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A description and evaluation of the physical and financial characteristics of dairy farms operating on soil types classified as poorly drained and associated with high rainfall

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Abstract

The physical and financial performance data used for analysis were obtained over a 6-year period (2010–2015), from two different databases including a nationally representative data set of dairy farmers and a detailed data set of seven individual farms. Initial analysis indicated significant variations across soil type and region, across a wide range of physical and financial parameters. Further detailed analysis was completed using a group of seven farms participating in a Heavy Soils Programme (HSP), which were compared to different cohorts of the nationally representative database (National Farm Survey [NFS]), ranked on net profit per ha. The HSP farms utilized larger quantities of grass DM per ha per year than the median of the NFS farms, at similar grazing season lengths, but were using lower levels of purchased feed. Economic analysis indicated the HSP farmers achieved significantly lower net profits per hectare to the NFS median group but significantly higher net profits per kg of fat and protein. The HSP farms also achieved significantly greater overall net farm income per year (€83,788), when compared to the median nationally (€67,898), over the 6-year period (excluding owned land and labour). The mean return on assets ascertained by the HSP farmers was also significantly greater, at 5.75% per year compared to 3.49% achieved by the median of NFS farms. In conclusion, this study has indicated that efficient dairy businesses operating on poorly drained soils can be as profitable as those across all ranges of soil types.

KEYWORDS
economic analysis, farm systems, key performance indicators

1 | INTRODUCTION

Irish dairy farming is characterized by pasture-based systems of milk production (Dillon, Roche, Shalloo, & Horan, 2005), with efficiency dependent on maximizing the effectiveness with which grass is grown, utilized and converted into milk by dairy cows (Holmes, 2009). Irish dairy farms typically operate a spring-calving system, aiming to capitalize on a long grass-growing season, while matching peak milk production with peak grass growth (Horan, Coleman, McCarthy, & Brennan, 2009; Läpple, Hennessy, & O'Donovan, 2012). Generally, the climate in Ireland is well suited to growing large quantities of grass (Hennessy & Roosen, 2003), with the potential to produce between 12 and 16 t of grass DM per ha (Hanrahan et al., 2017; O'Donovan, Lewis, & O'Kiely, 2011), but production can be curtailed due to adverse soil type or climatic conditions (Brereton, 1995; Ryan, 1974). High annual rainfall combined with poorly drained soils in certain parts of the country makes both grazing and machinery work difficult when soil traffic ability is impaired (Shalloo, Dillon, O'Loughlin, Rath, & Wallace, 2004). Despite these challenges, a 2011 study showed that 30% of Irish milk was produced from land that was classified as heavy (O'Loughlin et al., 2012). While previous studies have evaluated the effect of soil type and climate on system efficiency (Shalloo et al., 2004), there has been little research completed using econometric approaches or which included a more in-depth analysis including actual farm performance information or captured the capital value of land as part of the analysis.

The levels of grass utilization are a key measure of efficiency on Irish dairy farms, and with mean values remaining relatively low at 7.8 t DM per ha (Hanrahan et al., 2018), there is significant potential for improvement. Unsurprisingly, there is a significant difference in the levels of grass utilization, costs of production and profitability between soil types (Hanrahan et al., 2018; Kelly et al., 2012; Shalloo et al., 2004), with previous research reporting that grass production may be reduced by as much as 25% on poorly drained soils (Thomasson, 1979). Ryan (1974) quantified this reduction at 2 t DM per ha, with Morrison, Jackson, and Sparrow (1980) reporting that soil type also affected the seasonal distribution of grass growth, in turn also restricting grazing season lengths. A previous modelling study has shown that comparably high levels of profitability can be achieved on less favourable soils types where high levels of grass utilization are achieved, through appropriate stocking rates and best grazing management practices (Patton, Shalloo, Pierce, & Horan, 2012). Furthermore, there are opportunities in areas which have challenging soil types and problematic climatic conditions, not often discussed in other studies, associated with the availability and cost of land, mainly driven by lower levels of demand for agricultural land either through leasing or purchase. In many cases, forestry is the only realistic alternative to grassland production with market values of just over €12,500 per ha as standard. Ultimately, the return for the investment made will be affected by land value and not just net profit per hectare. However, the performance efficiency on heavy soils requires further investigation using commercial farm data to determine the potential of universal performance metrics across a longitudinal time horizon. On-farm research could improve the understanding around the limitations of such soil types and quantify how much potential could be realized, be it through improved management practices, increased drainage, altered soil fertility, farmer technical ability or a combination of all of the above.

The objective of this study was to describe and compare the performance of dairy farms, using a number of physical and financial performance metrics, operating on soil types classified as poorly drained and associated with high rainfall, relative to a nationally representative group of farms, including farms operating at high and low levels of efficiency nationally, as defined by net profit per hectare. It is expected that farm efficiency and in essence the farmer's management capabilities will be a greater barrier to profitability than the soil type being farmed.

2 | MATERIALS AND METHODS

2.1 | Data

Farm performance was evaluated to determine the associated effects of soil type and region on farm productivity, efficiency and profitability, across two separate databases: one using a nationally representative database across all soil types and a second data set containing seven farms that were located on soil types classified as poorly drained and associated with high rainfall. This analysis was conducted over a 6-year period (2010–2015).

2.2 | National Farm Survey

The National Farm Survey (NFS) is a survey conducted by Teagasc on an annual basis since 1972 and provides data of farm performance nationally (Hennessy & Moran, 2014). The NFS is conducted as part of the Farm Accountancy Data Network of the EU and fulfils Ireland's statutory obligation to provide data on farm output, costs and income to the European Commission. A nationally representative sample of approximately 1,100 farms from all farming sectors is surveyed as part of the programme each year, which are selected in conjunction with the Central Statistics Office (CSO). Each farm is assigned a weighting factor so that the results of the survey are representative of the national farming population. The NFS classifies each farm based on its main farm enterprise, which is calculated on a standard gross output basis. For the purpose of this study, only specialized dairy farms were used for data analysis. A specialized dairy farm is a farm with >60% of the farm gross output yielded from dairy production. The analysis was conducted on NFS data from the 6-year period (2010–2015), containing on average 262 specialized dairy farms each year and 1,570 surveys in total. The NFS data were divided into six defined geographical regions (locations), which are Border and midlands, Dublin and east, Southwest, Southeast, South and West; for the purpose of this study, the regions are labelled as 1, 2, 3, 4, 5 and 6 respectively. Farms within the survey are also categorized into high, medium or low-quality soil types, which are distinguished by soil groups 1, 2 and 3 respectively. Farms are classified by soil group depending on their use range. Soil group 1 has the widest use range, and soil group 3 contains farms with limited use range. The outputs from the survey provide a range of physical and financial performance indicators for each farm such as farm details, stock details, product yields, sales, purchases, costs and profits including full reconciled farm management accounts. These data were subsequently subdivided into different categories for comparative purposes ranked by net profit per hectare; these were NFS top 20%, median and bottom 20% of farms nationally, with each year ranked individually.

2.3 | Heavy Soils Programme

Seven monitor farms were part of the Teagasc Heavy Soils Programme (HSP) over the period 2010–2015. These HSP farms can be predominantly classified in the Kilrush and Abbeyfeale soil series, which are poorly drained and fine in texture, with compact plastic subsoils (Gardiner & Radford, 1980). All farms were part of the programme from the beginning (i.e., 2010). These farms were originally chosen as monitor farms for the region to allow for on-farm research and dissemination of up to date advice. The seven farms are located in Rossmore, Co. Tipperary (N 52°35.824′, W 08°00.899′); Lisselton, Co. Kerry (N 52°27.852′, W 09°33.113′); Ballinagree, Co. Cork (N 51°58.932, W 08°55.340′); Doonbeg, Co. Clare (N 52°43.692′, W 09°29.903′); Athea, Co. Limerick (N 52°27.560′, W 09°18.563′); Castleisland, Co. Kerry (N 52°12.904′, W 009°28.110′); and Kiskeam, Co. Cork (N 52°12.250′, W 09°08.157′). The farms were selected with the help of a local Teagasc advisor based on a number of criteria, namely each farm must have been willing to cooperate with the programme, to collect and share data and they must have been farming land which had been classified as being heavy soils. On average, 75% of each of the farms included in the HSP were classified as being poorly drained and required drainage work to achieve full grass production potential. The data from each farm were sourced from a range of data sources, which included the following: the Teagasc e-Profit Monitor (PM), PastureBase Ireland (Hanrahan et al., 2017), Irish Cattle Breeding Federation (ICBF) (ICBF, 2017), the milk processor which they supplied and through the completion of a monthly web-based detailed recording system for all activity data on the farm. All physical and financial data relevant for the farm were available through those identified sources.

The Teagasc e-PM is a farm financial analysis tool used by the farmer in conjunction with their Teagasc advisor on an annual basis for financial benchmarking. It compiles data on farm inputs and outputs of each farm for each year including the following: gross output, variable and fixed costs, gross margin and net profit, in addition to, milk production details, sales, purchases, individualized farm working expenses, direct payments and a range of physical performance metrics such as stocking rate (livestock units [LU]/ha), concentrate supplementation and grazing season length. PastureBase Ireland is a web-based grassland management decision support tool, with the dual function of data collection and storage, which allows the farmers participating in the programme to provide farm physical data while benefitting from the decision support aspect of the application. ICBF HerdPlus is a herd management tool which collates large quantities of data at herd and animal level, including herd performance and genetic evaluations from services such as milk recording and genomic testing. This provides full milk production and fertility performance outputs for each herd. All milk quality and quantity information was supplied by the milk processor with the farmers also completing regular web-based survey updates on farm performance. Data were formatted and aligned using the same methodology for both data sets to ensure a consistent comparison.

2.4 | Data analysis

The HSP and NFS data were analysed and compared using a range of physical and financial performance metrics which were firstly examined using a series of calculations through Microsoft Excel, prior to full statistical analysis. These key performance indicators (KPIs) included farm size (ha), cow numbers, stocking rate (LU/ha), milk production per cow and per ha, concentrate fed per cow, grazing season length (days), proportion of purchased feed, grass utilization (kg DM/ha), gross output, gross margin, production costs and net profit per ha and per unit of product and overall return on assets. Grass utilization per ha was calculated using the approach outlined by Hanrahan et al. (2018) using the Unité Fourrage Laitière (UFL) energy system (O'Mara, 1996), which uses UFL as the unit of energy within the calculations. These calculations account for the energy cost associated with maintenance, milk production, pregnancy, liveweight change and growth of the stock. These physical performance indicators have been previously identified as factors associated with efficiency on farm (Hanrahan et al., 2018; Kelly et al., 2013) and were chosen due to their significant link with profitability. The financial performance of each group of farms was characterized by the universal farm performance metrics, gross output (milk and stock sales less stock purchases), variable costs (expenses which are linked to and change with output including herd, parlour and feed costs), gross margin (gross output—variable costs), total costs (total farm working expenses including interest and leases [excluding owned land and labour]) and net profit (gross output—total costs) per ha and per kg of milk fat and protein, which were calculated from the data provided by the PM and NFS to ensure that the same methodological approach was used.

The return on assets for each farm category was calculated with the HSP and NFS farms valued at €12,500 and €25,000/ha, respectively, based on land market values, generated through industry consultation, with reference to a recent Irish land price review (Myler, McAuley, Donnellan, Hanrahan, & Loughrey, 2017). Capital expenditure and infrastructural investment required were valued at a baseline of €4,000 per livestock unit for the HSP farms and further examined at a value of €5,000 and €6,000 per livestock unit under sensitivity analysis, with the value for NFS farms held constant at €3,500 per livestock unit. The greater cost on HSP farms is due to a greater infrastructural requirement for winter housing, land drainage, soil fertility, etc. with the sensitivity analysis also demonstrating return on assets at greater levels of investment. A new parameter, net farm income, was used to compare overall farm performances across farm categories, which was generated from total farm revenue and expenditure including subsidies and direct payments. For the purpose of the return on assets calculation to ensure consistency across all farms, interest and hired labour were added back to net farm income, and a total labour input (including owner/operator labour) was then charged at a flat rate of €0.06 per litre. Return on assets was calculated by the following equation:

$$\text{Return on Assets (ROA)} = (\text{Net Farm Income} + \text{Interest} + \text{Hired Labour} - \mathit{TotalLabour})/\text{TotalAssets}$$

2.5 | Scenarios

Data were analysed under a range of scenarios to evaluate the performance of dairy farms operating on soil types classified as poorly drained and associated with high rainfall, relative to a nationally representative group of farms including farms operating at high and low levels of efficiency nationally, as defined by net profit per hectare:

2.5.1 | Scenario 1

An evaluation of the physical and financial performance of a nationally representative group of farms across soil type and region.

2.5.2 | Scenario 2

An evaluation of the physical performance of HSP farms relative to the performance of the top 20%, median and bottom 20% NFS farmers ranked on net profit per hectare.

2.5.3 | Scenario 3

An evaluation of the operational financial performance of HSP farms relative to the performance of the top 20%, median and bottom 20% NFS farmers on a per unit of land and a per unit of product basis, ranked on net profit per hectare.

2.5.4 | Scenario 4

An evaluation of the overall financial performance including a return on assets sensitivity analysis, of HSP farms relative to the performance of the top 20%, median and bottom 20% NFS farmers ranked on net profit per hectare.

2.6 | Statistical analysis

The statistical analysis was completed in a two-stage process using the statistical analysis programme SAS (SAS Inst. Inc., Cary, NC). The effect of soil type and region on physical and financial performance of the NFS farms (*Scenario 1)* was completed using general linear models in PROC GLM, with year (2008–2015), region (Border and midlands, Dublin and east, Southwest, Southeast, South and West) and soil type (groups 1, 2 and 3) included as class variables. The physical and financial performance variables investigated in *Scenario 1* included the following: grass utilization (kg DM/ha), stocking rate (livestock units [LU]/ha), grazing season length (days), concentrate supplementation (kg as fed/cow), proportion of purchased feed, milk production variables (L/cow and kg milk fat and protein per cow and per ha) and a full range of profitability variables including the following: gross output, production costs and net profit (€/ha and €/kg of fat and protein). The interaction between soil group and region was also tested, however to complete this soil group by region interaction analysis, the number of regions had to be reduced from 6 to 5, with Dublin and east being combined with Southeast, as all three soil groups were not represented in the Dublin and east region, preventing model outputs from being generated for all soil groups across all regions.

For *Scenarios 2, 3 and 4*, the association between farm category (i.e., HSP and NFS farms categorized as NFS top 20%, NFS median and NFS bottom 20% based on net profit per ha) on a range of farm physical and financial performance metrics including stocking rate, milk production, grass utilization, outputs, costs and profit were determined using general linear models in PROC GLM. Farm category and year and their interaction were included as class variables, with the least square means of each factor for farm category and year determined.

3 | RESULTS

Scenario 1 evaluated the physical and financial performance of NFS farms across soil type and region (Table 1). The results indicate significant variation in a wide range of both physical and financial variables in both soil type and region. Stocking rate and milk production per cow were significantly higher in soil group 1 and region 2 (Dublin and east) compared to all other soil groups and regions ($p < 0.05$). Concentrate feeding was also greatest in region 2, with the level of concentrate supplementation statistically similar in soil groups 1 and 2. Grass utilization and grazing season length were significantly higher in soil group 1 compared to soil groups 2 and 3 ($p < 0.001$), with the proportion of purchased feed on farm differing across regions ($p < 0.001$) but not across soil groups. Gross output per ha and total costs per ha differed across all soil groups ($p < 0.001$), with soil group 1 having the greatest gross output (€3,931 ha^{-1} year^{-1}), with total costs of €2,700 ha^{-1} year^{-1} and a net profit of €1,170 ha^{-1} year^{-1} ($p < 0.05$). Region 4 (Southeast) recorded the highest net profit per ha at €1,258, which was significantly greater than the Border and midlands, Dublin and east and the South regions ($p < 0.01$). There was a significant interaction between soil group and region across all variables tested (Table 1) except for gross output per kg of fat and protein where there was no interaction found.

Scenario 2 compared the physical performance of HSP and NFS farms, with the NFS farms subdivided into three farm categories (NFS top 20%, NFS median and NFS bottom 20%) ranked by net profit per ha (Table 2). The HSP farms operated with significantly lower stocking rates than all NFS categories ($p < 0.01$), but HSP farms had similar cow numbers and milk yields (L/cow) to the NFS top 20% and NFS median farm categories. Year had no significant association with cow numbers but was significantly associated with stocking rates ($p < 0.01$) and milk yield per cow ($p < 0.01$), with 2015 having the greatest milk yield per cow, in terms of L and kg of fat and protein per cow, across all years. The HSP farms fed similar levels of concentrates and total purchased feeds to the NFS top 20% of farms but significantly lower levels to the NFS median or bottom 20% ($p < 0.05$). There were slight fluctuations in feeding levels across years with 2013 being the highest year for the usage of purchased feeds ($p < 0.01$). HSP farms had similar milk fat and protein composition to the top 20% of NFS farms, with a significant rising trend in both variables and also milk yield per ha across years, across all farms (Table 2). The HSP farms had similar milk yields per ha to the bottom 20% of NFS farms which was significantly lower than the median and top 20% ($p < 0.001$). The grazing season lengths obtained by the

TABLE 1 The least square mean and the associated *p*-value of a range of physical and financial variables describing specialized dairy farms from the Teagasc National Farm Survey across soil group and region from the years 2010–2015

	Soil group (SG)			*p*-value	Region						*p*-value	
	1	2	3	SG	1	2	3	4	5	6	Region	SG*Region
Stocking rate (LU†/ha)	2.44^{a}	2.27^{b}	2.20^{b}	***	2.27^{bd}	2.47^{c}	2.14^{a}	2.35^{bc}	2.20^{ad}	2.39^{bcd}	***	***
Farm size (ha)	38.8^{a}	36.3^{b}	33.7^{b}	*	38.8^{a}	43.4^{b}	34.5^{c}	35.7^{c}	34.3^{c}	30.9^{c}	***	***
Milk yield (L/cow)	5,152^{a}	4,910^{b}	4,391^{c}	***	4,767^{a}	5,307^{b}	4,670^{a}	4,723^{a}	4,680^{a}	4,759^{a}	***	***
Milk fat and protein yield (kg/cow)	391^{a}	371^{b}	332^{c}	***	357^{a}	397^{b}	352^{a}	361^{a}	355^{a}	365^{a}	***	***
Concentrate (kg/cow)	1,019^{a}	1,037^{a}	909^{b}	*	1,141^{c}	1,256^{d}	827^{ab}	797^{a}	880^{b}	1,029^{c}	***	***
Grazing season length (days)	245^{a}	235^{b}	234^{b}	***	223^{c}	230^{d}	243^{b}	249^{a}	239^{b}	244^{ab}	***	***
Proportion of purchased feed				NS	0.21^{c}	0.23^{e}	0.16^{ab}	0.15^{a}	0.17^{bd}	0.20^{cd}	***	***
Grass utilized (kg DM/ha)	7,430^{a}	6,570^{b}	6,506^{b}	***	6,569^{b}	7,232^{a}	6,451^{b}	7,254^{a}	6,683^{b}	6,824^{ab}	***	***
Gross output (€/ha)	3,931^{a}	3,393^{b}	3,066^{c}	***	3,276^{ab}	4,096^{c}	3,243^{ab}	3,470^{a}	3,261^{b}	3,434^{ab}	***	***
Gross output (€/kg of fat and protein)	4.84^{a}	4.85^{a}	5.00^{b}	*	4.82^{b}	4.99^{a}	4.97^{ac}	4.90^{abc}	4.88^{bc}	4.83^{abc}	*	NS
Total costs (€/ha)	2,700^{a}	2,311^{b}	2,063^{c}	***	2,501^{a}	2,856^{c}	2,102^{b}	2,207^{b}	2,138^{b}	2,345^{ab}	***	***
Total costs (€/kg of fat and protein)				NS	3.72^{b}	3.61^{b}	3.30^{ac}	3.22^{a}	3.28^{a}	3.51^{bc}	***	***
Net profit (€/ha)	1,170^{a}	1,067^{b}	964^{b}	*	738^{a}	1,050^{b}	1,138^{bc}	1,258^{c}	1,136^{b}	1,082^{bc}	***	***
Net profit (€/kg of fat and protein)				NS	1.06^{a}	1.32^{c}	1.67^{bd}	1.69^{d}	1.58^{b}	1.32^{c}	***	***

Notes. Soil group (SG): 1 = high; 2 = medium; and 3 = poor-quality soil types.
Regions: 1 = Border and midlands; 2 = Dublin and east; 3 = Southwest; 4 = Southeast; 5 = South; 6 = West.
Means with different superscripts values differ significantly ($p < 0.05$).
*($p < 0.05$); ***($p < 0.001$).
†Livestock units.

TABLE 2 The least square mean and the associated *p*-value of a range of physical variables describing a group of farms located in soils that have poor permeability and are located in areas of high rainfall (HSP) and specialized dairy farms from the Teagasc National Farm Survey (NFS) categorized by net profit per hectare, across the years 2010–2015, as well as the least square mean and the associated *p*-value of a range of physical variables describing the yearly variation of the HSP and NFS farms combined

	Farm category (FC)				*p*-value	Year						*p*-value	
	HSP	NFS Top 20%	NFS Median	NFS Bottom 20%	FC	2010	2011	2012	2013	2014	2015	Year	FC*Year
Stocking rate (LU†/ha)	1.73^{a}	2.77^{b}	2.26^{c}	2.03^{d}	***	2.09^{a}	2.15^{abc}	2.11^{ab}	2.28^{cd}	2.32^{d}	2.24^{bcd}	**	NS
Cow numbers	85^{b}	79^{b}	73^{ab}	68^{a}	**							NS	NS
Farm size (ha)	69^{a}	34^{b}	39^{c}	40^{c}	***							NS	NS
Milk yield (L/cow)	$5,186^{ab}$	$5,495^{b}$	$5,026^{a}$	$4,401^{c}$	***	$4,979^{a}$	$5,007^{a}$	$4,881^{a}$	$4,996^{a}$	$5,024^{a}$	$5,276^{b}$	**	NS
Concentrate (kg/cow)	833^{a}	888^{a}	992^{b}	$1,111^{c}$	***	932^{abc}	838^{b}	$1,001^{a}$	$1,114^{d}$	954^{ac}	898^{bc}	***	NS
Milk protein (%)	3.45^{a}	3.45^{a}	3.41^{b}	3.36^{b}	***	3.37^{a}	3.39^{ab}	3.40^{b}	3.40^{b}	3.44^{c}	3.51^{d}	***	NS
Milk fat (%)	3.99^{ab}	4.02^{b}	3.95^{a}	3.89^{c}	***	3.88^{a}	3.91^{ab}	3.95^{bc}	3.97^{cd}	4.02^{de}	4.05^{e}	***	NS
Milk fat and protein yield (kg/cow)	397^{a}	422^{b}	380^{a}	328^{c}	***	372^{a}	376^{a}	370^{a}	379^{a}	384^{a}	410^{b}	***	NS
Milk fat and protein yield (kg/ha)	503^{a}	971^{b}	718^{c}	566^{a}	***	638^{a}	656^{ab}	648^{a}	703^{bc}	729^{cd}	762^{d}	***	NS
Grazing season length (days)	244^{ab}	252^{b}	242^{a}	226^{c}	***	243^{b}	243^{b}	237^{a}	236^{a}	243^{b}	244^{b}	**	NS
Grass utilized (kg DM/ha)	$7,665^{a}$	$8,597^{b}$	$6,809^{c}$	$5,818^{d}$	***	$6,901^{a}$	$7,220^{ab}$	$7,047^{ab}$	$6,899^{a}$	$7,383^{b}$	$7,883^{c}$	***	NS
Proportion of purchased feed	0.14^{a}	0.17^{a}	0.18^{b}	0.21^{c}	***	0.16^{ac}	0.15^{c}	0.19^{b}	0.22^{d}	0.18^{ab}	0.15^{c}	***	NS

Notes. Means with different superscripts values differ significantly ($p < 0.05$).
($p < 0.01$); *($p < 0.001$).
†Livestock units.

TABLE 3 The least square mean and the associated *p*-value of a range of financial variables describing a group of farms located in soils that have poor permeability and are located in areas of high rainfall (HSP) and specialized dairy farms from the Teagasc National Farm Survey (NFS) categorized by net profit per hectare, across the years 2010–2015 and the least square mean and the associated *p*-value of a range of financial variables describing the yearly variation of the HSP and NFS farms combined

	Farm category (FC)				*p*-value	Year						*p*-value	
	HSP	NFS Top 20%	NFS Median	NFS Bottom 20%	FC	2010	2011	2012	2013	2014	2015	Year	FC*Year
Gross output (€/ha)	$2,411^{a}$	$4,782^{b}$	$3,512^{c}$	$2,671^{a}$	***	$2,750^{a}$	$3,267^{b}$	$3,020^{c}$	$3,867^{d}$	$3,830^{d}$	$3,330^{b}$	***	NS
Gross output (€/kg of fat and protein)	4.81^{ab}	4.93^{c}	4.89^{bc}	4.74^{a}	***	4.37^{a}	4.98^{b}	4.67^{c}	5.45^{d}	5.19^{e}	4.40^{a}	***	NS
Variable costs (€/ha)	899^{a}	$1,534^{b}$	$1,374^{c}$	$1,305^{c}$	***	$1,012^{a}$	$1,112^{a}$	$1,343^{bc}$	$1,533^{d}$	$1,398^{b}$	$1,271^{c}$	***	NS
Variable costs (€/kg of fat and protein)	1.79^{a}	1.59^{b}	1.91^{a}	2.39^{c}	***	1.64^{a}	1.76^{b}	2.13^{c}	2.27^{d}	2.00^{e}	1.72^{ab}	***	NS
Gross margin (€/ha)	$1,514^{a}$	$3,142^{b}$	$2,119^{c}$	$1,330^{d}$	***	$1,756^{a}$	$2,105^{c}$	$1,705^{a}$	$2,242^{b}$	$2,331^{b}$	$2,021^{c}$	***	NS
Gross margin (€/kg of fat and protein)	3.03^{a}	3.35^{b}	3.00^{a}	2.41^{c}	***	2.74^{b}	3.22^{a}	2.60^{c}	3.22^{a}	3.21^{a}	2.68^{bc}	***	NS
Total costs (€/ha)	$1,512^{a}$	$2,628^{b}$	$2,411^{c}$	$2,416^{c}$	***	$1,924^{a}$	$1,991^{a}$	$2,284^{bd}$	$2,594^{c}$	$2,461^{bc}$	$2,197^{d}$	***	NS
Total costs (€/kg of fat and protein)	3.01^{a}	2.69^{b}	3.31^{c}	4.25^{d}	***	3.10^{a}	3.15^{a}	3.53^{b}	3.74^{c}	3.41^{d}	2.97^{e}	***	NS
Net profit (€/ha)	900^{a}	$2,143^{b}$	$1,083^{c}$	215^{d}	***	832^{a}	$1,247^{b}$	763^{c}	$1,226^{b}$	$1,342^{d}$	$1,101^{e}$	***	***
Net profit (€/kg of fat and protein)	1.80^{a}	2.24^{b}	1.58^{c}	0.44^{d}	***	1.28^{a}	1.83^{b}	1.10^{c}	1.68^{d}	1.78^{bd}	1.43^{e}	***	**

Note. Means with different superscripts values differ significantly ($p < 0.05$).

($p < 0.01$); *($p < 0.001$).

HSP farms (244 days) were similar to the top 20% (252 days) and median NFS (242 days) farms with significant variation across all farm categories in grass utilization per ha ($p < 0.01$). The highest level of grass utilization was achieved by the top 20% of NFS farms at 8,597 kg DM per ha per year, whereas the lowest was 5,818 kg DM per ha per year recorded by the NFS bottom 20% of farms. Across all physical variables tested (*Scenario 2*), there was no farm category by year interaction observed.

Scenario 3 compared the financial performance of HSP and NFS farms, with the NFS farms subdivided into three farm categories (NFS top 20%, NFS median and NFS bottom 20%) ranked by net profit per ha (Table 3). The HSP farms had similar gross outputs (€/ha) to the bottom 20% of NFS farms, which was significantly lower than the NFS median and top 20% ($p < 0.001$). However, on a per unit of product basis (€/kg of fat and protein), the HSP farms did not differ in terms of gross output to the NFS median and the bottom 20% of NFS farms. The HSP farms had the lowest variable costs per ha across farm category (€899; $p < 0.001$), with similar variable costs per kg of fat and protein to the NFS median. Variable costs were greater in 2013, than all other years both per ha and per kg of fat and protein ($p < 0.05$). Gross margin per ha was statistically different across all groups ($p < 0.001$). The HSP farm group had a lower gross margin per ha than the NFS median but greater than the bottom 20%, with the HSP farms having similar gross margin per kg of fat and protein to the NFS median. Gross margin tended to fluctuate greatly across years ($p < 0.001$; Table 3). Total costs of production per ha were significantly lower on HSP farms (€1,512; $p < 0.001$). The total costs per kg of fat and protein differed significantly across all farm categories with the HSP farms having higher costs than the top 20% of NFS farms but lower than the median ($p < 0.001$). Total costs on all farms varied significantly across years, on a per kg of fat and protein basis with only years 2010 and 2011 being similar, with significant variation across all other years. Net profit varied significantly across all farm categories both per ha and per kg of fat and protein ($p < 0.01$). The HSP farms had a lower net profit per ha than the NFS median but a higher net profit per kg of fat and protein, with the results also indicating a major gap in profitability in comparison with the top performing farms nationally.

Net profit varied significantly by year throughout the study, with a farm category by year interaction also presents for both net profit per ha and net profit per kg of fat and protein ($p < 0.01$). On an annual basis, net profit varied substantially across farm categories as indicated by the farm category by year interaction (Table 3), with the more efficient farms experiencing lesser fluctuations in net profits proportionately across years. Net profit per ha on HSP farms experienced a proportionate change of 60% across the years of 2010–2015, which equates to an absolute change of €29,429 from the highest to the lowest year, in comparison with 44% (€26,381) and 73% (€21,959) on top 20% and median NFS farms respectively (data not shown). On a net profit per kg of fat and protein basis, the proportionate change across farm categories, across years, was 53%, 32% and 51% for HSP, top 20% and median NFS farms respectively.

Scenario 4 further compared overall financial performance including a return on assets and sensitivity analysis, of HSP farms relative to the performance of the top 20%, median and bottom 20% NFS farmers ranked on net profit per hectare (Table 4). The analysis indicates significant variation across and between all farm categories for both net farm income and return on assets. The top 20% of NFS farms had the greatest annual net farm income of €100,832, in comparison with the HSP, NFS median and bottom 20% at €83,788, €67,898 and €25,545 respectively ($p < 0.01$). However, on a return on assets basis, the HSP farms obtained significantly higher return across the analysis period at 5.75%, in comparison with the NFS top 20%, median and bottom 20% at 5.26%, 3.49% and 1.25%, respectively ($p < 0.05$), at a capital expenditure and infrastructural investment of €4,000 per LU for HSP farms and €3,500 for NFS farms. HSP and NFS farms were valued at €12,500 and €25,000/ha respectively. Under sensitivity analysis with greater capital expenditure and infrastructural investment on HSP farms, a reduction in return on assets was observed. However, at a €5,000 investment per LU, the return on assets achieved by HSP farms did not differ from that of the top 20% of NFS farms and was significantly greater than the NFS median ($p < 0.001$). When this investment on HSP farms was increased even further to €6,000 per LU, while the return on assets reduces to significantly lower than the top 20% of NFS farms ($p < 0.05$), it remained significantly greater than the NFS median group ($p < 0.001$), at a return on assets for HSP farms of 4.74%. Both net farm income and return on assets also varied significantly across years; however, across the variables investigated, no farm category by year interaction was observed (Table 4).

4 | DISCUSSION

4.1 | Key performance indicators

The abolition of European Union milk quotas in 2015 has provided the opportunity for Irish dairy farmers to once again expand milk production nationally (Läpple & Hennessy, 2012). This poses the question of what is the national expansion potential given the diverse range of soil types across the country as well as the implications for farm profitability. In order to realize this potential, this firstly requires the measurement of current farm performance using key performance and profitability indicators. Previous research indicates the requirement to focus on the key system components that give a competitive advantage to a system (Langemeier, 2010). In Ireland's case, pasture-based systems provide a cost-benefit advantage due to their ability to convert cheap feed in the form of grazed grass (Dillon et al., 2005) into low cost milk, in comparison with other feedstuffs (Finneran et al., 2010), in an environmentally sustainable manner (O'Brien et al., 2010). Key performance indicators which provide a measurement of such a competitive advantage and are associated with profitability on farm include grass utilization (kg DM/ha), grazing season length (days) and the proportion of purchased feed on farm (Hanrahan et al., 2018; Kelly et al., 2012; Läpple et al., 2012). To

TABLE 4 The least square mean and the associated *p*-value of financial variables describing a group of farms located in soils that have poor permeability and are located in areas of high rainfall (HSP) and specialized dairy farms from the Teagasc National Farm Survey (NFS) categorized by net profit per hectare, across the years 2010–2015 and the least square mean and the associated *p*-value of financial variables describing the yearly variation of the HSP and NFS farms combined

	Farm category (FC)				*p*-value	Year						*p*-value	
	HSP	NFS Top 20%	NFS Median	NFS Bottom 20%	FC	2010	2011	2012	2013	2014	2015	Year	FC*Year
Net farm income (€/year)	83,788^{a}	100,832^{b}	67,898^{c}	25,545^{d}	***	59,946^{a}	78,072^{b}	58,706^{a}	72,976^{b}	73,259^{b}	74,135^{b}	***	NS
Return on assets (%)†	5.75^{a}	5.26^{b}	3.49^{c}	1.25^{d}	***	3.41^{a}	4.56^{b}	3.27^{a}	4.06^{c}	4.54^{b}	3.77^{c}	***	NS
Return on assets (%)‡	5.19^{a}	5.26^{a}	3.49^{b}	1.25^{c}	***	3.27^{a}	4.42^{b}	3.13^{a}	3.92^{c}	4.4^{b}	3.64^{c}	***	NS
Return on assets (%)§	4.74^{a}	5.26^{b}	3.49^{c}	1.25^{d}	***	3.16^{a}	4.3^{b}	3.02^{a}	3.8^{c}	4.28^{b}	3.53^{c}	***	NS

Notes. Net farm income is the remuneration to fixed factors of production of the farm (work, land and capital) and remuneration to the entrepreneur's risks (loss/profit).
Means with different superscripts values differ significantly ($p < 0.05$).
***($p < 0.001$).
†Return on assets was calculated with HSP land market value and capital expenditure cost of €12,500/ha and €4,000/Livestock units (LU), respectively, and NFS land market value and capital expenditure cost of €25,000/ha and €3,500/LU respectively.
‡Return on assets was calculated with HSP land market value and capital expenditure cost of €12,500/ha and €5,000/LU, respectively, and NFS land market value and capital expenditure cost of €25,000/ha and €3,500/LU respectively. §Return on assets was calculated with HSP land market value and capital expenditure cost of €12,500/ha and €6,000/LU, respectively, and NFS land market value and capital expenditure cost of €25,000/ha and €3,500/LU respectively.

rank efficiency performance and to provide a benchmark for farm potential, analysis was required to understand how the top, median and lower efficiency farms are performing nationally across different soil types.

4.2 | Physical and financial performance

The variation in physical performance across farm categories is most notable in the differences in stocking rate at farm level, with this having a large influence on other measurements such as milk production per ha. Although HSP farms had the lowest stocking rates of all farm categories, they are utilizing greater quantities of grass DM per ha than the NFS median group of farms combined with lower levels of purchased feed. Due to the nature of heavy soils, there are risks and costs associated with adverse weather events, such as the requirement for extra silage reserves, which are a factor of the lower stocking rates observed at farm level. While studies have reported that milk production per cow declines with increased stocking rates (Macdonald, Penno, Lancaster, & Roche, 2008; McCarthy, Delaby, Pierce, Brennan, & Horan, 2013), our analysis indicates that the most profitable farms had the highest stocking rates, grass utilization per ha and milk production both per cow and per ha, along with the lowest levels of purchased feed. However, it can also be inferred from the data that higher stocking rates do not necessarily result in increased profitability, akin to previous research which suggests that the ability to convert grazed grass into milk efficiently is the key driver of profit in pasture-based systems (Holmes, 2009). The HSP farms had lower financial performances per ha than the NFS median farms, with lower gross output, gross margin and net profit per ha; however, on a per unit of product basis, the lower cost of production on HSP farms resulted in a significantly greater net profit per kg of fat and protein. While the HSP farms had lower net profit per ha, their mean annual net farm income was significantly greater than the NFS median farms, combined with relatively high return on assets, when compared across farm categories at a range of investment levels. This indicates with a greater level of management there is scope for farmers on inferior quality soil types to achieve high overall financial performances and similar return on investments to that typical of free draining soil types when operated at high levels of grazing efficiency and maximizing output at low cost, however requiring relatively larger land blocks. The physical data in this study infer this can be achieved through increasing grass utilization to boost farm productivity while maintaining low levels of purchased feed. It can also be inferred from the data that more efficient farms experienced lesser fluctuations in net profits proportionately across years, resulting in these farms being able to deal with the low milk price years and capitalize on the high milk price years to a greater extent.

4.3 | Management skills and technical awareness

It is clear from the analysis and the level of technology adoption by the HSP farmers, such as using of PastureBase Ireland, ICBF HerdPlus and being involved in the HSP that they are focused on producing milk in a grass-based system with low costs of production. Their technical awareness is evident through their uses of these tools and management practices such as milk recording and their involvement in discussion groups. From the process of analysing the data and completing the study, we have inferred that the farmers participating in the HSP programme are adopting the same technologies and management practices with a focus on efficiency, as all top farmers across all soil types, such as regular grass measuring and budgeting, using EBI (Economic Breeding Index) to implement breeding programmes and practicing ongoing financial management. Grass cover estimation has been completed weekly throughout the grazing season on all HSP farms since 2010 and recorded through PastureBase Ireland. Given the nature of these soils, land drainage, soil fertility and pasture regeneration are a requirement to increase grass DM yields. In certain paddocks, such work results in increasing grassland productivity from 4 to 12 tonnes DM per ha, with Shalloo, Creighton, and O'Donovan (2011) outlining further benefits of reseeding on dairy farms. This progressive thinking is actually on the contrary to many management practices on the typical Irish farm in the past, where technical awareness and adoption were quite limited (Creighton, Kennedy, Shalloo, Boland, & O' Donovan, 2011) including the national reseeding levels hovering around 2% per annum (Shalloo et al., 2011). However, it has been demonstrated that the use of benchmarking and on farm trials investigating new practices have the effect of strengthening the relevance and acceptance of research (Rhoades & Booth, 1982), which is also evident from the improvements made on HSP farms from 2010 onwards, which includes investment in farm infrastructure, soil fertility, drainage and reseeding to allow for increases in efficiency and scale to increase farm profitability. These observations reinforce the requirement for a more interactive approach to research dissemination at a broader farm level nationally, through the use of decision support tools that offer farmers a direct link to the latest research developments.

4.4 | Opportunities and constraints

The opportunities and constraints at farm level are likely to be quite different across farm categories with varying demographic structures. For example, in the case of the HSP farms, land tends to be more available to either rent or purchase which is reflective of the land market value of these areas and also the larger overall size of the HSP farms compared to all other farm categories ($p < 0.001$). In contrast, the highest performing farms nationally, in terms of profitability per ha, tend to have smaller farm sizes due to reduced land availability. Increasing stocking rates and the ability to utilize greater quantities of grass DM per ha is a common limitation across soil types, and it tends to be at varying levels with different soil types having various grass growth and stocking density potential (Brereton, 1995). The higher stocking rate of the top 20% of NFS farms would suggest there is little scope for further expansion unless accompanied with significant increases in grass growth. In contrast, there is considerable scope for expansion on the NFS median and bottom 20% farms and HSP farms through greater infrastructural investments to increase stock carrying capacities. However, in an Irish context, such increases in output must coincide with increases in grass utilization to remain sustainable long term (Creighton et al., 2011; Macdonald, Glassey, & Rawnsley, 2010; Ramsbottom, Horan, Berry, & Roche, 2015).

5 | CONCLUSION

This study indicates that higher average farm incomes and comparatively high returns on assets can be achieved on challenging soil types in locations of high rainfall, through high levels of technical management efficiency focusing on a grass-based system of milk production. This is achieved through utilizing large quantities of grass and efficiently converting this to milk, combined with stringent cost control. This group of HSP farmers has larger than average farm sizes with lower than average stocking rates resulting in a positive potential for expansion on these farms with increased grass DM yields and utilization. This requires best grazing management practices, adequate drainage, soil fertility and grazing infrastructure combined with strong technical management ability.

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