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TITLE: The potential to reduce the risk of diffuse pollution from agriculture while improving economic performance at farm level

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The potential to reduce the risk of diffuse pollution from agriculture while improving economic performance at farm level.

Abstract

Within the constraints of the EU Nitrates and Water Framework Directives, controlling and managing nutrient transfers to water from excessive nutrient use on agricultural land is a significant environmental policy challenge. This paper assesses whether there is room to reduce inorganic nitrogen and phosphorus fertiliser applications and imported feeds by exploring the extent to which application rates may have exceeded optimum levels using data envelopment analysis methodology. The investigation concentrates on specialist dairy and tillage farms in the Republic of Ireland stratified by land use potential as these agricultural systems are the most intensive and may pose the greatest risk in terms of managing nutrient transfers from agricultural land to water bodies. Results demonstrate inefficiency in the utilisation of nitrogen and phosphorus fertilisers across these systems. Second stage regression analysis indicates significant return to efficiency from agricultural education. Average over application of chemical fertilizers ranged from 22.8 to 32.8 kg N ha^{-1} and 2.9 to 3.51 kg P ha^{-1} in 2008 which research has shown is at least similar and greater than losses to leaching and runoff for N and P, respectively, from similar intensive agricultural land uses. Potential cost savings on chemical fertilisers across all systems on average ranged from €38.9 ha^{-1} to €48.5 ha^{-1}. Additionally, potential cost reductions on imported feeds of €65 to €84 per livestock were indicated for dairy farms versus efficient cohort benchmark farms. Average excess of imported feedstuffs equated to 5.82-7.44 kg LU^{-1} of N and 0.92-1.17 kg LU^{-1} of P. Such reductions have the potential to deliver a double dividend by reducing the risk of diffuse nutrient losses from agricultural land while improving economic margins at farm level.

Keyword: Nutrient management efficiency, data envelopment analysis, agriculture, water quality.

1. Introduction

Compliance with environmental legislation in the context of intensive, productivist agriculture is a significant policy challenge (Sutton et al., 2011). Much political and commercial pressure has been brought to bear on the agricultural sector to improve environmental performance while maintaining economic efficiency and competitiveness in a global marketplace (Jay, 2007). Consequently eco-efficiency has become a prevalent theme in the agricultural and environment literature (Asmild & Hougaard, 2006; Ebert & Welsch 2007; Lauwers, 2009 and Picazo-Tadeo et al, 2011). This is especially so in the European Union (EU) where member states are committed to management (mitigation or maintenance) of all water bodies to good ecological status by 2015 under the Water Framework Directive (OJEU, 2000).

Over application of chemical nitrogen (N) and phosphorus (P) in intensive agricultural regions of Europe, and throughout the developed world, has lead to excessive accumulations of these nutrients in soils, groundwaters and surface water bodies (Volk et al., 2009). It has been estimated that as much as 55 per cent of non-point water pollution of eutrophic surface waters in the EU is attributable to agriculture (Kersebaum et al., 2003), with the majority linked to losses of nitrogen (N) and phosphorus (P) nutrients from soil surfaces which can lead to eutrophication (Vörösmarty et al., 2010; Sutton et al., 2011). In the UK, DEFRA (2006) reported that around 70 per cent of N and 40 per cent of P pollution of inland waterways was derived from agriculture with the balance from industrial and municipal sources. Nutrient pollution from agriculture is acknowledged as one of the major sources of water quality impairments in the United States (Morgan and Owens, 2001; Ribaudo et al., 2001, Sharpley et al., 2008). The problem of eutrophication in Irish watercourses has been an issue since the 1970's (Flanagan and Toner, 1972, 1975; Inland Fisheries Trust, 1973, 1974). Recently 18 per cent of river channel across the Republic of Ireland was found to be slightly polluted; 10 per cent moderately polluted and 0.5 per cent seriously polluted. Agricultural sources were associated with 32 per cent of cases of slight and moderate pollution (EPA, 2008).

Much attention has been paid to controlling nutrient enrichment of watercourse by means of traditional command and control regulatory methods. Less emphasis has been placed on measuring nutrient management efficiency at farm level from an economic loss perspective (Huang et al., 1996; Brown et al., 2005; Picazo-Tadeo & Reig-Martínez, 2007). The optimum fertiliser rate is not always the rate at which maximum crop yield is achieved but must produce a satisfactory level of crop yield for profit; covering its costs while minimising nutrient losses to the environment. Excessive fertiliser applications over the optimum may often be attributed to such factors as risk aversion to lower yields, information asymmetry or incentive incompatible fertiliser pricing. However, over application of nutrients may have both economic and environmental consequences. Economic costs are incurred in two ways; the cost of wasted nutrient inputs at farm level and the cost of clean up associated with pollution caused as a result of such losses. In the absence of effective control, the cost of eutrophication is external to the farm, therefore the rational farm level decision is often to apply fertilisers up to the point of maximum private gains including some coverage for risk and uncertainty. The lower the relative price of fertiliser the greater the incentive to apply it to excess to offset potential risk and uncertainty. If asymmetric information is prevalent on crop nutrient requirement, soil fertility and farm level nutrient balances, then over application of fertiliser equalises the need to ascertain precise information and offsets risk while using the wider environment as a sink at no internal cost to the farm (Scott, 2005).

Chemical fertiliser prices in the Republic of Ireland reached record levels in 2008 (CSO, 2009a). Average prices increased by over 140 per cent between 1999 and 2008. Fertiliser consumption among farmers was seen to react to price as N fertiliser sales to farmers declined by 24 per cent and P by over 48 per cent during this period (DAFF, 2009). Hence, farmers had significant economic incentives for efficient fertiliser input usage.

Farmers apply chemical fertilisers because a benefit is derived through either increased output, income or both. However, plants absorb fertilisers only up to their requirements. Nutrients in fertilisers (principally N, P and potassium (K)) promote plant growth but application in excess of plant requirement can be exposed to leaching and runoff transfers from land to water where these hydrological pathways coincide with intensive agricultural landuse (Sharpley et al., 2003; Tunney et al., 2010). While the analysis of exact proportions of N and P required for optimal growth in grassland or tillage systems is outside the scope of this paper, productivity analysis techniques can measure farm nutrient management efficiency by examining farm inputs to output ratios across a sample of farms. Such an approach was adopted by Fraser and Cordina (1999); Reig-Martinez and Picazo-Tadeo, (2004); Theodoridis and Psychoudakis (2008); Barnes et al., (2009) and Uzmay et al., (2009). Nutrient accounting systems have been proposed as a means of managing nutrients at farm level. These measure the nutrient inputs onto the farm (through feedstuffs and fertilisers) and subtracts quantities exported from the farm through outputs such as milk, meat and cereals with a view to achieving a nutrient balance (Breembroek, et al., 1996; Ondersteijn et al., 2002; 2003; Berentsen, 2003; Nevens et al., 2006; Bassanino et al., 2007; Treacy et al., 2008; Ghebremichael and Watzin, 2011; Huhtanen et al., 2011; Nousiainen et al; 2011). Where nutrient inputs do not closely match nutrient off-takes then nutrients are potentially available for loss to the system, for example, via leaching and/or runoff to water.

The negative impacts of nutrient loss to receiving watercourses can be highly site specific due to the varying potential interactions of hydrology, soil type, atmospheric chemistry and farm level fertiliser practices (Doody et al., 2012). However, all other things being equal, the most intensive agriculture systems may pose the greatest risk due to the magnitude of the nutrient load into the farming system and especially when considering those systems with accumulating nutrient surpluses, above farm nutrient balances. With this background, this paper seeks to investigate the level of nutrient management efficiency across intensive agricultural systems in the Republic of Ireland. As soil types may influence the means of nutrient accumulation and the mode of transfers from land to water (Jordan et al., 2005), the analysis further uses a novel land use potential metric based on soils class as a basis for stratification and benchmarking.

2. Methodology

Farm level efficiency in the literature (Ahmad et al, 2002; Lohr and Park, 2007; Theodoridis and Psychoudakis, 2008) is generally measured using one of two methods; either Stochastic Frontier Analysis (SFA) or Data Envelopment Analysis (DEA). Stochastic Frontier Analysis is a parametric approach to measuring farm efficiency where a set of explanatory variables can be estimated. However, SFA necessitates assumptions regarding functional form and the inefficiency disturbance term which may bias results.

Data envelopment analysis (DEA) is a deterministic approach to efficiency measurement. It measures the relative efficiency of a decision making unit, farms in this instance, by comparing relative inputs to outputs. The DEA method establishes the most efficient farms and compares all others to the most efficient. The method uses linear programming to place a non-parametric frontier over the data (Charnes et al., 1978; 1979; 1981). This frontier consists of the most efficient farms and all other farms are measured by their relative distance to this frontier as a measure of their level of efficiency (Coelli et al., 2005). In general, DEA is more flexible than SFA when estimating technical efficiencies using different units and readily offers indicators of physical input usage which can be directly used to measure the level of input excess. The method has been applied in a number of developed countries to investigate agricultural efficiency (Cloutier and Rowley, 1993; Jaforullah and Whiteman, 1999; Fraser and Cordina, 1999; Gerber and Franks, 2001; Tzouvelekas et al., 2001; Barnes, 2006; Barnes et al., 2009). It is a non-parametric approach which doesn’t require functional form assumptions. However, DEA does not account for any stochastic variance from the frontier and this may lead to an over estimate of inefficiency as all variance from the frontier is assumed to be due to controllable inefficiency. DEA is also sensitive to extreme values and outliers which can lead unrealistic frontier construction (Cazals et al., 2002; Simar, 2003; Aragon et al., 2005).

An input orientated DEA model was adopted where output is assumed fixed and inputs variable. A variable return to scale (VRS) specification was employed as not all farms are assumed to operate at optimal scale. The use of the VRS specification permits the calculation of technical efficiencies devoid of scale efficiency effects. Coelli et al., (2005) specifies the VRS input orientated model as follows:

$$\begin{aligned} &\min_{\theta,\lambda} \theta, \\ &\text{st} \quad -q_i + Q\lambda \geq 0, \\ &\qquad \theta x_i - X\lambda \geq 0, \\ &\qquad I1'\lambda = 1 \\ &\qquad \lambda \geq 0, \end{aligned}$$

Where q_i is $M \times 1$ vector of outputs of i-th firm and x_i is a $N \times 1$ vector of inputs. X is a $N \times I$ input matrix and Q is a $M \times I$ output matrix. θ is a scalar (technical efficiency measure) and λ is a $I \times 1$ vector of constants. Finally, $I1'\lambda = 1$ is the variable return to scale constraint; this convexity constraint ensures that an inefficient firm is only benchmarked against similar sized firms.

The DEA method takes the i-th firm and seeks to radially contract the input vector x_i. The contracted input vector x_i produces a projected point $(X\lambda, Q\lambda)$ on the surface of the frontier. The linear programming problem must be solved n times, once for each firm in the sample. A value of θ is obtained for each firm. The technical efficiency score θ is constrained to falling in the range 0 to 1.

2.1 Data source and application of DEA

The main data source employed in this analysis is a National Farm Survey (NFS) conducted by Teagasc (Irish semi-state Agriculture and Food Development Authority) in 2008. The NFS is collected annually as part of the Farm Accountancy Data Network requirements of the European Union (FADN, 2005). The purpose of the NFS is to collect and analyse information relating to farm activities, financial returns to agriculture and demographic characteristics. A farm accounts book is recorded on a random representative sample of farms throughout the Republic of Ireland. In 2008 a total of 1,102 farmers were surveyed representing 104,800 farmers nationally (Connolly et al., 2009). Interviews were undertaken on site by a team of trained recorders.

This paper concentrates on specialist dairy and tillage farms as these are the most intensive land based agricultural systems and, by definition, may potentially pose the greatest risk in terms of managing nutrient transfer from agricultural land to water courses due to the magnitude of the nutrient input load. Data are collected on an enterprise specify basis for livestock systems and on an individual crops specify basis for tillage enterprises.

The data are also stratified by land use potential and this is established based on a soil class system which takes account of soil quality, altitude, topography and drainage as set out in the National Soil Survey of Ireland (Gardiner and Radford, 1980). Specialist dairying farms were stratified into two main groups for this analysis namely; average and good land use potential. The good land use potential category consists of soil classes 1 and 2 (out of six classes). Soil class 1 has no limitation on land use and soil class 2 has minor limitations due to soil texture, altitude or climatic conditions. The average land use potential category consists of soil classes 3 and 4. Soil class 3 has more significant use limitations associated with soil texture, altitude or climatic conditions, while soil class 4 has limitations associated with poor drainage.

There were a limiting number of observations in a third potential category "poor land use potential" hence analysis was restricted to good ($n = 137$) and average ($n = 88$) land use potential categories. It should be noted the analysis was also restricted to spring calving systems (for dairying) and tillage farms were exclusively related to land of good use potential. A DEA model were run for each of the aforementioned cohorts using the Win4Deap software package (Deslierres, 2002; Coelli et al., 2005).

Output for specialist dairy farms was measured in milk produced (l ha^{-1}). Inputs examined were chemical nitrogen (N) and phosphate (P) fertiliser usage (kg ha^{-1}) applied to forage area, N and P from imported feedstuffs (kg LU^{-1}) (Ewing, 1998), labour (hours LU^{-1}) and other variable costs (€ ha^{-1}, exclusive of aforementioned feed and fertilisers inputs). Nutrient management on a specialist dairy farm is determined principally by output (milk) versus inputs (imported feed and fertilisers). Connolly et al. (2009) reports that almost 60 per cent of total variable costs on specialist dairy farms was due to imported feeds and fertilisers. In Irish grassland systems manure generated by livestock is recycled back to forage areas, and farms in the sample who reported importing organic manures were excluded from the analysis as no data were available on quantities of organic fertiliser imported. Descriptive statistics for each category are presented in Table 1. As might be expected *a priori* specialist dairy farms with good land use potential had higher output and tended to use a higher magnitude of fertiliser inputs. Dairy farms of average land use potential imported higher magntudes of N and P in feeds.

Output for specialist tillage farms (barley, wheat and oats account for 98.5% of cereals produced in Ireland in 2008 (CSO, 2009b)) was measured in the form of gross output in € ha^{-1}. Similar inputs examined were N and P fertiliser usage (kg ha^{-1}), labour (hours ha^{-1}) and other variable costs (€ ha^{-1} exclusive of aforementioned fertiliser input).

Table 1: Farm level descriptive statistics by enterprise type and land use potential

Land Use Range	**n**	**Mean & S.D.**	**Litres Ha^{-1}**	**Other variable cost € Ha^{-1}**	**Labour (hours LU^{-1})**	**N Ha^{-1} (forage Area)**	**P Ha^{-1} (forage area)**	**N in imported feeds (kg LU^{-1})**	**P in imported feeds (kgs / LU^{-1})**
					Specialist Dairying				
Good land use potential	137	Mean	10,019	615.68	35.61	154.17	6.98	24.57	3.85
		S.D.	(3,042)	(223.53)	(21.05)	(65.47)	(6.23)	(13.21)	(2.08)
Average land use potential	88	Mean	8,539	505.93	36.99	123.37	6.61	27.25	4.27
		S.D.	(2,874)	(171.52)	(21.04)	(44.63)	(5.88)	(16.76)	(2.60)
					Specialist Tillage				
			€ hectare Ha^{-1} (Gross output)	**Other variable cost € Ha^{-1}**	**Labour (hours Ha^{-1})**	**N Ha^{-1}**	**P Ha^{-1}**		

Good land use potential	80	Mean	954.65	405.13	37.56	138.63	20.64
		S.D.	(241.62)	(156.73)	(35.48)	(41.91)	(9.57)

2.2 Second stage regression

It is common in DEA studies to undertake a second stage regression analysis to investigate factors which influence efficiency (Latruffe et al., 2008). The double bootstrap method (as advocated by Simar & Wilson, 2007) is applied here in a truncated regression of the DEA technical efficiency scores on a set of explanatory variables. Simar and Wilson (2007) outlined how DEA derived scores are serially correlated and biased, thereby making conventional inference invalid. They derived a double bootstrap methodology that enables consistent inference to be drawn from efficiency scores. This approach has been adopted in a number or recent DEA based studies (Latruffe et al., 2008; Wolszczak-Derlacz & Parteka, 2011).

Truncated maximum likelihood estimation (with right censoring at the upper bound of 1) was undertaken on each of the 3 sub-samples. Explanatory variables included in the analysis were i) Agricultural education of the farmer (binary variable were 1 equals some level of formal agricultural education), ii) Off-farm employment measured in average hours per week worked off-farm, iii) Farm size measured in hectares, iv) No of land parcels farmed as a measure of farm fragmentation and finally v) Milk recording (were milk in tested to indicate the productivity of individual cows) was included for the dairy sub-samples as a proxy for technology adoption. The results presented in this paper are derived from 1,000 bootstrap iterations using Stata (code adapted from Wolszczak-Derlacz & Parteka, 2011).

3. Results

3.1 First stage analysis – Estimation of efficiency scores

Data envelopment analysis assigns an efficiency score between 0 and 1 for each farm in the sub-sample examined. A fully efficient farm with no scope for improvement would be allocated an efficiency score of 1. The DEA model also indicates targets for efficient input use which can be used to directly assess and measure the level of excess input usage. The variable returns to scale model was adopted in this analysis as it assumes not all farms are operating at optimal scale. This allows calculations of technical efficiencies devoid of scale efficiency effects (Coeilli et al., 2005). All results were population weighted, i.e. the specialist dairy farms of good and average land use potential were weighted to represent a population of 8,195 and 5,322 respectively; specialist tillage farms were weighted to reflect a population of 5,120. Each farm in the NFS was representative of a numbers of farms in the population. The weights were generated with reference to size and system (Connolly et al., 2009).

The DEA methodology is based on the assumption that all observations in the sample belong to the potential production frontier. It is hence sensitive to the presence of extreme values or outliers in the data which maybe due to measurement error. In the first instance the Teagasc NFS as part of the FADN have significant protocols in place to ensure accurate data collection and farm enterprise allocations to eliminate and minimize errors. Additionally, results indicate that there is a large proportion in each subsample on the frontier and its construction is not driven by a few observations as indicated by Table 2. Using the procedure proposed by Simar (2003) an exploratory analysis was conduct to test for outliers, results from this screening did not indicate the presence of outliers across the 3 subsamples hence all observation were included for DEA analysis.

Specialist dairy farms had an average technical efficiency score of 0.83 to 0.88 which suggests these farms on average could reduce inputs by approximately 12 to 17 per cent without influencing output as illustrated by Table 2. Results also indicate that both specialist dairy farm cohorts on average were operating at over 90 per cent of optimal scale. Specialist tillage farms indicated an efficiency score of 0.84 suggesting that on average a 13 per cent reduction in inputs would not affect output. Results also indicate that specialist tillage farms were operating at 85 per cent of optimal scale.

Table 2: Technical and scale efficiency scores

Farm System	N	Scale efficiency	Technical Efficiency	Technical Efficiency Range (min-max)	Share of farms with efficiency score of 1 (%)
Dairy – Good land use potential	137	0.91 (0.10)	0.88 (0.14)	0.54 - 1	32%
Dairy – Average land use potential	88	0.91 (0.10)	0.83 (0.16)	0.37 - 1	30%

Tillage – Good land use potential	80	0.85 (0.15)	0.84 (0.16)	0.48-1	44%

***Standard deviation in parenthesis**

To test statistical robustness, technical efficiency scores were bootstrapped using 1,000 iterations (Simar and Wilson, 1998; 2000) and the results in each case passed at 95% confidence interval test. The widths for confidence intervals ranged from a mean width of 0.05 to 0.06. These results indicate a low statistical variability for the efficiency estimates across all cohorts.

Results for input usage targets indicate that specialist dairy farmers with good land use potential tended on average to over apply chemical fertiliser on forage area to the greatest extent at 32.78 kg N ha^{-1} and 2.91 kg P ha^{-1} compared to the frontier benchmark cohort farms. Average cost saving on inorganic fertilisers of €48.5 ha^{-1} could be achieved by operating at the benchmark standard using average 2008 fertiliser prices (CSO, 2009a). The respective cost saving of inorganic fertiliser for specialist dairy farms of average land use potential was €44.8 ha^{-1} as excess N was indicated at 28.23 kg ha^{-1} and average excess P at 3.38 kg ha^{-1} as outlined in Table 3.

Imported animal feed was predominantly in the form of concentrates, hence cost saving related to the average cost of dairy concentrates for 2008 (CSO, 2009a). Results indicated that dairy farmers of average land use potential tended to over utilise imported feed to the greatest extent at 7.44 kg LU^{-1} of N and 1.17 kg LU^{-1} of P. This was equivalent to 294 kg LU^{-1} of concentrates compared to the benchmark farms in this category and had a cost implication of €84 per livestock unit based on 2008 prices. The over utilisation of imported feeds was somewhat less among specialist dairy farms of good land use potential at 5.82 kg LU^{-1} of N and 0.92 kg LU^{-1} of P, equivalent to 230 kg LU^{-1} of concentrates and with a cost implication of €65 LU^{-1}.

Table 3: DEA analysis of over application of N and P on specialist dairy farms.

		Average excess chemical fertiliser on land			**Average excess imported feed**			
Land use range	**N***	**N application (kg Ha^{-1})**	**P application (kg Ha^{-1})**	**Cost** 2008 Ha^{-1}**	**N feeds (kg LU^{-1})**	**P feeds (kg LU^{-1})**	**Concentrate equivalent (kg LU^{-1})**	**Cost** 2008 LU^{-1}**
Good land use potential	136	32.78	2.91	€48.5	5.82	0.92	230	€65
Average land use potential	89	28.23	3.38	€44.8	7.44	1.17	294	€84

*** Results weighted to population**
****Average prices CSO, (2009a)**

Results for tillage farms indicate over application of chemical fertiliser compared to the cohort benchmark of 22.81 kg N ha^{-1} and 3.51 kg P ha^{-1}. Potential cost savings for specialist tillage farms compared to the benchmark was €38.9 ha^{-1} as illustrated by

Table 4. However, it should be noted that, while these potential savings seem quite significant, reduced fertiliser usage will inevitably initiate a market adjustment which will potentially affect equilibrium prices. Long run cost savings are much more complex to estimate across all farm systems.

Table 4: DEA analysis of over application of N and P chemical fertiliser on specialist tillage farms.

Land use range	N*	N application (kg Ha^{-1})	P application (kg Ha^{-1})	Cost** 2008 Ha^{-1}
Good land use potential	80	22.81	3.51	€38.9

*** Results weighted to population**
****Average prices CSO, (2009a)**

3.2 Second stage – Truncated regression analysis

The second stage double bootstrapped estimates are presented in Table 5. Estimates presented the table are bias adjusted coefficients with the degree of statistical significance based on the bootstrapping procedure. The dependant variable represents efficiency (DEA scores), hence coefficients with a positive sign indicate sources of efficiency.

Results indicate significant efficiency returns to agricultural education across all cohorts. This was significant at the 5 per cent level for dairy farmers of good land potential and at the 1 per cent level for both the dairy cohort of average land use potential and the tillage cohort. Number of hours worked off-farm had a negative influence across both dairy cohorts, significantly so for farms of good land potential (5 per cent level). Dairying is a time intensive enterprise and farmers spending greater quantities of time on off-farm employment have less time to concentrate on farm management and this is reflected in efficiency. Farm size had a positive effect on technical efficiency, but the effect was only significant for the dairy cohort of average land use potential. The positive impact of farm size on technical efficiency is a reoccurring theme in the literature (Latruffe et al., 2008). The number of land parcels farmed represents a proxy for farm fragmentation and as expected had a negative effect for dairying but it was not significant. Finally milk recording as expected had a positive effect on the efficiency of the dairying cohorts but the effect was not significant.

Table 5: Results of double bootstrap truncated regression of technical efficiency scores

	Dairy – Good land use potential	**Dairy – Average land use potential**	**Tillage – Good land use potential**
Agricultural Education	0.064*	0.069**	0.089**
Off-farm employment	-0.003*	-0.0009	0.0007
Farm size	0.0003	0.003**	0.0002

No. of land parcels	-0.0003	-0.01	0.002
Milk recording	0.0079	0.034	
Constant	0.73**	0.63**	0.67**

**** Significant at 1% level *Significant at 5% level.**

4. Discussion

Results from this study suggest average over application of inorganic fertilisers of between 22.8 to 32.8 kg N ha^{-1} and 2.9 to 3.51 kg P ha^{-1}. Jordan et al., (2012) in a study of 4 intensively instrumented Irish agricultural catchments (2 grassland and 2 arable - Fealy et al., 2010; Wall et al., 2011) found total N exports, as measured by high resolution hydro-chemistry, of between 8.9 and 28.8 kg N $ha^{-1}yr^{-1}$ (3 catchments indicating exports of over 20 kg N ha^{-1}) and total phosphorus exports of between 0.175 and 0.784 kg ha^{-1} yr^{-1}. The predicted over utilisation in terms of N and P inputs normalised to land area envelop and provide some margins in terms of potential savings and losses to the environment that could be significant to water quality targets.

Despite both studies involving benchmark intensive agriculture systems the results are not directly comparable, however, there are distinct similarities between over application at farm level and nutrient loss as measured at the outlet of these experimental agricultural catchments. That said, losses may also occur due to the legacy effects of previous management (Schulte et al., 2010) that will abate with time in specific hydrological pathways. Future research and data collection in this area could provide information on the issue of nutrient legacy and further implications for increasing efficiency. Farmers with a formal agricultural education had significantly higher level on efficiency across the cohorts examined in this study.

There are three broad approaches to promoting the efficient and appropriate use of nutrients in agricultural production. These measures include regulation, market based economic instruments and education (OXERA, 2003). The regulatory framework is set down at EU level through the Nitrates Directives and implemented at national or regional level through a National Action Plan which established statutory guidelines for farm level nutrient management practice (including maximum application rates and timings for chemical and organic fertilisers). Economic instruments such as taxes or levies, agri-environment based subsidies or tradable permits have a role in altering consumer behaviour, especially where disincentive fertiliser input price prevail and producers are risk adverse. To be effective, policies (regulation or economic instruments) need to be correctly targeted, have low enforcement and administration costs, be equitable and devoid of socially undesirable effects. However, given the common property nature of watercourses, it can be very difficult to identify the source of diffuse pollution. Ideal policy solutions include an education and extension component to enhance farmers' skills and knowledge (Scott, 2005; Barnes 2009). Indeed, second stage regression results highlight the significant effect of agricultural education on farm efficiency.

As outlined by Scott (2005), education is generally a prerequisite for the success of any policy. Extension programmes focusing on delivering efficiency gains and associated improved farm level gross margin offers some scope for achieving improved nutrient management and reducing the associated environmental risk.

Inadequate and inaccurate information relating to specific crop nutrient requirements and farm nutrient balances are potentially contributing factors to diffuse pollution from agriculture. Promotion of nutrient management practices such as periodic soil testing and adoption of nutrient budgeting and management systems would assist in addressing any asymmetric information gaps at farm level and may encourage farmers to inform themselves on optimum nutrient levels for their crops (Blackstock et al., 2009). Extension work, based on a participatory approach which engages farmers, may influence farm level nutrient management practices and promote desirable normative behaviour. However, further research is required to investigate the factors that drive farmer uptake of nutrient management best practice and adoption of technology in this area.

Catchment or area-specific incentives may be more efficient in achieving environmental goals due to prevailing local geographic and hydrologic conditions (Sharpley et al., 2003; Ghebremichael and Watzin, 2011). Management practices based on acquired and calculated knowledge of optimum soil nutrient levels to meet crop production requirements may require additional farmer time and effort (record keeping and nutrient budgeting) but the potential payoff in terms of improved bottom line performance are illustrated from the results of this study. Finally, delivery of public goods through agriculture is at the forefront of the Common Agricultural Policy (CAP) agenda. Efficient management of farm nutrients meets productivity and environmental goals of the CAP. Enhanced policy measures in this area which actively promotes information symmetric efficient nutrient management has the potential to delivery on economic and environmental public good objectives.

5. Conclusions

Using data from a National Farm Survey dataset and data envelopment analyses to compare farming enterprises, this study found inefficiency in the utilisation of inorganic N and P across specialist dairy and tillage farms . Significant potential cost savings on fertilisers and imported feeds was hence indicated across these systems. There is an opportunity for inefficient producers to reduce fertilisers (and imported feeds) without affecting output by adopting similar practices to those of the most efficient farms. The average potential cost savings on fertilisers ranged from €44.8 ha^{-1} to €48.5 ha^{-1} for dairy farms and €38.9 ha^{-1} for tillage systems. Additionally, potential cost reductions on imported feeds of €65 to €84 LU^{-1} were indicated for dairy farms versus efficient cohort benchmark farms.

Efficient inorganic fertiliser applications and imported feed purchase has the potential to deliver a double dividend, win-win situation by reducing the risk of nutrient loss (or decreased accumulation that will mitigate legacy effects) and diffuse pollution from agricultural land thereby assisting in the achievement of environmental water quality objectives while improving economic margins at farm level.

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