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A case study of longitudinal trends in biophysical and financial performance of spring-calving pasture-based dairy farms

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ABSTRACT

The objectives of the present study were to characterize the trends in production and profitability temporally, when ranked by the proportion of feed purchased, and when ranked by average operating profitability (i.e., net profit/ha). A dataset of 315 Irish pasture-based dairy farms with complete records for 8 consecutive years was used in this analysis. The farms were characterized by expansion and intensification during the 8-year study period, as evidenced by the annual increase in milk fat and protein yield per cow (+15%; $P < 0.001$); mean annual pasture DM consumed/ha also increased linearly (+19%; $P < 0.05$); production costs increased linearly ($P<0.01$) while net profit was highly variable between years. When ranked by proportion of feed purchased, production costs increased ($P<0.001$) with greater reliance on bought in feed. When ranked by quartiles (highest to lowest) for 8-year average net farm profit/ha, the highest profit quartile contained, on average, smaller farms with greater technical efficiency, measured by greater milk yield per cow and grass utilisation, that when affected simultaneously by a combination of milk price reduction and adverse weather experienced a greater reduction but highest nadir and fastest recovery in farm profitability.

KEYWORDS: dairy systems; pasture; profit; supplement

Introduction

Dairy farm systems are complex and represent the collective response of milk producers to remain viable and grow in the face of risk and uncertainty (Howden *et al.,* 2007). Dairy farming is widely acknowledged to be financially volatile, with an ever-changing landscape of milk and input prices, variable and overhead costs, milk yield, and other variables that affect farm financial returns (Horan and Roche, 2020). The challenge for farmers is to develop and implement operating systems that have the optimum combination of resources and activities to mitigate these risks and provide sustainable economic returns (Rougoor *et al.,* 1998).

There is increasing international interest in the multi-functional benefits of grazing systems (Dartt *et al.,* 1999; Dillon *et al.,* 2008; Ramsbottom *et al.,* 2015). Consumers often associate grazing with ‘naturalness’ and improved animal health and welfare (Kriegl and McNair, 2005). While the proportion of grass in the cows diet can vary considerably in pasture-based dairy systems (Washburn and Mullen, 2014), from an economic perspective, grazing systems of milk production have been reported to have lower variable and overhead costs as well as greater operating profit/ha (IFCN, 2018) when compared with the more heavily mechanised housed dairy systems. However, the ability of grazing systems to flex costs in response to milk price volatility is limited as the overhead costs associated with pasture production have already been incurred, and to changes in cow numbers, which are decided on the expectation of long-term average pasture production. The system is also heavily dependent on climatic repeatability for the provision of the majority of the cow’s diet (Roche *et al.,* 2009). Therefore, for grazing systems, the two greatest challenges to resilience are milk price and climate variables that positively or negatively affect either the production or utilization of pasture.

Evaluations of financial performance must consider both the long-term average profitability of the business and the stability of farm profit over time. Economic sustainability has traditionally focused on the design and capability of systems to achieve a desired outcome (Folke *et al.,* 2002). More recently, however, the concept

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of system ‘resilience’ or ‘robustness’ has been applied to the evaluation of agricultural systems as a key aspect of economic sustainability (Peeters *et al.,* 2015). A number of different definitions of resilience are proposed, including: 1) the capacity of any system to absorb or mitigate the effects of changes and maintain essential function (Darnhofer *et al.,* 2008); 2) the capability to be both technically and financially efficient (Dillon *et al.,* 2008); or, 3) the ability to respond opportunistically to changing operational conditions (Rodriguez-Pinto *et al.,* 2011).

The objectives of the present study were to a) characterize the temporal trends in Irish dairy farm profitability; b) to quantify the effect of supplementary feed use on farm production and profitability over time; and c) to compare the temporal variability in farm profitability of high and low profit farms. For the purposes of the analyses, we focused on the capacity of farms to ‘rebound’ from unfavorable situations (Paton *et al.,* 2014) and, in particular, to recover economically from periods of both weather and milk price adversity.

Material and Methods

The seasonal-calving grazing system

The optimum management protocol for seasonal-calving grazing systems was described in detail by Macdonald and Penno (1998); Shalloo *et al.* (2004); Macdonald *et al.* (2008). Briefly, management protocols aim to have the cow directly harvest as much pasture as possible. Mechanical harvesting of silage is practiced when pasture growth exceeds herd demand. Cows are provided with concentrate feeds and/or conserved forages (i.e., supplementary feeds) when pasture growth is less than their energy requirements during winter.

In temperate grazing systems, there is minimal pasture growth during winter and early spring and a peak of pasture growth in late spring and early summer (Roche *et al.,* 2009). As a result, cows are offered conserved forage and supplementary feeds to minimize their requirements for fresh pasture during winter. They are then provided with a predominantly pasture diet between early spring and early winter. Compact spring calving and breeding protocols ensure that the maximum numbers of cows are in peak lactation to coincide with peak pasture growth (Roche *et al.,* 2017).

Farm physical data

Data used in the present study were obtained from the Irish national dairy farm database (eProfit Monitor, Teagasc, Republic of Ireland). The database was established in 2002 and contains farm physical and financial data for the dairy and other enterprises of approximately 4,000 individual dairy farmer users (Ramsbottom *et al.,* 2015). Dairy farmer users of eProfit Monitor are, on average, larger scale, stocked more intensively, and more profitable than the average dairy farmer surveyed annually through the National Farm Survey (NFS) (Hennessy *et al.,* 2015). In the present study, farm physical and financial performance data were extracted for 315 spring calving dairy farmers who were continuous users of the programme during each of the eight years between 2008 and 2015, inclusive.

Monthly numbers of cows, replacement heifers, and non-dairy stock per farm were averaged across each calendar year to determine average livestock units (LU) for each of the three respective livestock categories (>2 year old = 1 LU; 1-2 year old = 0.7 LU and 0-1 year old = 0.3 LU). Farm stocking rate was calculated by dividing the total number of LU by the number of hectares (ha) of forage area (pasture and forage crop area combined) farmed. The percentages of each type of livestock farmed were calculated by dividing the annual average number of LU in each category by the total number of LU on the farm in each year.

Total volume of milk produced on farm (both sold and consumed on farm by calves) per farm was divided by the average dairy cow livestock units present on the farm to calculate average milk yield/cow per year. Average annual milk fat and protein content were obtained from the milk processor and used to calculate per cow lactational yield of milk fat and protein. When referring to whole farm performance, per hectare calculations were obtained by dividing the relevant farm yield by the total number of ha farmed. When referring to the dairy enterprise performance, per hectare calculations were calculated by dividing the relevant farm yield by the number of ha assigned to the dairy enterprise. The number of ha assigned is calculated by dividing the number of dairy cow livestock units by the farm stocking rate.

Using the farm physical data, farms were categorized in each year by the percentage of annual feed and forage requirements purchased for the dairy enterprise. Systems 1, 2, 3, or 4 refer to farms where <10, 11-20, 21-30, or >30% of the cow’s annual feed requirements were obtained from purchased feed. This categorization was considered to be representative of increasing levels of system intensification (as categorized by Ramsbottom *et al.* (2015)). Subsequently, farms were categorized as average System 1, 2, 3, or 4 by averaging the proportion of purchased feed over the 8 year period (2008-2015).

Farm financial data

All financial data are expressed in euro (€[1]) unless otherwise stated. Market values were used where animals were purchased or sold off farm. Where transfers from the dairy herd to the heifer or dry stock enterprises took place, standard monetary values per animal were used for all farms and years. Dairy cows were valued at €700 each; newborn replacement and beef calves transferred from the dairy enterprise were valued at €300 and €150, respectively. Similarly, the standard cost of €1,000 per head was used where replacement heifers were transferred at the point of calving to the dairy enterprise.

Farm gross revenue output was calculated by combining milk sales receipts, dairy and beef cattle sales and other sales such as crop or forage sales, and the standard value of calf transfers to beef and replacement heifer enterprises. The cost of purchased freshening dairy heifers and cows or the standard value of freshening heifers transferred from the farm’s replacement heifer enterprises were deducted, and an adjustment made for stock inventory change, where applicable. Variable costs include feed and fertilizer, breeding and veterinary costs, and farm contractor costs, as well as other variable costs such as milk recording, parlor expenses, and bedding costs

[1] At the time of writing (mid-June 2019), €1 was approximately equivalent to £0.89, $US1.13, and $NZ1.72.

(detailed further in Teagasc (2011)). Most of the other variable costs were apportioned in the eProfit Monitor system on a percentage livestock unit basis. For example, if the dairy enterprise accounted for 60% of the farm's total livestock units, then 60% of the total livestock variable costs were allocated to the dairy enterprise.

Overhead costs include machinery running and lease costs, hired labor, repairs and maintenance, depreciation, electricity, phone and transportation expenses, as well as the costs of leasing land and milk quota (where applicable). For all enterprises, overhead costs were allocated in proportion to the percentage of the farm gross revenue output attributed to the enterprise.

Farm net profit was calculated by deducting total variable and overhead costs (excluding the imputed value of owner labour) from farm gross revenue output. Farm net profit/ha was calculated by dividing farm net profit by the total number of ha farmed. Dairy net profit/ha was calculated by dividing total dairy enterprise net profit by the total area farmed. Similarly, other enterprise net profit/ha was calculated by dividing the net profit of all other enterprises by the total area farmed. Premia payments, the farming subsidies paid to dairy farmers from the Irish Government and the EU to support farming income, were totaled and expressed on a per hectare basis by dividing the total amount by the number of ha farmed. These payments, established based on historical production levels, were excluded from the calculations of farm net profit.

Using the farm financial data, farms were ranked by the average net profit/ha over the 8 farm financial years (the calendar years 2008-2015) within each of five geographical regions that differ in their seasonal production of pasture and rainfall (see Ramsbottom *et al.,* 2015). The regions were farms located in county Cork (the Cork Region); farms from counties Cavan, Clare, Donegal, Galway, Leitrim, Mayo, Monaghan, Roscommon and Sligo (the Northwest Region); farms from counties Carlow, Kilkenny, South Tipperary, Waterford and Wexford (the South East Region); and, farms from counties Kerry and Limerick (the South West Region). Within region, farms were subdivided into four sub-groups for average farm net profit: highest 8-year average farm net profit/ha; next highest 8-year average farm net profit/ha; second lowest 8-year average farm net profit/ha; lowest 8-year average farm net profit/ha.

Data analyses

All analyses were undertaken using a mixed model framework in PROC MIXED (SAS, 2005), where herd nested within region was included as a repeated effect with a first order autoregressive covariance structure assumed among records within herd. The first analysis estimated the annual least squares means and also the longitudinal trends in physical and financial performance over time; fixed effects included in the model were year and region. The second series of analyses quantified the association between 8-year average system of milk production and the various physical and financial characteristics; fixed effects included in the model were year, region, 8-year average system (i.e. 1-4) as well as the interaction between 8-year average system and year. A third series of analyses were conducted to quantify the association between 8-year average farm net profit/ha (i.e., independent variable) and the various physical and financial characteristics (i.e., dependent variables); fixed effects included in the model were year, region, 8-year farm net profit/ha (as quartiles) as well as the interaction between 8-year farm net profit/ha (as quartiles) and year.

Output and input price indices, rainfall and income

Milk and cattle price indices, the agricultural input prices prevailing and average farm income on specialist grazing dairy farms (representative of all Irish dairy farms during the study period; 2008-2015) are presented in Figure 1. Clear variation is evident in the prices paid for both milk and cattle and the inputs consumed on farms during the

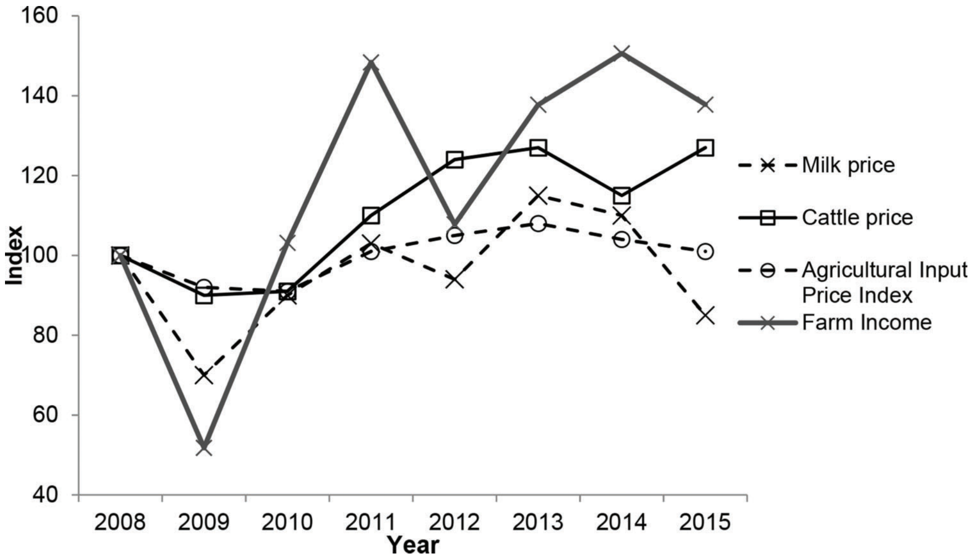

Figure 1: Index of average manufacturing milk price, cattle price, agricultural input price index, and annual farm income for pasture-based dairy farms during the 2008-2015 period (adjusted to 2008 = 100)[1].
[1]Sources: Milk and cattle prices (CSO, 2008-2015); agricultural input price indices (CSO, 2008-2015); farm income (Teagasc, 2008-2015).

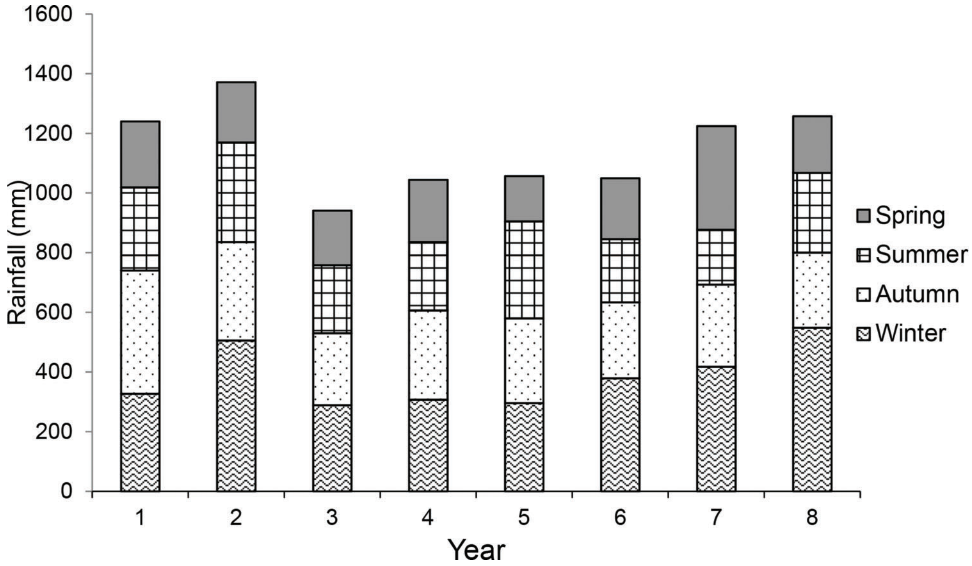

Figure 2: Annual total and seasonal[1] average rainfall for the 2008-2015 period for the entire Republic of Ireland (Met Éireann, 2018)
[1]Seasons: Spring – February-April; Summer – May-July; Autumn – August-October; Winter – January and November-December.

study period. The combination of high annual rainfall, (Met Office, 2008-2015), in particular during the summer grazing months, and low milk and cattle prices in 2009 was of particular interest in the present study to evaluate the capacity of grazing dairy farms to withstand and recover from a confluence of adverse events. The low national dairy farm income evident in 2009 (Figure 1) was an outcome of the combined effects of both low milk prices (Figure 1) and adverse weather (Figure 2) experienced by the whole of the Irish dairy sector.

Results and Discussion

Inter-year variability in production and profit on pasture-based dairy farms

Unlike most temporal datasets, which include a changing population of farms over time (Offerman and Lampkin, 2005; Arfini and Donati, 2013; DairyNZ, 2008-2015; Ramsbottom *et al.,* 2015; Teagasc, 2008-2015), the analyses in the current study represent temporal comparisons of economic performance on the same farms using a large consistent dataset of matched farms over an 8-year period. Consequently, this dataset permits a more thorough evaluation of the association between milk and input price and climatic challenges on farm biophysical characteristics and profitability as the farms managed variability and developed across the years.

Summary statistics for a range of performance parameters for the 315 spring-calving farms over an 8-year period are presented in Table 1. Expansion and intensification were features of most farms during the study period. The total area farmed and the area of the milking platform increased over the period by 9.7 ha to 71.6 ha and by 3.7 ha to 49.6 ha, respectively, while the scale of the dairy enterprise increased by 33.6 LU to 115.3cows. The proportion of dairy cows and replacements increased by 8% over the 8-year period and comprised 94% of all animals on the study farms in 2015.

Production increases were also achieved on the farms over the study period. Stocking rate increased linearly ($P < 0.001$) by 0.027 LU/ha to 2.3 LU/ha in 2015, while milk production increased linearly ($P < 0.01$) by 457 L/milking platform ha per year. Milk fat and protein yield increased ($P < 0.01$) by 4.4 and 3.0 kg/cow per year and 24.9 and 19.7 kg/milking platform ha per year, respectively. Furthermore, pasture DM utilized/ha increased linearly ($P < 0.05$) by 0.2 t DM/ha per year and was 19% greater ($P < 0.001$) in 2015 than in 2008.

Farm gross output and total variable and overhead costs increased linearly ($P < 0.05$) between 2008 and 2015 (Table 2). While average milk price was 33.8 c/L during the study, it ranged from a low of 23.7 c/L in 2009 to a peak of 40.5 c/L in 2013. Similarly, variable, overhead, and total costs/ha varied significantly between years, being lowest in 2009 (€945, €768, and €1,713, respectively) and greatest in 2013 (€1,604, €918, and €2,522, respectively). The least profitable and most profitable years were 2009 and 2014, respectively, with milk price and dairy net profit/ha differences of 16.2 c/L and €1,007/ha, respectively between the two years. Overall, farm net profit/ha averaged €1,109 during the study period and ranged from a low of €416 in 2009 to €1,400 in 2014. Of the total net farm profit, the dairy enterprise contributed on average 98%. Although declining by over 24% during the study period, premia payments contributed an additional €474/ha on average to total farm receipts. Net farm profit as a percentage of total farm receipts averaged 29.1% and ranged from 14.9% in 2009 to 33.3% in 2014.

There were increases in farming intensity, specialization, and scale during the 8-year study period. The general trends towards intensification and greater operational scale evident within the study period are similar to previous reports from both housed dairy production systems in the United States (Brown and Schulte, 2011) and the UK (AHDB, 2017) and pasture-based systems of milk production, such as those in New Zealand (DairyNZ, 2008-2015). With further specialization and continuing milk price volatility likely in future years, inter-year variability in farm profitability is likely to increase as a greater proportion of gross farm output is derived from the sale of milk.

Table 1: Least squares means for measured biological characteristics for a matched sample of seasonal spring-calving, pasture-based dairy farms (n=315) during the years 2008 to 2015, inclusive

Year	2008	2009	2010	2011	2012	2013	2014	2015	SE[1]	P value	Linear
Total farm (ha)	61.9^{a}	62.1^{a}	64.1^{b}	66.0^{c}	66.7^{c}	68.2^{d}	69.4^{d}	71.6^{e}	1.54	<0.001	<0.001
Owned land (ha)	45.9^{a}	46.3^{ab}	47.0^{bc}	47.5^{bc}	47.7^{c}	48.3^{cd}	48.9^{de}	49.6^{e}	1.32	<0.001	<0.001
Pasture (ha)	61.0^{a}	61.1^{a}	63.1^{b}	65.0^{c}	66.0^{c}	67.4^{d}	68.7^{d}	71.1^{e}	1.53	<0.001	<0.001
Milking platform (ha)	39.9^{a}	39.5^{a}	40.3^{b}	40.7^{b}	41.3^{c}	42.0^{d}	42.7^{d}	44.6^{e}	1.07	<0.001	<0.001
Stocking rate (LU/ha)	2.10^{a}	2.16^{b}	2.16^{b}	2.18^{b}	2.22^{c}	2.26^{d}	2.26^{d}	2.31^{e}	0.022	<0.001	<0.001
Supplement (kg DM/cow)	781^{a}	825^{b}	930^{c}	677^{d}	991^{e}	1,192^{f}	800^{ab}	786^{ab}	23.7	<0.001	0.66
Pasture DM used (T DM/ha)	8.3^{ab}	8.2^{a}	8.4^{b}	8.9^{c}	8.4^{b}	8.2^{ab}	9.1^{d}	9.9^{e}	0.10	<0.001	<0.05
Pasture used (% total DM)	83.6^{a}	82.1^{b}	80.8^{c}	85.9^{d}	79.3^{e}	75.5^{f}	83.6^{a}	84.6^{a}	0.46	<0.001	0.88
Dairy cows (LU)	81.7^{a}	86.5^{b}	91.3^{c}	95.6^{d}	97.0^{d}	101.9^{e}	104.7^{f}	115.3^{g}	2.28	<0.001	<0.001
Dairy LU (% of total LU)	65.8^{a}	67.1^{b}	68.1^{cd}	68.4^{c}	67.7^{bd}	68.5^{cd}	69.1^{d}	71.9^{e}	0.54	<0.001	<0.01
Milk yield (L/cow)	5,181^{a}	4,908^{b}	5,308^{c}	5,173^{a}	5,167^{a}	5,269^{c}	5,169^{a}	5,579^{d}	36.0	<0.001	0.10
Milk production (L/ha)[2]	11,333^{a}	11,303^{a}	12,600^{b}	12,703^{b}	12,768^{b}	13,378^{c}	13,374^{c}	14,995^{d}	58.2	<0.001	<0.001
Total production (L/farm)	420,275^{a}	420,476^{a}	480,499^{b}	488,575^{bc}	495,530^{c}	531,264^{d}	533,655^{d}	639,273^{e}	11,432.4	<0.001	<0.001
Fat content (%)	3.94^{a}	3.96^{b}	3.97^{c}	4.04^{d}	4.11^{e}	4.12^{e}	4.18^{f}	4.24^{g}	0.011	<0.001	<0.001
Protein content (%)	3.45^{a}	3.41^{b}	3.44^{a}	3.46^{c}	3.46^{c}	3.48^{d}	3.54^{e}	3.63^{f}	0.006	<0.001	<0.01

[a-h]Values in the same row not sharing a common superscript are significantly different ($P < 0.05$).
[1]Pooled standard error.
[2]Per milking platform hectare.

Table 2: Least squares means for measured financial characteristics for a matched sample of seasonal spring-calving, pasture-based dairy farms (n=315) during the years 2008 to 2015, inclusive

Year	2008	2009	2010	2011	2012	2013	2014	2015	SE[1]	P value	Linear
Milk price (c/L)[2]	34.7^{a}	23.7^{b}	31.2^{c}	36.0^{d}	33.1^{e}	40.5^{f}	39.9^{g}	31.8^{h}	0.09	<0.001	0.24
Gross output (€/ha)	2,945^{a}	2,129^{b}	2,877^{c}	3,322^{d}	3,235^{e}	3,841^{f}	3,730^{g}	3,547^{h}	43.2	<0.001	<0.05
Total variable costs (€/ha)	1,019^{a}	945^{b}	1,061^{c}	1,122^{d}	1,331^{e}	1,604^{f}	1,383^{g}	1,347^{e}	19.1	<0.001	<0.05
Total overhead costs (€/ha)	818^{a}	768^{b}	806^{a}	855^{c}	874^{c}	918^{d}	947^{e}	956^{e}	15.9	<0.001	<0.001
Total costs (€/ha)	1,837^{a}	1,713^{b}	1,867^{a}	1,977^{c}	2,204^{d}	2,522^{e}	2,330^{f}	2,303^{f}	29.5	<0.001	<0.01
Net profit (€/ha)	1,108^{a}	416^{b}	1,010^{c}	1,344^{d}	1,031^{c}	1,319^{d}	1,400^{e}	1,244^{f}	28.5	<0.001	0.12
Dairy net profit (€/ha)	1,075^{a}	411^{b}	994^{c}	1,308^{d}	1,006^{c}	1,353^{d}	1,418^{e}	1,204^{g}	25.8	<0.001	0.11
Other enterprise net profit (€/ha)	33^{a}	6^{b}	16^{ab}	77^{c}	25^{ab}	-34^{d}	-18^{d}	73^{c}	10.2	<0.001	0.95
Premia payments (€/ha)[3]	514^{a}	507^{a}	514^{a}	498^{ab}	486^{b}	451^{c}	432^{d}	391^{e}	9.0	<0.001	<0.001

[a-h]Values in the same row not sharing a common superscript are significantly different ($P < 0.05$).
[1]Pooled standard error.
[2]Average price paid per litre of milk sold to the processor.
[3]Premia payments are farm subsidies received from the Irish Government and the EU to support farming income.

Inter-farm variability in farm feeding system and profit

Profitability and performance of pasture-based dairy farms are affected by many factors, and much inter-farm variability exists regardless of the planned feeding system. The proportion of farms in each feeding system varied between years in the present study. Farms appeared to change feeding strategies opportunistically, responding to changes in milk price and weather conditions. For example the number of farms in Systems 1, 2, 3 and 4 were 31%, 53%, 14% and 2% respectively in 2011 and 3%, 36%, 34% and 27% in 2013. Farms in System 1 were defined by larger milking platforms ($P < 0.001$) and herd sizes ($P < 0.001$), and they utilized more pasture/ha when compared with System 4 farms (Table 3; 24.8 ha, 58.1 cows, and 2.2 t DM/ha, respectively). In comparison, milk yield/cow and per ha were greater in the highest feed input systems (+855 L/cow and +3,124 L/milking platform ha in System 4 compared with System 1 farms; $P < 0.001$); but, milk fat and protein contents were less than in System 1 farms (-0.36% and -0.13%, respectively; $P < 0.001$; Table 3).

Farms in System 1 were characterized by lower gross output per hectare ($P < 0.001$), but also lower total production costs per hectare ($P < 0.001$). However, net profit per ha was not different for System 1 farms compared to System 3 farms (Table 4). There was a significant interaction of system and year for total costs/ha ($P < 0.01$; Figure 3). Ultimately the net profit of System 1 farms was €604/ha in 2009 compared with €432, €385, and -€35/ha for Systems 2, 3 and 4 farms, respectively ($P < 0.001$; Figure 3), highlighting this farming system's ability to buffer downturns in milk price, while adapting to a challenging weather year. Additionally the variation in net farm profit per hectare for farms in System 1 was €998/ha (ranging from €604 in 2009 to €1,602 in 2013) representing a proportional change of 77% in 8-year farm net profit per hectare. For

Table 3: Least squares mean for measured biological characteristics in seasonal spring-calving, pasture-based dairy farms categorized by system of milk production for the years 2008-2015, inclusive

System category[1]	1	2	3	4	SE[2]	P value
Number of farms	19	206	70	20		
Total farm (ha)	88.1[a]	66.6[b]	64.0[bc]	51.4[c]	4.18	<0.001
Owned land (ha)	67.1[a]	48.1[b]	46.8[b]	37.5[b]	3.58	<0.001
Pasture (ha)	87.8[a]	66.2[b]	63.2[bc]	50.8[c]	4.13	<0.001
Milking platform (ha)	57.4[a]	41.6[b]	39.1[bc]	32.6[c]	2.80	<0.001
Stocking rate (LU/ha)	2.20	2.18	2.26	2.17	0.056	0.42
Supplement DM fed (kg/cow)	436[a]	742[b]	1,140[c]	1,713[d]	26.4	<0.001
Pasture DM used (T DM/ha)	9.4[a]	8.8[ab]	8.5[b]	7.2[c]	0.23	<0.001
Pasture used (% total DM)	90.6[a]	84.4[b]	76.8[c]	66.0[d]	0.45	<0.001
Dairy cows (LU)	133.7[a]	95.1[b]	96.2[b]	75.6[c]	6.14	<0.001
Dairy LU (as a % of total LU)	68.8	67.4	70.1	70.0	1.37	0.14
Milk yield (L/cow)	4,892[a]	5,117[a]	5,425[b]	5,747[c]	88.8	<0.001
Milk production (L/ha)[3]	11,656[a]	12,143[a]	13,485[b]	14,780[b]	562.6	<0.001
Total production (L/farm)	629,891[a]	483,445[b]	539,782[ab]	465,831[b]	30,167.0	<0.01
Fat content (%)	4.16[a]	4.08[b]	4.04[bc]	3.97[c]	0.028	<0.01
Protein content (%)	3.53[a]	3.49[ab]	3.47[b]	3.40[c]	0.014	<0.001

[a-d]Values in the same row not sharing a common superscript are significantly different ($P < 0.05$).
[1]Systems1, 2, 3, and 4 refer to systems in which <10%, 10-20%, 20-30% or >30% of total annual feed requirements are purchased respectively.
[1]Pooled standard error.
[2]Per milking platform hectare.

Table 4: Least squares means for measured financial characteristics in seasonal spring-calving, pasture-based dairy farms and categorized by 8-year average system of milk production for the years 2008-2015, inclusive

System category[1]	1	2	3	4	SE[2]	P value
Number of farms	19	206	70	20		
Milk price (c/L)[3]	34.3[a]	34.0[a]	33.6[b]	32.7[c]	0.19	<0.001
Gross revenue output (€/ha)	2,990[a]	3,079[a]	3,468[b]	3,363[ab]	108.4	<0.001
Total variable costs (€/ha)	940[a]	1,150[b]	1,404[c]	1,569[d]	40.8	<0.001
Total overhead costs (€/ha)	766[a]	840[a]	931[b]	980[b]	37.9	<0.01
Total costs (€/ha)	1,707[a]	1,990[b]	2,335[c]	2,545[d]	69.5	<0.001
Net profit (€/ha)	1,297[a]	1,097[b]	1,124[ab]	794[c]	65.5	<0.01
Dairy net profit (€/ha)	1,229[a]	1,067[a]	1,139[a]	859[b]	59.8	<0.01
Other enterprise net profit (€/ha)	80[a]	38[a]	-11[b]	-59[b]	16.5	<0.001
Premia payments (€/ha)	478	465	478	536	20.6	0.17

[a-d]Values in the same row not sharing a common superscript are significantly different ($P < 0.05$).
[1]Systems1, 2, 3, and 4 refer to systems in which <10%, 10-20%, 20-30% or >30% of total annual feed requirements are purchased respectively.
[2]Pooled standard error.
[3]Average price paid per litre of milk sold to the milk processor.

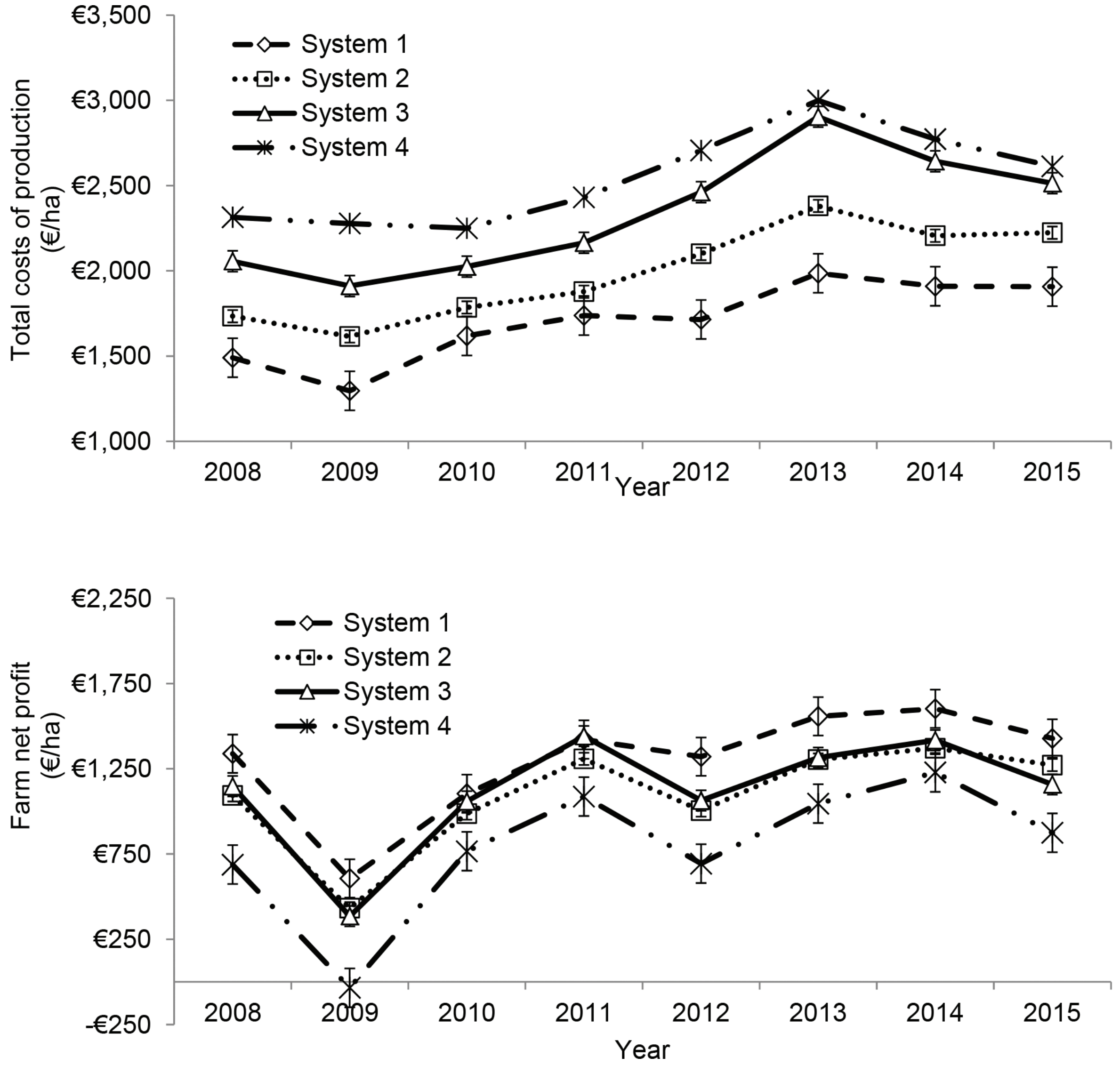

Figure 3: Annual mean (±SE) total costs of production (€/ha) and farm net profit (€/ha) in seasonal spring-calving, pasture-based dairy farms categorized by system[1] of milk production for the years 2008-2015, inclusive
[1]Systems 1,2,3 and 4 refer to Systems in which <10%, 10%-20%, 20%-30% or >30% of total annual feed requirements are purchased respectively.

farms in System 4, the respective values were €1,264/ha and 159%.

Herd mean milk production responses to increasing levels of feed supplementation was low to moderate, averaging 0.69 kg of additional (i.e., marginal) milk per kg of additional feed DM. The marginal milk production response to additional feed varied between 0.55 (2009) and 1.17 (2011) kg of additional milk/kg supplementary feed DM (between 33 and 70 g of milk fat and protein). Such responses are lower than the responses of between 0.8 and 1.2 kg milk/kg additional feed DM reported in controlled experiments (Coleman *et al.,* 2010; Macdonald *et al.,* 2017). Lower responses have been reported, however, in experiments investigating the importation of supplementary feed into grazing systems without altering the stocking rate (Roche *et al.,* 2006). The low marginal response effect is likely explained by a relatively high substitution rate of concentrate for pasture.

Previous studies have indicated that 85 to 90% of revenue on intensive pasture-based dairy farms consists of milk sales (Dillon *et al.,* 2008) and increasing milk production is a key strategy to increase profitability (Parker *et al.,* 1997) when milk price is above average. Across the years considered in the present study, greater levels of feed supplementation resulted in greater milk production; however, they were also associated with greater production costs, more so in higher milk price scenarios. In addition to greater feed costs/ha with greater amounts of purchased feeds, overhead and non-feed variable costs were also greater. These results are consistent with previous studies. Ramsbottom *et al.* (2015) and Neal and Roche (2020) reported that total costs increased by between €1.53 and €1.66 per €1.00 increase in feed costs. In Ramsbottom *et al.* (2015) these cost increases were due to increases in overhead (€0.35/€1 feed costs) and non-feed variable costs (€0.18/€1 feed costs) associated with higher input systems of milk production. These results are particularly relevant to pasture-based farmers and their advisors who might consider adjustments to their milk production system in response to variable milk prices. Although Ho *et al.* (2013) cautioned against using any partial efficiency measures to assess the profitability of dairy enterprises due to the wide range of levels of technical efficiency and intensity, the results from the current study indicate that there are important system effects on farm production costs as currently implemented on Irish dairy farms. Our results do not support transitioning from low to high feed systems even in high milk price years.

Resilience - the interaction between year and farm profitability category

When ranked by quartiles (highest to lowest) for farm net profit/ha averaged across all 8 years, the highest profit quartile was characterized by smaller farms (19% smaller than the average of the two lowest profit quartiles) with better technical efficiency, including greater pasture utilized/ha, and milk produced/ha (+0.83 t DM/ha, and +2,461 L/milking platform ha farmed, respectively, between highest and lowest farm net profit quartiles; Table 5). The highest and second highest profit quartiles were the most specialized dairy farm categories, having the greatest ($P < 0.001$) proportion of dairy cows to total livestock units. The highest profit quartile achieved greater milk yield/cow compared with the second highest profit quartile (+237 L/cow; Table 5) ($P < 0.001$). Importantly there was no difference in the proportion of the diet coming from pasture across profit categories varying from 80.7% to 82.3% ($P = 0.28$; Table 5) which contrasts with both Ramsbottom *et al*. (2015) and Neal and Roche (2020) who found that increasing the proportion of pasture in the diet was associated with greater profitability. Consistent with the two previous studies however, greater profitability was associated with greater pasture use in this matched sample of dairy farms.

Profitability/ha was positively associated with total costs/ha ($P < 0.001$; Table 6). Total variable costs/ha were highest for the highest and second highest profit categories ($P < 0.001$; Table 6). Total overhead costs/ha were not affected by year or profit category. The magnitude of difference between profit quartiles observed is similar to previous financial evaluations internationally from countries as diverse as Australia (DairyAustralia, 2017), Finland and Norway (Sipilainen *et al.,* 2014), and the UK (AHDB, 2017). The results presented here are also consistent with previous reports on the profitability of high performance grazing systems based on medium levels of milk production/cow, high stocking rates (Macdonald *et al.,* 2001; Macdonald *et al.,* 2008), high levels of pasture utilization (Ramsbottom *et al.,* 2015), and low levels of purchased feed (Ramsbottom *et al.,* 2015; Macdonald *et al.,* 2017). While Neal and Roche (2020) did not find an association between proportion of imported feed and profit, they observed that higher use of imported feed increased average production costs.

Over the 8-year study period, 2009 was the year of lowest milk price coupled with greatest precipitation (i.e., greatest challenge for utilizing grazed pasture). The response of farmers to the especially low milk prices prevalent in 2009, coupled with significantly above average precipitation (30% greater in summer; 12% greater in autumn: and 32% greater in winter than average), reflects the capacity of individual farming businesses to manage adverse biophysical and financial conditions. Three elements of farm business resilience reported previously (Darnhofer *et al.,* 2010, Peeters *et al.,* 2015) were considered in the present study: 1) the magnitude of the decline in profitability arising from low milk prices and poor weather; 2) the nadir profit within each of the quartiles within the challenging circumstances of 2009; and, 3) the ability of farms to resume normal profitability subsequent to the milk price and poor weather challenges.

While farms in all profit quartiles declined in farm net profit/ha in 2009 compared with the previous year, the magnitude of the decline was greatest in the highest profit quartile category (Figure 4). The highest profit quartile also had the greatest decline in total gross output/ha

Table 5: Least squares means for measured biological characteristics in seasonal spring-calving, pasture-based dairy farms balanced for region and categorized into highest, second highest, second lowest, or lowest quartile for 8-year average farm net profit/ha (€) for the years 2008-2015, inclusive

Profit category	Highestprofit	Second highest profit	Second lowest profit	Lowestprofit	SE[1]	P value	Profit category * year
Number of farms	79	79	79	78			
Total farm (ha)	59.0[a]	65.9[ab]	68.5[b]	71.5[b]	2.88	<0.05	0.24
Owned land (ha)	45.4	48.4	48.6	50.6	2.47	0.52	0.72
Pasture (ha)	58.6[a]	65.2[ab]	68.1[b]	71.0[b]	2.85	<0.05	0.25
Milking platform (ha)	40.6	43.3	41.4	40.0	1.96	0.67	0.85
Stocking rate (LU/ha)	2.42[a]	2.28[b]	2.13[c]	1.96[d]	0.032	<0.001	0.11
Supplement DM fed (kg/cow)	887	896	862	905	33.0	0.81	0.20
Pasture DM used (T DM/ha)	9.9[a]	9.0[b]	8.3[c]	7.4[d]	0.12	<0.001	0.54
Pasture used (% total DM)	82.3	81.6	82.0	80.7	0.62	0.28	0.07
Dairy cows (LU)	99.5	103.4	95.0	87.8	4.35	0.07	0.13
Dairy LU (as a % of total LU)	71.6[a]	69.6[a]	66.3[b]	65.5[b]	0.89	<0.001	0.31
Milk yield (L/cow)	5,511[a]	5,274[b]	5,131[b]	4,967[c]	58.2	<0.001	0.38
Milk production (L/ha)[2]	13,944[a]	13,409[ab]	12,554[b]	11,483[c]	377.1	<0.001	0.12
Total production (L/farm)	546,509[a]	538,709[ab]	485,692[bc]	437,411[c]	20,833.3	<0.001	0.07
Fat content (%)	4.12[a]	4.08[ab]	4.05[b]	4.04[b]	0.019	<0.05	0.79
Protein content (%)	3.52[a]	3.50[a]	3.46[b]	3.45[b]	0.009	<0.001	0.14

[a-d]Values within rows not sharing common superscripts are significantly different ($P < 0.05$).
[1]Pooled standard error.
[2]Per milking platform hectare.

Table 6: Least squares means for measured financial characteristics in seasonal spring-calving, pasture-based dairy farms balanced for region and categorized into highest, second highest, second lowest or lowest quartile for 8-year average farm net profit/ha (€) for the years 2008-2015, inclusive

Category	Highest profit	Second highest profit	Second lowest profit	Lowest profit	SE[1]	P value	Profit category * year
Number of farms	79	79	79	78			
Milk price (c/L)[2]	34.3[a]	34.0[a]	33.6[b]	33.4[b]	0.13	<0.001	0.71
Gross revenue output (€/ha)	3,831[a]	3,376[b]	2,978[c]	2,553[d]	51.8	<0.001	<0.001
Total variable costs (€/ha)	1,345[a]	1,279[a]	1,185[b]	1,101[c]	28.9	<0.001	0.08
Total overhead costs (€/ha)	876	910	858	824	25.6	0.12	0.36
Total costs (€/ha)	2,220[a]	2,188[a]	2,042[b]	1,924[b]	48.7	<0.001	0.14
Net profit (€/ha)	1,611[a]	1,189[b]	937[c]	630[d]	18.0	<0.001	<0.001
Dairy net profit (€/ha)	1,561[a]	1,162[b]	928[c]	674[d]	18.4	<0.001	<0.001
Other enterprise net profit (€/ha)	69[a]	32[b]	27[b]	-40[c]	10.7	<0.001	0.51
Premia payments (€/ha)	502[a]	485[ab]	462[b]	447[b]	13.8	<0.05	0.19

[a-d]Values within rows not sharing common superscripts are significantly different ($P < 0.05$).
[1]Pooled standard error.
[2]Average price paid per litre of milk sold to the milk processor.

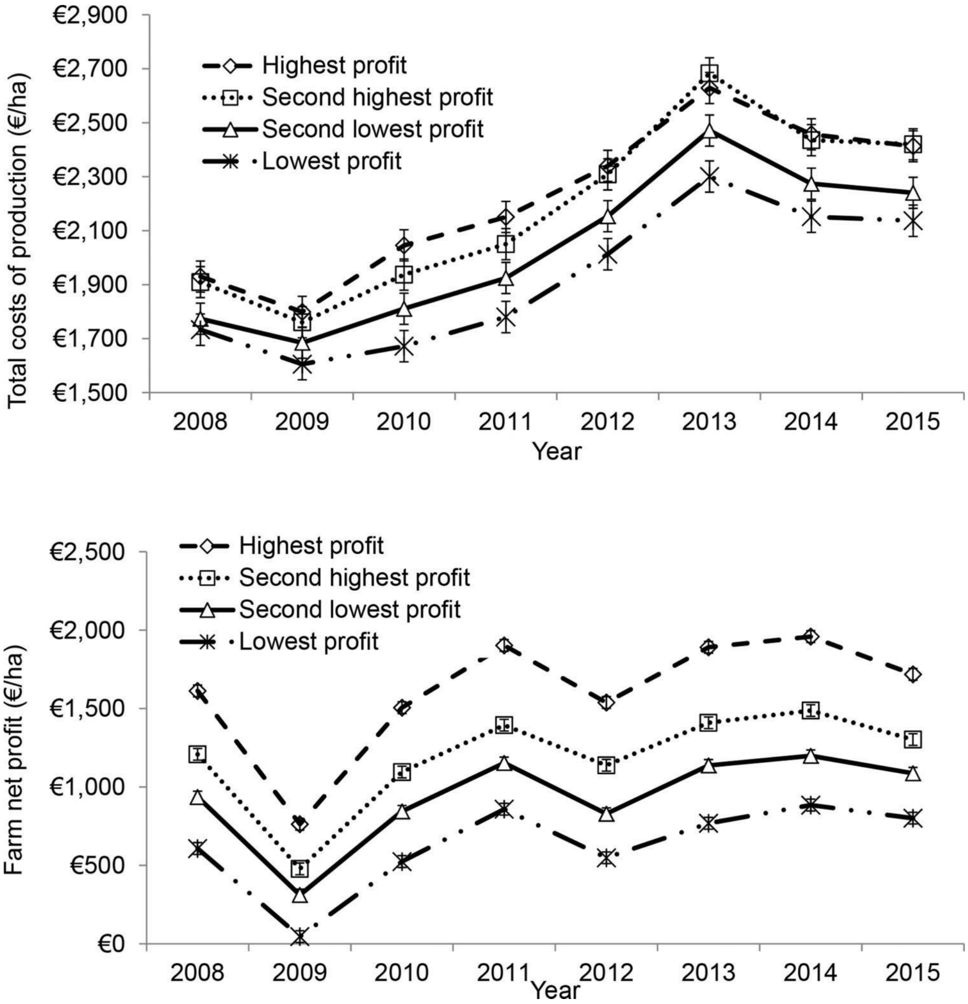

Figure 4: Annual mean (± SE) total costs of production (€/ha) and farm net profit (€/ha) in seasonal spring-calving, pasture-based dairy farms balanced for region and categorized into highest, second highest, second lowest or lowest 8-year average farm net profit/ha for the years 2008-2015, inclusive.

between 2008 and 2009 (€981/ha; $P < 0.001$). The comparably greater degree of dairy specialization within the higher profit quartiles probably contributed to the greater reduction in profitability. The fall in milk price between 2008 and 2009 affected more specialized farms to a greater extent than less specialized farms. Pasture management, as evidenced by greater pasture utilisation rates, was better on these farms; feed supply may, therefore, have been more adversely affected by the challenging year. Dairy cows accounted for 71.6% and 65.5% of all livestock farmed on the highest and lowest profit farms, respectively (Table 5; $P < 0.001$). This study supports the results of Kelly *et al.* (2011), where they identified an increased risk to profit associated with increased farm specialization during periods of depressed milk prices. The marked inability of the highest profit quartile to reduce costs to a greater nominal or proportional extent than other quartiles was, probably, because of their already low total cost of production/L ($P < 0.001$) and, consequently, a reduced capacity to further lower production costs in 2009, without having a significant negative effect on farm biophysical performance.

When considering farm net profit/ha, dairy farms in the highest profit quartile remained the most profitable category even in years of low milk price and biophysical challenges (Figure 4). The net profit of farms in this quartile was €763/ha in 2009 compared with €478, €311, and €46/ha for the second highest, second lowest, and lowest net profit quartiles, respectively (Figure 4). The variation in profit from highest profit (2014) to lowest profit (2009) year was €1,196 and €838/ha for the highest and lowest profit quartiles, respectively. These results support Purdy *et al.* (1997), who reported that while mixed enterprise farms (such as the lower profit quartile farms in this study) have less variability in financial performance, they also had less average profitability. The greater use of pasture by the highest profit quartile (Table 5) is also consistent with Neal and Roche (2020) who identified maximizing pasture harvested as a key contributor to profitable pasture-based dairying. Similarly Peeters *et al.* (2015) reported that pasture-based systems of milk production appear to be more resilient to price crises than higher supplementary feed input systems. However, it is the greater utilization rather than the proportion of pasture in the cows' diet that is associated with greater profitability.

The results of the financial analysis also indicate that high profit, pasture-based dairy farms have greater capacity to recover after low milk price and challenging biophysical years. The net profit/ha of the high profit quartile increased by €743/ha between 2009 and 2010 compared with increases of €618/ha, €533/ha, and €478/ha for the second highest, second lowest, and lowest profit quartiles, respectively ($P < 0.001$; Figure 3). This recovery was underpinned by a substantial increase in the value of farm gross output/ha between the two years that varied from €990/ha to €545/ha for the highest and lowest profit quartiles, respectively.

Conclusions

Pasture-based production systems with a greater reliance on imported feeds had consistently greater farm production costs across a variety of milk prices over time, including during particularly unfavourable climatic years. Separately, the results also indicate that although low milk prices result in a comparably greater reduction in profitability within the highest profit cohort of dairy farms studied, these farms remained most profitable and most 'resilient' exhibiting greater average profitability and a greater capacity to recover after low milk price and challenging biophysical years. Further research is required to better understand the fluctuations within profit category and system of milk production between years. Finally, the results reinforce the economic importance of pasture utilization on farm profitability on pasture-based dairy farms.

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