NUTRITIONAL STANDARDS FOR FARM LIVESTOCK
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BEEF CATTLE

A report for the British Society of Animal Science

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Contents

Main recommendations

1. **Dietary energy requirements:** In general, estimates of energy *requirements* are broadly in line with other published models and appear to produce diets in which performance matches expectations in many situations. A number of operators have found it necessary to make adjustments to *supply* from published standards. This is an unsatisfactory situation that needs to be resolved. The energy requirements of modern genotypes need to be assessed, although this information may be available from studies undertaken and models developed in Europe and North America.

2. **Dietary protein requirements:** The current MP model under-predicts MP requirements relative to other systems. It is suggested that modifications of the rumen model, developed by the Feed into Milk project, be may be applicable to beef cattle. The possibility for doing this should be explored, with a view to incorporating them into rationing systems for beef cattle. Estimates of maintenance requirements for growing cattle and lactating cows are significantly lower than those of other published models, and are in urgent need of revision. A number of studies with finishing continental heifers have shown that this type of animal responds positively to an increase in MP supply in excess of requirements as presently estimated by the UK ME/MP system. These issues could be suitable addressed within a DEFRA LINK project, similar in nature to ‘Feed into Milk’.

3. **Voluntary food Intake:** Improved predictions of grass silage intake, based on NIRS calibrations, have been developed in the UK. In the UK, considerable efforts have been made by commercial laboratories (through the FAA scheme) to promote the use of silage intake predictions, based on NIRS analysis, for dairy cows. Consideration should be given to making the NIRS prediction of silage intake by beef cattle, developed at ARINI Hillsborough, more widely available. Models to predict the intake of and production from grazed grass should be reviewed.

4. **Requirements for Minerals and vitamins:** Although developed almost 20 years ago, UK estimates of requirements appear to be broadly in line with more recent recommendations published in other countries. Therefore, reviewing these should be given a low priority. However, the benefits of providing certain trace elements (e.g. zinc, selenium and chromium) at levels generally considered adequate for maintenance and growth merit further study. In addition, discrepancies between estimates in phosphorus requirements for older cattle merit further examination and resolution.

5. **Nutrient requirements of the calf:** Applied studies are required to evaluate the possible benefits of increasing higher levels of milk replacer, especially during the first three weeks of life, than is currently practised, and to explore interactions with starter composition.

6. **Product quality:** It is clear that diet can have a significant effects on both carcass and product quality, and in particular the fatty acid and antioxidant content of meat. However, further studies are needed to characterise responses to nutrients of modern genotypes with respect to carcass and meat quality. The absence of any current financial incentive or public demand for nutritionally enhanced foods (with, for example, improved fatty acid profiles) should not be seen as a reason for not undertaking this work.

7. **Environmental impact:** It is suggested that where effective nutritional models are used, this will minimise environmental impact directly related to diet, although further studies are required to reduce methane emissions by cattle through dietary manipulation.

8. **Technology transfer:** A strategy is needed for the transfer of information from research to end-users. This would best be achieved as a joint DEFRA/industry initiative.

Introduction

Nutritional standards for beef cattle, based on extensive research, have been published in the UK and overseas over many years. Some of the databases most commonly used in the UK are listed in Annex 1. It is clear that the essential components of an effective nutritional model for beef cattle are:

- reliable estimates of requirements for energy, protein, minerals, trace elements and vitamins for target growth rates and milk yields;
- a reliable prediction of feed intake;
- a prediction of the supply of energy and nutrients from the feed consumed;
- the effect of nutrient intake on product quality.

An effective beef rationing system relies on reliable estimates of both requirements and supply. This report deals predominantly with estimates of requirements, although reference is made to the need for improvements in predicting the supply of essential nutrients, primarily through improvements in predicting voluntary intake.

Beef production in the UK encompasses a wide range of rearing systems involving animals of different sex (male, female and castrates) originating from different production systems (dairy or beef) with different target objectives (meat production or breeding). The main classes of livestock are illustrated in Annex 2[1]. An additional dimension to this complexity is the wide range of breeds and crosses used in the industry. The beef industry is thus a multi-faceted one, in which the need for reliable nutrition models will be influenced, to some degree, by the intensity of production. Thus, for example, the need for reliable estimates of the energy requirement of intensively reared bulls may be greater than for over-wintered store cattle.

In addition to improving the efficiency of production, the use of effective nutritional models may help to minimise the environmental impact of cattle through reductions in nitrogen, methane and heavy metal emissions by cattle.

This review attempts to identify those aspects of nutrient supply where further research and application may be justified. In doing so it is recognised that beef production in the UK encompasses a wide range of enterprises, and in practice precision in the supply of nutrients may be difficult to achieve.

Dietary energy requirements

The energy systems used for cattle and sheep have been the subject of a number of comprehensive reviews (Van der Honing and Alderman, 1988; Buchanan-Smith and Fox, 2000; Sinclair and Wilkinson, 2000). In general, these – and the research on

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[1] Data kindly provided by Mr W.P. Harper.

which they are based - have tended to concentrate on predicting nutrient supply, while animal requirements have been derived using older empirical relationships that may not be entirely applicable to modern genotypes.

For much of the first half of the last century, energy systems for cattle were based on the Kellner starch-equivalent system or on fodder units calculated from it. Newer systems, based on metabolizable energy[2] (ME) were adopted in most countries from about 1970 onwards. In the UK, the change from starch equivalent to ME was accompanied by the publication of MAFF Technical Bulletin 33 (MAFF, 1975), and this has formed the basis of rationing for beef cattle ever since. In a number of other European countries and in North America, a net energy (NE) approach was adopted. Requirements for net energy were based on ME, but included an adjustment for the partial efficiency of utilisation (k) of ME for growth.

In the UK, the ME system appears to provide reasonable estimates of energy retention in productive animals, although a number of operators have made adjustments to estimates of supply to produce rations that produce performance that matches. Certainly, it appears to overestimate the energy requirements of late maturing continental cross bulls, especially when these are taken to heavier weights. Some ten years ago, Fox *et al.* (1992) published the Cornell Net Carbohydrate and Protein System (CNCPS), and compared the output from their model what was then the basis of cattle rationing in the United States (NRC, 1989). They concluded that their model provided better estimates of animal performance, although since their estimates of energy requirements were based on NRC (1989), the improvement in prediction of animal performance was most likely achieved through improved predictions of nutrient supply. It appears, therefore, that estimates of energy requirements are generally satisfactory, although they may need modification for some situations.

Current systems of estimating energy requirements adopt a factorial approach. A particular failing is that the ME system fails to describe adequately the effect of different forms of energy on rumen function or the effect of these on the composition of animal products. There is therefore a need for the development of more mechanistic models that predict responses to nutrients, and in particular partitioning of nutrients between the different metabolic processes. Given the similarity between beef and dairy cattle in metabolic processes, the development of a common model for both would be appropriate.

Dietary protein requirements

The Metabolisable protein (MP) model, introduced in 1992 (AFRC, 1992), forms the basis of estimates of protein requirements and supply for beef cattle in the UK. It's introduction ten years ago provided a better conceptual description of the nitrogen (N) fraction of feeds and attempts to distinguish between rumen fermentable energy (i.e.

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[2] Gross energy minus energy in faeces, urine and methane.

that which gives energy for microbial growth) and non-fermentable energy than systems previously employed. In common with other systems (e.g. NRC, 2000), requirements were derived using a factorial approach. Although each of the components, when considered individually appear sound, the system as a whole was not thoroughly tested in production experiments. Indeed, few studies have been conducted that were designed to validate protein requirement systems or to meet the requirements for validation. Frequently, protein supplementation has been confounded with changes in digestibility or energy intake, making the data difficult to interpret, since it is not always clear whether any increases in gain is the result of increased MP or ME intake.

Requirements for MP are calculated from the sum of MP for maintenance and for production (i.e. growth, pregnancy, lactation and wool). In a review for MAFF of the MP system, Cottrill *et al.* (1996) concluded that estimates of requirements of metabolisable protein for maintenance are too low, leading to over-prediction of liveweight gain. This view has been supported by recommendations recently published in N America. For example, NRC (2000) and AFRC (1993) estimates of maintenance requirements for a 400-kg beef animal are 340 and 205 g MP day^{-1}, respectively. As a result, most users of the MP system have arbitrarily adjusted estimates of requirements or supply to produce rations that they believe will work in practice. This is clearly unsatisfactory, and the discrepancy needs to be resolved. Failure to do so will result in either the underfeeding of MP or overestimation of gain from a given supply of MP, while the MP model will be discredited.

The MP system has been criticised for its inadequacy in predicting energy supply to micro-organisms. Given the importance of microbial protein to the overall supply of metabolisable protein, particularly with beef cattle and sheep, this is a major shortcoming. Improving the prediction of the supply of energy to the rumen microbes and the yield of microbial protein formed a major element of the recently completed DEFRA LINK project ('Feed into Milk'). As a result of studies undertaken during the course of this study, recommendations have been made for a new rumen model for dairy cows. It is reasonable to assume that components of the rumen model, together with changes in feed characterisation, could have direct application to beef cattle also and improve the prediction of microbial protein supply. It is recommended that the rumen model developed for Feed into Milk should be evaluated for beef cattle (with approval of the Feed into Milk consortium).

Estimates of requirements of MP for gain, pregnancy, lactation and wool production are similar to those in other systems and are likely to require little revision.

Other protein models currently used for dairy cows in the UK include the Cornell Net Carbohydrate and Protein System (CNCPS; Fox *et al.*, 1992) and the French PDI system (Vérité *et al.*, 1987). Alderman (2001) reviewed the CNCPS model (for dairy cows) on behalf of the Feed into Milk consortium, comparing it with other estimates of requirements (AFRC, 1993; NRC, 1988). No similar critical evaluation has been undertaken for beef cattle in the UK, nor is it clear the extent to which the CNCPS beef model is used in the UK. Some advisors in the UK also use the PDI system, but again the extent to which it is used specifically for beef cattle is not clear.

Dietary minerals, trace element and vitamin requirements

Standards used in the UK are generally based on those published by ARC (1980), and modified by Todd (1982). For many of the trace elements and major minerals, the recommended requirements published recently by NRC in the USA (NRC 2000) are broadly similar to those recommended by Todd (1982). The requirements for calcium and phosphorus were also reviewed in 1991 (AFRC, 1991). Examples of estimates of requirements for a 250 or 450 kg steer gaining at 1.0 or 1.5 kg liveweight day^{-1} are illustrated below.

	1.0 kg LWG day^{-1}			1.5 kg LWG day^{-1}		
Calcium	Todd (1983)	AFRC (1991)	NRC (2000)	Todd (1983)	AFRC (1991)	NRC (2000)
250 kg LW	34	26	33	48	39	44
450 kg LW	39	29	31	51	41	39
Phosphorus						
250 kg LW	17	26	16	21	39	21
450 kg LW	31	29	18	35	41	21

For calcium, AFRC (1991) generally recommended lower daily intakes than either Todd (1983) or NRC (2000), that were broadly similar. For phosphorus, estimates of requirements for younger animals were again similar between Todd (1983) and NRC (2000), but interestingly the allowances recommended by Todd (1983) are substantially higher than those of NRC (2000) for older animals. The reason for this appears to be that phosphorus requirements for growing cattle in NRC (2000) are expressed per kg of *net protein gain*, while those of Todd (1983) and AFRC (1991) are expressed per kg *liveweight gain*. By adopting the NRC (2000) approach, a reduction in the proportions of lean to fat deposited - as is the case with older animals - will be associated with a relative reduction in phosphorus requirements. Given the current emphasis on reducing the use of phosphorus in UK agriculture, these discrepancies merit further attention.

There is increasing evidence that feeding certain trace elements at levels above those recommended for maintenance, growth and production may have benefits in terms of animal health. For example, the use of chromium[3] (for which no dietary requirements have been established) can reduce the adverse effects of stress in cattle, while supplementation with zinc and selenium has been shown in some circumstances to reduce mastitis in lactating cattle. In view of potential welfare implications, this

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[3] Note that chromium is currently not an approved additive to livestock diets within the European Union.

evidence warrants further examination.

Voluntary feed intake

Factors that influence and regulate the voluntary feed intake (VFI) of beef cattle are complex and not clearly understood, although it appears that the dominant factors are physiological demand due to maintenance needs and potential for production, and limits in gastro-intestinal capacity. There is a wealth of evidence to show that, in growing animals in particular, there is a curvilinear relationship between dietary energy concentration and VFI, particularly on concentrate-based diets. Intake increases as net energy concentration increases, until a point is reached where metabolic controls become the main factor that limits intake, and no further increase in intake is observed.

Since the majority of beef systems in the UK rely on silage as the main winter feed, accurate predictions of silage intake are a fundamental prerequisite of any nutritional model designed to estimate the amount of forage consumed and supplementary feed required to achieve a given level of production. A number of models have been developed that aim to predict intake of forages by cattle, with varying degrees of complexity and accuracy. ARC (1980) reviewed a number of published equations for predicting the voluntary intake of grass silage by cattle. They concluded that the effects of breed and sex of cattle on intake were small, but acknowledged that the data base on which these conclusions were based were limited. Since then, considerable research effort has been directed towards identifying factors that affect intake with a view to developing equations to predict voluntary intake, particularly of forages, either as the sole feed or when given in conjunction with other (mainly concentrate) feeds. The effects of concentrate feed level and silage dry matter content and fermentation characteristics on intake by beef cattle were confirmed in the "RUMINT" series of studies. More recent studies at ARINI, Hillsborough, have confirmed the importance of the fibre fraction, organic matter digestibility, dry matter content, the amount of residual sugars and the crude protein content of the silage on silage dry matter intake (DMI). In addition, the form of the nitrogen, whether as soluble or as ammonia-N appeared to have an important effect on silage intake. Perhaps surprisingly, however, fermentation characteristics, i.e. pH and concentrations of total volatile fatty acids (VFA's) or individual acids (lactic, acetic, propionic, butyric) were only weakly related to intake.

The importance of fibre in influencing intake was further emphasised by NRC (2000) who reported that on all-forage diets the best-fit equation to predict intake included terms for both crude protein and acid detergent fibre (ADF). Given the fairly high correlations between dietary energy metabolizability and fibre concentrations (Mertens, 1994), this relationship is perhaps not surprising. However, neither this equation, nor equations reported in an earlier NRC (1987) review satisfactorily predicted intake, indicating the involvement of other feed and/or animal factors.

In the Hillsborough studies, the best predictor of intake was based on near infra-red reflectance spectroscopy (NIRS) calibrations, suggesting that aspects of silage not normally analysed by conventional analytical techniques may have a significant impact on silage DMI. This has resulted in the development of NIRS predictions of silage intake which offer greater accuracy than has been possible using chemical analyses. Consideration should be given to making these NIRS calibrations more widely available.

Prediction of intake from grazed grass poses particular problems for beef producers. A number of computer models have been developed elsewhere to predict the intake of and production from grazed grass (e.g. "Quickfeed" developed in New Zealand). These may be applicable under UK conditions and merit assessment.

Nutrient requirements of the calf

Calf rearing is a very specialised skill, and is increasingly carried out in specialised units. Although there is some debate over the definition of a calf[4], calf rearing includes both the pre-ruminant and post-ruminant animal.

Considerable research was undertaken in the UK during the middle and latter part of the last century to establish the nutrient requirements of calves. The data from these studies, and those undertaken elsewhere, was comprehensively reviewed and by Roy (1980), and the nutrient standards outlined in that publication still form the basis of recommendation to-day. In North America, standards recommended by Davis and Drackley (1998) have been widely used and certain feed manufacturers in the UK have also referred to them on some occasions. As part of their series on the nutrient requirements of dairy cows, NRC (2001) has recently reviewed the nutrient requirements of young calves. With respect to the pre-ruminant calf, Tanan and Newbold (2002) concluded that in using the systematic approach adopted by NRC (2001) and others there is a risk of underestimating energy requirements and overestimating nutrient supply during the first three weeks of life. They concluded that dairy heifer calves should be offered a higher level of milk replacer, especially during the first three weeks of life, than is currently practised, and that concentrations of protein and lactose can be increased, and fat decreased, to optimise composition of gain. They acknowledged, however, that good calf management and effective use of colostrum have a direct impact on nutrient requirements (e.g. through the effect of environmental temperature) and nutrient supply (e.g. through the effect of colostrum on development of the digestive tract and, thus, digestibility).

Nutrient requirements of growing dairy heifers

Heifer rearing programmes for dairy heifers to calve down at two years of age are well established, to achieve average daily gains of 0.75 kg day^{-1} and a liveweight of about 550 kg at parturition. It is reasonable to assume that the principles apply to beef heifers also, although in practice slightly lower target rates of gain may be adopted under some rearing systems.

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[4] Under statutory Instruments in the UK, the calf is normally defined as cattle up to six months of age.

Nutrient requirements of pregnant cows

It is generally assumed that the nutrient requirements for pregnancy are proportional to the birth weight of the calf, and therefore factors that influence this will also have a major effect on determining the nutrient requirements. While factors such as the parity of the dam, the sex and number of foetuses and the nutrition of the dam have all been shown to influence the birth weight of the calf – and therefore nutrient requirements – the breeds of the sire and dam appear to have the greatest effect. AFRC (1990) lists birth weight ranging from 26 kg (Angus) to 43 kg (Charolais, Simmental); alternatively the equation of Roy (1980) may be used for calculating the birth weight of the calf based on the mature weight of the breed of the dam.

As AFRC (1980) noted, the factorial approach to calculating energy allowance of pregnant cows is made difficult because of two inter-related processes, namely defining the maintenance requirement of the dam and foetus and, secondly, ascribing an efficiency of utilisation of dietary ME to the process of foetal growth and maintenance. Although indirect evidence is available to suggest that maintenance energy requirements increase during gestation (AFRC, 1980), Ferrell *et al.*, (1976) were unable to confirm this using comparative slaughter techniques. In Technical Bulletin 33 (MAFF, 1975), half of the energy accounted for by the increased heat increment associated with gestation was allocated to the production of the concepta, and this was added to the energy deposited in the concepta to give the ME requirement for growth. The remaining half was assumed to arise from the demands of maintenance of the foetus and the dam. ARC (1980) made no attempt to apportion energy demand; maintenance requirement of the dam was assumed to be the same as for a non-pregnant animal, and the additional energy requirement was assumed to be entirely due to the growth of the concepta. NRC (2000) assume that approximately 0.75 of the increase in energy cost associated with pregnancy may be attributable to metabolisms of the tissue of the uterus and of the foetus itself (NRC, 2000). In principle, differences in approach should be resolved, although in practice differences between the different systems are small. On many beef units, the nutrition of the pregnant beef heifers and cows is given a relatively low priority on many beef units, and this is therefore reflected in recommendations for research in this area. It is more likely to be justified for dairy heifers and cows, although the results of any research would be applicable to beef cows as well.

In AFRC (1993), estimates of protein requirements for pregnancy are based on the daily tissue protein retention for pregnancy to produce a 40 kg calf as proposed by ARC (1980). These are then scaled as proportionately for calves of different weight. Metabolisable protein is assumed to be utilised (k_{nc}) with an efficiency of 0.85. NRC (2000) use a similar approach but different equations, with the result that AFRC (1993) recommends slightly higher requirements for pregnancy (e.g. 179 g net protein at 280 days of gestation compared with 156 g day^{-1} for NRC 2000).

Carcass and Product quality

There is increasing consumer demand for leaner meat. As a result, carcass quality - and specifically the amount of carcass fat - directly affects the value of the meat produced. Beef producers are therefore particularly interested in the effect of diet on carcass quality. There is considerable evidence to show that present and previous nutrition can have a significant effect on the ratio of fat to lean tissue in finishing cattle, although the results of studies have not always been consistent. In particular, there is conflicting evidence on the effects of protein - and particularly rumen undegraded protein – and the form of energy (starch vs. fibre) on the effects on carcass composition. Since much of the research was undertaken in the latter half of the last century, not all of it may be applicable to modern genotypes or crosses used in the UK.

Research and epidemiological studies undertaken over the last couple of decades or so have indicated that the total amount of fat and the relative proportions of individual fatty acids in the human diet may have a marked effect on the incidence of a number of diseases, and in particular cardio-vascular diseases. At the same time, it has been shown that the composition of fat in animal products is influenced by the fatty acid content of the diet consumed by the animal. However, the effects of these studies have yet to be reflected in consumer demands for 'healthier' meat. Although there is currently no financial incentive to produce meat with, for example, higher concentrations of polyunsaturated fatty acids or improved n3:n6 ratios, research is needed on genotype/nutrition interactions in respect of both carcass quality and product quality.

Modelling systems

Current estimates of nutrient requirements have been obtained using empirical models. While these may be capable of providing broad generalisations of the impact of diet on production and product quality, in the longer term the development of mechanistic models, which consider both energy and protein supply and take account of interactions between them, are likely to be necessary. These will also, inevitably, bring voluntary food intake into true focus as a response to be predicted, rather than an input to be assumed. A number of mechanistic models and semi-mechanistic models have been developed which describe the digestion and metabolism of a wide range of substrates (e.g. Baldwin *et al.*, 1997; Dijkstra and France, 1996) in ruminants generally, or of beef cattle in particular (e.g. Fox *et al.*, 1992). While some are currently being used, others are still being validated. The main disadvantage of this approach is that the models frequently require more information than is currently available to operate reliably. Their main strength is that they can accommodate new information on digestion and metabolism as it occurs. The development of such models will improve the ability of beef producers to provide meat that more closely matches the needs and requirements of consumers. Basic similarity in basal metabolism would justify the joint development of models for both beef and dairy cattle.

Conclusion

The beef industry in the UK is a complex one. It involves a wide range of inputs, a broad spectrum of production systems and many different outputs designed to meet market requirements. Each of these different production systems has different needs and priorities in terms of the detail required in establishing nutrient requirements. It is against this background that this review has attempted to identify key areas where improvements in our understanding of nutrient requirements and supply would be most helpful for the industry as a whole, and these are summarised at the start of this document.

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Annex 1. Published standards for nutrient requirements most commonly used for diet formulation in the UK.

	Reference	Current use in UK
Energy		
ME	AFRC, 1993	Forms the basis of most rationing systems.
NE	NRC, 2000	Only recently published, and so not widely used in practice.
CNCPS	Sniffen *et al.*, 1992	Has been used in the UK for rationing dairy cows to a limited extent. It is not clear to what extent the beef model has been used.
	Roy, 1990	Basis of energy requirements of calves.
Protein		
MP	AFRC, 1994	Forms the basis of most rationing systems. Has been extensively modified by users, in conjunction with supply, to deliver recommendations believed by the operator(s) to be appropriate.
MP	NRC, 2000	Only recently published, and so not widely used in practice.
PDI	Verite *et al.*, 1987	Is used by a few feed manufactures in the provision of advice and recommendations for customers.
CNCPS	Sniffen *et al.* 1992	Has been used in the UK for rationing dairy cows to a limited extent. It is not clear to what extent the beef model has been used.
	Roy, 1990	Basis of nutrient requirements for calves.
Minerals & vitamins		
	ARC, 1980	Formed the basis of MAFF *et al.* (1983) recommendations.
	Todd, 1983	Modification of ARC (1980). Forms the basis of most rationing systems used in the UK, although generally considered as the *minimum* allowances. For a number of trace elements, levels above these minima are usually fed.
	NRC, 2000	Recommendations broadly similar to those of MAFF *et al* (1983), but with a few notable exceptions (see text).
	Roy, 1990	Basis of mineral requirements of calves.

Annex 2: Main categories of beef cattle

Category	**Age range**	**B = Beef** **D = Dairy**	**Steer**	**Heifer**	**Bull**
Bucket reared calves	4 days-12 weeks	B & D	Y	Y	Y
Beef calves bucket reared	12 -30 weeks	B	Y	Y	
Dairy Heifer calves	12 - 30 weeks	D		Y	
Beef yearlings 1st summer	4 -12 month	B	Y	Y	
Dairy Heifers 1st summer	4 -12 month	D		Y	
Intensive bulls Holstein/Friesian	6 – 14 months	B			Y
Intensively finished suckled bulls	9 – 15 months	B			Y
Beef cattle 2nd winter	8 – 18 months	B	Y	Y	
Beef cattle 2nd winter finishing	12 – 18 months	B	Y	Y	
Beef cattle heavyweight finishing	18 – 30 months	B	Y	Y	
Dairy heifers 2nd winter	9 – 18 months			Y	
Beef finishing cattle at grass	18 – 30 months	B	Y	Y	
Dry beef cows		B			
Pre calving beef heifers		B			
Lactating beef cows & heifers					
Working Bulls		B			
Growing Bulls for stud duties		B			