

Discussion

Increasing Grazing in Dairy Cow Milk Production Systems in Europe

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Abstract: In temperate regions of Europe where grass grows for most of the year, grazed pasture is the lowest cost feed for milk production. Grazed pasture can make a contribution to dairy cow feeding systems in other parts of Europe, but is less important. While there are many challenges to maintaining or increasing the proportion of grazed grass in dairy cow diets, there are also opportunities to increase its contribution. Grass use and quality can be challenging for several reasons, including the cow and sward interaction, and factors influencing dry matter intake. Adapting grazing management strategies can provide opportunities for incorporating grazing and perhaps increase grazing in dairy cow milk production systems. Pasture management tools and techniques offer the opportunity to increase herbage use at grazing. While there are many benefits of grazing including economic, environmental, animal welfare and social, there are also the challenges to maintaining grazed pasture in dairy cow diets. The objective of this paper is to present an overview of the challenges and opportunities for grazing in dairy milk production systems.

Keywords: grazing; dairy system; grassland management; low-cost feed; sustainable

1. Introduction

While there is an increasing demand for food production globally as population size increases [1], it is imperative that an increase in food production takes place in a sustainable manner to minimise the environmental impact. Grassland usually occupies area not suitable for growing human edible crops in many regions [2]. In temperate regions pasture-based dairy cow milk production systems make use of a human inedible feed source, grass, and convert it to human edible food, especially protein-based in the form of milk and meat. Increased demand for food and feed, drought and environmental considerations mean that self-sufficient farming systems will likely become more important in the future. Such systems should be based on local or on-farm produced feed [3]. Agricultural policy, e.g., the Common Agricultural Policy reform in the EU, and increased environmental legislation such as the Kyoto Protocol, Gothenburg Protocol and the EU Nitrate Directive, is putting increased pressure on European farmers to ensure that milk production is both economically and environmentally sustainable. In temperate regions, increased grass use is a key driver of farm profit [4,5]. In other regions, where milk production cannot be fully pasture-based, grazed grass can still contribute to the feeding system during periods of optimum pasture growth. In general, across Europe, the proportion of grazed grass in dairy cow diets is declining as production systems intensify [6,7], despite the benefits of grazing. The availability of labour, calving pattern, use of high genetic merit cows, increasing number of cows

per farm and land fragmentation are some of the reasons for the decline in grazing. Pasture-based milk production systems tend to be based mostly in temperate regions. Overall, there are many challenges and opportunities for grazing in milk production systems in Europe. Challenges include infrastructural constraints such as facilities, farm fragmentation, farm size and mechanization, and cultural constraints such as cow type, pasture management skills, government policy (EU and local) and milk price. Grazing systems are associated with opportunities for greater global sustainability, increased product quality, improved animal welfare, and increased labour efficiency [8].

The objective of this paper is to present an overview of the challenges and opportunities for grazing in dairy milk production systems.

2. Challenges

2.1. *Herbage Production and Quality*

In temperate regions grass covers the ground almost completely throughout the year and it intercepts light for growth [9]. However, grass growth is highly variable [10], both seasonally (e.g., [11]) and between years and regions (e.g., [12]). Grass growth is influenced by many factors; some are within the control of the farmer, including grazing management, sward renewal policy and fertiliser management, while other factors are outside his/her control including weather (e.g., rainfall, temperature, solar radiation) and soil type. Due to these influencing factors pasture supply is variable and can be difficult to predict thereby resulting in reduced control of feed supply for the farmer. Often, dairy farmers in temperate regions opt for seasonal calving systems so that feed demand and pasture supply are somewhat synchronised.

Climate change is likely to increase the influence of weather conditions on grass growth in Europe. The predicted effects of climate change vary depending on the models and data used (e.g., [13]). The effects will vary; resulting in changes in rainfall patterns, increased summer temperatures, more extreme weather events, and in southern Europe, likely increased drought. In temperate regions of Europe and Northern Europe, total annual dry matter (DM) production is predicted to increase (e.g., [13–16]); however, seasonal production is likely to change, for example increased frosts in spring will reduce spring production [14]. In warmer areas of Europe, drought is likely to be an increasing problem, reducing potential grass growth significantly. In addition to affecting grass production, climate change is likely to influence grazing season length and grass use (e.g., [17]). The key focus within grazing systems to minimise the potential negative impacts of climate change will be around adapting the system to the changing circumstances, building resilience into the system through allowing some spare capacity in the form of, for example, feed buffers, stocking rates and financial performance. Ultimately climate change may result in the movement of dairy production from one region to another as climate changes.

As well as pasture growth and supply, pasture quality is also influenced by the factors previously mentioned, resulting in reduced control of feed quality as well as availability which are key issues associated with grazing for many farmers [4]. A well-balanced total mixed ration (TMR) diet has the potential to maximise milk production [18,19] and offers the option to adjust the diet to suit the nutritional requirements of the cow depending on stage of lactation, age, etc. This gives TMR diets an advantage over pasture-based systems in terms of maximising milk production per cow [19,20]. However, in temperate regions implementing TMR systems does not always make sense as they do not allow the exploitation of grazed pasture which is the lowest cost feed source in many regions [21,22].

The nutritional value of pasture varies with season, growth stage and age of regrowth. Leafy swards in spring have a high feed value, while swards in the reproductive stage in summer have higher fibre content and lower digestibility. Grass legume swards often have a higher feeding value than grass-only swards, e.g., Egan et al. [23] and Riberio Filho et al. [24]. Pasture management can be used to ensure high quality feed for milk production. Generally, for milk production, grazed grass is a higher quality feed than grass silage [25]. Grass quality can be optimised through pasture and

grazing management. For example, rotation length, pre-grazing herbage mass [26] and post-grazing sward height [27] can all influence grass quality as well as supply. Spring grass quality is greater than autumn grass quality at the same growth stage; and autumn grass quality tends to have a reduced energy supply compared to spring grass [28].

2.2. The Most Appropriate Cow Breed for Pasture-Based Milk Production

Dairy cows in pasture-based systems generally face a less stable feed supply in terms of quality and quantity compared to indoor feeding systems. Cows generally have to graze in the environment presented to them which is influenced by topography, farm shape and size, and farm infrastructure. They are often more exposed to variations in climatic conditions (e.g., precipitation and temperature) compared to cows in indoor systems. Therefore there is a requirement for a robust type animal suited to grazing in outdoor pasture-based systems [29,30]. Suitable breeds/strains for grazing systems are adapted to achieving a large intake of forage relative to their potential milk yield, have a high health and fertility status, have good conformation to walk long distances, and have high survivability rates [31,32]. To make the best use of grazed pasture, cows in pasture-based systems will have good reproductive performance [33], calve early in spring each year, and will be turned out for grazing immediately post calving to optimise the relationship between pasture supply and feed demand. Generally animal selection programmes based on high concentrate diets and little or no focus on fertility tend to result in animals with poor reproductive efficiency, as well as being unable to express their full genetic potential for milk production in grazing systems [31,34,35]. However, in a well-managed pasture-based system, Buckley et al. [36] found that high genetic merit dairy cows could produce up to 7000 kg milk cow⁻¹ year⁻¹. Recently, O'Sullivan et al. [37,38] have shown that selecting animals for pasture-based systems based on genetics (the Economic Breeding Index (EBI) [39] is the selection index in Ireland) results in dairy cows that can achieve a more positive energy balance and consistently produce milk with high contents of fat and protein across diverse pasture-based systems. These elite animals have a higher milk yield (circa 300 kg), higher fat content (circa 0.3%), higher protein content (circa 0.2%) with better overall fertility (replacement rate of 18% versus 28%) when compared to national average genetics in Ireland. The EBI centres on selection for a balance of traits which include production, reproduction, health, and beef. In the future selection based on the EBI will also include direct sustainability type traits like greenhouse gas emissions and nitrogen use efficiency. Delaby et al. [30], in a review, concluded that the characteristics of the robust cow type required in pasture-based systems must match high milk solids production with a capacity for high forage intake, have good fertility, calve without assistance, and remain healthy.

2.3. Interaction between Animals and the Sward

At the centre of pasture-based milk production systems is the pasture-cow interaction. This interaction provides challenges for many reasons including dairy cow DM intake (DMI) of pasture and milk production potential, the influence of other feed stuffs on substitution rate, grass allowance, etc. As a result, of this complex interaction pasture production and use are generally not optimised [40].

In pasture-based systems, dairy cow grazing intensity directly influences grass use and quality, and ultimately performance per ha [41,42]. Dry matter intake is often the most limiting factor for milk production in pasture-based systems. Globally, intensive pasture-based dairy mainly centres on perennial ryegrass (*Lolium perenne* L.) swards which are supplemented with artificial nitrogen. These swards are coming under some pressures in terms of the levels of fertiliser nitrogen used. Globally, systems that use large quantities of chemical nitrogen will likely be viewed less positively in the future. The introduction and use of clover, usually white clover (*Trifolium repens* L.), has the potential to both allow for reduced chemical nitrogen use in the swards as well as increasing the nutritional quality of the sward [23]. A key feature of pasture-based systems is confidence around the feeding value of pasture among farmers due to fluctuations in supply and quality which are influenced by factors such as stage of growth, species composition, sward nutrition and water content. This generally does not

appeal to farmers [40]. The feed efficiency of pasture-fed cows can be lower due to limited energy intake [19]. Van Vuuren and Van den Pol-van Dasselaar [43] calculated that a grass-only diet can support milk production levels of 22 to 28 kg cow⁻¹ day⁻¹.

2.4. Pasture Management

A range of skills are necessary to manage pasture-based milk production systems including animal and pasture management and feed budgeting skills. Managing dairy cow breeding is vital as pasture-based systems are best suited to compact seasonal (spring) calving to match feed demand to grass supply. A short breeding season (10 – 13 weeks) is desirable to achieve compact calving (i.e., all cows calve in a short period). To achieve this good heat detection is critical. Dairy cow body condition score (BCS) must also be well-managed at key times such as dry-off, calving and start of the breeding season. Good heat detection and cows with appropriate BCS will help achieve a high submission rate and a high in-calf rate in a short breeding season.

Farmers, and indeed extension officers, often consider grazing management to be complicated. In some European countries there is a dearth of knowledge around grazing management, and often grazing management skills have been lost, in a large part due to a move away from pasture-based systems to high input systems and automatic milking systems. There are many grassland management tools available for pasture-based milk production systems. These can be adapted to suit different countries, regions and indeed farms. For example, the spring rotation planner which is widely used in Ireland was adapted from New Zealand; the Netherlands introduced the FarmWalk programme for grassland management to dairy farmers in 2014. Pasture management tools are available for different parts of the year, e.g., spring, mid-season, and autumn, to help farmers manage the particular challenges in each season. Improved pasture management, through management and use of tools, increases herbage production and use, milk production from pasture, and often farm profitability [44].

Developing feed budgets within pasture-based systems help to increase farmer confidence in managing their system. Calculating the quantity of feed required for periods of low/no grass growth is an important component of feed budgeting. Ideally farmers will match their stocking rate (herd demand) to the quantity of grass their farm can grow. However, measurement of grass production is crucial if the optimum stocking rate is to be applied on a farm [45].

2.5. Farm Fragmentation and Scale

In pasture-based systems, the milking platform is the area within walking distance of the milking parlour available for cows to graze. On fragmented farms the size will vary, depending on the level of fragmentation. Usually blocks other than the milking block are used for silage and other forage production and rearing of young stock. In such systems, management of the pasture on the milking platform is crucial to maximise production for grazing dairy cows. This includes ensuring the correct infrastructure is in place, optimising soil fertility, measuring and managing grassland, and matching stocking rate to pasture production.

Across Europe farm fragmentation is a huge issue. In general, grazing has been in decline across Europe [7]. As herd size increases fragmentation becomes a bigger problem and so there is a requirement for the development of clear strategies to maintain or increase the levels of grazed grass in the diet of dairy cows. This requires integrating grassland measurement and budgeting to increase confidence around grass availability with everyday grassland management practices at farm level.

Across Northern Europe the amalgamation of dairy farms is becoming more common. Generally this involves grouping cows from different farms at one site to increase milking and labour efficiencies, as well as achieving economies of scale and ultimately increased production efficiency. The grazing area available for cows can be increased in instances where the amalgamated farms are adjacent to each other. In most cases, the herd size becomes too big for the area available for grazing and so the quantity of grazed grass declines, or is eliminated from the cow diet, in favour of indoor feeding or zero grazing (fresh grass harvested and fed indoors), silages and concentrate. Over all this type of

system results in more machinery, more time feeding and overall less efficient systems across all of the definitions of efficiency. Financial performance declines [45–47], labour efficiency declines [48] and environmental efficiency declines [49,50]. While it could be argued that at high milk price [51] the higher input systems can be competitive on a unit of land basis, in general they will be substantially less profitable per unit of milk output.

The potential for increased intensification away from the natural competitive/comparative advantage of grass-based systems is something that may need policy to prevent in the future. The relaxation of the EU milk quota policy was designed to allow milk production to flow to areas of natural advantage. While this has occurred to a certain extent, with the expansion in dairy in Ireland since the 2007–2009 period at circa 75%, there has been little expansion across mainland Europe. There is considerable debate about the impacts of agriculture in areas of climate change policy, nitrates directive, ammonia emissions ceilings and biodiversity. These are all areas that require greater focus within the farm gate. Policy instruments (e.g., the Nitrate Directive, Water Framework Directive, Climate Action Plan, Ammonia Ceilings Directive) can all be used to ensure that the future includes a balanced perspective of economics and sustainability in agriculture both at a local, national and a global level.

2.6. Technology

Technology has an increasing role in milk production systems across Europe. Farmer adaption of new technologies varies. Farmers must trust the technology and see benefits, and introduction of any technology must be cost efficient. One of the greatest technological advances in milk production systems in Europe, and indeed worldwide, has been the development of robotics for automatic milking systems (AMS). These systems have automated the milking process which is the most labour intensive aspect of milk production systems [52]. Farmers are installing AMS as they offer benefits in terms of life-style, labour efficiency/requirement and they can facilitate off-farm employment. Traditionally, the main markets for AMS have been in countries with high-yielding cows, high milk prices, high labour costs and indoor feeding systems [53]. However, more and more farms across Europe are adapting their production systems to AMS. With the increased use of AMS, there has been a decline in grazing as indoor feeding systems becomes more common place [54] allowing all cow related activities—feeding, milking, and housing—to take place under one roof. Jago and Burke [55] and Shortall et al. [56] investigated the use of AMS in pasture-based systems concluding that they can be successfully integrated without compromising the fundamentals of grass-based systems, although some compromise between production per cow and per ha might be required, i.e., more cows may be necessary to maximize the output per milking unit and so production per cow might decline but production per ha increase.

3. Opportunities

3.1. Economic and Labour Efficiency

Economic efficiency is defined as maximising the returns from a fixed set of resources, e.g., land, labour and capital [57]. In dairy production systems, land is one of the main fixed resources. Ultimately the farmer has to choose the milk production system employed on that fixed resource. In pasture-based systems, the land surrounding the milking parlour is particularly important as this is the land area accessible to livestock. In temperate regions, grazed grass is the most economic feed source for milk production (e.g., [4,21]). Grazed grass is almost a complete diet (contains fibre, protein, energy, minerals, etc.); if it can be incorporated into dairy cow diets it has the potential to significantly contribute to the economic sustainability of milk production systems and reduce production costs, particularly around purchased feed and conserved forage. Dillon et al. [4] in an analysis of milk production systems internationally, found that generally as the proportion of grazed grass in the dairy cow diet declined, costs of production tend to increase. In Ireland, the quantity of grass used by the dairy

herd can explain 44% of the variation in the cost of milk production [5]. Grass intake of greater than 600 kg DM cow⁻¹ year⁻¹ makes grazing financially attractive in the Netherlands [58].

Labour is a high cost in any dairy production system, and the availability of skilled labour is a concern for producers. In all milk production systems the labour requirement is different and varies across the year depending mainly on calving and breeding patterns. In pasture-based systems where compact calving is practiced, the requirement for labour is concentrated in a short period (3–4 months) usually in the spring and early summer around calving and breeding as pasture-based farming systems generally have cows with significantly shorter calving intervals, empty time and time from calving to first service compared to cows fed indoors [3]. Pasture-based spring calving systems have a greater net profit per farm than less seasonal calving systems largely driven by a reduced requirement for labour [59].

In recent times, milk price volatility has increased and is one of the greatest challenges for milk producers. In temperate regions, grazed grass is the lowest cost feed for milk production. Increasing farm self-sufficiency in terms of livestock feed supply through grass production and use offers farmers insulation from volatile feed costs and milk prices [60,61].

Other economic and labour efficiency advantages of grazing include a reduced requirement for reseeding and therefore associated labour and costs, and a reduced requirement for mechanical operations on the farm including silage harvesting, feeding, slurry spreading and bedding, and therefore a reduced requirement for feed and slurry storage.

3.2. Environmental

The pressure on agriculture to reduce environmental emissions continues to increase. At the country level, much laboratory research, field research and modeling, has been undertaken examining the effects of production systems on greenhouse gas (GHG) emissions [50,62,63], eutrophication [64–67] and biodiversity [68–71]. Many different methodologies have been used making direct comparisons across studies difficult. However, studies generally conclude that increasing resource use efficiency has a positive impact on environmental sustainability. One of the advantages pasture-based systems have is the production of feedstuffs, and therefore home grown protein, which reduces the requirement for purchased feedstuffs and the emissions associated with transporting and feeding that feedstuff. Pasture-based systems, which minimise the purchase of feedstuffs, are generally more resource efficient and have reduced total consumption of non-renewable energy compared to indoor feeding systems [72].

It is well accepted that there is a high N surplus in grazed grassland due to N fertiliser use, N fixation by legumes when present, and urine and faecal deposition by grazing livestock. In long-term productive grassland soils there is usually net N mineralisation [73]. Permanent grassland acts as a store for N [74,75], lowering the risk of N loss to water. Grazing systems that optimise pasture production and use tend to have a lower N surplus [76–79] because grassland has a high capacity to capture N as grass is present throughout the year and actively growing for 7 to 10+ months per year. In well-managed pasture-based systems, increasing stocking rate while maintaining fertilizer N input and concentrate increases productivity, making better use of the resource available, reduces N surplus and increases N use efficiency through increased grass use [76]. However, at very high stocking rates, N losses can increase because faeces and urine patches are not evenly distributed during grazing leading to increased localized leaching, denitrification and nitrous oxide emissions. Ammonia volatilisation is lower during grazing compared to during housing. New technologies in fertiliser management will help to minimise losses from N fertiliser application. Precision agriculture technologies such as GPS assisted fertiliser application minimises the risk of over application on parts of the field. Inhibitors, such as nitrification inhibitors and urease inhibitors, applied with fertiliser can minimise N loss in the field (e.g., [80,81]).

Grazing often occurs on permanent grassland which is cultivated or ploughed infrequently which minimises N losses. Adapting well-managed minimum cultivation techniques should result in

renewed swards which are at least as productive as those renewed using ploughing methods [82] but those methods minimize soil disturbance and consequently N and C loss [83]. Reseeding or renewing grassland replaces less productive species with ones that are faster growing and more efficient at using the nutrients available, therefore increasing N use.

Dairy cows grazing low pre-grazing herbage mass swards that are of high quality have lower CH₄ emissions (per cow and per kg milk solids produced) compared to cows grazing poor quality high pre-grazing herbage mass swards [26]. Incorporating other species into grassland swards can also reduce methane emissions. Enriquez-Hidalgo et al. [84] found a 12% reduction in methane emissions per kg DMI when cows grazed grass-white clover swards compared to grass-only swards.

Grasslands are an important sink for C with most of the C stored in the roots and the soil [85,86]. Increasing grazing can have a positive effect on C sequestration, especially on permanent grassland where it reduces the area under short leys, maize, and arable crops [87].

3.3. Milk and Milk Product Quality

Apart from genetics, dairy cow feeding system is the greatest influence on the quality and nutritional value of milk and milk products [88,89]. Dairy cow diet influences the taste and nutritional and chemical composition of milk and the products made from milk [90–92]. Grazed grass has positive effects on milk composition, increasing unsaturated fatty acids, conjugated linoleic acids, vaccenic acid, and omega-3 fatty acids compared to milk other diets, including grass silage and concentrate-based diets [88,93–95]. Martin et al. [96] found that milk from cows on predominantly grazed grass diets had greater vitamin A and E contents compared to that of milk from other cow diets.

As the food chain lengthens, there is increasing concern among consumers around food safety. The longer the food chain, the less sharing of information between farmers, processors, retailers, and consumers which has a negative effect on trust and understanding between the producers and consumers. In the EU, a large proportion of raw materials for animal feeds, particularly protein, are imported. Increasing the proportion of grazed grass in the dairy cow diet reduces the requirement for imported protein, and conserving grass as silage or hay for periods when there is inadequate growth or poor grazing conditions shortens that food chain.

Generally, consumers consider pasture-based milk production to be sustainable, safe, and delivering high quality milk as well as multiple ecosystem services [97]. Consumers perceive milk production to involve cows grazing in green fields which they consider being natural and local, and indeed such images are often portrayed on milk cartons and in marketing campaigns. Increasingly, consumers are willing to pay a premium for grass-fed dairy products and there is an increasing body of work to support the claims that grass-fed milk is nutritionally superior (e.g., [90]). Methodologies are being developed in order to substantiate claims around the grass-fed milk and milk products and allow payment systems to be developed [98].

3.4. Animal Welfare and Health

Ruminant animals, such as dairy cows, in their natural environment, obtain their nutrition through grazing. In general, grazing is considered more animal welfare friendly than housed or feedlot type systems. In grazing systems, animals have the possibility to express their natural behavior, are usually not restricted in terms of space, and can roam and therefore exercise. Additionally, grazing systems allow the expression of social hierarchy in herds as well as social contact; although contact can usually happen in indoor/feedlot systems too. Therefore, grazing livestock are usually able to express their natural behavior more than in indoor or feedlot systems.

Grazing systems provide more opportunities for uninterrupted lying compared to indoor systems [99]. Dairy cows on pasture usually have ample space for lying and generally because of the space can easily transition between standing and lying [100]. Additionally, they can lie on their sides and in more stretched positions which is often not possible indoors, particularly in cubicle housing [101].

In terms of animal health, the advantages of grazing are usually considered more important than the disadvantages, particularly in terms of claw health and udder health. The prevalence of lameness is generally low among grazing livestock [99,102,103] and locomotive ability is greater [99], though the risk of lameness increases as the distance walks increases, and if cow roadways are not maintained [104,105]. Access to pasture can also have benefits in terms of reduced incidence of mastitis [106]. The risk of mastitis is greater in cows housed indoors compared to cows at pasture [20,106,107]. Cows at pasture generally have more space and can avoid lying in dirty areas [101].

3.5. Technology

The use of technology in all aspects of agriculture is increasing. Technologies that can assist farmers with grassland management and budgeting are important in the promotion of grass-based milk production systems. There are a range of decision support systems available in different countries to facilitate on-farm grassland management such as PastureBase Ireland [44], the Grass Wedge [108], Herb'aVenir [109] and Pâtur'Plan [110]. Many of these give the farmer a visual representation of the herbage availability on farm and allow the farmer to anticipate the availability of herbage for grazing on the farm. Seasonal tools such as the spring rotation planner, the grass wedge and autumn budget (e.g., available from www.teagasc.ie; www.dairynz.co.nz) use the farmers data from his/her weekly grass measurement to provide information on grass availability, surpluses and deficits, and provide confidence in decision making around supplementation and fertilisation. This information is also very valuable for farmer discussion groups and other forms of peer to peer learning, mentoring and support. Additionally, farmer discussion groups are ideal places for farmers to learn about grassland measurement, management, and feed budgeting.

A grass growth prediction model such as that described by [12,111] can add further confidence around management decisions, particularly if it can use farm specific data such as feed demand, N fertiliser use and rotation length. Using satellite imagery to develop information around grass availability can provide an overview of grass supply on the farm remotely [112].

Adapting grazing management strategies allows grass to be included in dairy cow diets where it is available. For example, restricted access to grazing can be practiced [113–115] on farms or at times when there is limited land area available or when soil or weather conditions are poor. Restricted access to grazing, or on/off grazing, involves turning cows out to grass for a fixed period of time each day. Kennedy et al. [113] found that dairy cows provided with access to grass for three hours following morning and evening milking daily in spring achieved 90% of the daily pasture DMI of cows with fulltime access, and found no negative effect on milk production. Similarly, Kennedy et al. [114] found no negative effects of restricted access to grass in autumn for cows in late lactation. However, Pérez-Ramírez et al. [115] reported reduced milk yield and composition in spring and early summer when access to pasture was restricted. Altering the calving pattern in areas with low summer grass growth offers the potential to better match feed demand with grass growth. This could be achieved through two compact calving periods, one in spring and one in autumn, allowing the lactating herd to maximise the quantity of herbage converted to milk [116].

We are in a period of rapid development of technologies and decision support tools for grassland agriculture. New technologies are continuously being developed and new grassland Decision Support Tools (DSTs) and technologies such as virtual fencing and the GrassHopper [117], cow sensors [118], and remote sensing [119] will provide farmers with knowledge and assistance in allocating herbage for grazing within their production systems. They will also increase farmers' confidence in grazing management and herbage allocation [110]. However, any new technology must be tested and validated before it is made available for farmers. It must be better than what currently exists. It must not make grazing management and herbage allocation complicated, and above all it must not reduce farmer confidence in pasture-based milk production systems.

4. Conclusions

Overall, as farms have expanded over the last 20 years, there has been a move away from grazing and grazing systems as farmers intensify their operations in the hope of increasing income. This movement has been facilitated through increasing global demand for milk, an ever increasingly volatile milk price, increased impacts of climate change at farm level, and farmers dealing with a type of cow that was bred for production solely, ultimately resulting in longevity issues which reduced the focus on pasture-based systems. While recognizing these challenges to grazing systems, which are both within and external to the farmers control, a range of possibilities exist to facilitate the incorporating of grazing in milk production systems. Countries where pasture-based systems are the norm have many tools and technologies available that can be adapted to increase farmer confidence and help improve grazing management. New agricultural technologies will allow greater adaption of grazing management for efficient pasture-based milk production. Selecting a robust cow type and adapting cow breeding management and calving period can also increase the role grazed pasture plays in the diet of dairy cows. Overall, maximising the use of grazed pasture in milk production systems, be they full pasture-based systems or those where pasture contributes only a proportion of the diet, will increase the sustainability of dairy cow milk production systems. Ultimately policy/market-based instruments may be needed to ensure that there is greater focus on pasture-based systems.

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