

Sward Factors Influence on Pasture Dry Matter Intake of Grazing Dairy Cows: A Review

Review Article

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ABSTRACT

Successful pasture-based milk production systems pivot on balancing dairy cows' feed requirements with seasonal and annual fluctuations in pasture production. In order to maximise cow production from grazing dairy systems, it is necessary to reach an efficient utilization of grazed grass for feeding cows and the development of appropriate grazing management systems designed to maximize daily pasture dry matter intake (PDMI) per cow and per hectare, while maintaining high sward quality over the grazing season by keeping high pasture levels of crude protein, water soluble carbohydrates and digestibility of organic matter and low levels of acid and neutral detergent fibers in the swards. To maximize PDMI, cows need to consume plants that have characteristics that allow rapid consumption and lead to fast rates of passage through the rumen. This review considers the role of sward factors which affect the short-term feed budget of cows at pasture and, therefore, condition cow feed requirements at grazing and influence on PDMI. Furthermore, it highlights the relevance that have for the development of pasture-based milk production systems the study of the species of grasses and / or legumes that integrate the pastures, the changes on sward structure, the seasonality in grass production, the pasture chemical constituents, the sward botanical composition, the grass feeding value, the digestibility of pastures, the intensity of sward defoliation, and the importance of sward height and herbage mass in relation to maximizing PDMI. The amount of herbage consumed is the major determinant of cow production but it is yet one of the most difficult aspects of forage quality to predict. In this review, three methods for PDMI calculation are presented as faecal output/diet digestibility method, sward difference method and the grazing-behaviour method. Also, three equations for PDMI estimation are described considering different sward and animal variables.

KEY WORDS defoliation frequency and intensity, grazing dairy cattle, grass feeding value, grass / legume species, sward characteristics, pasture dry matter intake.

INTRODUCTION

Pastures for milk production systems in humid areas

During the past decades high milk prices have encouraged milk production systems worldwide to use high inputs of chemical fertilizers, supplemented feeds (such as silage and/or concentrate) and mechanized methods for forage conservation at the expense of reducing grazing grass (Peyraud *et al.* 2004) as the most suitable way to decrease the feeding costs of milk production (Dillon *et al.* 2005). A

tendency to maintain dairy cattle in a very high level of intensification has been observed in many European dairy farms due to the good relationship of milk price relative to concentrate (Peyraud and González-Rodríguez, 2000). Nevertheless, the abolition of European Union milk quotas by 2015 and the possibility of a drop in milk prices due to fluctuations in international dairy markets may be important factors that condition the future of milk production in humid areas (Roca-Fernández, 2011). In addition, it is predicted that an increase in the competitiveness between and

within countries and the changing of economic and politic environmental policies will occur. This new scenario leads to *an increased emphasis on production efficiency per animal* (cow) and *per unit of land* (hectare) (Dillon, 2006) looking for an efficient conversion of grass into milk. For this, it is necessary to have a better knowledge of the important role that sward factors play on pasture dry matter intake (PDMI) of grazing dairy cows.

Grass and legume species

The prevalence of grass and legume species used in intensive pasture-based milk production systems varies throughout countries. This is mainly due to differences in soil and environmental conditions. Some of the most common grass and legume species used in grazing dairy cattle systems are described above.

Perennial ryegrass

It is the most widely sown grass in temperate regions. It shows rapid establishment from seed and strong tillering to produce a dense sward that withstands grazing, and responds well to fertile conditions and inputs of nitrogen (N). When regularly utilized in medium to high input strategies, the yield of dry matter (DM) and the nutritive value are usually higher than for other grass species. Significant advances have been made in breeding varieties, classified according to heading date as early, intermediate or late. Maximum growth rate is reached during the reproductive phase and so early heading varieties can reach their maximum 4 to 6 weeks earlier than the latest varieties in the late heading group and post-flowering depression is usually more pronounced than for the late heading types (Laidlaw, 2005). Gowen *et al.* (2003) obtained higher DM intake and milk production from the late heading compared to the early heading perennial ryegrass cultivars when cows were stocked to allow adequate feed. Perennial ryegrass does not thrive under very dry conditions or on infertile soils, when it rapidly becomes stemmy and poorly tillered. In countries with the severe winter weather associated with continental climates (i.e. central Europe and North America), the crop may not survive and other grasses must be grown which show greater winter-hardiness. Tetraploid varieties of perennial ryegrass have been bred which tend to be slightly higher yielding and more digestible, with higher sugar and water contents, and also good intake characteristics (Hageman *et al.* 1993). Their seed size is nearly double that of the diploid varieties and their development is regarded as a major advance in grass breeding (Camlin, 1997). However, they have fewer, larger tillers than diploids, leading to more open swards and possible weed ingress. Nevertheless, the lower tiller density can give greater compatibility with white clover.

Italian ryegrass

It is the second most sown grass species in humid areas and establishes vigorously. It is most productive in the first year after sowing, producing heavy crops with numerous upright fertile tillers, and responding well in intensive systems with high inputs of N. Spring growth starts rather earlier than in perennial ryegrass, so after an early grazing, large crops of good quality can be cut for silage. The second cut must be taken no longer than four weeks after the first, as heading is very rapid in the second crop and quality falls accordingly (Corrall *et al.* 1979). Autumn growths may be grazed to lessen winter damage because, except in the seedling stage, the crop is less winter-hardy than perennial ryegrass.

Hybrid ryegrasses

These grasses species have been bred in an attempt to combine the productivity of Italian ryegrass with the greater longevity of the perennial forms. Most varieties are tetraploids and resemble the Italian parent more than the perennial. Despite breeders' improvements to overcome these limitations, they are only regarded as alternatives to Italian ryegrass and they have a place in medium-term leys for intensive pasture-based milk production systems.

White Clover

It is the most important legume in temperate areas. It is a perennial plant with small seeds that are best broadcast on the soil surface. It is always grown in association with grass. Its creeping stolons extend leaves into the sward canopy. The tap-rooted seedling plant eventually dies, leaving many independently rooted daughter plants developed from the nodes on the stolons. Classification of varieties is based on its leaf size. Small-leaved varieties have thin, highly branched stolons, and are productive and persistent in short swards under sheep grazing. Medium-leaved varieties are typical general purpose varieties. Large-leaved varieties have thick, less branched stolons; they can withstand N inputs better than other varieties, and are suited to milk production systems as they will also withstand grazing integrated with cutting. Cutting a drop for silage in early summer before the grass tillers have elongated sufficiently to over-top the clover's leaves will enhance the clover content of the swards.

Red clover

It is a less common legume and it may be drilled as a pure stand or more usually with a companion grass (usually an intermediate, tetraploid perennial ryegrass but timothy or meadow fescue are also alternatives), and it forms a two-year crop for silage with some autumn grazing (Frame, 1990). It can successfully be strip-seeded into an existing grass base (Haggar and Koch, 1983). Red clover has de-

clined in use because of the trend to longer-term swards, its sensitivity to increased cutting frequency (Sheldrick *et al.* 1986) and the susceptibility of popular tetraploid varieties to necrotic mosaic virus.

Animal production from grazed pastures can be improved through increased use of grass-legume mixtures with higher pasture dry matter intake (PDMI) and digestibility than species alone. N fixation by legumes is the driving force behind low input milk production systems of grassland farming, particularly where economic returns cannot justify reliance on N fertilizers or where their use is prohibited, i.e. in organic farming. In the mixed swards, legumes contribute to the crop yield and also provide N for the benefit of the associated grasses. Traditionally, plant breeding objectives were focused on increasing DM yield and pesticides and disease resistance, with little emphasis on sward factors that affect animal performance and PDMI such as grass-legume mixtures feeding value to know its capacity to satisfy animal requirements.

Digestibility varies between grass and legume species and it is considered as an important parameter to take into account for sustainable pasture-based milk production systems. Wales *et al.* (2005) suggested that the use of techniques to genetically modify plants will enable in the future the development of plants with elevated concentration of ruminal undegradable dietary protein and high energy-yielding compounds. Another major objective of grass breeding is to increase the length of the grass growing season. Using grass-clover mixtures will offer the possibility to extend the herbage growth season. Characteristics within-season growth pattern favour the grasses in spring, during reproductive growth, and the legumes in summer when temperatures are high (Lüscher *et al.* 2005).

Sward botanical composition

The botanical composition of a sward is largely a reflection of the mixture of species that were initially sown, together with such weed species that have gained entry during the establishment phase.

As the sward ages, its evolving composition becomes more dependent on the various climatic and environmental influences and that site, and on the grassland management imposed.

Vegetative expansion of successful sward components, germination and establishment from seed ensures that gaps are filled with those species or ecotypes that can best survive in the particular circumstances. Such a succession from the sown species (predominantly perennial ryegrass) to unsown (and usually less preferred), together with an increase in the range of dicotyledonous (broad-leaved) species, has been described as sward deterioration (Charles and Haggart, 1979). Nevertheless, this is arguably a pejorative

term for an entirely natural ecological progression towards a species composition adapted to the environment.

Seasonality in grass production

The requirement for feed in ruminants does not usually correspond to forage availability as outlined the grass growth curves. Therefore, systems have had to be developed with which: 1) reduce demand for feed by adapting the animal production system to meeting the limitations in supply of fresh herbage from a given area, i.e. manipulation of the reproductive cycle of the livestock or 2) require non-forages (such as grains of arable crop by products) to be fed or 3) require forages which grow during the gap in normal grass growth to be included or 4) retain excess herbage at times of oversupply to be fed during gaps (in this case, herbage or forage can be retained either by conservation or by deferring its use for grazing) or 5) manipulating the growth curve, i.e. by fertilizer N use to reduce imbalances in forage supply. Often, more than one of these strategies is adopted within the one system to synchronize forage supply and demand. Of all of these strategies, conservation of grass for silage or hay is the most adopted method to reduce seasonality throughout most of temperate regions.

Pasture chemical constituents

Herbage dry matter (DM) content

The DM content of the herbage on offer can have an effect on pasture dry matter intake (PDMI). John and Ulyatt (1987) found that increasing the DM content of the herbage can improve voluntary dry matter intake (VDMI). High water content is mentioned as a factor regulating DM intake in fresh forages (Forbes, 1995). In a pasture-based diet, the nutrient content will be diluted by the presence of water, which can vary from 85% in the early spring to 75% mid-summer.

The VDMI of cows fed grass, increases as the internal water content of grass decreases, but remains unaffected by external water present on the grass (Cabrera-Estrada *et al.* 2004). Surface water would be swallowed quickly during eating without being chewed with the remainder of the bolus (Cabrera-Estrada *et al.* 2003), as observed during rumination. Plant internal water cannot be swallowed immediately and it must be masticated, which probably limits DM eating rate. On average, PDMI increases by 134 g per percentage unit DM content in grass over the range from 12% to 30% of DM. Butris and Phillips (1987) have contrasting conclusions and they found that water external to the plant affected the daily eating time and VDMI of steers. Verité and Journet (1970) considered the threshold at which forage water content limits VDMI is between 150 and 180 g/kg DM with an estimated depression of 0.34 kg DM intake for each 10 g/kg decline in DM below this level. These authors

suggested that this was due to predominantly intracellular water which causes a bulk effect on the rumen. [Peyraud et al. \(1996a\)](#) hypothesized that the greater dilution of DM in fresh material may also decrease the rate of PDMI. In addition to the effect of internal water content, the herbage surface water might reduce the palatability of the herbage.

Crude protein (CP)

The CP content is associated with the leafiness of the plant, i.e. a high proportion of nutritionally desirable chloroplast protein ([Wheeler and Corbett, 1989](#)). [Mangan \(1982\)](#) classified plants CP in *three main groups*: fraction I (leaf protein), fraction II and chloroplast membrane proteins. Fraction I is composed of chloroplasts which contain about 75% of the total leaf protein and of this, about 50% is a single soluble protein (ribulose-1, 5-bisphosphate carboxylase). [Mangan \(1982\)](#) reported mean values for Fraction I of 5.3, 3.9 and 0.9% for alfalfa (*Medicago sativa*), red clover (*Trifolium pratensis*) and orchardgrass (*Dactylis glomerata*), respectively. On average, 70% of the true protein in cool season forage plants can be accounted for by Fraction I. Furthermore, Fraction I protein is similar across plant species (i.e. grasses and legumes) and it is rapidly degraded in the rumen. Fraction II constitutes about 25% of total leaf protein and it is derived both from chloroplasts and the cytoplasm. In contrast to Fraction I, this is a complex mixture, which may have a low rate of proteolysis and could result in a high proportion passing through the rumen undegraded ([Thomson, 1982](#)). The third fraction is constituted of chloroplast membrane proteins and constitutes about 40% of the chloroplast protein ([Mangan, 1982](#)). The chloroplast membrane protein can be divided into two main chlorophyll-protein complexes, chlorophyll-protein complex I and chlorophyll-protein complex II, which account for 28 and 49% of the membrane protein, respectively. These chlorophyll-protein complexes appear to be slowly degraded in the rumen.

Cell walls contain a cell wall associated protein called extensin due to their role in fibre cross-linking. This protein is less soluble than leaf proteins and is recovered in neutral detergent fibre (NDF). Extensins are covalently linked to polysaccharides associated with the plant cell wall, which may account for their insolubility ([Van Soest, 1994b](#)). Although the concentration of N in cell walls is lower in grasses than in legumes (129 vs. 170 g/kg DM of CP) ([Minson, 1990a](#)), N in cell walls accounts for a higher proportion of total N in grass than in legume leaves because of the higher cell wall concentration in grass than in legumes ([Buxton et al. 1996](#)). [Sanderson and Wedin \(1989\)](#) reported N concentrations in leaf cell walls of alfalfa and red clover to be 9.8 and 26.4 g/kg NDF and 4.2 and 4.6 g/kg NDF for stems, respectively.

Proteins can also be classified according to their nutritional characteristics into soluble protein, rumen degradable protein and rumen undegradable protein. Most of the CP of fresh forage is degraded in the rumen, with only 25% (on average) CP passing unchanged into the small intestine ([Minson, 1990c](#)). Dietary protein degraded in the rumen can be used very inefficiently if sufficient energy is not available to microbes to allow it to be incorporated into microbial protein ([Jarrige, 1989](#)). Thus, the rumen available energy determines the amount of degraded protein which can be utilised in the rumen with the excess being excreted in the urine. Once the limit for degraded protein use is reached, the only way for extra dietary protein to be utilized by the animal is if it by-passes the rumen and it is digested in the small intestine. One way to increase the amount of degraded protein that can be used in the rumen is to increase the soluble carbohydrate content of the herbage ([Moorby et al. 2006](#)).

Crude fibre

The cell wall of the plant has been traditionally defined in terms of the components that have been isolated from it. Some of them are described below.

Cellulose

It is the most abundant carbohydrate in the plant, but its amount or concentration is not a good measure of fibrousness or total fibre, although many nutritionists have used it for this purpose ([Van Soest, 1994c](#)). It has a highly variable nutritive availability depending on its association with lignin, silica, cutin and other factors ([Van Soest, 1985](#)). [Van Soest \(1971\)](#) reported average values for cellulose of 220, 229, and 187 g/kg DM for grasses, alfalfa and red clover.

Hemicellulose

It is a heterogeneous polysaccharide fraction largely existing in the secondary wall of the plant. It is more soluble in acids and bases than cellulose, but not more digestible ([Van Soest, 1985](#)). Digestibility of hemicelluloses is directly related with that of cellulose and inversely related to lignifications ([Van Soest, 1994c](#)).

These polysaccharides vary according to grazing season and plant stage of maturity. [Bailey \(1973\)](#) reported changes due to seasonal variations for ryegrass and orchardgrass of 12 to 20% for hemicelluloses and 14 to 28% for cellulose. He suggested that variations were due to increasing amounts of stem tissue. Little changes in the level of leaf and stem hemicellulose content occur in legumes during growth, however, a marked rise in stem cellulose usually results from increasing amounts of stem tissue ([Bailey, 1973](#)). Cool season grasses usually contain higher content of hemicelluloses than legumes.

Lignin

It is a non-carbohydrate polymer and it is often identified as limiting cell wall polysaccharide digestibility by ruminants (Buxton *et al.* 1996). Lignin is covalently bound to cell wall polysaccharides, but until recently little was known about the form of this cross-linkage (Jung, 1997). When the plant cell stops growing and initiates the maturation process, secondary wall deposition and lignifications begin. Lignin deposition begins in the primary wall and moves through the secondary wall. Lignin concentration is lower in grass cell walls than in legume cell walls, but it comprises up to 10% of DM in mature cool season grasses (Buxton *et al.* 1996).

From a nutritional stand point fibre carbohydrates can be measured by determining the NDF. The extraction of forages showed that NDF separated the potentially completely available matter from that which is insoluble or incompletely or partially digestible (Van Soest, 1993). Thus, NDF is consistent in representing the insoluble coarse fibre from forages that stimulates rumination and rumen function, which are vital to maintenance of the rumen ecosystem (Van Soest, 1993). Furthermore, the acid detergent fibre (ADF) was intended to isolate the components more resistant to digestion. In general, grasses contain higher levels of fibre (NDF) than legumes, confirmed by the NDF values reported by Polan (1997) and Rayburn (1994) on legume and grass pastures. Although this is true it does not mean that legumes are more digestible than grasses, since Buxton and Redfean (1997) demonstrated that legume fibre is more lignified and less digestible than that of grasses. Therefore, the reason why typically legumes are more digestible than grasses is because they contain less fibre (NDF), not because legume fibre is more digestible (Buxton and Redfean, 1997). Buxton *et al.* (1996) determined that depending on maturity, ruminants will digest 40-50% of NDF in legumes and 60-70% in cool season grasses.

Lignin concentrations have been used to predict digestibility *in vitro* of organic matter (IVODM) with a correlation coefficient of -0.97 (Morrison, 1980) and it is, therefore, considered that lignin concentration and digestibility are closely related. Work by Minson (1982) has confirmed that digestibility is negatively correlated with the crude fibre (CF) concentration in several forages including grasses. Variation does exist between grass species with temperate grasses generally having a higher VDMI than tropical grass species, which is associated with a lower level of fibre and higher digestibility of DM (Minson, 1990a). In a study carried out with five tropical grasses, the VDMI of leaf fractions declined from 69 to 52 g/kg over 37 days while the corresponding decrease in VDMI of the stem fraction declined from 49 to 35 g/kg (Laredo and Minson, 1973). This decrease in VDMI was associated with increases in lignin,

grinding energy, and the time leaf and stem were retained in the rumen. Differences among varieties of temperate grasses for DM digestibility tend to be greater when the digestibility of the fibre is at its lowest during mid- and late summer, than in spring and autumn when DM digestibility is greater (Wilkins, 1997).

Water soluble carbohydrates (WSC)

Non-structural carbohydrates are composed of WSC, fructans, starch, and pectins that are rapidly and completely digested in the rumen and, therefore, they are readily available sources of energy to ruminant animals. The latter are part of the cell wall structure, but are also rapidly and extensively degraded in the rumen (Hall, 1994). The WSC represent the more rapidly digestible part of the non-soluble carbohydrates of the plant. This fraction includes glucose, fructose, sucrose and trace amounts of melibiose, raffinose and stachyose (Smith, 1973). On average, glucose and fructose occur in about a 1:1 ratio and in a magnitude of 1 to 3% of forage DM. Sucrose occurs in larger amounts than the monomers, in the order of 2 to 8% DM (Smith, 1973). This author reported values of sucrose of 2.8 and 5.2% of DM when orchardgrass and ryegrass, reached a height of 20-25 cm respectively. Fructosans are fructose polymers that contain a terminal glucose residue (Smith, 1973) and are the main storage carbohydrates in leaves and stems of temperate grasses (0.6-5.4% of herbage DM). They do not occur in legumes where sucrose and starch are the main reserve carbohydrates (Van Soest, 1985).

Starch is the primary non-structural polysaccharide in species of the Leguminosae (Smith, 1973). Smith (1973) reported values of starch of 8.7, 8.6 and 7.4% DM during the vegetative stage of alfalfa, red clover and white clover, respectively and showed that amylopectin was the predominant starch found in alfalfa leaflets. Pectin, although a constituent of the plant cell wall, is a soluble carbohydrate (Hall, 1994). This polysaccharide has no bonding with lignin, even with increasing plant maturity (Hall, 1994), thus, it is dissolved in neutral detergent solutions. Grasses are low in pectin (2-5% DM) while legumes contain the highest quantities (6-14% DM) (Hall, 1994).

The WSC content of perennial ryegrass is a useful selection criterion for feeding ruminants; it reflects a balance between assimilation of carbon through photosynthesis and its use in plant growth and respiration (Humphreys, 1989). The WSC acts as a store of energy (Pollock, 1986) and it appears to be associated with tiller survival and sward persistency (Thomas and Norris, 1981) and it is a good indicator of regrowth after defoliation (Alberda, 1966).

Temperate grass species store WSC reserves in their tiller bases or stubble and then reserves are used to supply energy for continued growth and function when current energy

production is inadequate to meet demand following defoliation or during shading (White, 1973). A positive correlation between plant WSC concentrations before defoliation and subsequent regrowth after defoliation exists for perennial ryegrass (Donaghy and Fulkerson, 1997; Donaghy and Fulkerson, 1998).

Minerals

The mineral elements constitute some 10% of herbage DM. Soil is the primary source of supply of mineral elements to the plant, and as such, it is considered to be the main factor affecting mineral content in plants. Plant (genus, species, variety and stage of maturity), environmental (light, temperature and season) and management factors like fertilization will also affect mineral concentrations in pastures (Fleming, 1973; Mayland and Wilkinson, 1996). In general, at early growth stages there is a relatively rapid uptake of minerals.

As photosynthetic areas begin to increase, DM production outstrips mineral uptake with the result that, due to a natural dilution process, mineral contents decline (Fleming, 1973). The National Research Council (1989) (NRC) recognizes calcium (Ca), phosphorus (P), sodium (Na), chloride (Cl), potassium (K), magnesium (Mg) and sulfur (S) as the essential macro-minerals.

Calcium

Chronic Ca deficiency in ruminants fed grass is rare and never occurs in legume-based pastures (Minson, 1990d), with the exception of high producing cows (Buxton *et al.* 1996). Generally, cool season grasses contain less Ca than legumes.

Average Ca concentration from data obtained from Muller *et al.* (1995), Rayburn (1994), Fleming (1973), Powell *et al.* (1978), NRC (1989) and Minson (1990d) was of 4.9 and 15.8 g/kg of DM for grasses and legumes, respectively. As forage matures there is an increase in the proportion of stem, which contains less Ca than the leaf fraction (Minson, 1990d). Therefore, Ca concentrations will decrease as the plant matures.

Availability of Ca in feeds depends on the needs of the animal and it is rarely limited by a characteristic of the forage except where oxalate levels are high. Many of the estimates for availability quoted in the literature are of apparent availability. Apparent availability of 0.3 to 0.4 is commonly reported for Ca, P and Mg in herbage, but true availability (accounting for endogenous losses) are higher (Holmes, 1980a). Even when true availability is determined, the data require careful interpretation, as the availability of Ca is also influenced by level of intake and the values may only apply to the feeding conditions of the particular experiment (Butler and Jones, 1973).

Phosphorus

P in herbage appears to be more available than Ca (Butler and Jones, 1973). Unlike Ca, the quantity of dietary P absorbed from the upper small intestine is related to the quantity of P in the diet and it is not related to the need for P (Braithwaite, 1976). In contrast, NRC (1989) reported that absorption of P will vary with age of the animal, decreasing the efficiency at about 14 months of age. Thus, the estimated requirements are based on a decline in the availability of P from about 90% in calves to 55% in animals with body weight of over 400 kg. Typically grasses have lower contents of P compared to legumes (Rayburn, 1994; Muller *et al.* 1995). However, not only differences between species will determine mineral concentrations of P in plants, but also other factors like soil fertility influence this.

Magnesium and potassium

In general, legumes are appreciably higher in Mg concentration compared to grasses (Fleming, 1973; Grumes, 1983; McDowell, 1985; Minson, 1990e). Mg concentrations usually range from 1.5 to 3.1 and 3.0 to 5.5 g/kg in grasses and legumes, respectively. Recommendations on Mg requirements of different classes of livestock are complicated due to considerable uncertainty regarding the availability of Mg in the diet (Reid, 1983). Mg availability in pastures is lower than in concentrates and preserved forages (Reid, 1983; NRC, 1989).

In sharp contrast to most nutrients, net Mg absorption is lowest from young, highly succulent pastures and it increases with forage maturity (NRC, 1989). Thus, efficiencies of Mg absorption in forages range from 7-33 and 5-30% DM as reported by Reid (1983) and McDowell (1985), respectively. Under grazing situations where most of the animal's nutrients come from lush, highly fertilized pastures and for high producing lactating cows in early lactation, the suggested requirements range from 0.25 to 0.30% of the diet (NRC, 1989). Under these situations, the NRC recommended some supplemental Mg in a readily available form be provided, such as magnesium oxide (MgO). A deficiency of Mg can depress production in two ways: by an acute deficiency leading to *hypomagnesaemia tetany* or by a chronic subclinical deficiency like a decrease in milk production. However, the balance of other constituents such as K also influences the incidence of hypomagnesaemia (Butler and Jones, 1973).

K, like almost all nutrients in plants, decreases in content with maturity (McDowell, 1985). The NRC (1989) reported that young, lush forages in cool weather may be high in this mineral. This is true for good quality grass and mixed pastures. According to Ward (1966), the high levels of K appear to interfere with Mg metabolism and utilization, and are considered to be a factor in grass tetany. This is sup-

ported by several studies (Newton *et al.* 1972; Kemp, 1983; Poe *et al.* 1985; Minson, 1990e), where it was demonstrated that feeding high levels of K depressed absorption of Mg in the rumen stomach. Taking into account that minerals are abundant in pasture forages (with the exception of Mg), especially when legumes are present, a balanced mineral mixture fed as part of the supplement will probably meet nutritional needs of cattle.

Oligoelements

Although trace minerals comprise less than 0.01% of the total mass of an organism, many are essential for normal function (Fisher, 1975). A trace mineral is considered essential if its deficiency results in an impairment of function (Fisher, 1975; Underwood, 1979) or if its withdrawal from the body induces the same structural and physiological abnormalities regardless of species (Fisher, 1975). These abnormalities are accompanied by specific biochemical changes, which can be prevented or cured, once the deficiency is corrected (Underwood, 1979).

There are fifteen trace minerals considered essential in mammalian nutrition, such as: arsenic (As), chromium (Cr), cobalt (Co), copper (Cu), fluorine (F), iodine (I), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), selenium (Se), silicon (Si), tin (Ti), vanadium (V) and zinc (Zn) (Ullrey *et al.* 1977). These are classified according to their biological function. In enzymes, they act as a cofactor or as an essential part of enzyme structure. They maintain protein and nucleic acid stereochemical structure. They participate in ionic interactions affecting cell permeability and mineral matrix and also act as direct catalysts in the promotion of reactions.

The stage of plant maturity and method of forage handling influence the availability of trace elements to the animal. In immature pastures, Cu is not as available as in dried forages cut at the same stage of maturity (Horvath and Reid, 1980). As the plant matures there is a gradual decline in the trace mineral content, particularly in Cu and Zn. The type of cultivar can influence the trace mineral content (Gladstone and Loneragan, 1967). Some plants are known for their Se and Mo concentrating ability, while alfalfa and other legumes do not take up Se (Burk, 1978).

Cu deficiency

It occurs in cattle either as a primary or secondary problem. In a primary deficiency, there is a decreased level of Cu in the diet. In a secondary deficiency, there is a failure of Cu absorption or utilization caused by an imbalance or excess of other elements in the ration (Ullrey *et al.* 1977). During periods of rapid pasture growth, protein level and protein solubility are high, making the Cu in the forage less available (Underwood, 1977). Cu deficiency produces

clinical signs which are generally related to its role as a catalyst or as an essential component of various metallo enzymes or metal activated enzyme systems (Fisher, 1975).

Zn deficiency

It shows clinical signs in calves as a stiff gait, swelling of the hocks and knees, subcutaneous fluid accumulation and parakeratosis of the skin. Parakeratosis of the rumen epithelium, delayed wound healing, reduction in thymic size and defects in cell mediated immunity have also been described (Miller and Miller, 1960; Good *et al.* 1980). An autosomal recessive trait has been described in Holstein-Friesian breeds. It is a metabolic fault where there is a failure of intestinal absorption of Zn. The calves are stunted, lethargic and subject to skin disorders. In cows, the signs are parakeratosis around the dew claws and heel bulbs. This extends up the hock and between the legs. A dermatosis also develops at the base of the teats (Schwartz and Kirchgessner, 1975). Decreased fertility and abnormal estrus behavior has been also found in cows and retarded testicular growth in bulls (Miller, 1970; Underwood, 1977).

Se deficiency

Se is well recognized as an essential trace element, and its deficiency has been associated with impaired growth, fertility and health in farm livestock (Schwarz and Foltz, 1957; Weiss *et al.* 1990; Ferguson, 1996; Hansen and Deguchi, 1996; Koketsu and King, 1996). Failure of reproductive function and a high incidence of retained placentas have been associated with Se deficient rations (Harrison and Conrad, 1984; Ishack and Erickson, 1986). A Se level of 0.1 mg/kg of DM in the ration is considered satisfactory for growing animals (Underwood, 1977; Julien *et al.* 1979; Horvath and Reid, 1980). This can be achieved by: a) adding Se salts to the ration, the mineral mix or salt mix, b) parental administration of Se, or c) application of Se to the soil. In the EU only inorganic sources of Se, sodium selenate and sodium selenite, are currently approved as feed additives, with a maximal legal dose rate of 0.5 mg of Se/kg of DM. This value is higher than the limit of 0.3 mg of Se/kg of DM set by FDA regulations in the United States, where both inorganic and organic sources of Se, such as selenized yeast, are approved.

Sward characteristics

On dairy farms where pastures are the main constituent of the diet, *herbage mass* (HM) is the amount of grass dry matter (kg DM) per unit of surface (ha). In grazing studies estimates of the herbage mass, also called it as *pasture on offer*, should be determined for rationing purposes, as its nutritional quality dictated the performance of an animal when the stocking rate is fixed, or for adjustment of stock-

ing rate when a fixed grazing pressure is desired (Vartha and Matches, 1977).

Stocking rate (SR)

It is defined as the number of animals (cows) per unit of area of land (ha) for a given time period, has been long recognized as *the most important factor* governing milk output per unit area of pasture (Mott, 1960; McFeely *et al.* 1975; Combellas and Hodgson, 1979; O'Donovan *et al.* 2004). In most European countries, pressure on land use is high and maximizing milk performance per unit of area is more than a challenge to maximize profitability of milk output per ha.

Grazing pressure (GP)

It is defined as the number of animals (cows) per unit mass of herbage (kg DM/ha), implies the productivity of a particular area. When the SR increases, the GP also increases. Now it is important to introduce the concept of *Daily Herbage Allowance* (DHA), defined as the weight of herbage DM per animal (kg DM/cow/day), that decreases when the level of competition between animals increases (Baker and Leaver, 1986) reducing, thereby, the opportunity for pasture selection. This results in a reduction in PDMI and the animal is prevented from satisfying its nutritional requirements which culminates in reduced animal performance (Mott, 1960). When the productive area is a limiting factor, individual performance has less importance and the aim is to *maximize the milk output per hectare*. But at present times when supplementation with concentrates or other conserved forages are getting economic responses, individual animal performance should be considered to fulfill the genetic potential of the cow with a high efficiency of grass feeding and reduce the substitutive effects of supplementation.

Low GP, on undergrazed land with high DHA, leads to increased forage productivity resulting in high output per cow while low output per ha (Roca-Fernández *et al.* 2011; Roca-Fernández *et al.* 2012). At intermediate GP, however, the type of response may vary. Plants may be stimulated by intermediate levels of grazing intensity or, at the other extreme, be inhibited by any level of grazing. An intermediate response, with growth not being inhibited by low-level grazing intensities, is typical of many pastoral grasses. The combination of high GP with low DHA gives medium output per animal while high output per ha (Roca-Fernández *et al.* 2011; Roca-Fernández *et al.* 2012). Increasing the GP to very high level, on overgrazed land with very low DHA, cause a reduction in forage productivity resulting in low output per animal and low output per ha.

The potential of grazing with an adequate SR can be quite high. Stakelum and Dillon (1990) showed that pastures with high GP in spring/early summer produced swards of lower HM, lower post-grazing sward height (SH), higher

proportion of green leaf and lower proportion of grass stem and dead material compared to swards with low GP. A state of equilibrium must be attained whereby animal production from pasture and sward quality are optimized, as low rates of pasture utilization, with low GP, will result in wastage and may also reduce animal production during the summer months (Dillon, 2006). When number of animals are high enough to match the pasture on offer (HM), the *efficiency of herbage utilization*, defined as the proportion of herbage removed relative to that available, increases and *sward quality*, defined as the grass nutritive value for feeding animals, is higher due to an improved *sward structure*, defined as the proportion of leaf, stem and dead material in the upper and lower sward horizons (Stakelum and Dillon, 2007a; Stakelum and Dillon, 2007b) generated from the grazing animal.

Thomas (1980) gives further detailed descriptions and definitions of the different *grassland components*. The *tiller* is the basic unit of sward structure, which consists of a vertical axis bearing leaves. The *stem* is the main axis of the tiller which bears the leaves while the *pseudostem* or vegetative stem is part of a vegetative grass tiller formed by the concentric leaf sheaths which performs the supporting function of a stem. *Leaf* consists of lamina, ligule and sheath. Sward structural variation occurs due to the variation in tiller development and changes in tiller morphology. The structure of a grazed sward can be divided into four components. There is a horizontal separation into an upper grazed horizon (>4 cm) and a lower ungrazed horizon (<4 cm) and a vertical separation of the grazed and rejected area of the pasture (Brereton and Carton, 1986). Sward structure plays a role in determining the quantity of herbage eaten by the grazing animals (Stobbs, 1973), and the proportion of the biomass that is removed from the pasture. Other elements of sward structure include HM, DHA, SH, bulk density and textural characteristics such as shear and tensile strength.

Herbage availability

It can be defined as the relative ease or difficulty with which herbage is harvested by the grazing animal (Wade, 1991). Herbage availability is a complex parameter that takes into account the qualitative and quantitative aspects of the sward and interactions with DHA. In continuous grazing, DHA is theoretically unlimited and PDMI increases asymptotically with HM and/or SH. Delagarde *et al.* (2001) has shown good relationship between PDMI and SH: $PDMI = 12.1 (1 - e^{-0.34 SH})$ where maximum intakes are obtained for SH averaging 9-10 cm but rapid decreases of intake when SH was below 7 cm. On rotationally grazed swards, the herbage availability may be determined by the proportion of green leaf in the grazed horizon.

Wade *et al.* 1989; Wade *et al.* 1995 concluded that herbage availability increased with an increasing proportion of green leaf in the bottom of sward when animals cease grazing. This was demonstrated by Parga *et al.* (2000), comparing two swards differing in the proportion of green leaf material below 15 cm, but with the same proportion above 15 cm. At high DHA, PDMI was similar for both swards, but when DHA was reduced from 17 to 12 kg OM per day, PDMI was reduced less in the sward with the higher proportion of green leaf material below 15 cm. Peyraud *et al.* (2004) showed that DHA of green leaf was a better predictor of DM intake than DHA. And, PDMI will be predicted more accurately when using the DHA of green leaves. Thus, increasing leaf blades mass at the bottom of the sward by appropriate grazing management in early spring may play a major role in increasing PDMI while maintaining a low residual SH over the entire grazing season and increasing herbage utilization.

Applying a high SR in spring grazing produces swards with higher tiller density, higher live/dead tiller ratio and improved herbage digestibility to a continuously grazed pasture (Baker and Leaver, 1986). Korte (1981) and Holmes and Hoogendoorn (1983) showed that swards which were laxly grazed in spring had a higher proportion of stem and dead material in summer than swards which were grazed more severely. Therefore, leafy vegetative swards were obtained by severe grazing in spring, which removed reproductive tillers. Swards that had a higher proportion of stem and dead material had a lower digestibility (Korte *et al.* 1984). According to these findings, it was concluded that severe spring grazing management of perennial ryegrass dominant pastures should aim to leave low residual HM as this would result in a leafy vegetative sward in summer.

Defoliation, sward height and methods of herbage mass determination

Defoliation

It is defined by its frequency, intensity, uniformity and timing in relation to the developmental phases of plants or swards. The *frequency of defoliation* refers to the time interval between successive defoliations cut or grazed. Generally, more frequent and more intensive defoliation reduces herbage yield. Several studies have shown that under cutting, the yield of herbage DM produced over the season as a whole is inversely related to the frequency of defoliation (Bartholomew and Chestnutt, 1977; Reid, 1983). Decreasing the frequency of defoliation can, however, have a deleterious effect on sward quality. Increasing the interval between harvests usually increase the proportion of cell wall and lignin while both cell wall digestibility and true DM digestibility are reduced (Wilman *et al.* 1977).

Duru (2003) found a significant decrease in lamina percentage with increasing cutting frequency. Regrowth after defoliation can be influenced by residual photosynthetic tissue, carbohydrate and other reserves, the rate of recovery in root growth and nutrient and water uptake, and also by the quantity and activity of meristems remaining. Fulkerson and Slack (1995) studied the effect of defoliation frequency and height on the regrowth potential of perennial ryegrass. They found that regrowth after frequent short defoliations was only 65% of the less frequently defoliated plants, which was associated with lower stubble WSC content. It was concluded that defoliating plants at the three leaf stage of the regrowth cycle allowed full regrowth potential and the replenishment of WSC reserves and optimizing tiller status.

Defoliation intensity covers such terms as severity, duration, height, percentage of utilization, residual leaf area and regrowth reserves. It represents the proportion and physiological status of the biomass of shoot or entire plant removed at a particular defoliation. Grass quality and leaf production were greatest with severe grazing compared with lax grazing (Kristensen, 1988). Lowering the cutting height increased DM yield (Binnie and Harrington, 1972). However, Binnie (1980) found that taking an initial lax defoliation followed by subsequent close defoliations produced a slight yield advantage over consistent close defoliation. Spring grazed swards intensively produced higher concentrations of green leaf, digestible nutrients and DM digestibility but lower concentrations of grass stem and senescent material in early summer (Hoogendoorn *et al.* 1992). Binnie and Harrington (1972) found that lowering the cutting height increased sward digestible DM, CP and CF. Turner *et al.* (2006) reported a trend for decreasing metabolic energy (ME) with increasing defoliation interval for a number of grass species as a result of decreasing digestibility which was associated with the increasing proportion of sclerenchyma and vascular tissue (Ducrocq and Duru, 1997). The depression in growth rate with increased frequency of defoliation is the greatest in early season when growth rates are the highest (Binnie *et al.* 1997). However, in grazing studies there is no evidence of a depression in animal performance with shorter grazing cycles (Marsh *et al.* 1971), even when comparing 15 and 30 day rotations (McFeely *et al.* 1975). The absence of an effect on animal performance may be related to the fact that comparisons of rotation length have been undertaken at one SR only and inefficiencies in herbage utilization may mask treatment effects on grass production. Nevertheless, current recommendations suggest a minimum rotation length of 18 days in early season, increasing up to 50-70 days for late autumn grazing. The *timing of defoliation* refers to the developmental phases of plants and season of year. Internode (or stem)

extension does not normally occur in temperate species during the vegetative phase of growth so that a crowding of tillers occurs at the base of the plant. Cutting or grazing at this stage of growth results in the removal of leaf material only. Subsequent regrowth arises from the extension of leaf primordia from the terminal meristem and from the meristems of auxiliary tillers, all of which remain undamaged below the cutting or grazing height. Once stem extension has begun, cutting or grazing may remove the terminal meristem and any unexpanded leaves which remain. Further regrowth is only possible from tiller buds below the cutting height in the axils of old leaves (Jewiss, 1972). Binnie (1980) observed that treatments with initial defoliations in the early vegetative, stem elongation and flowering stages of growth gave higher annual yields than treatments in which the initial defoliation was taken at an intermediate stage of growth when the majority of the stem apices had just been elevated above the height of defoliation. Carton *et al.* (1989) observed that delaying the first cut increased DM yield. Results from such authors indicate that the influence of initial defoliation on productivity is related to the grass growth stage. Lawrence and Ashford (1966) suggested that initial defoliation at a critical stage of plant development impacts on subsequent yield and quality.

The quantity of herbage consumed or removed from pastures following grazing is defined as *herbage utilization* and it is closely correlated with post-grazing SH. It is difficult, however, to compare calculated herbage utilization percentages across experiments as calculated utilization increases as cutting height increases. Some of the factors that affect herbage utilization include the *turnout date*, *restricting grazing time* and *DHA*, which is closely related to SR and the level of supplementation offered.

Turnout date is critical for good herbage utilization. O'Donovan *et al.* (2004) reported that early spring turnout to pasture has positive effects in subsequent grazing rotations. During the mid-April to early July period pastures initially grazed in early spring (February-March) produced swards of higher quality and higher milk production potential than swards initially grazed in mid-April. The positive effects of *early spring grazing* are due to a higher leaf proportion and greater digestibility compared to later grazed swards.

Additionally, Virkajärvi *et al.* (2002) found that an earlier turnout date decreased post-grazing SH (-1.4 cm), which indicated increased herbage utilization. Allocating herbage in early spring may also positively affect PDMI. Kennedy *et al.* (2005) showed that dairy cows in early lactation, that were turned out to pasture full-time post-calving, produced the same amount of milk as cows that remained indoors until early April, but with a lower milk fat content (38.6 vs. 41.6 g/kg) and higher milk protein content

(33.6 vs. 30.7 g/kg). The cows on the early spring grazing system continued to maintain a higher milk protein content and higher PDMI than their indoor counterparts for 12 weeks after the experimental treatments were no longer imposed.

Farmers often fed buffer forages to compensate the weekly variation in grazing conditions. In fact, giving conserved forages (hay or silage) always results in high substitution rate (SRt) with grazed grass, often over 1.0 and very low or negative MR (Chenais *et al.* 2001; Peyraud and Delaby, 2001) when the offered amount of grass would have been sufficient to feed the dairy herd. Buffer forages then contribute to poor herbage utilization. During periods of grass shortage, feeding buffer forages has two purposes. It maintains the intake level of the cow and MY because the SRt falls below 0.3. It allows recover a correct amount of available grass for subsequent grazing periods.

Kristensen *et al.* (2007) reported that *restricting grazing time* forces the dairy cow to graze more efficiently, although the reduction in PDMI and animal performance cannot be fully compensated.

Comparison of individual animal production in a system of restricted grazing with supplementary feeding and a system of full-time housing showed that a high milk production of 9,000 kg/cow/year is achieved in both systems (Beeker *et al.* 2006). Although it is widely reported that PDMI increases as higher DHA are allocated (Peyraud *et al.* 1996b; Dalley *et al.* 1999; Delagarde *et al.* 2001; Bargo *et al.* 2002; Maher *et al.* 2003) a balance has to be found whereby sward quality in subsequent grazing rotations is not compromised due to higher post-grazing residuals (i.e. poorer herbage utilization).

This decrease in herbage utilization is a matter of concern because although PDMI can be increased by offering larger DHA, the negative effects of higher residuals in subsequent grazing are also clear (Taweel, 2006). Combellas and Hodgson (1979) suggested that PDMI is near maximum when herbage utilization is 50%. Dalley *et al.* (1999) reported that herbage utilization decreased from 54 to 26% as DHA increased from 20 to 70 kg DM/cow/day. Virkajärvi *et al.* (2002) reported that increasing DHA from 19 to 27 kg DM/cow/day decreased herbage utilization from 77.7 to 61.0%, respectively.

Data from Johansen and Höglind (2007) illustrated that when 12 to 24 kg DM/cow/day of DHA was offered, PDMI increases by 0.24 kg for each extra kg DM of DHA and herbage utilization decreased from 72% to 51%, respectively. Wales *et al.* (1999) reported that as DHA was increased on medium HM swards (4.9 t DM/ha), herbage utilization dropped from 52 to 29%, while on low HM swards (3.1 t DM/ha) utilization values decreased from 35 to 23%.

Grazing management based on sward height measurements

Sward surface height is a good practical indicator for use in grazing management which enables achievement of high herbage utilization and livestock performance. By recording SH, a dairy farmer should be able to improve the use of grass by maximizing animal intakes and reducing grass wastage. Grazing down to the recommended post-grazing SH will prevent swards becoming stemmy and maintain high sward tiller density and, consequently, high sward quality through the grazing season and produce high levels of livestock performance.

Methods of herbage mass determination

The first measurements of the amount of grass DM per unit of surface, or herbage mass (HM), and its nutritional quality, were made in grazing studies where pastures were the main constituent of the diet and dictated the performance of an animal, the herbage on offer was determined by cut and weight for rationing purposes. Frame (1981) classified the methods for HM estimation as *direct* (clipping) and *indirect* (height measurement).

Direct methods

DM has become the conventional basis for expression of HM. Whatever, the objective or type of trial the basic operation is to cut and measure a sample of fresh herbage of a predetermined size and shape and at a specified height. After collection and weighing, the sample is oven-dried and DM is obtained. Drying is necessary since the amount of moisture in the herbage (usually 75-85%) depends upon the stage of growth, plant species and variety, fertilizer N and the amount of external water in the form of rain. In practice, the number of samples taken will be determined by the number that can be handled with the resources and time available. Although recommendations for the number of samples required cannot be made, many reports feature between 5 and 12 sub-samples per plot (Frame, 1981). Cutting and weighing is the most accurate method of estimating forage yield. But cutting is costly, in terms of time and labour, and it may also influence production and composition of forage as well as grazing behaviour. Therefore, a rapid, indirect, non-destructive technique for making accurate estimates of grass DM yield would benefit grazing trials (Bransby *et al.* 1977).

Indirect methods

The simplest manual instruments used for measuring HM are pasture ruler and plate disc. Pasture ruler relies on a positive relationship between forage yield and uncompressed canopy height. In Europe, the sward stick is widely used (Barthram, 1986), which measures plant height rather

than compressed SH. It employs a 2×1 cm window that is lowered vertically on a shaft until its base touches the vegetation. The height contact above the ground is recorded in 0.5 cm bands. However, canopy height can be difficult to measure due to the subjectivity associated with which plant or plant parts should be considered to form a mean height measure (Heady, 1957), so researchers have added several types of discs or plates to the rule to incorporate an area dimension to the measurement. Plate discs consist in grass meters with a light and horizontal plate (called "*weighted disc*", "*rising plate*", "*drop-disc*" or "*pasture disc*") of 0.3x0.3 m that can slide up or down a central, vertical and graduated stem (Frame, 1993). These holes allow the use of the plate as a squared paper for estimating ground cover or for measuring the occurrence of forage species under the sampling area.

A method called visual obstruction was proposed by Robel *et al.* (1970a) and Robel *et al.* (1970b). A striped pole often called the Robel pole measures the lowest point of the pole not visually obstructed by vegetation when placed vertically in swards. Numerous transects are walked and the observer stops at intervals, sets the pole vertically in the vegetation, steps back 4 m from the pole, and reads the last visible number toward the lower end of the pole at three heights (0.5, 0.8 and 1.0 m). Such observations are made at the four cardinal directions around the pole. Michalk and Herbert (1977) compared this method with hand-clipping and ground cover measures and they obtained a good correlation between SH and HM, with $r^2 = 0.81$. Harmony *et al.* (1997) found this technique the most suitable in comparison with rising plate meter, with $r^2 = 0.63$. Similar conclusions were found by Ganguli *et al.* (2000) in the same comparison, with $r^2 = 0.87$. Ackerman *et al.* (1999) obtained a lower value ($r^2 = 0.59$) in a two-year trial and they concluded that this technique has potential for practical use. Benkovi *et al.* (2000) found $r^2 = 0.88$ and Vermeire *et al.* (2001) found $r^2 = 0.90$. As can be seen, all papers reviewed consider visual obstruction technique as a good method for non-destructively estimating. However, there are some considerations about the use of this technique as shown by Heady (1957), some factors difficult include exact measures of pasture height: the highest point may be difficult to identify when plants are lodging or dropping, when the point is the tip of a structure, and when several parts are nearly the same height. The second consideration is that not many references exist in the literature and investigations on the performance of this method in different vegetation types are limited (Ganguli *et al.* 2000).

More complex electronic instruments such as the electronic capacitance meter, first reported by Fletcher and Robinson (1956) and sonic sward stick (Hutchings *et al.* 1990) have been developed to improve speed and precision

of sampling. The sonic sward stick calculates SH from the flight time of an ultrasonic pulse bounced off the sward surface. Electronic capacitance meter uses a single rod probe and an electronic system that accumulates the readings from a number of sampling sites within a pasture plot. The reading-system relies on differences in dielectric constants between air and herbage and it measures the capacitance of the air-herbage mixture, responding to the surface area of the foliage (Sanderson *et al.* 2001). A variety of capacitance meters have been built under this principle and incorporating various modifications. However, readings are affected by water in vegetation (Murphy *et al.* 1995) including litter and are not an accurate method during or immediately following rainfall. Commercial instruments often come with standard equations and the precision of this instrument depends on the adjustment on these equations. Usually the most used regression model for herbage mass estimation is linear, however, some works with plate meters showed an exponential response in highest values of disk meter values and with capacitance meters. The logical model for rotationally grazed pastures, grazed to a short residual height, is a linear equation that passes through the origin (Rayburn, 1997). Under continuously grazed pastures where a thatch build-up occurs, a regression model using a Y intercept is most appropriate.

Grass feeding value and digestibility of pastures

The grass nutritive value gives an indication of its potential value to feed grazing animals, but its feeding value (nutritive value \times voluntary intake) is of most importance to know its capacity to satisfy cow requirements (Holmes, 1980b). All animals have a minimum requirement for nutrients to maintain essential processes and prevent loss of body weight. Additional nutrients are required by the growing animals to synthesize muscle, adipose tissue and bone, and by the lactating cows to synthesize fat, protein and lactose in milk. While the major requirement is for energy-yielding nutrients, there are specific requirements for amino acids, glucose, fatty acids, minerals and vitamins which depend upon the stage of development, size, type and level of production of the animal (Ulyatt, 1973). The grass feeding value is, therefore, defined as its capacity to promote animal production, and depends upon its ability to supply nutrients to the animal (Beever *et al.* 2000). It has three main components: the amount of grass that the animal will eat (voluntary intake), the content of nutrients in the grass (nutrient content) and the ability of the animal to absorb and utilize the nutrients (nutrient availability). The ruminant's ability to extract nutrients from grass is mainly dependent on digestive processes carried out by microbes resident in the reticulo-rumen. Thus, the grass feeding value is not solely a feed characteristic, but depends on a complex

three-way interaction between the ruminant animal, its feed and the microbial population of its rumen.

The growth characteristics of grasses, with particular reference to their distinct phases of vegetative and reproductive development, need to be taken into account. From a nutritional point of view, plant material can be divided into the cell contents fraction (organic acids, soluble carbohydrates, crude protein, fats and soluble ash) and the cell wall fraction (hemicellulose, cellulose, lignin, cutin and silica) (Minson, 1990b).

The cell contents are highly digestible and readily available in the rumen. On the other hand, the availability of plant cell walls varies greatly depending on their composition and structure. As grasses mature, the cells contents decrease (an exception is non-structural carbohydrates, mainly fructans, which increase in stem, stem base and inflorescence) (Holmes, 1980b) and the cell walls increase (this is, generally, due in part to an increased stem to leaf ratio) (Munro and Walters, 1981). In the early stages of plant growth, cell contents may represent at least two-thirds of forage DM, with protein being a major component. However, the sugar fraction of grasses is highly labile and the amounts present in the plant at any stage of growth depend on prevailing environmental conditions such as light and temperature. Cool season grasses have a higher cell wall concentration than legumes, especially in leaves, but a lower cell wall concentration compared to warm season grasses (Buxton *et al.* 1996).

Grass feeding value may be also affected by forage species, variety, environment and, in particular, previous management of the sward. Results reported by Thomson *et al.* (1985), Ulyatt *et al.* (1988), Beever and Thorp (1996), Harris *et al.* (1997) and Polan (1997) suggested that feeding value of legume species is higher than grass species. Relative to grasses, legumes contain higher proportions of CP, organic acids and minerals, but lower proportions of soluble carbohydrates. True protein and amino acids vary normally between about 90% of total CP in the young plant to 70% in the mature plant, but maturity has little effect on the amino acid composition of either grasses or legumes. At all stages of growth, Italian ryegrass has shown a higher proportion of leaf to stem than other grass species. The prevailing environment also influences the rate of development of leaves and stems. Hence, management decisions regarding harvesting of the crop, either by grazing or cutting, have a major bearing on the quality of forage harvested and also on the annual yield of digestible nutrients contained from forage. Grass feeding value will also vary with weather conditions, and among the climatic variables that influence on it light and temperature are the most important factors followed by moisture (Van Soest, 1994a).

Measurement of digestibility is one of the first important steps in evaluation of forage quality. Digestibility is the proportion of food consumed which disappears in the digestive tract and as such defines quantitatively the nutrient availability per unit of feed intake. For this reason, it is a major component of nutritive value (Thompson and Poppi, 1990). In contrast, Van Soest (1965) considers that chemical composition is what determines the nutritive value of forages, as digestibility is dependent upon the proportion of the total forage made up by the soluble part and the lignifications of the fibrous residue. Plant cell contents are almost 100% digestible, whereas cell wall digestibility varies with lignifications and rate of digestion of cell walls.

The digestibility coefficient of a nutrient is referred as to the proportion of that nutrient eaten that disappears across the whole gut, i.e. for organic matter (OM), the OM digestibility coefficient (OMD) is considered a better estimate of nutritive value than DM digestibility, as it is not affected by the ash content of the forage, which can be quite variable due to soil contamination. It was found that the most practical measurement of sward quality is the proportion of live leaf in the sward directly ahead of the cows and related to the OMD. It is desirable that the proportion of live leaf in the sward is not less than 65%. Also, OMD is considered to be closely correlated with energy availability. Genetic improvements in DM digestibility of forages result in improvements in animal performance by increasing the energy content of the diet and its VDMI (Wilkins and Humphreys, 2003).

The digestibility of a particular pasture species is influenced by many factors including the time of growing season (Wilman *et al.* 1976) as the sward changes from vegetative to reproductive growth. These changes in grass digestibility are mainly associated with differences in the proportions of green leaf, mature stem and senescent material and are likely to influence the feeding value of the grasses (Ulyatt, 1981). The beginning of ear emergence is the point at which the rate of fall of digestibility changes from a slow to a high rate (Minson *et al.* 1960). With increasing maturity, the digestibility of the stem decreases at a much faster rate than that of the leaf, the leaf-sheath digestibility declines at an intermediate rate. Temperate grasses generally have a high DM digestibility, averaging 700 g/kg over the year; however, there are seasonal variations (Ulyatt, 1981).

In general, legumes are typically more digestible than grasses (Buxton and Redfear, 1997). This was corroborated by Steg *et al.* (1994) by comparing the OM digestibility between ryegrass and white clover at two maturity stages (early and late vegetative stage). On average, the undegradable fraction of OM was lower for white clover than for ryegrass (135 vs. 170 g/kg OM). For all forages, undegradability increased as the growing season progressed. In con-

trast, rumen degradation of NDF was significantly higher for grasses than for clover (820 vs. 770 g/kg). Buxton and Redfear (1997) also reported lower values of rumen NDF degradation for legumes. Depending on maturity, ranges for NDF digestibility were 400-500 g/kg DM of NDF in legumes and 600-700 DM g/kg in cool season grasses.

Pasture digestibility was compared with hay and silage digestibility by Holden *et al.* (1994). Forages were based on orchardgrass, and less amounts of Kentucky bluegrass and smooth brome grass. True DM digestibility was 300 g/kg higher for pasture (737 g/kg) than for hay (560 g/kg DM) or silage (569 g/kg DM). Holden *et al.* (1994) suggested that although grass harvested for hay and silage was visibly more mature than the grazed pasture, it was more likely that the digestibility of pasture was higher due to a higher content of non-fibre carbohydrates (305 g/kg DM) in pastures compared to hay and silage (216 vs. 215 g/kg DM, respectively).

Based on these findings, lush pastures have a high feeding value and can be used as the only forage source fed to lactating dairy cows. However, more energy available in the rumen will usually be required in order to optimize microbial protein synthesis.

Berzaghi *et al.* (1996) compared digestibility of diets based on pasture either with or without supplementation of 5.4 kg of cracked dry corn. Total OM (719 vs. 699 g/kg) and rumen true digestibility (643 vs. 587 g/kg) were higher when cows were not supplemented. In contrast, rumen OM digestibility as a part of total tract digestibility was not different between diets (681 vs. 623 g/kg). This suggests that site of digestion might have shifted from the rumen to the duodenum due to the greater passage of undigested starch in cows that were supplemented with corn (Berzaghi *et al.* 1996).

Peyraud and Astigarraga (1998) observed a 0.02 unit decrease in OMD on pastures at the same age of regrowth when N fertilisation was decreased. They showed that in French deep and rich soils (10% OM) reducing N fertilizer from 320 kg to almost zero N did not affect MY, while CP content of unfertilized swards remained greater than 15%. In contrast, in soil with low N supply capacity (2% OM) reducing N fertilization led a reduction in MY of 2.5 kg per day and in PDMI of 2 kg, while CP content in the herbage fell below 12%. Therefore, reduced PDMI was mostly mediated through reduced CP content of the herbage, while HM and sward surface height may be of influence. Peyraud and Astigarraga (1998) also calculated that, to maintain a daily milk production of 0.80 to 0.85 kg of milk protein, a daily intake of 3 kg of CP is required in the ration of dairy cows.

In general, legumes have characteristics that lead to a higher animal performance compared to grasses. PDMI and

milk production have been shown to be higher in mixed perennial ryegrass-white clover swards compared to pure perennial ryegrass swards (Wilkins *et al.* 1994; Wilkins *et al.* 1995). Phillips and James (1998) and Ribeiro-Filho *et al.* (2003) have showed that increasing the content of white clover in pasture has increased MY by 1-3 kg per cow per day in several short-term trials conducted at similar DHA. The difference increases with clover content and reaches a maximum when white clover content averages 50-60% (Harris *et al.* 1998). As a consequence of higher energy intake, milk protein content tends to increase on mixed pastures.

Rogers *et al.* (1982) showed that cows consuming white clover pasture produced more milk and gained more BW (85 vs. 80 kg) due to a 30% higher PDMI. Harris *et al.* (1997) showed that in mixed swards with perennial ryegrass, MY was increased by 20% when dairy cows consumed a diet with 80% clover. Clovers contain less structural carbohydrate, leading to more rapid rates of breakdown of OM, N and cell walls (Aitchison *et al.* 1986; Beever *et al.* 1986; Beever and Siddons, 1986) and the retention time is less compared with ryegrass (Ulyatt, 1973). Besides the positive effect of legumes on VDMI, it is also probable that leaves of legumes are more favorable for prehension than stems and sheaths of grasses. One of the main advantages of white clover is that the rate of decline of nutritional quality throughout the plant-ageing process is far less than for grasses (Peyraud, 1996). At grazing, the difference in DM intake between pure grass pastures and grass-clover mixtures increases with increasing age of regrowth. Ribeiro-Filho *et al.* (2003) showed that PDMI declines by 2.0 kg/day on pure ryegrass pastures compared to 0.8 kg/day on mixed pastures. This makes mixed pastures easier to manage than pure grass pastures. Age of regrowth can be increased without adverse effect on quality. Despite the clear advantages in the intake of white clover over perennial ryegrass, there are issues that need to be considered such as the cost of increased prevalence of bloat and the additional costs of maintaining swards high in white clover content.

Yield benefits of grass-clover mixtures can be considered equivalent to 150-350 kg/ha fertilizer N. Grass-clover mixtures fertilized with 50 or 150 kg/ha/year N attained yields in the range of the heavily fertilized (450 kg/ha/year N) monocultures of the highly productive grass, with clover percentage in the mixture ranging from 30 to 80% (Nyfeler *et al.* 2009). This study confirms that the productivity of mixed pastures is directly related to the contribution of clover. The DM production of grass-clover mixtures increases by 7.2 to 7.9 and 9.2 t/ha for clover contributions of, respectively, less than 20%, 20-40% and 40-60% in summer. On good and deep soils and with a sufficient water supply

in summer, mixed pastures produce almost as much DM as the pure grasses pastures receiving 200 to 250 kg/ha (9.6 vs. 9.8 t/ha).

Maximizing pasture dry matter intake by grazing dairy cows

The amount of herbage consumed is the major determinant of herbivore production, yet is one of the most difficult aspects of forage quality to determine or predict (Buxton *et al.* 1996). To maximize PDMI, animals need to consume plants that have characteristics that allow rapid consumption and lead to fast rates of passage through the rumen. Rook (2000) defined intake of herbage as the product of bite mass and bite rate, and time spent grazing as the product of meal duration and number of meals per day. The following formula is being applied to determine the PDMI:

Daily pasture DM intake= (bite mass×bite rate) × (meal duration×number of meals).

The major regulators of PDMI by herbivores include: physical limitations, physiological control and psychogenic factors (Mertens, 1985). Rates of digestion and passage of indigestible particles through the digestive tract is slow in ruminants so that the physical capacity of the digestive tract, particularly the reticulo-rumen, limits intake of certain forages. Forbes (1993) suggested that increasing speed and/or extent of digestion and the rate of passage of particles such as by grinding, increases intake. Blaxter *et al.* (1956) reported positive relationships between intake and digestibility. This means that plant species or parts having high digestibility are consumed to a greater extent than those with a lower digestibility (Thompson and Poppi, 1990). The filling effect of herbage is related to the volume of ruminal contents (Buxton *et al.* 1996) and to the proportion of cell wall constituents or NDF of the forage (Van Soest, 1965). The percent of cell wall content of forages has a negative correlation (-0.83) to PDMI according to values reported by Van Soest (1971). Furthermore, VDMI is usually lower for grasses than for legumes. Harris *et al.* (1997) showed that PDMI of cows eating 50 and 80% clover were 11% higher than for 20% clover diets. Minson (1990) also obtained a linear relation between VDMI and the proportion of legumes in a mixed pasture.

Physiological control of intake is based on the concept that animals regulate intake to meet their energy demand (Forbes, 1993). This is unlikely to occur with high producing lactating cows under a grazing situation. Hodgson (1977) implied that under ideal grazing situations, where quantitative sward limitations are minimized, intake increases as digestibility of the forage increases, until reaching levels of OM digestibility close to the maximum for

fresh herbage. Thompson and Poppi (1990) also showed that animals grazing legumes had a lower amount of material in the rumen and a higher intake, yet the intakes were not sufficient for the animals to reach their genetic potential for growth.

Animals on legume pastures appear not to have reached a physical upper limit to distention or an upper limit to energy metabolism. In contrast, animals on grass pastures appeared to be closer to a physical upper limit.

Psychogenic factors are important regulators of VDMI in ruminant animals, especially in high producing dairy cows under grazing conditions. In this case, PDMI can be affected by sward characteristics, environmental and management factors. Sward mass, height and uniformity are one of the main variables that can significantly affect PDMI by ruminants. Intake per bite is the primary animal response to variations in the physical characteristics of the sward canopy and it has been shown to be positively related to herbage mass, pre- and post-grazing sward height (SH), daily herbage allowance (DHA), stocking rate (SR), grazing pressure (GP) and herbage utilization (Hodgson, 1986).

Among the main factors influencing the ability of ruminant animals to consume high intakes of herbage in pasture-based systems are also the environmental factors. The effect of temperature on feed intake of ruminants has been reviewed by Webster (1976). Food intake decreases at high temperatures and it increases at low temperatures (Ragsdale *et al.* 1950).

MY may decrease at temperatures above 18 °C and food intake above 26 °C (Head *et al.* 1976) due in part to the direct effects of thermal stress on the cow causing suppression of activity and the indirect decline is due to the quality of the forage.

Furthermore, forages grown under high temperatures have a higher stem to leaf ratio. Animals will select leaves, instead of consuming the whole plant, and bite size and rate of intake will decrease. Also, the rate of maturation rises with temperature; alfalfa grown at 17 °C took 52 days to reach early bloom but only 21 days at 32 °C (NRC, 1981). Light intensity is another factor that affects forage composition and indirectly PDMI. At high light intensity, WSC increase and cell wall carbohydrates decrease (Van Soest, 1994). Both temperature and light intensity variations during the grazing season will indirectly affect PDMI by changing PDMI, plant digestibility and NDF content. However, in practice the effects on intake and performance are less than predicted from controlled-temperature studies, because cows compensate lower daytime intake by nighttime grazing. Moreover, sward factors that influence on grazing system such as SR, GP and DHA, pre- and post-grazing SH, herbage utilization and type and amount of supplement are other important factors that affect PDMI.

Methods and equations for determination of pasture dry matter intake

Methods for estimation of pasture dry matter intake

The development of reliable methods of measuring individual animal intake at pasture is essential for the development of efficient grazing management systems. Various methods have been proposed to estimate daily intake of herbage during grazing, namely the *faecal output/diet digestibility method* (Langlands, 1975), *sward difference method* (Walters and Evans, 1979) and the *grazing-behaviour method* (Forbes and Hodgson, 1985). For the majority of situations, methods based on the use of faecal output/diet digestibility appear to be the most reliable as they combine simplicity of sampling with a high degree of precision (Peyraud, 1996).

Sward difference techniques have many limitations in terms of individual animal intake estimations because each animal has to be grazed separate, correcting for growth of herbage occurring while grazing, and differences in cutting height before and after grazing. This method may be extremely inaccurate on heterogeneous swards, while for short grazing periods with clean homogeneous swards it may be optimal. Methods based on grazing behaviour should be reserved to more analytical types of studies concerning relationship between animal and sward structure.

Methods based on faecal output / diet digestibility are more suitable for intake estimates that span a number of days and give some indication of the animal-to-animal variability.

The marker most commonly used to measure faecal output up until recently was chromium sesquioxide ether suspended in oil in gelatine capsule (Raymond and Minson, 1955) or as shredded paper impregnated with Cr₂O₃ (Corbett *et al.* 1958). The main concern with this technique was the possibility of diurnal variation and its consequential error in estimation of faecal output. To overcome this source of error, controlled-released devices have been developed.

The other component of the equation is herbage digestibility, which would be ideally estimated using an ingestible marker naturally occurring in the herbage providing an individual-animal estimate. Although many plant components have been evaluated as “internal marker” digestibility markers (Kotb and Luckey, 1972), none have proven satisfactory results due mainly to difficulties with analysis as a chemically discrete entity.

As a consequence herbage digestibility is usually estimated using *in vitro* procedures previously calibrated with *in vivo* measurements (Tilley and Terry, 1963). Dove and Mayes (1991) identified three possible sources of error with *in vitro* procedures: (1) the relationship between *in vitro* and *in vivo* estimates may not apply to the test animal as

estimates are frequently established with mature animals for near maintenance; (2) even if the relationship is applicable, only a single digestibility value is applied to all test animals, regardless of differences that may result due to the level of intake or supplement intake; (3) individual test animals may select a diet that differs in digestibility to that used in chemical analysis. These factors can be large sources of error in the estimation of PDMI, since a small error of digestibility (with highly digestible grass) can lead to larger errors in the estimate of intake (Langlands, 1975).

In recent times plant wax components, namely n-alkanes, have been suggested as markers for the estimation of PDMI (Mayes *et al.* 1986; Dillon and Stakelum, 1989). Faecal recovery of long-chained n-alkanes was incomplete, but Mayes *et al.* (1986) argued that this incomplete recovery would not matter if the animal were dosed with a synthetic, even chained alkane as an external marker for the estimation of faecal output, provided the pair of natural (odd-chain) and synthetic (even-chain) alkanes had similar faecal recoveries.

There is now a considerable body of information supporting the assumption that satisfactory results are obtained if intake is estimated using natural n-alkane C33 and dosed C32 n-alkane (Dove and Mayes, 1991; Ferreira *et al.* 2007; Oliván *et al.* 2007).

The accuracy of the estimates of intake obtained using herbage and faecal alkane concentrations also depends on obtaining a representative sample of the consumed herbage, accurate administration of synthetic alkanes to grazing animals, dosing procedures and obtaining a representative sample of faeces plus sample preparation and extraction for alkane analysis.

The major advantage of the n-alkane technique is that the estimate of intake is on an individual-animal basis and also compatible with studies where grazing test animals are fed supplements.

Equations for estimation of pasture dry matter intake

Because determination of PDMI by ruminants demands the use of labor-intensive and indirect techniques that have several sources of error, equations based on animal and sward characteristics have been developed to predict PDMI of cows.

Caird and Holmes (1986) used data from 9 experiments conducted with dairy cows grazing perennial ryegrass, consuming 1.2 kg/day of concentrate, and producing 21.5 kg/day of milk on average to predict total dry matter intake (TDMI).

Animal variables included total organic matter intake (TOMI, kg/day), herbage organic matter intake, concentrate dry matter intake (CDMI, kg/day), body weight (BW, kg), milk yield (MY, kg/cow/day), herbage organic matter di-

gestibility and week of lactation. Pasture variables included herbage mass (HM, t of OM/ha), DHA (kg OM/cow/day), and SH (SHT, cm). For rotationally grazed cows the best equation recorded ($r^2=0.68$) was:

$$\text{TOMI} = 0.323 + 0.177 \text{ MY} + 0.010 \text{ BW} + 1.636 \text{ CDMI} - 1.008 \text{ HM} + 0.540 \text{ DHA} - 0.006 \text{ DHA}^2 - 0.048 \text{ DHA} \times \text{CMDI}.$$

Vázquez-Yañez and Smith (2000) used data from 27 grazing studies with dairy cows to obtain regression equations to predict TDMI and PDMI. Mean milk production and supplementation amount were 15.9 and 1.9 kg/day, respectively. Independent variables included 4% factor corrected milk (FCM, kg/cow/day), days since calving, DHA (kg DM), NDF in pasture available (NDFp, % DM), NDF in pasture selected (NDFs, % DM), percentage of legumes in pasture (LEG, %), amount of concentrate supplemented (kg DM), amount of forage supplemented (kg DM), total supplementation (SUP, kg DM), DHA and total supplementation interaction (DHASUP), BW (kg) and change in BW (CBW, kg/day). The best equation ($r^2=0.95$) for TDMI estimation was:

$$\text{TDMI} = 4.47 + 0.14 \text{ FCM} + 0.024 \text{ BW} + 2.00 \text{ CBW} + 0.04 \text{ DHA} + 0.022 \text{ DHASUP} + 0.10 \text{ SUP} - 0.13 \text{ NDFp} - 0.037 \text{ LEG}.$$

The best equation to estimate PDMI ($r^2=0.91$) was the following:

$$\text{PDMI} = 4.47 + 0.14 \text{ FCM} + 0.024 \text{ BW} + 2.00 \text{ CBW} + 0.04 \text{ DHA} + 0.022 \text{ DHASUP} - 0.90 \text{ SUP} - 0.13 \text{ NDFp} - 0.037 \text{ LEG}.$$

While equations developed by Caird and Holmes (1986) and Vázquez-Yañez and Smith (2000) included pasture and supplement variables, the NRC (2001) equation is based on animal variables such as FCM (kg/d), BW (kg) and week of lactation (WOL) following the expression:

$$\text{DMI} = (0.372 \times \text{FCM} + 0.0968 \times \text{BW}^{0.75}) \times (1 - e^{-(0.192 \times (\text{WOL} + 3.67))}).$$

Bargo *et al.* (2002) used a dataset of 56 measures from researchers who measured DM intake four times during the grazing season using Cr_2O_3 as a fecal marker in dairy cows that grazed an orchardgrass pasture and were supplemented with 8.7 kg/day of a corn based concentrate. Cows, pasture and supplement information reported in that study were used to estimate TDMI with the equations of Caird and Holmes (1986), Vázquez-Yañez and Smith (2000) and

NRC (2001). TDMI estimated by the equations of NRC (2001) (21.9 kg/day) or Caird and Holmes (1986) (21.2 kg/day) did not differ from that measured by Cr₂O₃ (21.6 kg/day) ($P>0.05$), but estimation of TDMI by the equation of Vázquez-Yañez and Smith (2000) (24.4 kg/day) was higher than measured TDMI ($P<0.05$). This indicates that estimation of TDMI using the equations of Caird and Holmes (1986) and NRC (2001) was accurate for this particular dataset with high producing cows, with the advantage that the NRC (2001) equation is simpler and it only requires animal factors.

CONCLUSION

Pasture-based milk production systems are characterised by a dynamic interaction of plants and cows. The assessment of the important role that sward factors play on daily pasture dry matter intake of grazing dairy cows should be the basis on which build sustainable pasture-based milk production systems in humid regions taking into account that an efficient conversion of grass to milk is highly necessary for profitability and competitiveness of grazing dairy systems. For this, it is essential to apply good grassland management practices at farm level whether increasing the stocking rate or grazing pressure at pasture, changing the sward structural characteristics by increasing the amount of leaf proportion in the swards or combining low pre-grazing herbage mass with high daily herbage allowance in order to achieve greater herbage utilization, with lower post-grazing residues to maintain higher sward quality on subsequent grazing rotations. The quality of pastures in these conditions, with lower content of dry matter and fibers and higher levels of crude protein, water soluble carbohydrates and digestibility of organic matter provide higher milk quality (with higher content of milk protein). All this, without penalizing individual milk production and paying attention to grassland management as the best practice to achieve high daily intake of grass with high quality to satisfy cow needs at all times thought the lactation curve of animals.

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