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Scientific appraisal of the Irish grass-based milk production system as a sustainable source of premium quality milk and dairy products

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Abstract

The Irish dairy industry is critically important to the economy and general well-being of a large section of the Irish population. Its quality, sustainability and maintenance are the key for a vibrant rural society in the future. Two important elements for the future of this industry include (a) the quality, marketing and sale of dairy products on the export market and (b) sustainability from the perspectives of people, planet and profit. This paper provides a short review of current scientific evidence in relation to a number of topics, each of which is important in maintaining and developing dairy product quality and the sustainability of the Irish dairy industry. The topics addressed in the paper are as follows: the parameters of milk composition; milk processing; hygiene quality and safety; farm management practices and the regulations that govern such practices; animal health and welfare; environmental impacts; economic implications for farm families and rural communities; and the overall future sustainability of the family-based dairy farm structure.

Keywords

dairy industry • environment • milk quality • product quality • sustainability

Introduction

Farming practices are primarily determined by climate and the resources available to farmers. A mild climate, fertile soils and abundant rainfall are the natural resources that have enabled Ireland to become one of the world's leading producers of milk and dairy products. The climate permits dairy cows to graze outside for up to 300 d of each year (O'Donovan *et al*., 2011). Grass growth in Ireland exceeds the European average by more than one-third, providing a comparatively low-cost, high-quality and sustainable diet for Ireland's dairy herds. Approximately two-thirds of Ireland's land mass is used for agriculture (4.44 million hectares), with 80% used for pasture, hay and grass silage (Irish Food Board [Bord Bia], 2017; Department of Agriculture, Food and the Marine [DAFM], 2017).

Ireland's temperate climate enables Irish dairy farmers to use pasture as a low-cost primary feed resource producing a seasonal milk supply (Finneran *et al*., 2012). The Irish dairy industry is characterised by sustainable milk production from grazed pasture and the delivery of high-quality products to Ireland's milk markets. In this paper, the Irish pasture-based system of milk production is examined from the perspective of its attributes that are important to consumers and its sustainability. The paper will consider research findings that suggest that the Irish pasture-based system produces milk with good and healthy composition, achieves high efficiency in relation to greenhouse gas emissions and has established an audit system that ensures Irish milk producers operate in accordance with the highest international standards in relation to animal health, animal welfare, food safety and food quality, resulting in a sustainable social and economic dairy industry. The scientific evidence in some instances is generated from studies that are currently ongoing at the Teagasc Animal and Grassland Research Centre at Moorepark, Co. Cork, Ireland. This paper provides a short review of current scientific evidence in relation to a number of topics, each of which is important in maintaining and developing the sustainability of the Irish dairy industry. The topics addressed in the paper are as follows: the parameters of milk composition; milk processing; hygiene quality and safety; farm management practices and the regulations that govern such practices; animal health and welfare; environmental impacts; economic implications for farm families and rural communities; and the overall future sustainability of the family-based dairy farm structure.

Pasture-based milk production

Typically, in Irish pasture-based feeding systems, cows are maintained outdoors, grazing fresh pasture during the warmer

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months and being dried off and housed indoors in the winter months leading up to the spring calving period (Dillon *et al*., 1995). In Ireland, the research targets for efficient milk production are to have 90% of the cows calved in a 6-wk period in early spring each year (French *et al*., 2015). Cows then go to grass, resulting in the best fit between grass supply and feed demand, and the lactation extends from early February to late November. Within such a system, the most efficient dairy farms are, on average, stocked at 2.35 cows/ha, producing >400 kg milk solids (MS)/cow (>950 kg MS/ha) and utilising >9.5 t dry matter (DM)/ha (French *et al*., 2015). Minimum concentrates are fed to these cows at an approximate level of 350 kg/yr. In Ireland, well-managed grass has a high nutritive value, which can meet the feed requirements in spring, summer and early autumn. Dillon *et al*. (2005) showed that the total cost of milk production tends to increase as the proportion of grazed grass used decreases. Shalloo (2009) showed that 44% of the variation in milk production costs in Ireland can be explained by the quantity of grass utilised/ha by the dairy herd. Grass DM intake/cow in an intensive grass-based system in Ireland is approximately 3.5 t DM/yr (French *et al*., 2015). A description of the grass-based milk production system, showing the feed input and milk output for the dairy cow over a 12-mo period, is provided in Figure 1.

Alternative systems of production that incorporate, for instance, a total mixed ration (TMR) diet, combined with year-round indoor housing, are widely used in the USA and a number of European countries (van Arendonk and Liinamo, 2003, Barberg *et al*., 2007). Such systems involve feeding cows a TMR diet composed of a mix of grass and maize silage, carbohydrates and concentrates, which achieve a high milk production performance per cow through greater control of feed intake quality and increased daily DM intake (Charlton *et al*., 2011). Van den Pol-van Dasselaar *et al*. (2014) showed that the economic benefit of grazing in the Netherlands depends on the proportion of fresh grass intake of grazing dairy cows. Grazing is financially attractive if the grass intake is >600 kg DM/cow per year. If the intake falls below this threshold, grazing is less profitable than keeping the cows in the barn.

Up until 31 March 2015, the quantity of milk produced in the European Union (EU) was regulated by quotas. As EU farmers decide on their level of milk production within the new system (no longer limited by quotas as to how much they may produce), it has been suggested that if there is an increase in milk production, it will probably lead to a reduction in the overall level of grazing in many EU countries (Hennessy *et al*., 2015). Fragmentation of farms is a major problem across Europe in relation to grass-based milk production (Latruffe and Piet, 2013). The size of the block of land around the milking parlour, or within walking distance of the milking parlour, dictates the quantity of grazed grass available to the dairy cow herd. Across Northern Europe, there is an increasing trend to amalgamate dairy farms. Usually, cows are grouped together at one site to improve efficiencies in relation to milking and labour use. However, in many instances, the amount of grazing ground available to the amalgamated herd is reduced, resulting in less grazing and a reduced grazing season.

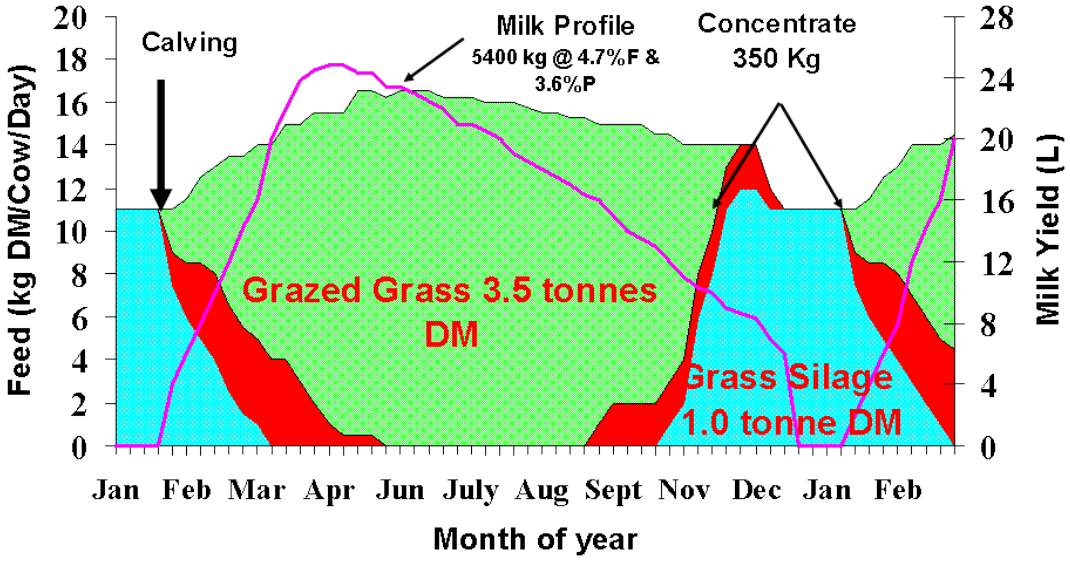

Figure 1. Description of the grass-based milk production system showing the feed input and milk output for the dairy cow over a 12-mo period. DM = dry matter.

Milk composition and processability

Animal nutrition directly affects the quality and nutritional value of dairy products (Downey and Doyle, 2007). Irish cows are predominantly fed pasture for the majority of the lactation, which influences milk composition, processability and the sensory characteristics of the milk, which in turn determine the quality of Irish dairy products (O'Brien and Guinee, 2016). Studies on cows offered significant quantities of grazed grass (Kelly *et al*., 1998; Coakley *et al*., 2007; Wyss *et al*., 2010; Butler *et al*., 2011; O'Callaghan *et al*., 2016) revealed that their milk contained increased levels of the unsaturated fatty acids, conjugated linoleic acids (CLAs), vaccenic acid, and omega-3 fatty acids, which are considered beneficial to human health, compared to the milk produced by cows on other diets, such as grass silage and concentrate-based diets. This was considered a positive and important finding as unsaturated fatty acids are believed to be better for human health (Haug *et al*., 2007). Milk from cows on largely grazed grass diets was also found to be higher in vitamins A and E compared to the milk produced by cows on non-pasture diets (Martin *et al*., 2004). However, much of this research was conducted over short periods during the lactation season, sometimes using cross-over studies or replicated Latin square designs. There is limited information available comparing the composition and quality of raw milk produced by cows on different feeding regimes over an entire lactation season. However, such a study has recently been carried out by O'Callaghan *et al*. (2016).

The study of O'Callaghan *et al*. (2016) involved two cow herds; one was housed indoors and offered a TMR diet, with the second maintained outdoors on a perennial ryegrass pasture (a typical Irish grass-based diet). The study was conducted from 11 March 2015 to 28 October 2015. Results indicated that the milk produced by cows on the pasture diet had significantly higher yearly average protein content than that of the milk produced by the cows on the TMR diet. Importantly, from a manufacturing perspective, the contents of true protein, casein and whey protein were found to be significantly higher in the pasture-based milk. An increase in the protein content of pasture-based milk compared to TMR-based milk was also reported in a study by Couvreur *et al*. (2006), which found a linear correlation between the increase in milk protein content and the increase in the pasture content of the cows' diet. The O'Callaghan *et al*. (2016) study found that pasture-based feeding systems produced milk with significantly higher concentrations of saturated fatty acids $C_{11:0}$, $C_{13:0}$, $C_{15:0}$, $C_{17:0}$ and $C_{23:0}$, as well as unsaturated fatty acids $C_{18:2n6t}$, $C_{20:1}$ and $C_{20:4n6.}$ The authors also reported that the CLA content of the pasture-based milk was more than twice that of the TMR-based milk. The TMR feeding system produced milk with increased concentrations of $C_{16:0}$, $C_{18:2n6c}$, $C_{18:3n6c}$, $C_{22:0}$ and $C_{22:1n9.}$ Seasonal variations in the milk composition of pasture-based systems have been described in previous studies (Auldist *et al*., 2000; Bargo *et al*., 2003; Mehra et al, 1999; O'Brien *et al*., 1999a, 1999b, 1999c). In a pasture-based system, the lactation profile of each individual cow is almost identical to the lactation profile of the entire herd. Thus, there is the potential to exercise greater control over the selection of milk at each defined stage of lactation. The pasture-based system can ensure the absence of late lactation milk from any individual cow or group of cows in a herd by imposing a specific cow drying-off (cessation of milk) strategy (Guinee and O'Brien, 2010), whereas the separation of late lactation milk is more difficult with the year-round calving pattern normally associated with confined milk production systems. O'Callaghan *et al*. (2016) reported that a principal component analysis of the average fatty acid profiles showed a quite distinct and clear separation of milks throughout lactation in relation to the two feeding regimes. The study makes an important contribution to identifying how pasture-derived milk can be verified by fatty acid profiling. An extended version of the study of O'Callaghan *et al*. (2016) is currently ongoing and is focussed on identifying and comparing differences in milk (in relation to composition, sensory value, volatiles and processability) and milk products (butter, cheese, whole milk powder and infant formula) produced from grass and TMR diets. The findings can then be used to benchmark the profile of milk produced from the Irish grass-based system against that of TMR-based systems in use in the USA and other EU countries. This should provide the basis for developing procedures to identify and verify milk produced by these different cow-feeding regimes.

Milk quality and safety

Food safety is an issue of ever-increasing concern as the food supply chain lengthens. The sharing of knowledge and the process of improving trust and understanding among farmers, processors, retailers and consumers are major priorities within the dairy industry. The quality and safety of milk are judged using a range of criteria relating to the composition of the milk, the hygiene maintained at each stage of production and the testing for residues of veterinary medicines, including antibiotics. The DAFM is the designated authority responsible for enforcing milk quality standards and safety legislation covering each stage of production. Farm inspections are conducted routinely, and DAFM's veterinary inspectorate, in consultation with the Food Safety Authority of Ireland, is responsible for the design and implementation

of a national milk residue-monitoring plan (as required under EU Directive 96/23/EC, 1996). Veterinary provision for dairy animals exists to ensure the good health of the animals, but it is necessary to ensure that any veterinary intervention does not compromise milk safety or quality. Regulations exist with regard to the use of veterinary drugs (including antibiotics and sulphonamides). Specific withdrawal periods are designated to ensure that milk from antibiotic-treated cows does not enter the food chain. A range of residue testing is conducted, including testing for residues classified as B1 (antibacterial substances: antibiotics such as penicillins, tetracyclines, quinolones, aminoglycosides and macrolides; and sulphonamides such as sulfadiazine, sulfadimethoxine, sulfamethazine and sulfathiazole). Ireland's National Residue Control Programme is conducted as directed under EU Council Directive 96/23/EC (1996); each member-state is required to implement a residue-monitoring plan and to submit their programmes annually to the European Commission for approval. In Ireland, this is conducted using a targeted sampling process. Samples are initially screened using a microbial inhibition test. In positive samples, chromatographic methods are used to identify and confirm the identity and quantity of antibiotic present. Milk processors (the purchasers of milk) are responsible for checking milk quality and safety at the initial processing of the milk, prior to allowing the milk through to the product manufacturing line. Samples are taken from every tanker, and if the milk does not pass, all of the milk in that tanker is removed and is not processed. As a consequence, there is no possibility that consumers could ever buy commercial milk containing antibiotics. Similar stringent regulations apply with regard to the use of anthelmintic drugs in the treatment of health problems, such as liver fluke, in milk-producing animals. Various anthelmintic drugs are designated as 'non-administration' or 'administration with strict adherence to withdrawal periods' in relation to their use with cows and in-calf heifers (www.hpra.ie). These regulations are devised by the Health products Regulatory Authority (HPRA) and managed through the Sustainable Dairy Assurance Scheme (SDAS), which is operated by Bord Bia (Irish Food Board) (www.bordbia.ie). Discussions are currently taking place between Teagasc and the milk processors as to how they can address, through research and appropriate procedures, the identification and treatment of new residues in milk. Examples of such residues include trichloromethane (TCM), chlorates, quaternary ammonium compounds and phthalates. Currently, each year, 25,000–30,000 milk samples are taken from suppliers by the milk-purchasing company and screened for TCM by Teagasc. A well-developed advice programme and control plan have been established for use by farmers (Gleeson and O'Brien, 2009; Ryan *et al*., 2013).

Farm management practices

Milk production practices on Irish farms are strictly controlled. Three national schemes have been established to regulate these practices and are described in the following sections.

Sustainable Dairy Assurance Scheme in Ireland

Bord Bia's national Sustainable Dairy Assurance Scheme (SDAS) (www.bordbia.ie) has been developed in cooperation with milk producers, processors and regulatory authorities. It sets out the necessary criteria that suppliers must meet in order to produce milk to the required standard. In addition, and very importantly, the scheme has the capacity to assess and record data obtained from each farm that supplies milk. This enables the SDAS to demonstrate that the milk used in the production of dairy products meets both sustainability and quality assurance criteria. The scheme is fully accredited under the European Standard for Product Certification: ISO 17065. The process involves an initial independent audit to evaluate the milk producer's capability to meet the SDAS's requirements. Once the producer has demonstrated the ability and capacity to comply with the requirements, the producer's herd is audited for certification. When the herd is certified, the producer is issued with a certificate and listed on the Bord Bia register and database.

Animal Identification Movement System

The bovine Animal Identification Movement System (AIMS) is operated by DAFM (www.agriculture.gov.ie) and was established to provide an effective animal identification and tracing system. This was seen as an important component in guaranteeing the safety and quality of milk and milk products. The system has four elements: tagging, bovine passport, on-farm bovine herd register and a computerised database. Under the system, all calves have to be tagged within 20 d of birth. The owner is required to register the birth of each calf on a central birth registration database. Once the registration is crosschecked and validated, a passport for each animal is issued by the registration agency. The passport must accompany the animal and be updated each time the animal is moved during its lifetime. The farmer is required to maintain an up-to-date herd register of all bovine animals on the farm. This must include a record of all animal births, all animals entering and leaving the farm and all animal deaths. As a consequence, the AIMS database can be used to verify the origin, identity and life history of each animal entering the food chain. It can also be used to assist in the identification and tracing of bovines that may have come in contact with infectious diseases, enabling veterinary certification. The database is used to provide a wide range of statistical information on the Irish cattle sector.

Economic Breeding Index

The long-term genetic selection for high milk yield has potential to be a major cause of health and welfare problems in dairy cows (Oltenacu and Broom, 2010). This selection has also contributed to changes in the form and size of dairy cows, affecting their behaviour and other adaptive mechanisms (Ingvartsen *et al*., 2003). The European Food Safety Authority's (EFSA) panel on 'Animal Health and Welfare' (https://www.efsa.europa.eu/en/panels/ahaw) has proposed that greater weight should be given to dairy cow fitness and welfare traits when these may conflict with selection for milk yield. Genetic selection for improved fertility, health and longevity is likely to improve welfare as well as profitability for the farmer. This approach has been adopted in the Irish breeding programme over the past 15 yr and is embodied in the Economic Breeding Index (EBI) (www.icbf.com). The EBI is a single-figure profit index. It contains information on seven sub-indexes, which are related to profitable milk production. These are milk production, fertility and survival, calving performance, beef carcass, cow maintenance, cow management and health. The relative weighting given to milk production is only 33%, with the remaining 65% relating to functional traits such as fertility, survival, lameness, mastitis, calving and management traits. This has resulted in an increase in the reproductive performance of the national herd, as well as an increase in survival.

There have also been improvements in particular characteristics associated with milk quality. Milk somatic cell count (SCC), which is an indicator of udder health, has reduced significantly in recent years. This is due to a combination of improved farm practices (achieved through the regulation of these practices) and the introduction of inductive payments. A national mastitis control programme, referred to as the 'CellCheck' programme, is administered by Animal Health Ireland (AHI) (www.animalhealthireland.ie). This is the national body with responsibility for reducing milk SCC. Data obtained from Irish milk-recorded herds shows that 53% of herds had an annual average SCC of ≤200,000 cells/mL in 2014, compared to 26% of herds in 2010. AHI's goal is that 75% of the milk supplied by Irish farmers will have an SCC of ≤200,000 cells/mL by 2020. Achieving this goal would place Ireland significantly above the EU requirement of 400,000 cells/mL. A major improvement has also been made in relation to reducing bacterial levels in milk. EU legislation requires that the total bacterial count (TBC) of milk be within 100,000 cells/mL. A significant proportion of the milk that leaves farms in Ireland (destined for processing plants) is at a TBC level of <30,000 cells/mL. A hygiene programme developed by Teagasc has made an important contribution to achieving this improvement. The programme provides farmers with guidance on effective products and practices that improve hygiene standards in the production and storage of milk. The Teagasc guidance may be viewed at http://www.agresearch.teagasc.ie/moorepark/milkquality/CleaningGuides/index.asp.

Improvement in milk storage has also been achieved. On-farm milk storage is normally at temperatures of ≤4°C, which is less than that required by EU legislation (≤6°C). The duration of storage is ≤48 h for the majority of the lactation period (excepting the early and late weeks of lactation in February and December, when milk volume is reduced significantly).

Animal welfare

Animal welfare involves providing animals with the opportunity to express natural behaviour, as well as the maintenance of their health (Dawkins, 2004). Allowing animals to graze outdoors in groups permits social contact and allows herd hierarchy to occur within the herd, as well as allowing animals to display normal behaviour (Legrand *et al*., 2009). In Ireland, cows are usually outdoors from the middle of February to late November (O'Donovan *et al*., 2011). In the remaining 2–3 mo, when cows are not milking and are preparing to calve, they are kept in comfortable housing and fed silage indoors. Two Teagasc studies have investigated the welfare of cows in a typical Irish pasture-based production system and have shown that animals may be better able to express their natural behaviour when grazing outdoors, compared to when they are maintained and fed indoors. The first study (Olmos *et al*., 2009) examined cow welfare during the peri-partum period: a period starting 3 wk prior to calving and lasting up to 3 wk after calving. Dairy cows have a greater likelihood of experiencing health problems, such as lameness, mastitis, as well as metabolic and uterine disorders, during this time. The cows were assigned to either a housed system, in which they were in indoor cubicles all year round and fed a TMR diet, or to a typically Irish pasture-based system, i.e. one in which they were indoors in a cubicle house during the dry period (up to 8 wk prior to calving) and outdoors on a pasture-based diet after parturition. Results showed that the pasture-based cows were at greater risk of nutritional and metabolic stress in the first 10 d after calving than the TMR-fed indoor-housed cows. However, this was not found to be associated with any superior immune status of the indoor-based cows or the poorer health of the pasture-based cows. No differences were found between the two groups in relation to immune health indicators. In fact, the pasture-based cows showed a tendency for improved reproductive welfare compared to the indoor-housed cows. Although pasture-based cows were at a greater risk of nutritional and metabolic stress, they were in a less-intensive system, resulting in a reduced energy output (e.g. in relation to milk production). It was suggested that the ability of the cow to monitor her biometric status in the early lactation period allowed her to readjust her

milk energy output, so that her energy intake from pasture is sufficient both for milk production and the maintenance of her health and welfare.

The second study (Olmos *et al*., 2007) examined cow welfare in relation to cow lameness, which can be a debilitating and painful condition constituting a major health disorder in cows. It can have significant economic consequences for dairy farmers when it occurs in their herd. The study compared pasture-based cows and indoor-housed cows, as described in the previous study. From Day 85 after calving to the end of the production cycle, pasture-based cows had less-severe hoof disorders, better locomotion ability and a reduced likelihood of clinical lameness compared to similar indoor-housed cows. The pasture-based system was found to facilitate longer, uninterrupted lying times, which are known to have beneficial implications for lameness. Restlessness and reduced lying times are indicators of lack of comfort, udder problems or overcrowding in the housing facilities, each of which may contribute to hoof disorders. It was concluded that the pasture-based system improved cow welfare in relation to lameness compared to the indoor housing system. It should be noted that the benefits of pasture-based systems in relation to lameness only occur when cow tracks are properly maintained.

Environmental impacts

Generally, grass-based systems are very efficient in their use of resources as they use homegrown feedstuffs, minimising the need for purchased feedstuffs and, thereby, the resources used in their production (such as area, energy and machinery). The total consumption of non-renewable energy is less in grass-based systems compared to that in indoor systems (Le Gall *et al*., 2009). Two studies conducted at Teagasc addressed these issues and examined the environmental impacts of a typical Irish pasture-based system and a TMR indoor-housed milk production system. The first study (O'Neill *et al*., 2011) examined the enteric methane (CH_4) emissions and milk production of two herds of spring-calving Holstein-Friesian cows. One herd consumed a grazed perennial ryegrass diet, and the second herd received a TMR diet. The study was conducted over a 10 wk period in early lactation. The grass group received an allocation of 17 kg DM grass/cow per day. The TMR diet contained maize silage, concentrate blend, grass silage, molasses and straw. The study found that spring-calving cows consuming a high-quality perennial ryegrass diet in the spring produced less enteric CH_4 emissions/cow per unit of intake and per unit of fat and protein, compared to the cows on the standard TMR diet.

In the second study (O'Brien *et al*., 2012) a comparative life cycle assessment (LCA) was conducted, in which a seasonal grass-based dairy farm and a confinement dairy farm were compared in relation to how their different approaches to milk production affected the environment. The environmental impacts considered by the study were global warming, eutrophication, acidification, land use and non-renewable energy use. The LCA evaluated on-farm impacts, off-farm impacts (i.e. pollutants and resources associated with the production and supply of purchased farm inputs) and the total environmental impact (on-farm and off-farm impacts combined) of the two milk production systems. The genetic merit of the two cow herds used in the study were similar. Grazed grass was the predominant feed consumed by the grass-based cows, and a TMR diet was consumed by the cows in the confinement system. The results suggested that a seasonal grass-based system has a lower environmental impact (in relation to potential resource use and pollutants) than a confinement system for a given level of milk and per farmland area. The study found that when expressed per unit of milk and per farmland area, the total environmental impact of the confinement system was greater than that of the grass-based system. On a total farm basis (in relation to on-farm and off-farm area), all the environmental impacts studied, except global warming, were lower for the grass-based system. It was suggested that the greater environmental impact of the confinement dairy system was due to the greater use of concentrate feed and a longer manure storage period.

Economics of dairy farming

In order to evaluate the current economic position of the majority of Irish dairy farms, it is necessary to examine the key indicators of competitiveness, viz. the costs per kg of MSs and the costs as a percentage of output. These indicators were examined in a study by Thorne *et al*. (2016), which drew on a range of official data sources (for 2015) as well as expert opinion in EU member-states. Irish cash costs per product volume were found to be well below the EU average. This suggests a positive outlook in the short-to-medium term for the average-sized Irish dairy farm. Ireland had the lowest costs per unit of production of any of the key dairy regions in the Eurozone. Some deterioration was evident when total economic costs were calculated, and this should be a warning signal to Irish farmers operating average-sized dairy farms. Despite large milk price reductions in 2015, there was evidence of economic resilience in the Irish dairy sector. In 2015, the sector had been partially insulated from the international dairy market price collapse by the reduction in the value of the euro against the currencies of Ireland's main trading partners. In 2015, grass growth in Ireland was very strong and grazing conditions were favourable. As a consequence, there was not a dramatic increase in feed expenditure, despite a significant increase in milk output.

Evidence of the resilience of the Irish dairy sector is also reported in the most recent National Farm Survey (Teagasc, 2016). This provides an overview of how Irish dairy farmers fared in the first year since milk quotas ended, and during which there was a major fall in milk prices. The removal of milk quotas allowed dairy farmers to respond to the fall in prices by expanding production. The survey reports that dairy farm income fell by only 4% to an average of €63,020, despite a decline in prices of between 20% and 25%. Dairy farmers who increased production were found to have been best placed to deal with the consequences of the slump in milk prices. The survey reported that average farm debt actually declined over the year (to €97,363) despite an increase in investment to fund the expansion in production. The increased investment appears to have been funded from working capital rather than through debt. The survey pointed out that such a reduction in farmers' working capital could prove a major problem should milk prices fail to recover in 2017.

An analysis of the current economic viability of Irish dairy farming is provided by French *et al*. (2015). They provide a blueprint for profitable milk production based on a typical 40 ha Irish grass-based dairy farm, operating at optimum productivity. They incorporated the following assumptions in their model: a target milk production of 1,260 kg MS/ha (450 kg MS/cow); 400 kg supplemental concentrate/ cow; milk price of 29 c/L (base price excluding value-added tax); and farm development costs of €3,000/ cow. Operating with these assumptions, they estimated that the target net profit for such a farm would be €2,388/ha or €1.92/kg MS. For each 1 c/L change in base milk price, the farm profitability would increase or decrease by €150/ha. Cost control is a key factor in achieving profitability. In the example provided, it was estimated that a net profit of approximately 40% of the gross output could be achieved. Such a return would ensure that the business is sustainable even at times of low milk prices and during periods of price volatility. Adjusting the stocking rate to match feed demand with grazed grass supply should result in a robust system that will withstand external input and output price fluctuations. This will, suggest French *et al*. (2015), provide the basis for achieving consistent farm profitability over time.

Social aspects of dairy farming

The overall social sustainability of dairy farming depends on how the dairy industry is viewed by the society in which it is located, as well as the quality of life of those directly engaged in dairy farming (McDonald *et al*., 2014). A range of factors affect how dairy farming is perceived by consumers of dairy products and the wider society in general. In relation to the future of the industry, the views of the potential successors to the current generation of dairy farmers are of major importance. In Ireland, at the present time, the dairy industry is considered to be innovative and as having a sustainable future (O'Donnell *et al*., 2008; Renwick *et al*., 2008). Its recognition in terms of importance and standing in Irish society is evidenced and explained by a number of factors: (i) the comprehensive reporting of industry matters in the national, regional and specialist press, as well as by television, ensures a high degree of transparency with regard to how dairy farming is carried out in Ireland; (ii) a significant proportion of the country's population has either a direct or indirect family connection with persons currently engaged in the dairy industry or who were recently involved in it; (iii) as a consequence of points (i) and (ii), the general public has a good understanding of the important economic and social contribution that the dairy industry makes to the country and believes that the vast majority of dairy farmers act responsibly with regard to animal welfare, protecting the environment and in ensuring the quality and safety of the milk they provide. It is also recognised that the spending power generated by the industry generally remains within local communities, making a major contribution to maintaining the economic and social viability of rural communities.

One of the core strengths of the Irish dairy industry is the central role played by the family in the operation of dairy farms. Dairy farming in Ireland is premised on a family farm structure that is able to provide a good standard of living for farmers and their families. The major benefit of a family-operated dairy farm model is that the goals of the family and the farm are viewed as being compatible with each other, as well as being consistent with achieving an enjoyable, healthy and low-stress way of life that is economically viable. A key factor (alongside that of economic profitability) in determining the sustainability of dairy farming in Ireland is how the next generation of potential farmers evaluate the quality of life and lifestyle offered by a career in farming. In a recent study of new entrant farmers in Ireland, McDonald *et al*. (2014) found a strong sense of ambition and entrepreneurial drive of new entrants to own and run successful family farms. According to the Central Statistics Office (CSO) (2012), young farmers, those under the age of 35 yr, generate greater economic returns from their holdings than those over the age of 55 yr and contribute significant annual working units, representing 15% of all labour input on Irish family farms.

Recent data shows that 77% of all dairy farms have a herd size of between 10 and ≤100 cows (CSO, 2016), with the average herd size on these farms being 68. It is envisaged that average herd size will increase to 90–100 cows by 2020. Almost all of these farms are family-operated farms, with the majority of labour provided by the farmer, with contributions by other family members varying between

farms. In a recent farm labour study (Deming *et al.,* 2015), annual and seasonal labour input on 94 Irish dairy farms was quantified over a 2-yr period across a range of herd sizes. The most common farm category had a herd size in the range of 56–110 cows, the category closest to the herd size of 90–100 cows envisaged by DAFM as being the average herd size in 2020. The average farm labour input for this herd size category was 4,255 h/yr. The farm labour input of the farmer was 76% of those hours, with the remaining 24% of labour contributed by other family members and employees. Employee labour constituted a small percentage, being just <20%. When calculated on an annual basis, the labour input by the farmer was found to be 3,234 h/yr, equating to 62 h/wk. When farmers were asked to quantify what they considered would be an acceptable working week, the average response was 57 h. The Deming *et al*. (2015) study draws attention to the need (in the view of farmers) for a reduction in farmers' working hours per week and the importance of the labour contribution made by the spouses and children of farmers in the operation of the family farm. The issue of labour on family dairy farms does not at this time appear to be deterring the next potential generation of farmers from considering a career in dairy farming, but in a time of technological change, the type and the quantity of labour required to operate a modern dairy farm need to be addressed through ongoing qualitative and quantitative research studies.

Conclusion

An innovative dairy industry needs to focus both on the requirements of its customers to ensure continued demand and on its consistent and sustainable production ability over time. Customers of dairy products are seeking high levels of quality assurance based on visibility and integrity across the whole dairy supply chain. Moreover, large global food companies that buy Irish products for sale in other countries are also looking for sources of supply that can demonstrate efficient and sustainable production, aligned to their own sustainability commitments to their customers. Consumers want to know that their food ingredients are produced using responsible farming practices at the producer level. These responsibilities come under the broad headings of social, economic and environmental impacts and animal health and welfare. It is crucial that Ireland can demonstrate that these responsibilities are fully met. The foregoing paper indicates the strict regulations within which the Irish milk production system operates (through e.g. SDAS and AIMS), together with scientific evidence of quality and sustainable practices and operations that are good for people, animals and the environment.

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