobilization of energy reserves was necessary for these animals to produce milk yields of 30 kg/day. In order to achieve higher milk yields than this, therefore, supplemental energy would be required. In comparison, in the same experiment, cows of similar genetic merit on a total mixed ration produced an average milk yield of 44.1 kg/day.

Where supplementary feeds are available in addition to the grazed pasture, the challenge for the farmer is to minimise the substitution rate (i.e. the reduction in pasture DMI per kilogram of supplementary feed consumed) in order that the grazed herbage, which is usually the cheapest feed, is used to its maximum whilst milk yield per cow is not restricted. There is also a negative relationship between substitution rate and milk response to supplementary feed; the lower the substitution rate the higher the milk response to supplements (Bargo et al, 2003).

Substitution rate tends to be lower when the overall energy balance of the animal is sub-optimal (Faverdin et al, 1991; Coulon and Rémond, 1991). At relatively high levels of daily herbage allowance (20 to 40 kg DM/cow/day), the substitution rate tends to be less at the lower than at the higher end of this range (Pérez-Prieto et al, 2011; Meijs and Hoekstra, 1984; Bargo et al, 2002). However, at lower levels of DHA (i.e. in the range 12-20 kg/cow/day), with high producing Holstein-Friesian cows in early lactation, Delaby et al (2001) found no interaction between substitution rate and DHA, up to a concentrate rate of 6kg/cow/day. Gibbs et al (2002a), with Holstein-Friesians on continuously grazed swards maintained at 8cm sward height, also found no substitution of grazed herbage for concentrate, up to a concentrate rate of 8kg/cow/day. In these latter situations, the shortfall in energy supply from grazing alone was substantial and concentrate input significantly improved the energy balance of the animals without significantly affecting herbage DMI, resulting in improvements in milk yield, milk protein content and live weight. Burke et al (2008) also observed a large response in milk production to supplementing cows on a restricted grass allowance (15 and 20 kg DM/cow/day).

The milk yield response to concentrate supplementation is dependent on, amongst other things the potential milk yield of the cow. The response also tends to be higher in situations where herbage allowance is restricted or grass height is low. With cows of low to moderate milk yield potential, the response may be in the range 0.4 to 0.6 kg milk/kg concentrate DM. However, with cows of high genetic merit, milk yield increases linearly as the amount of concentrate increases from 1.2 to 10 kg DM/day, with an overall milk response of 1 kg milk/kg concentrate (Bargo et al, 2003; Delaby et al, 2001). Reviewing this topic in 2003, Bargo et al (2003) concluded that, compared with pasture-only diets, increasing the amount of concentrate supplementation up to 10 kg DM/day increased total DMI by 24%, milk production by 22%, and milk protein percentage by 4%, but reduced milk fat percentage 6%.

Sayers et al (2003) and Wilson et al (2001) found no difference between starch-based or fibre-based concentrates in terms of their influence on herbage DMI, milk yield or milk fat content. Morrison and Patterson (2007) also found no difference in herbage intake, milk yield, milk composition or yield of milk components between rapidly degradable concentrate or slowly degradable concentrate supplements. However, Stakelum and Dillon (2003) did find that fibrous concentrates (beet pulp) had a less depressing effect on herbage intake than a starchy concentrate (barley). Gibbs et al (2002b) also found that, compared with a standard 18% crude protein dairy concentrate, a high starch concentrate reduced total eating time, grazing jaw movements and daily herbage intake. In this case the time taken to eat the starch-based concentrate reduced the time that could be spent grazing.

In relation to the protein level in supplementary concentrates, Delaby et al (1995) reported a positive response in milk yield (1.2 to 2.2 kg/day) and protein yield from high yielding cows fed a high crude protein (CP) concentrate (protected soya bean meal based) compared with a low CP concentrate (cereal based). However, Burke et al (2008) found that cows offered low CP supplements had similar levels of production to those offered high CP supplements and, in a review of the literature, Beever et al (2001) concluded that under feeding of protein was rarely a problem in the diet of grazed cows and that there was no advantage to feeding high protein concentrate.

Supplementation of grazing dairy cows with conserved forages (e.g. grass silage, maize silage or hay) is normally undertaken to maintain DMI and milk production at times when the supply of grazed herbage is limiting (e.g. in drought conditions or early or late in the season) (Phillips and Leaver, 1986; Roberts and Leaver, 1986; Delaby et al, 2003) or to increase milk output per hectare by increasing stocking rate, rather than specifically to increase milk yield per cow relative to that which could be achieved under grazing alone. The integration of silage with early spring grazing was discussed earlier in Section 4.5 on extending the grazing season.

The response to feeding supplementary forages in terms of animal performance depends on the relative quality of the silage and the grazed herbage. Ferris (2007) reported inconsistent effects on milk yield from two experiments in which partial storage feeding (grass silage fed overnight) was compared with full-time grazing. A positive response in DMI and milk yield was obtained where grazing conditions were difficult and silage quality was good, whereas a negative response was obtained where grazing conditions were good but silage quality was moderate. The same effect of silage quality was shown by Mould (1992). For cows yielding 27 kg/d, it was found that offering high quality silage led to an increase in milk yield with lower fat content, but with poor quality silage, there was insufficient time to make up the nutritional difference by grazing, and therefore milk yield dropped for both high yielding (27 kg/d) and low yielding (20 kg/d). A similar result was obtained by Reis and Combs (2000) when feeding supplementary hay to grazing cows; DMI of grazed herbage was reduced by feeding hay, but neither total DMI nor milk yield were improved. Phillips and Leaver (1986) also found that grazing time was reduced by offering forage, particularly at the high levels of forage intake when cows were housed overnight.

Maize silage has a higher substitution rate than grass silage when fed as a supplementary feed to grazing cows. For example, Morrison and Patterson (2007) found that although the consumption of maize silage was higher than that of grass or whole-crop wheat silage when fed as buffer feeds after morning milking, the DM intake of grazed herbage was significantly lower in the cows on maize silage, so that there was no significant difference in total DM intake. Holden et al (1995) also reported no impact of supplementary maize silage on total DMI or on milk yield per cow. These latter authors did, however, find lower blood urea-N content in cows fed maize silage, so feeding maize silage in summer may be a useful way of reducing urinary N output in cows on very clover dominated swards.

6. Relationship between class of animal (cow breed, genetic potential, age and stage of lactation) and forage intake

The genetic potential of dairy cows for milk production, particularly in the Holstein-Friesian (HF) breed, has increased significantly over the last 20 years, to the extent that questions have been raised about the suitability of these high producing animals for grazing-based systems. There has been a considerable amount of research investigating the interaction between cow genetic potential and feeding system. These studies consistently show that cows with the highest milk yield potential tend to exhibit the highest DMI of grazed herbage and the highest daily milk yield per head (Buckley et al, 2000a, 2000b; O'Connell et al, 2000; Horan et al, 2006; Linnane et al, 2004; Kennedy et al, 2003a; McCarthy et al, 2007). The above studies were all undertaken with different strains of HF cows. The research also shows that cows with the highest milk yield potential also usually produce the highest yield of fat and protein, although the fat and protein concentrations tend to be higher in the lower genetic merit cows.

When different breeds have been compared, the HF consistently has the highest herbage DMI and milk yield per head, e.g. HF vs Jersey (Aikman et al, 2008); HF vs Jersey vs Jersey X HF cross (Prendiville et al, 2010); Dutch HF vs Irish HF vs French Montbeliarde vs French Normande (Dillon et al, 2003); HF vs Normande (Delaby et al, 2009).

However, this high level of intake and performance in high yielding HF cows is also associated with significant negative energy balance in early lactation, resulting in greater loss of live weight and body condition score and lower conception rates to first and second services, compared to lower yielding strains, breeds and crosses of cow. For example, Buckley et al (2000a), comparing groups of HF cows of different genetic merit (pedigree index), found that condition score, conception to first and second services, and pregnancy rate were significantly negatively correlated with pedigree index. Delaby et al (2009) also found that HF cows, despite being well fed and producing more milk, had a lower rate of success at first service and a 10% lower pregnancy rate than Normande cows. In the study by Dillon et al (2003), Dutch HF cows had significantly lower live-weight gain from weeks 12 to 40 of lactation than Irish HF, Montbeliarde and Normande cows. Both HF strains had lower body condition score at all stages of lactation than the Montbeliarde and Normande. It seems, therefore, that the high milk production of high genetic merit HF cows is achieved through greater mobilisation of body reserves in early lactation and lower live weight gain from mid- to end of lactation.

On the other hand, Vance and Ferris (2011a) compared Jersey X HF crossbred cows with HF cows and found that the HF cows exhibited similar levels of tissue mobilisation and deposition throughout the lactation to the Jersey X HF cows. Despite this, however, the Jersey X HF had significantly better fertility performance. The Jersey X HF cows had fewer days to first observed heat (8.8 days earlier), a higher conception rate to first service (23% higher), first plus second service (29% higher), and a higher pregnancy rate at the end of the breeding season (16%). Milk yield was higher with HF cows but genotype had no effect on fat plus protein yield since milk fat and milk protein content were highest with the Jersey X

HF cows. These authors suggested that hybrid vigour may have been a significant contributor to the improved fertility performance observed with the Jersey X HF cows.

The metabolic challenges on high yielding HF cows were also illustrated by Kennedy et al (2003b) when they observed high and medium genetic merit HF cows, at three different levels of concentrate supplementation, in their first and second lactations. These authors found that, although genotype had no significant effects on overall reproductive performance, there was a significant difference between year 2 and year 1. The cows had a significantly higher milk yield at first insemination in year 2 than in year 1 (36.9 v. 32.3 kg/cow/day) but reproductive performance was significantly reduced. Comparing year 2 to year 1, pregnancy rate to first service (37 v. 64%), pregnancy rate to first and second service (64 v. 81%) and overall pregnancy rate (78 v. 92%) were lower. In year 2 cows had significantly higher DM intake (20.6 v. 17.3 kg DM/cow/day) but greater live-weight losses from calving to first insemination (-86 v. -53 kg/cow), lower live-weight gain in the 90 days after their first insemination (+ 24.6 v. + 34.2 kg/cow), and lower plasma glucose concentrations (3.18 v. 3.61 mmol/l) than in year 1.

The basis for the higher DMI per cow per day in HF cows appears to be primarily a higher grass dry matter intake per bite and rate of intake per minute, as shown by Prendiville et al (2010) in their comparison of HF with Jersey and Jersey X HF cows. No differences were observed among the breeds in this study for grazing time, number of grazing bouts, grazing bout duration, and total number of bites. O'Connell et al (2000), comparing different strains of HF cows, also found no difference in total grazing time but found that high genetic merit cows had a higher biting rate and more grazing bouts of shorter duration than medium genetic merit cows. The study by Linnane et al (2004) comparing three strains of HF cows in three grazing systems showed no significant effect of strain on grazing time or the number of grazing bouts. In contrast, McCarthy et al (2007) who compared three different strains of HF, found that the New Zealand strain had a longer grazing time than a high production North American strain and a high durability North American strain.

Although herbage DMI and milk yield per head is consistently higher in high genetic merit HF cows, when compared per unit of body weight, a slightly different picture emerges. Prendiville et al (2010) found that on a per kilogram of body weight basis, the Jersey cows in their study exhibited a more aggressive grazing aptitude compared with the HF cows, denoted by large differences in bite rate, intake rate, and increased grazing time. This contrasted with the results of Aikman et al (2008) who concluded that, although feed passed through the digestive tract more quickly in Jerseys compared with Holsteins, the intake capacity of Jerseys was no greater than that of HF cows. However, this is perhaps not surprising since in this study the animals were selected on the basis of equal expected milk energy yield per kilogram of metabolic weight. In fact, Vance and Ferris (2011) found that Jersey X HF crossbred cows, whilst having a similar herbage DMI per head per day to purebred HF cows, did have a higher herbage DMI per kilogram of metabolic live weight (resulting from a longer grazing time and higher number of bites per day). This higher DMI per kg of metabolic live weight suggested a higher intake capacity and an improvement in overall efficiency, with a potential energy saving associated with the lower maintenance requirement of the lighter crossbred cows.

The effect of parity and the number of days in milk (DIM) on DMI and milk yield in spring calving HF cows was examined by McEvoy et al (2009), who were attempting to develop equations to predict DMI and milk yield for grass based systems. They used a dataset containing 335 observations from 134 HF dairy cows from two early lactation grazing studies. Total DMI increased with parity and DIM and ranged from 13.4 kg/cow/day (primiparous animals < 50 DIM) to 20.1 kg/cow per day (multiparous animals > 50 DIM). Actual milk yield increased with parity and decreased with DIM (range: 24.1 kg/cow/day (primiparous animals > 50 DIM) to 33.0 kg/cow/day (multiparous animals < 50 DIM)). Predictor variables which had a significant effect on grass DMI, total DMI and milk yield included body weight, body condition score, potential milk yield, DIM, daily herbage allowance (DHA > 4 cm), concentrate level and parity. The equations developed in this study accounted for 79%, 83% and 86% of the variation in grass DMI, total DMI and milk yield, respectively.

7. Key messages

Herbage legumes have a higher feed value than grasses, but their main benefit to livestock is from enhanced intake. Animal performance benefits reach a maximum when clover content is around 60% of the DM in the diet. Although this level may be possible in silage crops and in grazed grass/white clover swards for a short period in mid-late summer, it is difficult to maintain across the whole grazing season. From a whole farm perspective, however, clovers afford significant potential savings in fertiliser costs. The use of large-leaved white clover varieties with taller growth could be used to overcome reduced intake rates.

There is some evidence that cows show a preference for tetraploid over diploid perennial ryegrasses but variety maturity date had a greater effect on grass DMI and milk production. Later heading varieties, by virtue of their morphology (higher tiller density and leaf to stem ratio than early and intermediate heading varieties), resulted in higher grass DMI and milk production. Research to find early ryegrass varieties with similar morphology, coupled with extended grazing management, would potentially help to reduce costs significantly.

There is little evidence that perennial ryegrass varieties with a high sugar content have a significant effect on grass DMI and milk production. This is only likely to occur in situations where there is a deficiency of metabolisable protein.

Increasing N fertiliser application causes a reduction in herbage DM content, which in theory could adversely affect grass DMI, but there is little research evidence of this. The main issue with high levels of N fertiliser application is diffuse pollution – reduced efficiency of N use in the cow, increased urinary N excretion and increased N surplus per hectare.

Application of sodium to pasture can improve herbage DMI and milk production, particularly in cows of low production potential. More research should be carried out to determine more accurately the extent to which sodium can be used as a replacement for potassium fertiliser, given the problems of mineral imbalances which excess potassium can cause.

Slurry application to grass for grazing should be carried out by injection or trailing shoe rather than by surface spreading, since herbage DMI is reduced substantially (circa 30% nine weeks after application) after surface spreading.

In terms of the mechanics of grazing, herbage DMI is a function of average bite size, the number of bites per minute and the length of time available for grazing. The first two of these are related to herbage availability. Thus sward height, which can be equated with herbage mass, has a very major impact on herbage DMI, and is an essential tool for grassland planning, budgeting and dairy cow rationing. Increasing sward height results in higher milk yield per cow. However, there is a conflict between maximising individual cow performance and maximising milk output per hectare (or stocking rate).

The limitation of grass height alone as a tool for grazing management is that it does not take account of the number of grazing animals. However, translating grass height measurements into an estimate of herbage mass per hectare and relating this to stock number permits an estimate to be made of DHA per cow. The importance of DHA as a factor determining herbage DMI and milk production is well illustrated in the literature. For spring calving cows, the literature suggests an optimum DHA of 13 to 15 kg DM/cow in early spring (supplemented with approximately 3 kg DM/cow of concentrate) and 20 kg DM/cow during the main grazing season.

Whilst increasing sward height, herbage mass and total DHA may result in higher milk yield per cow, efficiency of sward utilisation is poorer. If sward heights are too high and stocking rates too low in the early part of the growing season, the ratio of leaf to stem in the sward falls and sward quality (e.g. digestibility, leaf bulk density) later in the season suffers. The important factor in promoting herbage DMI and milk production is the DHA of green leaf dry matter, not the DHA of total herbage DM. There is consistent evidence that green leaf mass is optimised in low rather than high mass swards. (e.g. 1600 kg DM/ha rather than 2400 kg DM/ha). A high grazing intensity (stocking rate) is required in spring to create such high quality swards.

Extending the grazing season in autumn or early spring has considerable potential for reducing cost of production, through savings in silage consumption. Grazing for as little as two hours per day can increase yield of milk and milk constituents. With high yielding cows, extended grazing from mid-February (in Ireland) should be based on a relatively low DHA of 13 to 15 kg DM/ha plus 3 to 4 kg DM concentrate. This both maintained milk yield and a high level of sward quality later in the season.

Bite mass and biting rate tend to be highest in the afternoon. There is some evidence that providing a fresh paddock at this time of day increases grass DMI.

Well-managed grazed herbage, unsupplemented, can support average milk yields per cow of 20-22kg/day over the whole season. With high yielding cows milk yields of up to 30kg/day are possible without supplementation, but only over a short period and by mobilising significant levels of energy reserves. With this type of cow, in order to achieve a satisfactory combination of high milk yield per cow, even with good sward utilisation and high levels of output per hectare, concentrate supplementation is required from turnout. Substitution rate of concentrate for grazed herbage is low at low levels of DHA (13 to 15 kg DM/cow), for example in early spring.

There is no benefit in terms of animal performance to feeding a forage supplement (e.g. silage), unless grazing conditions are poor and silage quality is good as it can reduce grazing efficiency.

The research shows consistently that cows with the highest genetic potential for milk production tend to exhibit the highest grass DMI (and milk yield). This is true within the Holstein-Friesian (HF) breed and in comparisons between HF and other breeds. However, there is clear evidence that this production advantage is associated with greater loss of live weight and body condition score, and poorer fertility performance. Jersey X HF crossbred cows produce lower milk yields but the same fat plus protein yield as HF cows and have significantly better fertility performance. These crossbred cows also had a higher herbage DMI per kg metabolic weight than HF, suggesting a higher overall efficiency.

Variables which have a significant effect on grass DMI, total DMI and milk yield include body weight, body condition score, potential milk yield, days in milk, DHA (above 4cm), concentrate level and parity.

AHDB DAIRY

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