Robust animals for grass based production systems

Delaby L.1, Buckley F.2,McHugh N.2, Blanc F.3

1 INRA, AgroCampus Ouest, UMR Physiologie, Environnement et Génétique pour l’Animal et les Systèmes d’Elevage, 35590 Saint Gilles, France

2 Teagasc, Animal & Grassland Research and Innovation Centre, Moorepark, Fermoy, Co Cork, Ireland

3 Université Clermont Auvergne, VetAgro Sup, INRA, UMR Herbivores, 63122 Saint-Genès-Champanelle, France

Abstract

A characterisation of dairy, beef and sheep best suited to profitable/sustainable production within the context of European [semi] intensive pasture-based systems will be conducted. To deliver optimal performance, pasture must be managed effectively, but pasture-based systems are less energy intensive and are climate sensitive. This induces challenges and constraints not normally posed to animals in intensive feeding environments and emphasises the importance of animal traits associated with robustness and adaptive abilities. A survey of French dairy farmers concluded that a robust cow is a “transparent” cow with a long lifetime. The traits required under grazing include: efficient converters of feed to product, such as high milk yield or milk solids (dairy) or meat yield/weaning weight (beef/sheep), good functionality, healthy, reproductively fit and finally exhibiting longevity. Unique to successful grazing, is a capability to achieve large intakes of forage to meet productive potential and an ability to adapt to fluctuating feed supply. In seasonal systems, grazing ruminants will be expected to conceive and give birth at the appropriate time each year, usually within 365 days. The optimum breed or strain will differ, based on local management constraints and objectives. However, general principles do apply and recommendations will be made based on this review with regard to the traits of interest for pasture based production.

Keywords: robustness, grass based system, grazing, selection

Introduction

As a consequence of the increasing world food demand associated with the growth of the human population, the future requires promotion of more efficient, sustainable livestock systems, and the use of greater proportions of non-human competitive products to feed farm animals. The ruminant’s natural ability to consume forages and sub-products and to produce high quality human food helps to develop and to improve forage based systems. Within these systems, grass-based systems using preferential grazing as animal feed, are viewed as economically and environmentally optimum. In temperate areas, well managed grass grazed is the unique forage which is correctly balanced to meet the nutritional requirements of both large and small ruminants.

In the context of this paper pasture-based systems may be characterised as systems where the primary feed source is grazed grass (typically ≥ 60% of the diet). The extent and efficiency with which grazed pasture is maximised will vary across Europe. Intensified pasture-based systems such as that practiced in Ireland are characterised by long term permanent pastures, the application of grazing management practices to maximise pasture production and quality in combination with relatively high stocking density to result in high milk solids or carcass production per unit area. Less intensified pasture-based systems, more typical of France, tend to be associated with a greater diversity environment; multispecies pastures (some with clover) or natural grasslands, seasonal climatic extremes, and availability of high quality alternative feeds. Common, however, is a lower cost of production, system resilience and environmental sustainability (O’Donovan & Delaby, 2016). A further advantage is greater societal acceptability as a ‘friendly livestock system’ (Cardoso *et al.*, 2016). But all these advantages of grass-based systems are only effective if the characteristics of the dairy, beef and sheep breeds can match the requirements and limits of such systems.

The objective of this synthesis paper is to highlight such specificities and to outline the key animal characteristics required by robust cattle and sheep in pasture-based systems.

A brief background to grass-based system specificities

Pasture-based systems are generally more constraining, less stable and more uncertain than indoor based systems, whereby, the system is designed to serve the animal. In pasture-based systems, the reverse is true. The system is such that the animal is faced with natural irregularities or antagonisms, e.g., inclement climatic conditions, parasitic agents etc. As the animal is *de facto* an integrated part of the system, the animal is expected to contribute to its ability to face environmental variability and hazards, this is called robustness. Genetically robust dairy cows are less sensitive to sub-optimal circumstances (Veerkamp *et al.*, 2013). In a recent paper Friggens *et al.* (2017) proposed a generic definition of animal robustness as “*The ability, in the face of environmental constraints, to carry on doing the various things that the animal needs to do to favour its future ability to reproduce* “.

In contrast to dairy cattle where only about 10% of the world’s milk production is from grazing systems, beef and sheep are primarily managed under grazing. Consequently, in general, different strains of individual beef or sheep breeds have, either not evolved from selection in different production environments, or they have not spread outside of their original geographical area (Buckley *et al.*, 2005). Dairy cows that are optimal in a pasture-based system of production share many general characteristics with cows that are appropriate for a non-pasture system. However, the relative importance of traits can differ (Washburn & Mullen, 2014). Nutrient demand intentionally coincides with seasonal forage availability, fertility is emphasised, as generally so does selection for high milk fat and protein content. Similar principles apply to beef and sheep where production is also chiefly based on the efficient conversion of grass to meat. As with seasonal pasture-based dairying, efficiency is optimised when beef cows/ewes give birth in spring with increasing herd/flock demand matched by increasing pasture supply.

Ability to adapt to grazing

Maximising grass intake is a key characteristic in grass-based systems (Delagarde *et al.*, 2001). Feeding behavior is inextricably linked to the nature of the feed on offer and the circumstance by which the feed is presented (Prendiville *et al.*, 2010). Systems based on grazed pasture intrinsically limit nutrient intake compared with indoor total mixed ration (TMR) diets. This is evident from studies conducted in the USA by Kolver & Muller (1998) who suggested a 20% decrease in daily intake with pasture-fed cows. A similar result was observed in Ireland by Kennedy *et al.* (2003) and Horan *et al.* (2006) where Holstein cows highly selected for milk volume were not capable of eating enough to satisfy the demand associated with the milk potential. The study of Prendiville *et al.* (2010) related feeding time of lactating dairy cows in their pasture-based study with comparable feeding times in a TMR-based indoor study (Aikman *et al.*, 2008) . Apart from environmental, plant, and management factors (Dillon, 2005), milk production from pasture is limited by the ability of the grazing animal to consume sufficient quantities of herbage (Stakelum & Dillon, 2003). Increased grass allowance induces higher level of grass intake but also higher level of refusals and decreases pasture utilisation (Pérez-Prieto & Delagarde, 2013 ; Delaby & Horan, 2017. Therefore, a balance must be achieved between performance on per animal and per hectare basis (McCarthy *et al.*, 2011). Effective pasture management enforces a limited grass allowance, balancing the dual objectives of generous feeding to achieve performance and high levels of pasture utilization, thus optimising farm profitability (Penno, 1998).

A study in beef cattle by Goodman *et al.* (2016) on rangeland pastures has observed behavioral adaptation to the decrease in food availability. Across two diverse temperament profiles, beef cows classified as fast eaters when indoors were shown at grazing to spend less time close to the drinker and to explore a larger area of the pasture. They were considered to express a “go getters” temperament. In contrast, slow eaters cows expressed a “laid back” temperament. Interestingly, the two contrasting temperament profiles were shown to be positively correlated to animal performance with “go-getters” showing shorter return to estrous after calving and heavier calf weaning weights than “laid-back” cows. These findings are in line with Prendiville *et al.* (2010) who showed that cows with higher production efficiency were more aggressive grazers. Pryce *et al.* (2005) observed that dairy animals that are lighter are capable of superior productivity within intensive pasture-based systems because of their lower maintenance requirements and higher production per unit of feed consumed. An ability to achieve large intakes of forage relative to their productivity potential should also confer an increased likelihood of survival, another integral component of optimal financial performance (Lopez-Villalobos *et al.*, 2000).

Ability to cope with variability of grass resources and to rebound

As grazing systems are subjected to the external environment, animals may be exposed to unpredictable disturbances from the external environment (severe climate, predation, diseases, Mirkena *et al.*, 2010). Animals react to such perturbations by initiating adaptive responses that may alter phenotype, physiology and/or behavior. These adaptive responses rely on underlying adaptive mechanisms that will support the ability of the animal to withstand and/or rebound from perturbation (resilience or indeed robustness). Such adaptive mechanisms were reviewed in several papers (Blanc *et al.*, 2006; Mirkena *et al.*, 2010; Mulliniks *et al.*, 2016) that outlined the key roles of metabolic flexibility, nutrients allocation, body reserves, behavioral strategies and temperament to explain the diversity in ability to rebound. In grass-based systems deviations in productive or functional traits are tolerated when animals are experiencing disturbances provided that they can react quickly when conditions become favorable again. For example, as described by Blanc *et al*. (2007), 40% of the ewe lambs that experienced a severe under nutrition from 3 to 9 months were still not cycling at 9 months of age. But after the introduction of ad libitum feeding, they reached puberty within a 3 weeks period and could be used for breeding. Such an ability to rebound is also observed for other life functions like growth (compensatory growth in heifers, Hoch *et al.*, 2003) or lactation as observed on the milk yield in a 10-days residence time grazing paddock (Roca-Fernandez *et al.*, 2012).

In temperate climates, grass growth is seasonal with maximum growth observed in spring (between mid of April to end of May; Northern Hemisphere), a variable decrease in summer and minimum or no growth observed in the winter months. This aspect is well illustrated with the 4 regional French and Ireland grass growth profiles simulated with the ‘Moorepark St Gilles’ grass growth model (Figure 1a and b - Ruelle *et al.*, 2018). This typical profile has large consequences on the feed resources available to animals, with an excess of grass often observed in spring and a deficit in winter. The summer period is probably the most variable period according to the latitude in Europe and depending of local temperature and rain regularity.*{Place here figure 1}*

Coupled with the seasonality in grass growth is the unstable nature of the nutritional value of grass, which changes firstly with the season, the age of regrowth and the phenological stages. Leafy grass or legumes in spring are characterised with a high nutritive value, in terms of energy, protein content and also voluntary intake. Although at this time the grass is highly palatable, the ratio between the grass energy content to the fill unit value, named energy density, can be too low to match a lactating animals energy demand. Matching the animal demands with grass only in the spring months can be a real challenge. With conserved grass, hay or silage not supplemented with concentrate, the feeding situation may be worse and can result in energy deficit periods as shown in Figure 2. This is particularly important for dairy cows in early lactation at grazing (Peyraud & Delagarde, 2013) or for suckling cows and ewes at the end of gestation when fed with poor forages quality indoor in winter. *{Place here figure 2}*

In these conditions, the challenge for the ruminant female is to maximise grass or forage intake and where deficits in energy requirements exist the ruminant must be able to react and limit the consequences of this imbalance. This imbalance between the grass energy supply and the energy demand of the lactating beef cow rarely occurs due to the relatively low milk production potential of the cow and milk yield demand of the often single suckled calf. However, for ewes rearing high litter sizes, managed at high stocking rates coupled with the low energy demand of grass can have a knock-on effect on lamb growth rate and the number of days to slaughter for individual lambs (Earle *et al.*, 2017a). Such physiological energy deficit resulting from high requirements concomitant with limited intake capacity have been exacerbated by genetic selection for productive traits such as milk yield in the North American Holstein (Kolver & Muller, 1998) and selection for high prolificacy levels in ewes (Safari *et al.*, 2005). This is well illustrated in the INRA Le Pin experiment where Holstein cows turned out at grazing with only 3 kg of DM of concentrate after a 9 to 11 weeks early lactation indoor winter feeding period. The Holstein cows with a greater milk yield potential had greater observed milk yields at the peak of lactation in winter and during all the spring grazing period. However, they also expressed a greater decline in the milk yield 6 and 12 weeks post-turnout (Table 1).*{Place here table 1}*

To cope with nutritional challenges resulting both from changes in seasonal grass availability and quality and changes in animal nutritive requirements, animals must be able to store body reserves when feed conditions are favorable and to mobilise them in limiting feeding conditions. Cows that can maintain a higher body condition score may have an advantage in pasture systems because they can draw upon body reserves if feed is limited (Pryce & Harris, 2006). As described by Delaby *et al.* (2010), the body condition score losses, reflecting body tissue mobilization in early lactation, are higher in Holstein breed with high genetic merit for milk yield and in low feeding levels compared with Normande low genetic merit for milk yield and high feeding levels. These observations were also reported by Roche *et al.* (2006) comparing North American or New Zealand Holstein cows with or without concentrate supplementation at grazing and by Dillon *et al.* (2006) within Irish experiments comparing different dairy breeds. An on-going sheep study in Ireland (McGovern & McHugh, 2017) has shown that greater body reserves mobilisation in early lactation is observed in ewes of high genetic merit for maternal traits relative to ewes of low genetic merit for maternal traits in a grass-based system. On an annual basis the animal must be able to limit the consequence of poor condition score (energy balance) on other functions such as fertility, sensitivity to disease, and ultimately longevity. But in reality, in both cows and high prolificacy ewes early in lactation, control of body reserve mobilisation is very difficult as it is highly associated with genetic merit (Walsh et al., 2008) and the body condition score at calving or lambing.

Ability to reproduce and achieve compact parturition

One of the main objectives of grass-based ruminant producers is to be at least self-sufficient in forages and if possible to be totally feed self-sufficient. At farm level, in grass-based systems, the first factor to determine the level of self-sufficiency is the global stocking rate (i.e. the number of cattle or sheep that can be fed on the farm area). The optimum stocking rate will be highly dependent of the local agro-climatic potential. Secondly a producer must match herd/flock demand to the seasonality of grass availability (Butler, 2014; Delaby & Horan, 2017; Earle *et al.*, 2017a). In ruminant production, the maximum energy demand usually occurs in the period immediately pre-parturition and during the weeks following parturition when milk production reaches its peak. Consequently, the optimal grass-based system parturition should occur in the weeks prior to high grass availability. Seasonality of reproduction in small ruminant species is a natural adaptation to the annual pattern of grass resources availability; in bovines, reproduction can occur at any time within the year.

Reproduction performance is one of the most important determinants of production efficiency and genetic gain in most dairy production systems (Esslemont & Peeler, 1993). The use of minimal supplementation coupled with seasonal calving requires cows that are reproductively efficient and adapted to obtain most of their nutritional needs from pasture (Washburn & Mullen, 2014). It is generally accepted that Holstein cows highly selected for milk yield are not suited to seasonal pasture-based systems due to reduced body condition score and inferior reproductive performance (Dillon *et al.*, 2006 – Table 2).*{Place here table 2}*

Furthermore, in order to maximise reproductive performance and lifetime production efficiency, heifers must conceive at around 15 months and calve by 24 months of age (Heinrichs & Hardgrove, 1987). In seasonal production systems, the relative importance of age at puberty is greater than in confinement and year-round calving systems. To achieve seasonal targets, an early onset of puberty is critical (Archbold *et al.*, 2012). Breed differences do exist suggesting differences in suitability for intensive compared with less intensive pasture based dairying and indeed beef production. The findings of Archbold *et al.,* (2012) indicate that Jersey×Holstein-Friesian heifers are earlier maturing than Holstein-Friesian heifers, whereas, continental breeds like Normande or Montbeliarde are a little bit later maturing. Larger European beef breeds were shown to grow faster to heavier mature weights, but reach puberty at older ages and have lower reproductive efficiency, especially in less favorable conditions (Morris *et al.*, 1993).

In countries or regions where the rain is evenly distributed across the year (40 to 60 mm monthly) and grass growth occurs in summer, the ideal parturition period is in spring (Figure 3). Spring turnout dates should be adapted according to the start of the grass growth and will be later in northern compared with southern Europe, or in uplands compared with lowlands. For cattle, a compact calving period in spring allows peak grass growth to coincide with the lactation period. For sheep, the shorter lactation period (3 months) allows for high stocking rates to be achieve during the highest grass growth period in the year. Moreover, during this period (i.e., spring and early summer), the grass nutritive value matches the animal nutritional requirements. An additional benefit of calving in the spring for dairy and beef cows is that the dry off period coincides with winter when the grass growth ceases and conserved forages can supply the lower nutritive value of the animal. In regions with frequent drought periods in summer, two parturition periods occurring at six months intervals may be optimal (Pottier *et al.*, 2007 – Figure 3). According to the area of the grazing platform, the herd size assigned to one period can be half/half or two third/one third, respectively in spring and autumn.*{Place here figure 3}*

Compact calving or lambing require a strictly managed compact breeding period and excellent fertility performance. This demands a return to cyclicity to coincide with the commencement of the breeding season and to successfully achieve pregnancy within a limited breeding period of 3 months for cattle and 1.5 month for ewes. In one lambing per year sheep farming systems, reproduction occurs in the post-weaning period whereas in the case of both beef and dairy cows reproduction occurs during early lactation. Ewes have a greater chance to recover body reserves prior to mating thereby increasing their ability to maximize prolificacy (i.e. litters of multiples). As prolificacy is one of the most important criteria of the lamb production system efficiency (Earle *et al.*, 2017b); maximising litter size or prolificacy is a function of the genetic strain (Dawson and Carson, 2002) and also the body reserves (‘flushing’) at mating (Coop *et al.*, 1966). In beef cattle when the breeding season occurs at grazing the increase in feeding level improves the energy status of the cows thereby reducing the period to cyclicity, specifically in thin cows (Friggens *et al.*, 2017). The dairy cow situation is more complicated as a consequence of the high nutrients demand for lactation at this period (Friggens *et al.*, 2010) and impacts a cascade of fertility characteristics. To obtain good reproductive performance, the luteal activity has to be restored and regular, the oestrus and heats should be well expressed and easy to detect and after AI, the fecundation should be effective and the embryo implantation success to re-calve (Bedere *et al.*, 2017a and b). This defines the proprieties of a robust cow according the objective of compact calving.

Ability for maternal care and to stay healthy

During parturition another important robustness characteristic of dairy, beef and sheep is the ability to deliver a viable offspring. Increased dystocia at parturition (caesarian, vaginal tearing) has a negative impact on subsequent reproductive performance especially in cattle (Meijering, 1984). Levels of dystocia must also be minimised to reduce labour requirements at parturition and also to provide a favorable perception to consumers of grass-based production systems. Maternal care traits such as mothering ability or progeny suckling ability are also of importance to ensure low levels of calf or lamb mortality in all systems but especially in extensive systems (Macfarlane *et al.*, 2010).

A survey of dairy farmers (Ollion, 2015) where farmers were asked to define a robust cow, 80% of farmers answered a “*cow with no problems, never sick, who doesn’t need to see the veterinarian*”. In terms of health, three traits are specifically relevant to grass-based systems. The first key characteristic is the ability of the animal to cope with parasite burdens. Parasite burden is a major issue in grass based systems as, when not controlled it can have negative effects on productivity and when anthelmintic treatments are used questions are raised in relation to its impact on the environment as well as anthelmintic resistance. At the animal level, genetic selection for reduce parasite burdens can be achieved (Moreno-Romieux *et al.* 2017; McHugh *et al.*, 2014). Animals on grass-based systems are also more susceptible to the effects of inclement weather and grass nutrients imbalance (excess of nitrogen, minerals), and are therefore at greater risk of metabolism or digestive disequilibrium such as bloating, grass tetany and also for ewes, pregnancy toxemia. Such nutritional disorders are often lethal and therefore non-occurrence is a necessity. The last major problem for grazing system concerns feet and legs diseases. Dairy cows must walk to the milking parlour two times per day, therefore lameness is a common occurrence. In addition, lameness in sheep, often characterised by scald or footrot is common within grass-based systems (O’Brien *et al.*, 2017). Lameness, in either sheep or dairy cows, has a negative impact on the animal’s ability to graze, thereby reducing energy intake and thus milk or growth performance as well as reproductive performance.

A robust animal must be a multi-functional animal

Robustness is a multi-factorial trait and relies on the ability of the ruminant female to be able to assume the highlighted productive and functional expectations, to cope with constraints and be resilient to disturbances. Recently Ollion *et al.* (2016) performed multivariate analysis to explore the diversity in the ways cows prioritise between life functions (milk yield, body condition change and reproduction success) in early lactation (time when dairy cows are experiencing an energy deficit). The concept of dairy cow profiles developed in this study helps to describe different types of cows beyond the breed effect. This method has been applied on the INRA Le Pin experiment (Cloet *et al.*, 2015) and four profiles with specific trade-offs have been highlighted (Figure 4). Some cows prioritise milk solids yield without a detrimental effect on reproduction (cluster 1) while others are less efficient with regard to fertility without compensating in milk solids (cluster 2) or are unable to compromise (cluster 4). Clearly, cluster 3 appears to be more in accordance with compact calving grass based systems with priority given to reproduction (pregnancy rate = 99% *vs* 64% on average) and maintaining body condition without impairing milk solids yield. It is possible to hypothesize that such differences between profiles are associated with a diversity in nutrient acquisition (forage intake capacity) and/or in nutrient allocation (Friggens *et al.*, 2017).*{Place here figure 4}*

Genetic improvement programmes should use a selection index that combines all the economically important traits appropriately for the local conditions and systems (Buckley *et al.*, 2005). An excellent example of success in this regard is the Irish Economic Breeding Index (EBI). Both genetic trends from the national population (Figure 5) and the most recent results from a controlled experiment at Teagasc Moorepark, “Next Generation Herd” (Table 2) are illustrations of the consequence of a better agreement in the selection criteria and producer goals (Buckley *et al.*, 2017). Experimental evidence from studies in beef and sheep also indicate that selection of females based on their genetic merit for maternal type traits may result in the selection of a more robust female for grass-based systems (McCabe *et al.*, 2016; McGovern and McHugh, 2017). A ‘better balance’ may also be obtained by crossbreeding (Dezetter *et al.*, 2015; Buckley *et al.*, 2014; Coffey *et al.*, 2016) due to a combination of both breed complementarity and heterosis.*{Place here figure 5}*

This concept of a well-balanced animal is well expressed by grassland farmers in response to an open multi-answer survey realized by Ollion *et al.* (2015) and presented in Ollion *et al.* (2018). The question was “What is a robust cow to you?” The first trait (80% of farmers speak about) cited by farmers was good health (never sick, no veterinary need) followed by morphology with 64% (solid legs, able to go grazing, good udder). The third trait quoted (33%) concerned reproductive function with an ideal of one calf every year. Intake capacity, milk yield and temperament closed the list, cited by 18 to 20% of the farmers. Besides quoting functional, productive or behavioral traits, farmers also characterised a robust cow through integrative characteristics or properties. “*Longevity*” was mentioned by 50% of the farmers followed by “*transparency”* (36%) *and* “*ability to adapt*” (33%). Transparency means that the animal is totally transparent within the system. This last expression (*The better females are those you never hear about*) was also reported by Brochard *et al.* (2016) in a survey concerning all the ruminant females.

Conclusion

For [semi] intensive pasture-based systems, robustness can be defined under three broad characteristics: 1/ match high milk or growth performance to high forage intake capacity, 2/ ensure high fertility (cattle) and prolificacy (sheep) and the delivery of offspring without assistance, and 3/ remain healthy. These three main objectives challenge breeding and genetic research to define and to be able to evaluate the best parameters to select future generations of ruminant livestock. Multi trait selection is definitely more complicated than single trait selection as has been the focus in the past. It must be cognizant of sustainability within future ruminant feeding systems.

References

Aikman P.C., Reynolds C.K. and Beever D.E. (2008) Diet digestibility, rate of passage, and eating and ruminating behavior of Jersey and Holstein cows. *Journal of Dairy Science* 91, 1103-1114.

Archbold H., Shalloo L., Kennedy E., Pierce K.M. and Buckley F. (2012) Influence of age, body weight and body condition score before mating start date on the pubertal rate of maiden Holstein-Friesian heifers and implications for subsequent cow performance and profitability. *Animal* 6, 1143-1151.

Bedere N., Disenhaus C., Ducrocq V., Leurent-Colette S. and Delaby L. (2017a) Ability of dairy cows to be inseminated according to breed and genetic merit for production traits under contrasting pasture-based feeding systems. *Animal* 11:5, 826-835.

Bedere N., Disenhaus C., Ducrocq V., Leurent-Colette S.and Delaby L. (2017b) Ability of dairy cows to ensure pregnancy according to breed and genetic merit for production traits under contrasted pasture-based systems. *Journal of Dairy Science* 100, 2812-2827.

Blanc F., Bocquier F., Agabriel J., D’Hour P. and Chilliard Y. (2006) Adaptative abilities of the females and sustainability of ruminants livestock systems: a review. *Animal Research* 55, 489-510.

Blanc F., Fabre D., Bocquier F**.**, Canepa S., Delavaud C., Caraty A., Chilliard Y. and Debus N. (2007) Effect of a post-weaning restricted nutrition on the initiation of puberty and the reproductive performances of early bred Merino ewe-lambs. *Options Méditerranéennes, Série A* 74 : 387-393.

Brochard M., Delaby L., Dumont B., Ezanno P., Foucras G, Frappat B., Gonzales-Garcia E., Hazard D., Moreno C. and Phocas F. (2016) Outils et leviers pour favoriser le développement d’une génétique adaptée aux enjeux de l’agro-écologie pour les élevages de ruminants. *Rencontres Recherches Ruminants* 23, 137-140.

Buckley F., Lopez-Villalobos N. and Heins B. J. (2014) Crossbreeding: implications for dairy cow fertility and survival. [*Animal*](http://www.ncbi.nlm.nih.gov/pubmed/24784768) 8: s1,122-33.

Buckley F., Holmes C. and Keane G. (2005) Genetic characteristics required in dairy and beef cattle for temperate grazing systems. *XX International Grassland Congress,* Cork Satellite Meeting, July 3-5, 61-75.

Buckley F., O’Sullivan M., McParland S., Lahart B. and Shalloo L. (2017) Teagasc’s Next Generation dairy herd – proofing the EBI. In *Irish Dairying – Resilient Technologies, Moorepark ’17 Open day* 4th July, 90-91. https://www.teagasc.ie/media/website/publications/2017/Teagasc-Moorepark2017-Booklet.pdf

Butler S. (2014) Nutritional management to optimize fertility of dairy cows in pasture-based systems. *Animal* 8:s1, 15-26.

Cardoso C.S., Hötzel M.J., Weary D.M., Robbins J.A. and von Keyserlingk M.A.G. (2016) Imagining the ideal dairy farm. *Journal of Dairy Science* 99, 1663-1671.

Cloet E., Blanc F., Ollion E. and Delaby L. (2015) La robustesse des vaches laitières : Une approche basée sur les compromis entre fonctions biologiques et perspectives de valorisation dans les schémas de sélection génétique, Mémoire de fin d’études, ISA Lille, 80 pages.

Coffey E.L., Horan B., Evans R.D. and Berry D.P. (2016) Milk production and fertility performance of Holstein, Friesian, and Jersey purebred cows and their respective crosses in seasonal-calving commercial farms. *Journal of Dairy Science* 99, 5681-5689.

Coop I.E. (1966) Effect of flushing on reproductive performance of ewes. *Journal of Agricultural Science* 67, 305-323.

Dawson L.E.R and Carson A.F. (2002) Effects of crossbred ewe genotype and ram genotype on ewe prolificacy, lamb viability and lamb output in the lowland sector, *Journal of Agricultural Science, Cambridge* 139, 169-181

Delaby L., Horan B., O’Donovan M., Gallard Y. and Peyraud J.L. (2010) Are high genetic merit dairy cows compatible with low input grazing system?, *Grassland Science in Europe* 15, 928-930.

Delaby L. and Horan B. (2017) Improved efficiency in temperate grass based dairy systems. In *Proceedings of the 54ª Reunião Anual da Sociedade Brasileira de Zootecnia*, 24 a 28 de Julho de 2017 – Foz do Iguaçu – Brasil. ISSN 1983-4357, 133-145.

Delagarde R., Prache S., D’Hour P. and Petit M. (2001) Ingestion de l’herbe par les ruminants au pâturage. *Fourrages* 166, 189-212.

Dezetter C., Leclerc H., Mattalia S., Barbat A., Boichard D. and Ducrocq V. (2015) Inbreeding and crossbreeding parameters for production and fertility traits in Holstein, Montbéliarde, and Normande cows. *Journal of Dairy Science* 98, 4904-4913.

Dillon P. (2005) Achieving high DM intake from pasture with grazing dairy cows. In: Dijkstra J., Taminga S., Bogers R.T. and Elgersma A. (eds), *Fresh herbage for dairy cattle: the key to a sustainable food chain*. Proceedings of the Frontis Workshop on fresh herbage for dairy cattle. Wageningen, The Netherlands: Wageningen Agricultural University, 1-26.

Dillon P., Berry D.P., Evans R.D., Buckley F. and Horan B. (2006) Consequences of genetic selection for increased milk production in European seasonal pasture based systems of milk production. *Livestock Science* 99, 141-158.

Earle E., McHugh N., Boland T. and Creighton P. (2017a) Effect of ewe prolificacy potential and stocking rate on ewe and lamb performance in a grass-based lamb production system. *Journal of Animal Science* 95, 154-164.

Earle E., Boland T., McHugh N. and Creighton P. (2017b) Measures of lamb production efficiency in a temperate grass-based system differing in ewe prolificacy potential and stocking rate. *Journal of Animal Science* 95, 3504-3512.

Esslemont R.J. and Peeler E.J. (1993) The scope for raising margins in dairy herds by improving fertility and health. *British Veterinary Journal* 149, 537-547.

Friggens N.C., Disenhaus C. and Petit H.V. (2010) Nutritional sub-fertility in the dairy cow: towards improved reproductive management through a better biological understanding. *Animal* 4:7, 1197-1213.

Friggens N.C., Blanc F., Berry D.P. and Puillet L. (2017) Review: Deciphering animal robustness. A synthesis to facilitate its use in livestock breeding and management. *Animal* <https://doi.org/10.1017/S175173111700088X>

Goodman L. E., Cibils A. F., Wesley R. L., Mulliniks J. T., Petersen M. K., Scholljegerdes E. J. and Cox S. H.. (2016) Temperament affects rangeland use patterns and reproductive performance of beef cows. *Rangelands* 38:5, 292-296.

Heinrichs A and Hargrove G (1987). Standards of weight and height for Holstein heifers. *Journal of Dairy Science* 70, 653-660.

Hoch T., Begon C., Cassar-Malek I., Picard B. and Savary- Auzeloux I. (2003) Mécanismes et conséquences de la croissance compensatrice chez les ruminants, INRA Productions Animales 16, 49−59.

Horan B., Faverdin P., Delaby L., Rath M. and Dillon P. (2006) The effect of strain of Holstein-Friesian dairy cow and pasture-based system on grass intake and milk production. *Animal Science* 82, 435-444.

Institut de l’Elevage (2015) *Guide de l’alimentation du troupeau bovin allaitant. Vaches, veaux et génisses de renouvellement*. Ed. Institut de l’élevage, Paris, 340pp.

Kennedy J., Dillon P., Delaby L., Faverdin P., Stakelum G. and Rath M. (2003) Effect of genetic merit and concentrate supplementation on grass intake and milk production with Holstein Friesian dairy cows. *Journal of Dairy Science* 86, 610-621.

Kolver E.S. and Muller L.D. (1998) Performance and nutrient intake of high producing Holstein cows consuming pasture or a total mixed ration. *Journal of Dairy Science* 81, 1403–1411.

Lopez-Villalobos N., Garrick D.J., Blair H.T and Holmes C.W. (2000) Possible effects of 20 five years of selection and crossbreeding on the genetic merit and productivity of New Zealand dairy cattle. *Journal of Dairy Science* 83, 154-163.

Macfarlane J.M., Matheson S.M., and Dwyer C.M. (2010) Genetic parameters for birth difficulty, lamb vigour and lamb sucking ability in Suffolk sheep. *Animal Welfare* 19, 99–105.

Meijering A. (1984) Dystocia and stillbirth in cattle: a review of causes, relations and implications. *Livestock Production Science* 11, 143–177.

McCabe S., Mc Hugh, N., O’Connell, N.E. and Prendiville, R. (2016) Comparative maternal performance of high and low replacement index beef cows. In *Proceedings of the British Society of Animal Science*, 07-April-2016, 93.

McCarthy B., Delaby L., Pierce K.M., Journot F. and Horan B. (2011) Meta-analysis of the impact of stocking rate on the productivity of pasture-based milk production systems, *Animal* 5:5, 784-794.

McGovern F. and McHugh N. (2017) An Irish New Zealand Animal Comparison – The INZAC Flock. *Teagasc Sheep Open Day*. Teagasc, 66-70.

McHugh N., Potterton S., Wall E. and T Pabiou (2014). Genetics of sheep health traits. In: *10th World Congress on Genetics Applied to Livestock Production*, Vancouver, Canada, p 896.

Mirkena T., Duguma G., Haile A., Tibbo M., Okeyo A.M., Wurzinger M. and Sölkner J. (2010) Genetics of adaptation in domestic farm animals: A review. *Livestock Science* 132, 1–12.

Moreno-Romieux C., Sallé G., Jacquiet P., Blanchard A., Chylinski C., Cabaret J., François S D., Saccareau M., Astruc J.M., Bambou J.C. and Mandonnet N. (2017) La résistance génétique aux infections par les nématodes gastro-intestinaux chez les petits ruminants: un enjeu de durabilité pour les productions à l’herbe. *INRA, Productions Animales*, 30(1) 47-56.

Mulliniks J. T., Cope E. R., McFarlane Z. D., Hobbs J. D. and Waterman R. C. (2016) Drivers of grazing livestock efficiency: how physiology, metabolism, experience and adaptability influence productivity. *Journal of Animal Science* 94(S6),111–119.

Morris C.A., Baker R.C., Hickey S.M., Johnson D.L., Cullery N.G. and Wilson J.A. (1993) Evidence of genotype by environment interaction for reproductive and maternal traits. *Animal Production* 56, 69-83.

O’Brien A.C., Mc Hugh N., Wall E., Pabiou T., McDermott K., Randles S., Fair S. and Berry D.P. (2017) Genetic parameters for lameness, mastitis and dagginess in a multi-breed sheep population. *Animal* 11, 911-919.

O’Donovan M. and Delaby L., (2016) Grazed grass in the dairy cow diet – how this can be achieved better ! *Grassland Science in Europe* 21, 350-365.

Ollion E. (2015) Evaluation de la robustesse des vaches laitières : entre aptitudes biologiques des animaux et stratégies de conduite des éleveurs. Thèse soutenue le 20 Nov. 2015, Clermont Ferrand, France, 254 pages. https://tel.archives-ouvertes.fr/tel-01312209/document

Ollion E., Ingrand S., Delaby L., Trommenschlager J.M., Colette-Leurent S. and Blanc F. (2016) Assessing the diversity of trade-offs between life functions in early lactation cows. *Livestock Science* 183, 98-107.

Ollion E., Cloet E. Brives H.and Magne M. A. (2018) Suitable cows for grass-based systems: what stakeholders do? *Grassland Science in Europe* 22, this volume.

Penno J.W. (1998) Principles of profitable dairying. *Proceedings of the Ruakura farmers conference* 50, 1-14.

Pérez-Prieto L.A. and Delagarde R. (2013) Meta-analysis of the effect of pasture allowance on pasture intake, milk production, and grazing behavior of dairy cows grazing temperate grasslands. *Journal of Dairy Science* 96, 6671-6689.

Peyraud J.L. and Delagarde R. (2013) Managing variations in dairy cow nutrient supply under grazing. *Animal* 7:s1, 57-67.

Pottier E., Delaby L. and Agabriel J. (2007) Adaptations de la conduit des troupeaux bovins et ovins aux risques de sécheresse. *Fourrages* 191, 267-284.

Prendiville R., Lewis E., Pierce K.M. and Buckley F. (2010) Comparative grazing behaviour of lactating Holstein-Friesian, Jersey and Jersey × Holstein-Friesian cows and it association with intake capacity and production efficiency. *Journal of Dairy Science* 93, 764-774.

Pryce J.E., Harris B.L., Montgomerie W.A., Jackson R, MacDonald K.A., Glassey C.B., Thorrold B.S. and Holmes C.W. (2005) Comparing feed allowances to inferred energy intake using data from a dairy grazing farm trial. *Proceedings NZ Society of Animal Production* 65, 225-230.

Pryce J.E. and Harris B.L. (2006) Genetics of body condition score in New Zealand dairy cows. *Journal of Dairy Science* 89, 4424-4432.

Roca-Fernandez A.I., Gonzales-Rodriguez A., Leurent S., Lopez-Mosquera M.E, Gallard Y. and Delaby L. (2012) Milk performance of two cow breeds at two levels of supplementation in long residence time grazing paddocks. *Grassland Science in Europe* 17, 267-269.

Roche J.R., Berry D.P. and Kolver E.S (2006) Holstein-Friesian strain and feed effects on milk production, body weight and body condition score profiles in grazing dairy cows. *Journal of Dairy Science* 89, 3532-3543.

Ruelle E., Hennessy D. and Delaby L. (2018) Development of the Moorepark-St Gilles grass growth model (MoSt GG model): a predictive model for grass growth in pasture based systems, *European Journal of Agronomy*, submitted.

Safari E, Fogarty, N.M. and Gilmour A.R. (2005) A review of genetic parameter estimates for wool, growth, meat and reproduction traits in sheep. *Livestock Production Science* 92, 271-289.

Stakelum G. and Dillon P. (2003) The effect of concentrate type and sward characteristics on herbage intake, diet composition and grazing behavior of dairy cows. *Irish Journal of Agriculture and Food Research* 42, 55-70.

Veerkamp R., Kaal, L., De Haas Y. and Oldham J. (2013) Breeding for robust cows that produce healthier milk: RobustMilk. *Advances in Animal Biosciences* 4(3), 594-599.

Walsh S., Buckley F., Pierce K., Byrne N., Patton J. and Dillon P. (2008). Effects of breed and feeding system on milk production, body weight, body condition score, reproductive performance and postpartum ovarian function. *Journal of Dairy Science* 91, 4401-4413.

Wasburn S.P. and Mullen K.A.E., (2014) Invited review: Genetic considerations for various pasture-based dairy systems. *Journal of Dairy Science* 97, 5923-5938.

Table 1: Effect of milk potential (evaluated with the peak of lactation) on milk and body condition score changes during the spring grazing period (adapted from the INRA Le Pin 2006-2015 experiment)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  |  |
|  | Milk yield (kg / day) | Body condition score [0 to 5] |
|  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
|  | Peak of lactation | At grazing turnout(lactation days) | 6 weeksafter turnout | 12 weeksafter turnout | At calving | At turnout | 12 weeks after turnout |
|  |  |  |  |  |  |  |  |
| Primiparous |  |  |  |  |  |  |  |
| > 35 kg at peak | 39.8 | 35.9 (74) | 30.5 | 25.3 | 3.25 | 2.50 | 2.10 |
| <35 kg at peak | 30.6 | 28.4 (78) | 25.6 | 21.9 | 2.85 | 2.60 | 2.40 |
| Multiparous |  |  |  |  |  |  |  |
| > 45 kg at peak | 51.0 | 45.7 (60) | 36.1 | 30.6 | 2.85 | 2.25 | 2.00 |
| < 45 kg at peak | 40.4 | 35.8 (66) | 31.5 | 26.1 | 2.60 | 2.40 | 2.25 |
|  |  |  |  |  |  |  |  |

Table 2: Reproductive performance observed in the INRA Le Pin experiment (The cow for the system? - 2006-2015) and in the Teagasc NGH experiment (Next Generation Herd – 2013-2016) in comparison with the objective for grass-based dairy system and compact calving management (12 weeks calving period).

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  |  |
|  | Objective | The cow for the system? (1) | NGH (2) |
| Feeding level |  | High | Low |  |  |
| Breed |  | Holstein | Normande | Holstein | Normande | NatAv | Elite |
|  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
| Milk yield (kg) |  | 8660 | 6000 | 6230 | 4670 | 5610 | 5410 |
| BCS at calving (pts [0 to 5]) |  | 2.85 | 3.50 | 2.65 | 3.10 | 2.75 | 2.90 |
| BCS losses (pts [0 to 5]) | 0.50 | -1.00 | -0.60 | -1.20 | -0.85 | - | - |
| Interval calving - 1st ovulation (days) | 25 to 30 | 41 | 33 | 39 | 30 | - | - |
| Normal cyclicity profile rate (%) | 80 | 48 | 65 | 44 | 77 | - | - |
| First AI in-calf rate (%) | 60 | 33 | 43 | 28 | 38 | 46 | 61 |
| 6 week in-calf rate (%) | 70 | 41 | 46 | 35 | 51 | 58 | 73 |
| 13 week in-calf rate (%) | 90 | 60 | 73 | 55 | 68 | 81 | 92 |
|  |

(1) High : In winter (100 days), early in lactation, total mixed ration with maize silage, dehydrated alfalfa and concentrate, ad libitum. At grazing (180 days), 0.35 ha per cow, 4 kg concentrate and 5 kg maize silage from July. In autumn (85 days), 5 kg maize silage, 4 kg concentrate and grass silage ad libitum.

Low : In winter (100 days), early in lactation, total mixed ration with grass silage and big bale haylage, ad libitum. At grazing (180 days), 0.55 ha per cow. In autumn (85 days), grass silage ad libitum. No concentrate.

(2) Two genotypes based on Ireland’s dairy selection index, the Economic Breeding Index (EBI): NatAv (n=45 annually) representing national average based on EBI and Elite (n=90 annually) representing the top 1%.

Figure 1: Annual grass growth profile according to the geographic localisation in France and Ireland (a) and the year in Normandy (b).



On an average of 10 years (Figure 1a), the grass growth profile of a same type of pasture with the same level of N mineral applied differs because altitude, rain, temperature and light differ. The grass growth starts early in Ireland (Co Cork - Fermoy - 52°08 N / 8°16 W), later in upland (Auvergne - Marcenat - 45°18’ N / 2°49’ E) and is higher in summer than in Normandy - Le Pin (Lowland - 48°44’ N / 0°08’ E) or in Poitou-Charentes - Lusignan (Lowland - 46°26’N / 0°07’ E), region with higher temperatures in summer and mainly less regular rains. Within a region, the average profile is also highly variable between years, week per week, due to the highly variable climatic conditions (Figure1b).

Figure 2: Changes in net energy requirements (dotted line) and energy intake (solid line) of beef cows in a winter calving system in France. Energy balance is negative during all the indoor building period because of low energy density of hay and increasing energy requirement from the end of pregnancy and early lactation. Energy balance becomes positive since cows are turned out and graze (after Institut de l’Elevage, 2015)



Figure 3: Grass-based system management recommendations for cattle and sheep according to the grazing season length and the risk of drought period in summer (after Delaby & Horan, 2017; Pottier *et al*, 2007; .Earle *et al*, 2017 a).



Figure 4: Expression profiles of priorities between milk solids yield, body condition score and pregnancy rate of Holstein and Normande cows. Deviations are expressed in relative proportion (%) of the mean value observed for the 457 lactations Clusters of lactation profiles were identified by multivariate analysis followed by clustering analysis. Values between brackets are number of lactations in each cluster.



Figure 5: Rate of genetic gain in Economic Breeding Index (EBI), Milk sub-index (MILK\_SI), Fertility sub-index (FERT-SI);€ per lactation) for dairy females born in Ireland between 1996 and 2017 - A. Cromie, Irish Cattle Breeding Federation, personal communication

