Defining resilience in pasture-based dairy farm systems

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Summary

- Resilient pasture-based milk production systems offer New Zealand and Irish farmers the greatest potential to efficiently and profitably produce high quality milk products within a resource constrained environment for discerning international consumers.
- The integrity of this system is based on high productivity swards, genetically elite adapted animals and a predominantly grazed pasture diet.
- Such systems can be improved through greater collaboration to deliver increased economic returns to producers through increased grazed pasture utilisation and further quantification and improvement of nutrient use efficiency, animal welfare and product quality.

Building resilience today for a sustainable tomorrow

Dairy farming is widely acknowledged to be financially volatile, with an ever-changing landscape of milk and input prices, variable and fixed costs, milk yield, and other variables that affect farm financial returns. The coming decades are likely to see increased pressures on food production systems, both on the demand side, from increasing population and per capita consumption, and on the supply side, from greater competition for inputs and climate change. Society's requirements are changing too, as discerning consumers have become increasingly engaged in how food is produced and sceptical about industrial-scale food processes. In addition to being more profitable and less complex to farm, future farm systems must be more transparent, supplying healthier foods from traceable production models, while also differentiating based on tangible evidence of improved environmental conservation, biodiversity and animal welfare, and a reduced reliance on hormones, chemicals, and antibiotics. Given the complex and increasingly multi-dimensional challenges faced by farmers, the concept of system resilience has recently gained much attention. Resilience is the capacity of any system to deal with change and uncertainty and maintain essential function and outcomes in the long term. The goals of resilient systems are to improve the livelihood of farmers, while simultaneously increasing or at least maintaining agricultural production per unit of land, improving products produced, and reducing environmental and animal welfare pressures generated by the production process.

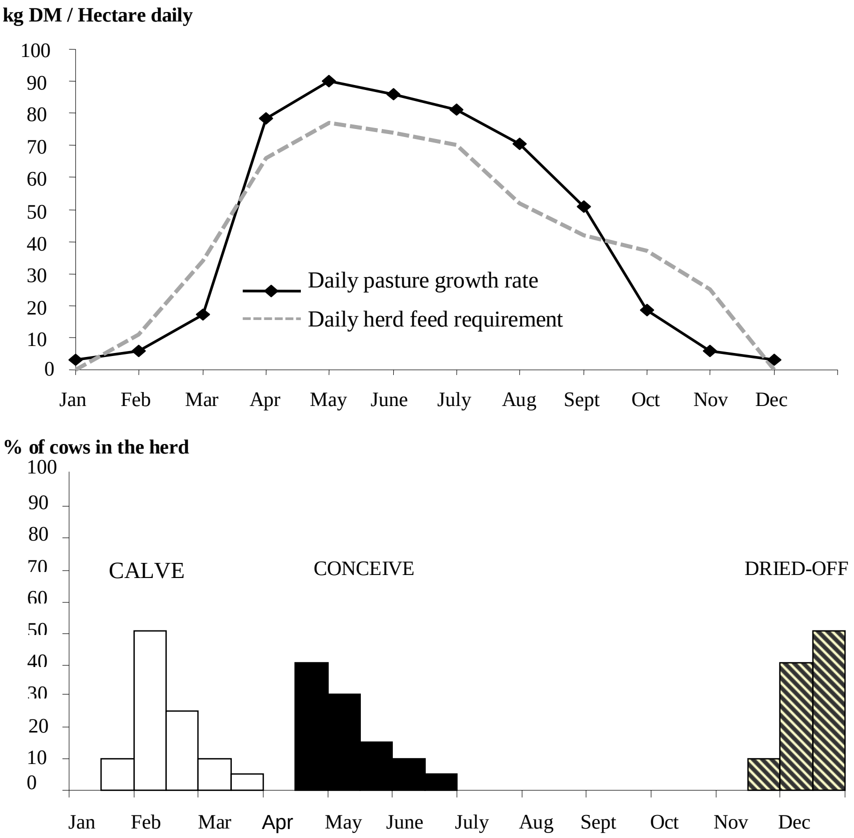
For grassland production models, such as those traditional to the dairy industries of New Zealand (NZ) and Ireland (IRL), improving the sustainable production of livestock products provides both challenges and opportunities. While the shift to more intensive production within both industries has put more pressure on natural resources, at the same time, there is a greater understanding of the role of pasture-based food production in efficiently converting human inedible feed to high quality nutrients, while building ‘natural capital’ and delivering a range of multifunctional services to society. In comparison with cropping, permanent pastures provide an important biological filter that reduces nutrient and chemical run off to surface and ground water, conserves soils and supports unparalleled biodiversity and carbon storage (Sousanna and Lemaire, 2014; Plantureux *et al.*, 2016). In a European context, improving the efficiency of grazing production systems is considered as the greatest primary opportunity to develop more resilient farming systems in the future and this paper examines the key components.

Resilient grazing systems and the art of compromise

Among dairy production systems, a grass-based model is peculiar in design, due to its high reliance on the natural forces of climate for the production of perishable feed and animals for the autonomous management of feed quality and utilisation. The overall integrity of this model of milk production is based on high productivity grassland management in combination with genetically elite adapted animal genotypes capable of compact seasonal calving and high productive efficiency on a predominantly pasture diet over a prolonged grazing season (Fig 1). Such systems are uniquely a compromise between dual objectives of maximising the utilisation of pasture and maintaining high animal intakes and performance, with minimal use of mechanisation, and capital infrastructure. Increasing pasture allowance to support higher levels of intake results in higher levels of refusals, decreased pasture utilisation, and lower feed quality in subsequent feeding cycles (Delaby and Horan, 2017); therefore, a balance must be achieved between performance on a per animal and per hectare basis (McCarthy *et al.*, 2011). Consequently, effective pasture management enforces a limited pasture allowance/cow.

From an economic perspective, pasture-based milk production is typically characterised by moderate levels of production/cow, but high marginal profitability per unit of milk produced (Dillon *et al.*, 2008). Resilient pasture-based systems must have a low production cost-base to insulate the dairy farm business from the dual impacts of climate and price shocks, and to allow farms to generate sufficient funds in better times to continue to fund strategic development in lean years. In an analysis of dairy production systems globally, Dillon *et al.* (2008) reported a strong quadratic relationship between the amount of grazed pasture in the diet and the cost of producing 1 kg of milk, with operating expenses per kg milk declining with increased reliance on grazed pasture (Fig. 2). Of particular significance to both NZ and IRL, the data indicated that increasing the proportion of grazed pasture in a system that already contains a high proportion of grazed pasture has even greater benefits in reducing the cost of milk production than in areas where grazed pasture constitutes a lower proportion of the diet, due to the comparatively increased importance of feed related costs in such systems. Similar to many other studies examining the explanatory factors influential for increased economic performance in grazing systems, the central importance of increased pasture utilisation (t DM/ha) was reported by both Ramsbottom *et al.* (2015) and Macdonald *et al.* (2017). A further consideration in pasture-based systems is the uniquely high costs of marginal milk (i.e., milk produced from additional imported feed supplements) and, as a result, both Ramsbottom *et al.* (2015) and Ma *et al.* (2018) have reported a linear decline in profitability with increasing feed importation in Ireland and New Zealand, respectively.

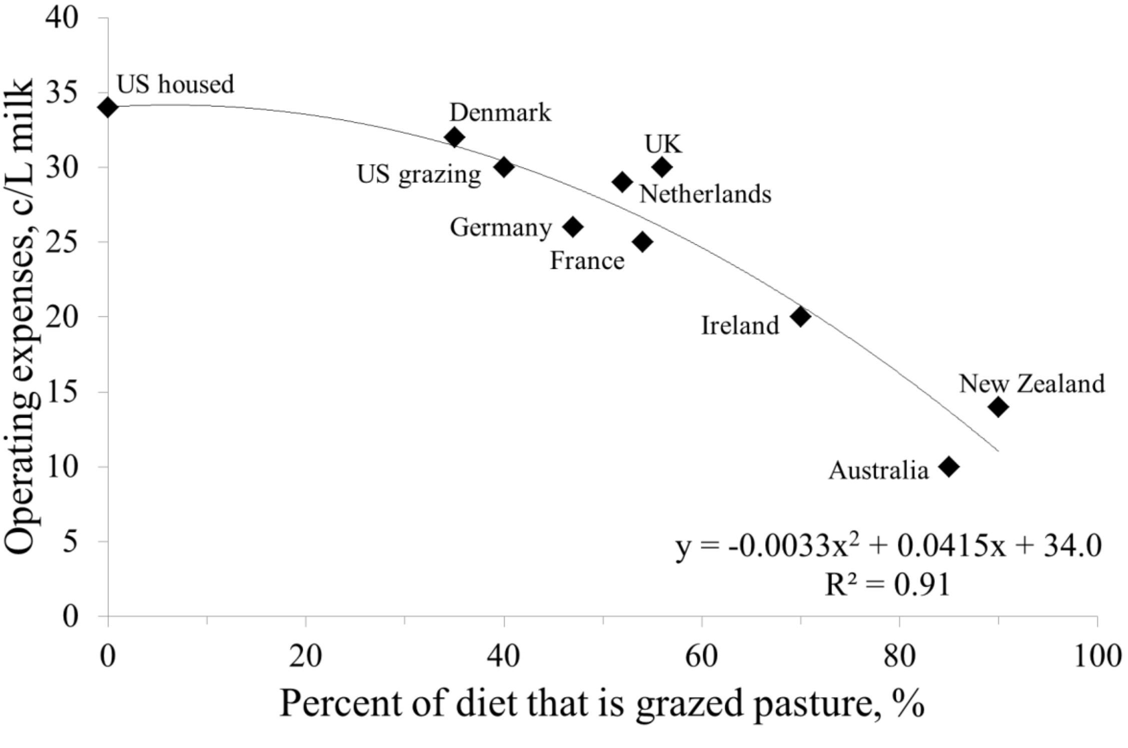
Fig. 1. A conceptual representation of the important synergistic impacts of calving date and stocking rate to better align pasture production and utilisation within profitable grazing systems.



Systems workload and complexity

Among the main challenges common to all dairy systems, the implementation of best practice management is highly dependent on the availability of skilled operatives. In expanding dairy industries and/or where additional improvements in management practice are required to improve system resilience, farm operatives skills requirement are greatly amplified, and while individual farmers can relatively quickly develop the desired management skills, it is a significant challenge to achieve successful widespread industry adoption. Although well designed grazing systems are considered to require fewer management interventions (in terms of nutritional management, mechanisation, etc.), when compared with more intensive and confined systems (Dillon *et al*., 2008), the seasonal nature of labour requirement and specificity of grazing and animal management skills require highly skilled and professionally organised operators. Consequently, the design of grazing systems, in terms of core decisions on stocking rate, animal selection criteria, pasture management, timing of calving, facilities, work organisation and outsourcing of non-core activities, are of paramount importance, and have a pervasive impact on system performance and profitability. It is now widely acknowledged that as dairy farms move from an owner-operator to team-based farm management, farming systems need to be even further simplified to reduce the complexity of decision making.

Fig. 2. The association between the percentage of the cow's annual diet that is grazed pasture and the cost of milk production (Dillon *et al*., 2008).



Robust animals for pasture-based systems

Although dairy cows that are optimal in a pasture-based system of production share many characteristics with cows that are appropriate for a non-pasture system, the relative importance of specific traits differs (Roche *et al*., 2017). Pasture-based systems are generally more constraining, less stable, and feed supply and quality is less certain than in housed production systems, wherein, 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 antagonisms (e.g., inclement climatic conditions, occasional feed restriction). As the animal is an integrated part of the system, the animal is expected to be robust and less sensitive to sub-optimal circumstances (Veerkamp *et al.*, 2013). The appropriate cow for grazing systems must be able to harvest pasture efficiently by re-calving every 365 days to ensure peak intake demand coincides with peak pasture supply. In addition, successful grazing systems require dairy cows that are capable of achieving large intakes of forage relative to their genetic potential for milk production (i.e., aggressive grazers), are easy care and robust to fluctuations in feed supply.

Excellent research over the last two decades has led to the production of multi-factor, profit-focussed, breeding indices (e.g., Breeding Worth (BW) and Economic Breeding Index (EBI) in NZ and Ireland, respectively). Selection of elite genotypes within these indices has been demonstrated to significantly increase both the robustness and profitability of pasture-based dairy systems. In Ireland, for example, the overall rate of genetic progress has increased in recent years due to the onset of genomic selection techniques and there is concurrent evidence of significant phenotypic progress across a variety of robustness traits within the national herd. Further advances in genomic technologies allied to additional improvements in animal nutrition are anticipated to result in even greater improvements within the national herd over the next decade to further contribute to the sustainable intensification of the dairy sector.

Grazing system intensification and stocking rate

Stocking rate (SR) is the key strategic decision for pasture-based dairy farms and is generally defined as the number of animals allocated to an area of land (i.e., cows/ha). Although the beneficial impacts of SR on grazing system productivity have been widely reported (McCarthy *et al.*, 2011), as part of a resilient system focus, the impact of SR on environmental efficiency must also be considered. Previous studies have indicated that where increased SR are associated with increased chemical fertilizer and supplementary feed importation, nutrient surpluses increase, and nutrient-use efficiency is reduced, resulting in increased losses to ground water and the general environment. Contrary to these findings however, both McCarthy *et al.*, (2015) and Roche *et al.* (2016) investigated the direct effect of SR on nitrate leaching; contrary to the simplistically held notion of a positive association, both studies reported either a stable or declining nitrate leaching with increasing SR; the critical proviso, however, was that strictly no additional N fertilizer or supplements were introduced at higher SR. It is now recognised that a number of changes to management practices are required to maintain low levels of nutrient loss within more intensive pasture-based systems, including increased grazed pasture utilisation, greater use of organic manures to replace chemical fertilizer, more strategic use of chemical N, reduced cultivation reseeding methodologies, improved grazing management and nutrient budgeting, and, importantly, the preferential management of higher risk farm areas. Previous studies have also reported that the carbon footprint of milk production will be reduced by maximising the use of grazed pasture at appropriate overall SRs (O'Brien *et al*., 2014).

In defining the optimum SR for resilient, pasture-based grazing systems, pasture production and utilisation is the principle consideration with additional consideration given to such factors as land class and usability, supplement use and the type of cow. To overcome this, Macdonald *et al.* (2008) introduced the concept of comparative SR (CSR), which was defined as kilograms of cow body weight (BW; at a standard body condition score: BCS) per tonne of all feed DM available. The optimum CSR from a profitability perspective was between 85 and 90 kg BW/t DM, equivalent to offering a 400 kg cow between 5.0 and 5.5 t DM total feed DM/year or a 500 kg cow between 6.0 and 6.5 t. In Table 1, the optimum SR is defined for farms that produce different amounts of pasture and feed different amounts of supplement.

Table 1. Stocking rate* (in shaded boxes: cows/ha) that optimises profit on farms growing different amounts of pasture grown and feeding different amounts of supplement/cow. The proposed stocking rates for a resilient system are highlighted (Roche *et al*., 2017).

	400 kg Cow					*500 kg cow*				
	Pasture grown, t DM/ha					Pasture grown, t DM/ha				
Supplement fed/ha, t DM	12	14	16	18	20	12	14	16	18	20
0.00	2.4	2.8	3.2	3.6	4.0	1.9	2.2	2.6	2.9	3.2
0.25	2.5	2.9	3.4	3.8	4.2	2.0	2.3	2.7	3.0	3.3
0.50	2.7	3.1	3.5	4.0	4.4	2.1	2.4	2.8	3.1	3.5
1.00	3.0	3.4	3.9	4.4	4.9	2.3	2.6	3.0	3.4	3.8
1.50	3.3	3.8	4.3	4.9	5.4	2.5	2.9	3.3	3.7	4.1
2.00	3.7	4.2	4.8	5.4	5.9	2.7	3.2	3.6	4.0	4.4

*All of these stocking rates equate to 80 kg live weight/t feed DM available.

Future opportunities, improved pastures and product characterisation

Improving Pasture Productivity

Traditionally, the most important breeding traits in grasses have been associated with high forage production, persistence and disease resistance, while identifying cultivar characteristics that can be utilised to improve animal performance is critical (Parsons, *et al*., 2011; Wims *et al*., 2013). Evidence from both Europe and New Zealand (Easton *et al*., 2002; McDonagh *et al*., 2016) has identified that relatively modest genetic gains have been achieved in grass productivity (+0.4 to 0.6% per annum) and feed digestibility (0.5-1.0 g kg^{-1} DM per annum). In contrast, much greater productivity gains have been achieved in cereals and maize breeding programmes (+1.0% and +2.6% per annum, respectively). It is also widely acknowledged that improved grass breeding is an area requiring further emphasis within research programmes to satisfy the requirements of leading pasture-based farmers' worldwide and to contribute to mitigate emissions and nutrient losses. On that basis, economic cultivar evaluation indices, similar to those used for dairy cattle improvement, have been developed in both Europe and New Zealand to evaluate grasses to improve farm financial performance. In Ireland (Pasture Profit Index; McEvoy *et al.*, 2011) and New Zealand (Forage Value Index; Chapman *et al.*, 2016), these indices rank grasses based on expected economic value for productivity, persistency and herbage digestibility. These new selection indices in grass breeding, in combination with on-farm cultivar evaluation, have the possibility to further increase the resilience of pasture-based systems through increased grazed pasture production, quality and utilisation.

The promotion of functional biodiversity, such as an abundance of soil organisms and the incorporation of legumes and mixed species within grazing swards is among the most recently acknowledged opportunities to further improve soil health and nutrient efficiency while also facilitating further productivity improvement. Although the focus of dairy farming on simple and productive forage systems has led to a limited range of plants within swards, there is increasing evidence that the the resilience of swards can be improved by sowing mixtures of grass cultivars and species. Traditionally, white clover was included in perennial ryegrass mixtures to improve sward nutritive value and reduce N fertilizer use. However, cheap N fertilizer, which reduced the variability in pasture production during spring and increased overall pasture production, led to a reduction in the use of white clover in these systems, with declining levels reported in temperate grazing regions such as Western Europe and New Zealand. Managing grasslands with less mineral N fertilizers and with an increased reliance on biological N fixation can reduce costs of inputs, avoid greenhouse gas emissions caused by their industrial synthesis, avoid the release of mineral N fertilizers to the environment, and increase the digestibility and protein concentration of herbage. A recent meta-analysis (Dineen *et al.*, 2017) to quantify the milk production response associated with the introduction of clover into perennial ryegrass swards, reported that at a mean sward clover content of 31.6%, mean daily milk and milk solids yield per cow were significantly increased by 1.4 and 0.12 kg/day, respectively, compared with grass only, but there was no significant effect on milk yield and milk solids yield per ha. Stocking rate and N fertiliser application were reduced by 0.25 cows/ha and 81 kg/ha respectively, on grass clover swards (3.32 cows/ha) compared with grass only (3.57 cows/ha) swards. Furthermore, the potential contributions of mixed species to improve pasture productivity, reduce environmental impacts and weed invasion and improve herbage quality have been reported (Moir *et al.*, 2012; Finn *et al.*, 2018) and require further investigation at the system level.

High value products from grazing

The nutritional composition, especially lipid profile and micronutrient composition of dairy products, can be modified through the animal's diet, resulting in products that are nutritionally more beneficial for human health. The lipid composition of milk, in particular is amenable to significant alterations generating fatty acid profiles that are more favourable towards a healthy lifestyle. The resulting products can also differ in their technological properties and texture and taste. While there remains a relative paucity of studies investigating the influence of these product differences on human health, improving scientific knowledge and emerging diagnostic capabilities are increasingly distinguishing the quality and human health benefits of pasture-fed dairy products. Further studies to validate these findings are required and require pasture-based industries to collaborate more closely. In addition, educating consumers on the role of the different fatty acids in promoting good health and on the levels of these fatty acids in food products is essential, enabling consumers to make informed decisions.

Resilience indicators for pasture-based milk production

The overall resilience and long term sustainability of the pasture-based dairy industries is dependent on increased productivity and improved efficiency of conversion of grazed pasture to animal products. Using Ireland as an example (Table 2) traditional financial and farm efficiency measures, the incorporation of additional environmental, system complexity, animal health and welfare and product quality indicators can more accurately describe the system-wide improvement focus required within grazing systems to protect the natural capital essential to the farm's future and reduce dependence on external inputs, such as fertilisers, crop protection products and medication. At expected future milk prices, substantial additional gains in average farm profitability can be achieved by the further refinement of grazing systems, on both average and the most profitable dairy farms (Ramsbottom *et al*., 2018), when compared with the target performance improvement areas for resilient systems (Roche *et al*., 2017).

Conclusions

Improved efficiency in dairy systems is a significant challenge for the future. The world demand for food will increase further with both population growth and increased economic prosperity, but milk production systems must be sustainable, without negative impacts on animals and the environment. Resilient pasture-based milk production systems have the capacity to absorb shocks and thrive within the changing and uncertain global milk production environment. Such systems, based on high productivity grassland management in combination with genetically elite adapted animal genotypes, are well placed to meet the increasing global demand for food within a resource constrained environment, while producing high quality products produced meet the highest standards of sustainability, sanitary quality and nutritional value for increasingly discerning consumers. Such systems can be further improved through collaborative efforts to deliver increased economic returns to producers based on increased grazed pasture utilisation and further quantification and improvements in environmental efficiency, animal welfare and product quality.

Table 2. Target Performance Indicators for Resilient Irish pasture-based dairy systems compared to average and top performing farms.

	NFS[1]	Top 10%[2]	Target
Dairy Economic Breeding Index (€)[3]	86	122	150
Calving interval (days)[3]	391	370	365
Herd maturity (No. calvings/cow)[3]	3.4	4.1	5.0
Optimum Soil Fertility (% farm area)	10	75	100
Fertilizer N (kg chemical N/ha)	180	250	150
Fertilizer P (kg chemical N/ha)	7	15	15
Fertilizer K (kg chemical N/ha)	7	15	30
Pasture grown (t DM/ha)[4]	9.5	12.5	16.0
Stocking rate (livestock units/ha)	1.9	2.3	2.9
Comparative stocking rate (kg BW[4]/ t DM)	85	85	85
Calving rate (% calved in 42 days)[3]	63	85	90
Pasture utilised (t DM/ha)[2]	7.3	9.6	13.0
Supplement (kg DM/cow)	1,050	910	500
Milk solids (kg sold/milking platform ha)	825	1,021	1,350
(kg/kg supplement DM)	0.4	0.6	0.9
Milk fat plus protein content (%)	7.8	7.9	8.6
Somatic Cell Count ('000 cells)	186	140	80
Total Production Costs (€/kg milk solids)	4.10	3.50	3.00
Net Profit (€/ha incl. full labour)[1]	473	1,032	2,500
Labour input (kg milk solids sold/ person)	15,000	33,000	50,000
Labour efficiency (h/cow/yr)	45	30	16
Grazing season length (No. days/cow)	235	265	280
Permanent grassland area (% of total area)	95	90	90
Carbon footprint (kg CO_2 eq./kg milk)	1.05	0.85	0.80
N / P use efficiency (%)	25 / 71	27 / 70	33 / 85
Biodiversity cover (% habitat area)	7	5	10

[1]National Farm Survey (2013 to 2016), [2]Ramsbottom *et al.* (2015), [3]ICBF (2016), [4]Body weight.

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