The evolution of grazing ungulates has been linked to the appearance of open grasslands in the Late Miocene in the New World and the Pliocene in the Old World (Janis 1993). These grazing Pliocene ungulates, some of which were the early ancestors of domestic sheep and cattle, were free to forage and select a diet that met their individual nutritional requirements. The selective foraging behaviour of these grazing ungulates will have been subjected to several millions of years of natural selection, optimising the balance between meeting their nutritional requirements efficiently whilst at the same time avoiding being killed, either by predators or as a result of eating plants that contain toxins. Since the domestication of sheep and cattle between 8000 and 10,000 yr ago (Clutton-Brock 1999), human farmers have taken an increasing level of control of the diets of their stock (in terms of both intake control and diet composition) as well as becoming increasingly effective at protecting their stock from wild predators. This has culminated in the past few decades in ruminant livestock production systems in which animals are kept housed all

Abbreviation: TMR; total mixed ration
year around, fed a single total mixed ration (TMR) (Coppock et al. 1981) and are free from predators (other than the humans that normally kill them once they have met their production potential). Clearly, the highly managed conditions in which some livestock are kept today are very different to the conditions in which their ancestors evolved over the past few million years. Some of the major differences between the two sets of conditions relate to foraging behaviour, both in the manner of eating i.e., grazing from pasture or eating prepared rations, and also in the extent to which the animal is able to select its own diet.

Diet selection and preferences by grazing herbivores, and the potential to improve livestock production by facilitating diet selection, have, in recent years, been subjected to relatively detailed research and subsequent reviews, and the main part of this paper summarizes this research. To date, the environmental and animal welfare implications of diet selection and grazing preferences in livestock have been subjected to little, if any. However, our growing understanding of the factors affecting diet selection, especially its evolutionary basis, can be used to consider some of the likely implications in these areas, and these are discussed towards the end of the paper.

**DIET PREFERENCES**

Before discussing diet preference research, it is important to define what is meant by preference, and contrast it to selection. Preference is defined as “what the animals select given the minimum physical constraints” (Parsons et al. 1994), whereas selection is “preference modified by environmental circumstances” (Hodgson 1979). In other words, preference is what an animal “wants” to eat, whereas selection is what it ends up eating due to some constraint (Rutter 2006). The traditional approach to grazing grass and clover is to offer it as a mixed sward, in which the two plant species are sown and grow as an intimate mixture. In this situation, if an animal “prefers” i.e., wants) clover, it has to search through the mixture to find its preferred herbage i.e., this is an example of selection. In order to study preference we need to remove the constraint of searching through a mixture. The usual approach to overcoming this constraint in order to study grazing preference is to allow the animals to graze adjacent monocultures of the two species being studied and this is the approach taken in the majority of the research reported below.

The majority of the extant research on diet preference in grazing ruminant livestock has used perennial ryegrass (*Lolium perenne* L., hereafter referred to as grass) and white clover (*Trifolium repens* L., hereafter referred to as clover) as model species. This research was subject to a full review by Rutter (2006). Consequently, the large amount of earlier research is summarized below, followed by a more detailed review of the comparatively small amount of relevant research reported since Rutter’s (2006) review.

**Summary of Partial Preference for Legumes**

Both sheep and cattle show a partial preference for clover of approximately 70%, i.e., white clover forms 70% of their diet, and ryegrass 30%, when given free-choice to graze adjacent grass and clover monocultures (Rutter 2006). Similar partial preferences have also been reported for other legumes, e.g., 74% preference for sula (cf. 26% annual ryegrass) in lactating sheep (Rutter et al. 2005a) and 70% preference for lotus (cf. 30% perennial ryegrass) in dairy heifers (Torres-Rodriguez et al. 1997). Preference for clover appears to be influenced by physiological state, with lactating animals generally showing a higher preference for clover than dry animals, e.g., 79.7 versus 65.8% clover in lactating and dry sheep, respectively (Parsons et al. 1994), and 73.8% clover in lactating dairy cows (Rutter et al. 2004a) versus 63.9% in dairy heifers (Rutter et al. 2004b), although further research is needed to verify these findings. The proportion of clover offered (by ground area) influences preference, with a higher preference for clover the more that is offered, in lactating dairy cows (Rutter et al. 2004a), dairy heifers (Rutter et al. 2004b) and sheep (Parsons et al. 1994). Given that grazing animals prefer clover, their selective grazing can lead to a reduction in the relative availability of the legume in the sward (i.e., the proportion of clover decreases whilst the proportion of grass increases). Preference for clover is also influenced by its relative availability, with a decline in clover in the diet as the relative availability declines (Rook et al. 2002). The results of Cosgrove et al. (1996) suggest that clover preference varies with season, with New Zealand dairy heifers showing a partial preference of 65% for white clover in February, but their preference was not significantly different from 50:50 in December or May. Cosgrove et al. (1996) speculated that these changes in preference over the season were due to differential changes in the “palatability” of the two herbage species, but argue that further research in this area is needed.

One of the most consistent findings of diet preference research is that both grazing sheep and cattle show a clear diurnal pattern of preference. Preference for clover is strongest in the morning, with the proportion of grass in the diet gradually increasing over the course of the day (Rutter 2006). Figure 1 includes a typical diurnal pattern of preference for white clover in grazing lactating dairy cattle. Both sheep (Penning et al. 1991) and lactating dairy cattle (Rutter et al. 2004a) can eat clover more quickly than grass, i.e., the dry matter intake rate of clover is typically 1.5 times higher than the dry matter intake rate of grass (Chapman et al. 2007). In contrast, the intake rates of grass and clover are not significantly different in dairy heifers (Rutter et al. 2002).

**Preference in Cattle Offered Silage or Cut Herbage**

Two experiments by van Dorland et al. (2008) investigated diurnal patterns of preference in housed dairy...
cows. In one experiment, cows that were given a choice between ryegrass silage and either red or white clover silages showed a partial preference of 74% for white clover and 69% for red clover silages (based on total daily intake), and showed a diurnal pattern of preference very similar to that reported for grazing cattle (Fig. 1). In contrast, in another experiment, cattle given a choice between freshly cut ryegrass and either freshly cut red or white clover showed a stronger preference for cut ryegrass, with the proportion of total daily intake from cut white clover being 37% and from cut red clover being 45% (van Dorland et al. 2008). Also, the cattle fed cut forages did not show the typical diurnal pattern of preference. Although there was a strong (>90%) preference for cut red clover in the first hour of the study (between 0800 and 0900), preference changed very little over the rest of the daylight hours, at approximately 40% for cut white clover and 50% for cut red clover (Fig. 1). This is in marked contrast to studies at pasture, and led van Dorland et al. (2008) to argue that “the preference for ryegrass over white clover throughout the day contradicts the hypothesis formulated by Rutter et al. (2004a) that partial preference for clover ... has a fundamental biological basis in cattle.” However, van Dorland et al.’s (2008) results from cut forages need to be interpreted with caution. The problem was raised by the authors themselves and relates to diurnal patterns in the chemical composition of herbage, especially grass. Previous studies have shown that the chemical composition (especially water soluble carbohydrate content) of grass changes over the course of the day (Orr et al. 2001), and cows can tell the difference between hay that is cut in the morning and that cut in the afternoon (Mayland et al. 2000). In van Dorland et al.’s (2008) study, the herbage was cut early morning and early afternoon (before 1600), then fed “within a day”, but unfortunately the diurnal changes in chemical composition of the material that was fed were not analysed. Herbage does not stop metabolism and photosynthesis the instant it is cut. The metabolism of leaf water soluble carbohydrate will continue for some time after cutting, and material on the outside of a heap (i.e., in light) has the potential to continue photosynthesis. Combine these ongoing changes in chemical composition with a variable interval (“within a day”) between cutting and feeding, and it appears likely that the cattle were fed cut material that showed different diurnal changes in chemical composition from day to day. So whilst the cows had 21 d to become accustomed to the new feeds, it is possible that daily changes in the diurnal pattern of the chemical composition of herbage confounded their ability to learn the post-ingestive consequences of diet choice over this period, and it is for this reason that they failed to express diurnal patterns of preference. In contrast, the cows in van Dorland et al.’s (2008) experiment that were eating silage were “used to silage feeding”, and were likely fed material that did not show daily changes in the diurnal pattern of chemical composition, allowing the animals to express a clear diurnal pattern of preference (Fig. 1).

Further research is required to investigate the factors affecting preference of cut forages, although such research needs to ensure that the chemical composition of the material being fed is recorded, and possibly manipulated in a systematic way by varying the delay between cutting and being offered to the animals. Such work could help shed new light on the factors influencing partial preference and diurnal patterns of preference, and could help improve our understanding of the theoretical basis of mixed diets in ruminants.

**The Theoretical Basis for Mixed Diets in Ruminants**

The various theoretical explanations for mixed diets in ruminants are reviewed by Rutter (2006), and are summarised in this section. The majority of the theoretical explanations are, to some extent, underpinned by evolutionary factors. As discussed in the introduction, the diet selection and foraging behaviour of the wild ancestors of domestic sheep and cattle will have been subjected to several millions of years of natural selection, and some influences, e.g., anti-predator behaviour, are likely to have continued to have been influenced by natural selection for much of their domestication history as well.

Two related factors that are likely to influence diet selection are the need to balance carbon (C) and nitrogen (N) in the diet as well as maintaining rumen function. Clover has a higher proportion of N relative to C (Whitehead 1995) such that animals eating purely clover are likely to consume an excess of N, which would require energy to process and excrete. Natural selection would have favoured animals that eat a diet that...
balances C and N, as well as optimising their efficiency of nutrient capture in general, and this is likely to be one factor contributing to mixed diets in ruminants. Whilst both cattle (Rutter et al. 2002; Orr et al. 2004) and sheep (Orr et al. 1997) can graze clover only without any apparent problems, this is likely to lead to a change in the rumen microflora such that their ability to digest cellulose is less efficient than those animals that maintain a higher proportion of fibre-rich material in their diet. Again, natural selection would have been likely to have favoured those animals that maintained the ability to digest cellulose as they would have been at a competitive advantage should environmental factors (e.g., seasonal changes in herbage quality) require them to change to diets with higher levels of fibre.

Many plants have evolved chemical defences against herbivory, and these chemicals cause negative post-ingestive consequences such that animals develop conditioned taste aversions to those plants (Provenza 1995a). There will have been evolutionary pressure on animals to learn to avoid eating plants that cause them to feel ill, and Provenza (1996) proposed that these conditioned aversions are a basis of mixed diets in ruminants. There is some evidence to support this so as fasted sheep show a stronger preference for grass than non-fasted sheep (Newman et al. 1994), and it is possible that they have learnt that the rapid ingestion of a large amount of clover can lead to bloat (ruminal tympany), so they eat more grass to minimise this risk.

Predation is a major factor in the evolution of animals (Lima and Dill 1990), and natural selection will have favoured those animals, including Pliocene ungulates, that developed effective anti-predator behaviours. The risk of attack from wild predators would have been reduced following the domestication of sheep and cattle, but innate anti-predator behaviours still persist in domestic ruminants (Boissy et al. 2005). Sheep and cattle are described as crepuscular i.e., showing peaks in foraging activity at dawn and dusk (Albright and Arave 1997), sheep (Champion et al. 1994) and cattle (Gibb et al. 1998) generally avoid grazing at night (in temperate regions), and it has been argued that this is an innate anti-predator strategy (Rutter 2006). The most effective way for a ruminant to avoid grazing at night would be to fill the rumen with fibrous material with a low passage rate (i.e., grass and not clover) before dusk. In contrast, at dawn it makes sense for the animal to consume the feed with the highest intake potential i.e., clover. Consequently, innate anti-predator behaviour not only accounts, in evolutionary terms, for mixed diets in ruminants, but it can also account for the diurnal pattern of preference, with animals incorporating more grass in their diets towards dusk in an endeavour to avoid grazing at night.

Diet selection behaviour could also have been influenced by a variety of other evolutionary factors, such as avoiding eating faeces (to minimise risk of disease and/or parasites) as well as the need to “sample” dietary options to assess the relative quality of feed materials available (Dumont and Gordon 2003). Another important evolutionary factor is the flexibility to adapt to a changing environment, and Provenza (1995b) defines three types of “memory” that have evolved in herbivores to help them track changes in the environment. The first of these “memories” is that programmed into the genes of the species over many generations; the second is the transgenerational information passed from mother to offspring and the third memory results from the animal learning through its own experiences. Provenza (1995b) argues that these three memories interact, linking the past with present experiences and shaping the present and future foraging behaviour of individual animals.

So it is likely that there will have been a number of different, sometimes competing, evolutionary drivers influencing diet selection, with natural selection, over millions of years, playing a role in helping the animal determine the optimal balance between these. Although domestication will probably have influenced this balance, there is compelling evidence that domestic animals maintain at least some of these evolutionary traits. The next section discusses how, by considering these, we can increase animal production.

**PRODUCTION IMPLICATIONS**

From the previous section it is apparent that domestic sheep and cattle have clear diet selection goals, with a desire to eat mixed diets, and with dietary preferences changing over the course of the day. In current agricultural practice, when grass and clover are grazed together they are invariably done so as an intimate mixture. In order to express its diet preference, the grazing animal has to spend 70% of the day searching through this mixture selecting clover, and 30% of the time searching through the same sward looking for grass. This need to search imposes a constraint (i.e., it is an example of selection), but does it affect production? Dairy cows grazing adjacent monocultures of grass and clover give between 11% (Cosgrove et al. 2001) and 12% (Nuthall et al. 2000) more milk than cows grazing mixed grass/clover swards. Ewes and their accompanying lambs showed higher liveweight gains when grazing adjacent grass/clover monocultures compared with those on mixed swards (Venning et al. 2003, 2004). These results indicate that, in grazing lactating sheep and dairy cows at least, there is a potential cost associated with selection, and that intakes and production can be boosted by offering animals separate feeds so aiding their diet selection.

In the results presented so far, the animals offered separate monocultures have been given continuous free choice between either grass or clover 24 h a day. However, Rutter et al. (2001) demonstrated that continuous free choice is not necessary to achieve the production benefits of separation. Cows grazing clover only after morning milking and then grass only after afternoon milking (i.e., matching their diurnal pattern of
preference, a treatment known as “temporal allocation”) produced just as much milk as cows offered a free choice between grass and clover monocultures 24 h a day. Under rotational grazing, cows offered a fresh area of clover after morning milking and a fresh area of grass after afternoon milking produced 14.6% more milk than cows offered fresh areas of a mixed grass/clover sward after both milkings (Rutter et al. 2003). Further discussion of the production benefits of spatially separate swards are given in a review by Chapman et al. (2007).

What is the Minimum Spatial Scale Required for the Benefits of Separation?
Rutter et al. (2005b) reported a study on diet selection and intake in beef heifers offered ryegrass and white clover monocultures sown as a series of adjacent strips at different widths (12, 36 and 108 cm) and as an intimate mixture. The heifers selected approximately 60% clover from the strips sown at 108 and 36 cm, but only approximately 40% from the 12 cm strips or the mixed sward. From this, Rutter et al. (2005b) concluded that the heifers could select their desired diet from strips of at least 36 cm width, but not from strips at 12 cm or less, so the critical scale for heifers to be able to select their chosen diet lies between 12 and 36 cm. Although the heifers in Rutter et al.’s (2005b) study did not show any differences in intake (discussed below), the fact they could select their chosen diet from strips 36 cm wide (or less) suggests that the intake and production benefits discussed above can be achieved with sheep and lactating cows with a similar scale of separation. This means that the benefits of separation discussed in this paper could potentially be achieved from grass/clover swards in which the two herbages formed distinct monoculture “patches” that were at this critical scale (or larger). One possible way to achieve this would be for plant breeders to select grass and clover varieties that, when sown together, adopt a patchy habit at the appropriate scale, allowing the benefits of separation to be delivered without the need to sow monoculture swards.

Does the Facilitation of Diet Choice Always Give Production Benefits?
Animals feeding from spatially separate forages do not always achieve higher intakes compared with animals eating mixed swards. In the study looking at different width strips of grass and clover, Rutter et al. (2005b) found no significant differences in intake between the four different treatments (i.e., a mixed sward and adjacent strips of grass and clover monocultures at 12, 36 and 108 cm widths). One possible explanation is that the comparatively low nutritional requirements of beef cattle mean that they can achieve their required daily intake even with the selection costs imposed by searching through a mixed sward for their desired diet. Similarly, in contrast to studies of dairy cows at pasture, offering housed lactating dairy cows a choice between separate grass and clover as either cut forage or silage did not affect intake or milk yield (van Dorland et al. 2007). These results could be explained by the animals eating either silage or cut forage achieving higher intakes rates than can be achieved by grazing cattle. This would allow the animals eating silage or cut herbage to achieve their daily intake requirement in less time than grazing animals, so that any selection costs (i.e., time spent sorting the feed) have little, if any, impact on daily intake.

Even if animals given a free choice do not eat more or show higher levels of production than those offered a mixed feed, there can still be economic benefits associated with offering dietary choice. Atwood et al. (2001) found that beef calves offered dietary choice showed similar intakes and weight gains to those on a mixed ration, but the feed cost per day was higher for animals on the mixed ration ($1.58 d⁻¹) compared with those offered a choice ($1.48 d⁻¹). As a result, feed cost per unit weight gain was higher ($1.84 kg⁻¹) in animals on the mixed diet compared with those offered a choice ($1.49 kg⁻¹). Atwood et al. (2001) argued that these economic benefits were due to the animals on choice diets being able to select nutrients and/or to avoid toxins depending on their individual requirements and experiences, something that the animals on the mixed ration were unable to achieve.

From the studies conducted to date, it appears that the separation of grass and clover gives intake and/or production benefits in grazing animals that have a high nutritional requirement and where herbage intake rates either limit, or are close to limiting, daily intake. In other situations, e.g., low nutritional requirements or animals fed cut forage or silage with a high intake rate potential, there does not appear to be any intake or production benefit. However, as Atwood et al. (2001) demonstrated, there can still be economic benefits to offering dietary choice. There may also be other advantages to feeding ruminant livestock separate feeds, and these will be discussed in the following two sections.

ENVIROMENTAL IMPLICATIONS
One of the least studied areas of diet selection in ruminants is its environmental implications. As discussed earlier, there is likely to have been evolutionary pressure in ruminants to optimise the efficiency with which they capture nutrients. One intriguing finding from in vitro studies by Merry et al. (2002) suggests this might be the case. They studied microbial protein synthesis in an artificial rumen “fed” different proportions of ryegrass and red clover silages, and found the optimum efficiency of microbial protein synthesis was achieved with 70% clover and 30% grass, i.e., in the middle of the range of preference for clover shown by grazing ruminants. This supports one of the theoretical reasons for mixed diets, i.e., that the animals are balancing their C and N intake and optimising their
own efficiency of nutrient capture. There is also experimental evidence showing that animals that are allowed to exhibit some degree of diet choice select a diet that optimises their own efficiency of nutrient capture. Atwood et al. (2006) found that lambs offered a free choice to select their own diet from three iso-caloric and iso-nitrogenous foods that differed only in the proportion of cereal grains (70, 50, 40%) had a higher food conversion efficiency than animals that were fed only the 70% cereal ration. They argued that this improved food conversion efficiency in animals on the choice diets was achieved because individual animals were able to select and balance foods that met their changing nutrient needs.

If animals are able to optimise their own efficiency of nutrient capture, there could be significant environmental benefits in allowing animals to select their own diets. The first, and most obvious benefit of improved nutrient use efficiency is that each unit of product requires less feed input, reducing the direct costs (both financial and environmental) of producing the feed and also the indirect costs associated with, e.g., transporting it to the animal. Second, improved nutrient use efficiency results in less pollution from excreted waste nutrients (especially diffuse nitrate pollution) and improves the ratio of unit production per unit pollution. Cattle with a higher feed conversion efficiency also have lower emissions of methane (DeRamus et al. 2003), a potent greenhouse gas. Although requiring further research, it is possible that facilitating the self-selection of diets in ruminant livestock could result in a significant reduction in the environmental pollution arising from livestock agriculture.

**ANIMAL WELFARE IMPLICATIONS**

Cattle and sheep evolved as “grazers”, and have (until recently) been kept in predominantly grazing based systems since they were domesticated. However, the intensification of Western agriculture in the second half of the 20th century has led to the development of management systems for some ruminant livestock, particularly cattle, in which the animals have little or even no opportunity to graze. Instead, the animals are kept off pasture, sometimes all year round, and fed cut forage which has often been ensiled and/or incorporated with other feedstuffs into a TMR (Coppock et al. 1981). These “zero-grazing” systems may have implications for animal welfare, and these are discussed below.

**Do Cows Prefer to Graze?**

Before considering whether there are any animal welfare implications arising from the diet preference studies discussed earlier, it is first worth considering whether or not domestic ruminant livestock prefer to graze, i.e., whether or not the prevention of grazing behaviour in “zero-grazing” systems compromises animal welfare. As discussed earlier, sheep and cattle evolved as “grazers”, and grazing could be considered part of their normal behaviour (Albright and Arave 1997). Consequently, “zero-grazing” could contravene one of the UK Farm Animal Welfare Council’s “Five Freedoms”, namely freedom to express normal behaviour (Farm Animal Welfare Council 1993). Cattle with access to pasture are sometimes perceived as having better welfare as a result of this freedom (von Keyserlingk et al. 2009). Preference testing is commonly used to help understand animal welfare issues, and it has been applied in several studies looking at whether cattle prefer to be indoors (where they can eat a silage based diet), or whether they would prefer to be at pasture (where they can graze).

Krohn et al. (1992) found that, when given a free choice, cows spent more time at pasture than indoors in the summer, and preferred to lie down outside in the summer but inside in the winter. Legrand et al. (2009) found that cattle preferred pasture, spending on average 13.0 h a day outside, predominantly at night. Pasture use during daylight hours decreased with the temperature humidity index, indicating that the cows were choosing indoors to escape the heat outside. In contrast, Charlton et al. (2009) found that cattle spent 92% of their time indoors. One possible explanation for the apparent preference for indoors in this last study was the fact that the pasture was some distance (88 m) from the indoor area. Spörndly and Wredle (2004) found that cows spent 80% of their lying time outdoors when given access to pasture that was near (50 m) to indoor housing, but preferred to lie indoors when pasture was more distant (260 m).

Alternatively, the cattle used in Charlton et al.’s (2009) study may have preferred indoors because they came from a herd which had largely been kept indoors and had not previously grazed to any great extent. Whilst other factors could have influenced this result, previous experience could have played an important role in influencing their preferences. This raises an important issue in considering animal welfare: do animals “miss” something they have not experienced? Many domestic animal species show vacuum behaviours, e.g., domestic hens in battery cages show “sham” dust bathing behaviour on the cage floor, even though they have had little or no previous experience of suitable dust bathing substrates (Duncan 1998). However, the fact that the cows in Charlton et al.’s (2009) study showed a partial, but strong, preference to remain indoors suggests that they did not “miss” having access to pasture. If this is the case, it might be better for their welfare if cattle are kept either permanently indoors or permanently outdoors, rather than experience a period at pasture in the summer, which means that when housed over the winter their welfare suffers (as a result of missing something previously experienced). This hypothesis warrants testing, as some countries have animal welfare legislation requiring that cattle spend at least part of the year at pasture (Rushen et al. 2008). For example, Swedish legislation requires replacement dairy heifers older than 6 mo to be turned out to pasture.
Do Mixed Rations Have Implications for Animal Welfare?

The second potential animal welfare issue with “zero-grazing” is associated with the “mixed” part of “total mixed rations”. One of the aims when feeding a TMR is to ensure the thorough mixing of all the components that constitute the ration to prevent “sorting” by the animal (Coppock et al. 1981). “Sorting” occurs when then an animal attempts to select specific dietary components and reject others within the TMR, and is considered as undesirable by farmers as it leads to waste of the components rejected by the stock. Feeding concentrates separately from forage can also increase the incidence of metabolic disorders in adult dairy cows (Østergaard and Grohn 2000) as the animals can eat excessive amounts of concentrates leading to ruminal acidosis (Maekawa et al. 2002). The mixing of rations is believed promote a more balanced intake of nutrients across the day in growing dairy heifers (DeVries and von Keyserlingk 2009).

In contrast, Manteca et al. (2008) argue that removing the ability of animals to select their own diets, either by offering total mixed rations or grazing monocultures, compromises their welfare. Although total mixed rations are formulated to meet the needs of the “average” animal in a group, the nutrient requirements of significant proportion of individuals within any group is likely to differ from this average such that for these animals the mixed ration offered contains a surplus of some nutrients and a deficit of others (Atwood et al. 2001). Consequently, a significant proportion of the animals in the group will either need to eat an excess of some nutrients or will not consume sufficient quantities to meet their requirements of other nutrients. Manteca et al. (2008) argue that this imbalance of nutrients in some animals will lead to stress and so compromise their welfare. Similarly, animals are likely to differ in their tolerance to toxins (Manteca et al. 2008). So whilst the majority of animals may be able to tolerate small levels of toxins in a diet, those animals with a lower toxin tolerance will either need to restrict their total intake of a mixed ration or endure the negative consequences of the toxins, again compromising their welfare.

One aspect of diet selection in relation to animal welfare that was not really addressed by Manteca et al. (2008) is the consistent finding, as discussed earlier in this paper, that both sheep and cattle show a diurnal pattern of diet selection. By offering a thoroughly mixed feed, an animal has little, if any, opportunity to express this diurnal pattern, even when the mixed ration meets the individual’s average daily requirement. In thwarting the attempt of an animal to achieve their diurnal pattern of preference, an animal eating a mixed ration may experience an ongoing state of frustration whenever it feeds. The state of frustration has long been associated with suffering (Dawkins 1980), and although mild frustration may be of “trivial importance”, if frequent and involving a fundamental activity, it can impair an animal’s fitness (Broom and Fraser 2007). Eating is of fundamental importance to animals, and ruminant livestock spend several hours a day performing the activity. Consequently, any frustration caused by feeding mixed diets has the potential to be serious enough to compromise animal welfare. Also, even when the nutrient composition of a mixed ration meets the “average” need of an animal, the fact that the composition of ration stays the same when the animal’s preference is changing over the course of the day suggests this problem could potentially affect all sheep and cattle (and possibly other species) fed mixed rations, and not just the significant proportion proposed by Manteca et al. (2008).

Whether or not livestock do experience frustration when eating mixed diets, and how this would manifest itself, is not yet clear. When eating a TMR, cattle will often toss their heads back, resulting in feed being thrown over their backs (Albright 1993). Whist this could be interpreted as the expression of a positive emotional state associated with the consummative part of feeding, it could also be interpreted as a behavioural response indicative of the state of frustration. Clearly, further research is needed to establish whether or not ruminant livestock find the consumption of mixed rations frustrating. One possible approach would be to measure the motivation of animals to gain access to separate feed components compared with free access to a mixed ration. Care would be needed when devising any practical choice feeding system to ensure the animals did not eat excessive quantities of high quality concentrates as this could lead to the metabolic disorders discussed earlier.

CONCLUSIONS

There is strong evidence that domestic ruminant livestock have clear diet preferences, that these change over the course of the day and with changes in physiological state, and they appear to have an evolutionary basis. It is appropriate, with 2009 being both the 200th anniversary of Charles Darwin’s birth and the 150th anniversary of the publication of the Origin of Species (Darwin 1859), to remind ourselves of the evolutionary origins of our domestic stock. Even after thousands of years of domestication, livestock appear to retain at least some of the survival traits that evolved in their ancestors. Rather than ignore these evolutionary traits, we should endeavour to consider them when designing livestock management systems. Research has already shown that the facilitation of diet selection in ruminants (by offering separate feeds) can increase production in grazing sheep and dairy cattle, and this research also has possible implications for both the environment and animal welfare. Making it easier for domestic livestock to express their own preferences may well be an important step in improving animal welfare.
to select their own diets could bring combined improvements in production, the environment and animal welfare, and this win-win-win scenario warrants further research.


Atwood, S. B., Provenza, F. D., Villalba, J. J. and Wiedmeier, R. D. 2006. Intake of lambs offered ad libitum access to one of three iso-caloric and iso-nitrogenous mixed rations or a choice of all three foods. Livest. Sci. 101: 142–149.


