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## Assessing the importance of soil testing in fertilizer use intensity: an econometric analysis of phosphorus fertilizer allocation in dairy farm systems.

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### **Abstract:**

*As global population rises there is added pressure on agricultural systems to intensify. On the other hand International organizations call their members to commit to environmental protection, including water quality. In Europe agriculture is a major water pollutant, with Phosphorus (P) considered to be contributing highly to water quality degradation. Hence, controlling phosphorus fertilizer use should be a priority. As farmers are responsible for the amount of phosphorus fertilization on their farm, they are expected to be aware of their soil P status. Farmers are advised to soil test their farms before they allocate P fertilizers, based on the assumption that soil test result will assist them in making informed decisions, and lately policy design discussions mention inclusion of soil testing in the agricultural policies regulations. To ensure the correctness of this decision a good understanding of the relation between soil testing and P fertilizer allocation is required. This paper examines dairy farm systems in Ireland, where farmers are strongly encouraged to soil test their farms regularly. National data were used in a censored tobit model to investigate the relation between a farmer's decision to soil test and Phosphorus fertilizer use intensity, among other factors. Results indicate a negative relationship suggesting that soil testing leads to reduced P fertilizer use.*

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#954



## Introduction

The increasing demand for food security calls for intensification of agriculture, globally and in Europe. At the same time international agreements and European legislation require this intensification to take place in a manner that respects the environment, including water quality (Sutton et al., 2011). Chemical fertilizers are considered important for stabilizing soil fertility and ensuring high agricultural yields (Jordan-Meille et al., 2012). However, continuous application of these fertilizers on agricultural land has led to losses in water bodies, negatively affecting water quality. Diffuse pollution from agriculture has been identified as a major water pollutant in Europe ((European Environmental Agency, 2012). At EU level the Water Framework Directive (WFD) outlines the main measures to mitigate the impairment of water quality from agricultural activities. Under the WFD, all rivers and other water bodies in each member state have to maintain high status (if they are assigned to it) or reach and maintain at least good status when this is not the case by the year 2021 (WFD; 2000/60/EC).

Particularly, the European dairy industry, which is the dominant farming system in a number of northern European countries, is challenged by these demands, especially since the abolition of the milk quota in 2015, which emphasized the pressure on dairy farmers to increase their production. Dairy farming is a pasture based system that depends on continuously high grass yields, rendering the use of chemical fertilizers necessary. Given the urge for dairy production intensification and the utmost importance of ensuring water quality protection, efficient use of fertilizers is important. Therefore, identifying the optimum amount of fertilizer to ensure grass growth without allowing further losses is essential.

Phosphorus (P) is considered the second most important nutrient for grass growth following nitrogen and it is applied on grassland mainly through chemical fertilizers (Heckenmüller et al., 2014). As dairy farming is a pasture based system, use of P chemical fertilizer is part of the standard dairy farm management process as it helps increase grass yields by providing P readily available to plants. However, excessive use can lead to losses from soil into water bodies leading to eutrophication and ecosystem quality degradation (Gourley et al., 2012). Phosphorus (P) losses from agriculture have been reported to majorly contribute to the diffuse pollution of water bodies across Europe (Carpender, 2008), emphasizing the need for the reduction of P fertilizer use. Given this, along with the finite nature of P resources, efficient P fertilizer use in dairy systems is of great concern (Mihailescu et al., 2015).

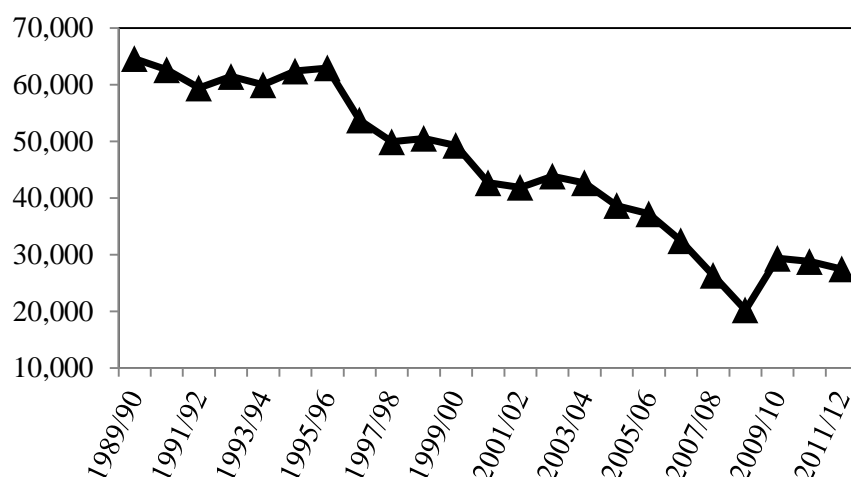
This study uses farm management and accountancy data to investigate P chemical fertilizer use intensity by dairy farmers in the Republic of Ireland. The Irish dairy sector contributes significantly to the Irish economy. There are approximately 18000 dairy farms in Ireland (18.4% of the total number of farms) totalling to a national dairy herd of 1.4 million cows. The sectors contribution to the total revenue from agriculture is close to 40%. The total domestic output reached 6395 million litres of milk in 2016 and the return from exports of dairy products estimated at 3.38 billion Euros (CSO, 2017).

The Irish dairy sector has a comparative advantage compared to grassland based systems in competitor countries, due to the country's temperate climate and long growing grass season that allow for the provision of low cost feed (Finneran et al., 2011) and extended grazing periods (O'Donovan et al., 2011). This, on the other hand, indicates a high dependency of the farm systems on grazed grass (O'Mara, 2008). In order to comply with the global food security objectives, Ireland has set as target to increase dairy production by 50% by 2025 (DAFM, 2010) by further intensifying its dairy production. As this target puts significant pressure on dairy farmers to increase their grass yields, they have to achieve this under the WFD regulations, incorporated in the Irish National River Basin Management Plans, which include restrictions in the amount and the timing of fertilizer applications.

Historically, Irish soils were considered P deficient, but P fertilizing was not effectively introduced until the 1950s, when a fertilizing recommendation system was introduced in Ireland which encouraged the use of chemical P fertilizer to mitigate this deficiency (Walsh and Kilroy, 1957). However, by the year 2000 (when WFD was first implemented), soil fertility in Ireland was remarkably

high, with P surpluses and excessive P inputs being reported (Coulter et al., 2005; Wall et al., 2016). As indicated in Figure 1, in year 2000, Ireland used approximately 40,000 tonnes of P fertilizer. After the enforcement of the WFD that year, P fertilizer use in Ireland has been steadily decreasing (Figure 1). According to the Teagasc National Farm survey, in 2015<sup>1</sup>, Irish dairy farmers applied on average 589.46 kg of chemical P fertilizer per farm.

**Figure 1: Phosphorus fertilizer use in Ireland from 1898 to 2012 (in tonnes)**



In spite of this steady reduction in P fertilizing, the Irish EPA reported in 2013 a steady decline in high status river bodies pointing at agriculture as the main polluter and considering P one of the major threats to Irish river ecosystems (Ni Chathain et al., 2013), implying that further measures need to be considered if effective water protection from agricultural P is to be achieved.

The maximum upper limits recommended chemical P inputs are provided by a statement delivered by the Irish Department of Agriculture, Food and The Marine (DAFM), based on the soil P index classification of each field, and in accordance with the national and EU policies regarding water quality. Table 1 shows the direct relation between soil P index with soil P content and P fertilizing recommendations for dairy farms.

**Table 1: soil P index description and relation to soil P content, soil response to P fertilizer and upper limits of P fertilizer recommended.**

Soil P index	Soil P content (ppm)	Index description	Response to P fertilizer	Available to build up	Average allowed rates
1	0.0 - 3.0	Very low	<i>Definite</i>	20	39
2	3.1 - 5.0	Low	<i>Likely</i>	10	29
3	5.1 - 8.0	Adequate	<i>Unlikely</i>	0	19
4	Above 8.0	Excess	<i>None</i>	0	0

As seen in Table 1 field soil P index is determined by the soil P content which can be identified following a filed soil test. In the case of a farmer being unaware of their soil P status the total amount of Phosphorus they are expected to apply should be at maintenance level, soil P index 3 (STATUTORY INSTRUMENT No. 426 of 2014). Soil testing in Ireland is provided to all farmers for a fee by Teagasc, the Irish agriculture and food development authority. The standard soil test includes testing for Phosphorus, Potassium, and soil pH, although more components can be included if desired.

According to current legislation, each farmer is legally responsible for the quantity of fertilizer applied on their farm, although it is not required for all farmers to soil test. According to the National Farm survey, in 2015, 38.8% of Irish dairy farmers' soil tested their farms in the previous 5 years. Following the cross compliance requirements of the EU Common Agricultural Policy, farmers that

<sup>1</sup> The latest data available

wish to avail of derogation regulations<sup>2</sup> and of rural development subsidy schemes are obliged to soil test to identify their fields and conduct a consequent nutrient management plan. However, given the importance of soil P status in defining the amount of optimum total P applicable, soil testing is highly recommended to all farmers in order for them to make accurate P input decisions. Additionally, identifying fields under soil P index 4 is considered essential for reducing unnecessary P application that may lead to further diffuse pollution (Newell Price et al., 2011).

It is clear that soil test results provide the farmers with adequate knowledge to design and apply a nutrient management plan on their farm. Regarding P it is expected that soil testing would affect farmers P input management decisions as it potentially would indicate a soil P status different than 3 (maintenance status). Regardless of the importance of P fertilizer allocation for farm economies and the environment no study has been conducted so far regarding its intensity of use. Additionally, policy makers and the scientific communities increasingly recognize the importance of accurate soil testing in P management decisions; however the relation between them has not been studied.

Regarding fertilizer use intensity, Breen et al. (2012) investigated the use intensity of N artificial fertilizers in Ireland using NFS data, and estimated the relationship between intensity of use and fertilizer prices using a fixed effect panel data model. Their study focused only on N fertilizing and did not include of technologies that can influence P allocation decisions. The FAPRI-Ireland model has, also, been used to examine the relation between changes in the CAP and allocation of Nitrogen fertilizers and the impact of the CAP on GHG emissions from agriculture (Binfield et al., 2008). When it comes to investigating management decisions in Ireland, research is limited to investigating the choice of a farmer to adopt - or not - a specific management option and the explanation of the relative effect of a variety of factors on this choice. Some examples would be Creighton et al. (2011) and Laple and Kelley (2013). Regarding particularly soil testing, Kelly (2014) investigated the dairy farmers' intention to soil test, dividing them into voluntary and non-voluntary adaptors but did not relate farmers' willingness to soil test with their fertilizer inputs.

The purpose of this study is to examine the factors affecting P phosphorus allocation at farm level, with particular interest in the relation between a farmer's decision to soil test and their grassland P fertilizer use intensity. We focus on the dairy sector in Ireland and we use a censored tobit model, on data provided by the Irish National Farm Survey (NFS), in order to estimate the change chemical<sup>3</sup> P fertilizer inputs due to farmers' decision to soil test on their farm. Tobit models have been used to estimate fertilizer demand in developing countries (Hamid et al., 2016; Waithaka et al., 2007; Yamano and Arai, 2011) however, the scope of those studies was the increase of fertilizer use to promote crops growth and they focus on farm and household economic capacity to support intensification, without taking into account environmental concerns. This study aims at identifying the factors that influence chemical P fertilizer use, with the ultimate goal to support policy design for its sustainable use. It specifically focuses on providing a better understanding of the relation between soil testing (among other factors) and P chemical fertilizer use intensity. Moreover, it encourages a discussion that can inform policy design regarding the promotion of motivational tools that could assist farmers in improving their fertilizer use efficiency.

## Methodology

### Data

The study derives data from the Irish Teagasc National Farm Survey (NFS). The NFS data has been collected in Ireland since 1972, and is part of the EU Farm Accountancy Data Network (FADN)

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<sup>2</sup> In 2014, Ireland was granted a derogation to allow intensive farmers a higher stocking rate of livestock manure, subject to them complying with strict rules that are overseen by the Department of Agriculture, Food and the Marine. The derogation increases the application limit of 170kg/ha of livestock manure (as indicated by the EU Nitrates Directive) to 210kg/ha each year.

<sup>3</sup> Organic fertilizer, containing mainly dung, urine and waste water is collected in large tanks at farm yards during periods of animal housing, and applied onto fields during the growing season. Under the empirical evidence based assumption that farmers apply all slurry or manure available to empty their tanks for the next housing season, only the change in chemical P fertilizer is investigated here.

requirements for Ireland. In this study we use data from the 2015 survey which contains a sample of 317 dairy farmers that are adequately weighted to represent all dairy farm enterprises in Ireland (for more information about the weighting process see Hennessy and Moran (2016)).

The estimated model is a censored tobit model with the dependent variable being the total amount of P fertilizer applied on the farm (in kg). Soil testing was represented by a binary variable indicating whether a farmer has soil tested any part of his/her farm in the past 5 years (Table 2). Additionally to soil testing several other important factors were included in the set of independent variables as they were assumed to be affecting P fertilizer use intensity<sup>4</sup>, which are described below:

**Binary variables:** Part time farming and soil type. A detailed description of these variables is provided in Table 2.

**Continuous variables:** age, monetary output from milk sales, total amount of manure an slurry applied on the farm, total area of grass land, stocking rate, total amount of chemical P and N fertilizers and the percentage of farm land that is rented. A detailed description of these variables is provided in Table 3.

**Table 2: Description of the binary independent variables used in the empirical model**

Variable	Description	Unit
<b>Soil test</b>	<b>Dummy variable indication if a farmer soil tests</b>	<b>(1=yes, 0=no)</b>
Part time farmer	Dummy variable indicating if farmer is part time	(1=yes, 0=no)
Soil type	Dummy variable indication if soil has poor land use potential (related to drainage capacity)	(1=yes, 0=no)

**Table 3: Description of the numeric continuous independent variables used in the empirical model**

Variable	Description	Unit
Age	Age of the main farm holder	Years
Milk sales	Total gross output from milk sales (€1000)	€1000
Manure	Volume of manure applied	Tonnes
Slurry	Volume of slurry applied	Tonnes
Grassland	Total area farm as grassland	Ha
Stocking rate	Livestock units (LU) per forage hectare	
N fertilizer	N fertilizer applied	Kilograms
K fertilizer	K fertilizer applied	Kilograms
Rented land	total grassland area that is rented	Ha

These variables were incorporated in the model and their effect on fertilizer amount was estimated as described in the next section. In order to provide an in depth interpretation of results, and given the limited amount of literature on the subject, the empirical analysis was followed by discussions with farmers and advisors who provided an elaborated opinion on the interpretation of the estimated coefficients.

## Empirical specification

We identify the factors influencing the adoption and intensity of use of phosphorous fertilizer using the standard tobit model (Tobin, 1958). The tobit model is considered a suitable model to be used for estimating the relationship between explanatory variables and the dependent variable, when the dependent variable has a number of its values clustered at a limiting value; usually zero (McDonald and Moffitt, 1980). Given that some farmers in the sample do not apply phosphorous fertilizer, the

<sup>4</sup> All explanatory variables used in all models were checked for statistical significance through  $\chi^2$  tests for discrete variables and a one sample t-test for continuous ones. Also, to account for multicollinearity, correlation matrices for all explanatory variables and V.I.F. indexes of all variables were checked. One originally selected variable was consequently not included, namely the amount of concentrate feed (in kg).

dependent variable is censored from below at zero. Using a left-censored limit of zero, the tobit regression model is specified as

$$Y_i^* = \beta X_i + \epsilon_i, \quad i = 1, 2, \dots, N, \quad (1)$$

$$Y_i = Y_i^* \quad \text{if } Y_i^* > 0$$

$$Y_i = 0 \quad \text{if } Y_i^* \leq 0$$

where  $Y_i^*$  is an implicit stochastic index (latent variable) for the  $i^{\text{th}}$  farm which is observed only when the observed dependent variable  $Y_i$  (total quantity of applied phosphorus fertilizer in the grassland area) is positive,  $\beta$  is a vector of parameters to be estimated,  $X_i$  is a vector representing the independent variables of the model and  $\epsilon_i$  is the error term (normally and independently distributed). The censored regression model (1) describes the probability of  $Y_i = 0$  (subject to  $x_i$ ) as

$$P\{Y_i = 0\} = P\{Y_i^* \leq 0\} = P\{\epsilon_i \leq -\beta X_i\} = P\left\{\frac{\epsilon_i}{\sigma} \leq -\frac{\beta X_i}{\sigma}\right\} = \Phi\left(-\frac{\beta X_i}{\sigma}\right) = 1 - \Phi\left(\frac{\beta X_i}{\sigma}\right) \quad (2)$$

and the expected distribution of  $Y_i$  when  $Y_i$  takes positive values

$$E\{Y^*\} = E\{Y_i | Y_i > 0\} = \beta X_i + E\{\epsilon_i | \epsilon_i > -\beta X_i\} = \beta X_i + \sigma \frac{\phi\left(\frac{\beta X_i}{\sigma}\right)}{\Phi\left(\frac{\beta X_i}{\sigma}\right)} \quad (3)$$

where  $\Phi(\cdot)$  is the cumulative normal distribution function, and  $\phi(\cdot)$  is the unit normal density function of  $Y$  and  $\sigma$  is the standard error of the error term. The expected value of all observations,  $E\{Y_i\}$  is derived by multiplying the expected value of  $Y_i$  conditional upon being above zero, with the probability of  $Y_i$  being above the limit, ( $P\{Y_i > 0\} = \Phi\left(\frac{\beta X_i}{\sigma}\right)$ ).

$$E\{Y_i\} = \beta X_i \Phi\left(\frac{\beta X_i}{\sigma}\right) + \sigma \phi\left(\frac{\beta X_i}{\sigma}\right) \quad (4)$$

The coefficients of the tobit model are estimated with the maximum likelihood (ML) estimation method. Contrary to linear models where the marginal effect of an explanatory variable  $x_{ik}$  on  $Y_i$  equals the value of the estimated coefficient  $\beta_k$ ; in non-linear models, such as tobit, the marginal effect of  $x_{ik}$  on  $Y_i$  depends on the value of  $\beta x$  at which it is evaluated (O'Neill and Hanrahan, 2012). As the tobit model describes the probability of observing a zero outcome (non-use of phosphorus fertilizer) and the expected value of  $Y_i$  if  $Y_i > 0$ ; it is possible to estimate the marginal effect of a change in  $x_{ik}$  on the probability of zero outcome ( $P\{Y_i = 0\}$ ), the marginal effect on the expected observed value of  $Y_i$  ( $E\{Y_i\}$ ). There are two marginal effects on the observed  $Y_i$  (McDonald and Moffitt, 1980):

$$\frac{\partial E(Y_i)}{\partial x_{ik}} = \Phi\left(\frac{\beta X_i}{\sigma}\right) \beta_k \quad (5)$$

$$\frac{\partial E(Y_i | Y_i^* > 0)}{\partial x_{ik}} = \beta_k \left[ 1 - \left(\frac{\beta X_i}{\sigma}\right) \left(\frac{\phi\left(\frac{\beta X_i}{\sigma}\right)}{\Phi\left(\frac{\beta X_i}{\sigma}\right)}\right) - \left(\frac{\phi\left(\frac{\beta X_i}{\sigma}\right)}{\Phi\left(\frac{\beta X_i}{\sigma}\right)}\right)^2 \right] \quad (6)$$

These formulas give the marginal effect with and without the information that the observed value is positive and they are referred to, respectively as conditional and unconditional marginal effects.

## Results and discussion

The analysis took place using the STATA11<sup>®</sup> statistical analysis software. A censored tobit model and the conditional and unconditional marginal effects were estimated. Estimation of probability was for a total of 301 observations, 16 observations that has missing information were automatically dropped. Table 4 shows the means and standard deviations of the variables used in the tobit model for continuous variables and the frequency (% of "yes") of the categorical variables.

**Table 4: Descriptive statistics of the explanatory variables**

Variable	Mean	St. Dev.	Frequency
Age	49.016	9.782	
Manure	248.156	249.602	
Slurry	769.459	446.404	
Milk sales	115.572	74.113	
Grassland area	56.312	71.021	
Stocking rate	1.326	0.472	
N fertilizer	8770.564	5796.413	
K fertilizer	1635.279	1624.367	
Rented land	0.249	0.777	
Soil type			60.51%
Part time farmer			29.02%
<b>Soil test</b>			<b>38.8%</b>

As seen in Table 4 the average age of farmers in the sample is 49 years old. Less than a third of the sample farmers are part-time farmers (29.02%). The average farm achieves annual revenue from milk sales of €115,572. The average farm utilizes 56.3 ha of grassland, most of which is privately owned and only 0.24 ha is rented. Stocking rates are relatively low (1.326 LU per forage ha). The cultivated land is generally of good production potential (60.5%). When it comes to fertilization, the average farm utilizes 248 tonnes of manure and 769 tonnes of slurry annually, which are complemented by the application of 8770 kg of N and 1635 kg of K chemical fertilizers. In order to support their decision-making regarding the use of fertilizers, 38.8% of the sample farms have performed a soil test on their farms within a period of 5 years.

Table 5 gives the maximum likelihood estimation results of the tobit model and the associated marginal effects according to equations 5 and 6. Interpretation is based on the “unconditional” marginal effects.

**Table 5: Tobit model estimation results: coefficients and marginal effects**

Dependant variable		P chemical fertilizer			
Variable	Tobit coefficient	Marginal effect unconditional expected value		Marginal effect probability of being uncensored	
<b>Soil test</b>	<b>-49.211 (-1.86)**</b>	<b>-42.417</b>	<b>(-1.88)**</b>	<b>-0.064</b>	<b>( 1.90)**</b>
Age	-2.118 (-1.15)	-1.886	(-1.16)	-0.015	(-1.16)
Manure	340.117 ( 2.93)***	289.212	(2.94)***	0.175	( 2.99)***
Slurry	-138.592 (-1.96)**	-117.849	(-1.99)**	-0.071	(-1.99)**
Milk sales (€1000)	-1.328 (-2.35)**	-1.129	(-2.35)**	-0.001	(-2.31)**
Grassland area	0.115 ( 0.93)	0.098	( 0.93)	0.000	( 0.91)
Stocking rate	40.941 ( 1.09)	28.463	( 0.87)	0.017	( 0.86)
N chemical	0.025 ( 3.05)***	0.021	( 3.07)***	0.001	( 3.00)***
K chemical	0.278 (10.25)***	0.237	(10.2)***	0.001	( 8.94)***
Rented land	-12.487 (-0.60)	-11.030	(-0.60)	-0.006	(-0.60)
Soil type	96.679 ( 3.01)***	82.209	( 3.09)***	0.049	( 3.11)***
Part time farmer	130.169 ( 2.37)**	110.687	( 2.42)**	0.067	( 2.44)**
_cons	-290.175 (-1.72)				
Log likelihood	-963.243	Pseudo R <sup>2</sup>	0.078	Weighted obs	301

Significant at: \*10%, \*\*5%, \*\*\*1%  
Absolute value of t & z statistic in brackets  
18 left-censored observations at P fertilizer>=0



As shown in Table 5 (highlighted) soil testing has a negative significant correlation with the total amount of P fertilizer used; thus the quantity of P fertilizer allocated is reduced by 6.4% if a farmer performs soil testing. This result verifies the hypothesis that soil testing leads to a decreased use of fertilizer. Discussions with experts and advisors showed that, as soil testing can indicate fields that should not receive any P fertilizer, in case they are found on a farm the total amount of fertilizer would be reduced, rather than the entire farm being treated at maintenance level (P index 3). On the other hand, of course, soil testing can indicate deficits of P in some fields (P index 1 or 2), which theoretically would lead to an increase of P demand. However, research has shown that Irish dairy farm fields have been over-fertilized up to today therefore this is not as common as the identification of P index 4 fields (Wall et al, 2016).

From the other factors co-examined in the model, milk sales and amount of slurry applied on farm had a significant negative correlation with P chemical fertilizer used. More specifically, regarding slurry, for every increase in slurry application by 1 unit (tonne), P chemical fertilizer used is reduced by 7.1% (see Table 5). The reduction of P chemical fertilizer use, as the use of slurry increases was an expected result as use of slurry has been found to improve soil quality parameters (Yagüe et al., 2012). As farmers and advisors confirmed, it is known to farmers that slurry is contributing to P increase in the soils and slurry and chemical P are considered to be complementing each other, so increasing the slurry amounts applied should lead to decreasing chemical fertilizer use. Increased P availability after slurry applications is confirmed by various studies, (for example Prior et al. (2013). Thus, it is logical that slurry could serve as an effective alternative for P chemical fertilization.

Regarding milk sales, the reduction of P chemical fertilizer is at 0.1% per €1000 of gross output, but it is significant. In the follow-up discussions farmers and experts revealed this negative relation to be a surprising result. Indeed Breen et al. (2012) who had investigated the impact of the same variable on N fertilizer demand found a positive correlation. A possible explanation for this contradiction between the result and the literature and expert knowledge may derive from the assumption that higher milk sales are correlated to larger herds with high slurry production effectively spread on the farm; hence, given the negative correlation between slurry spread and P fertilizer (see previous paragraph) these farmers tend to slightly reduce their chemical fertilizer inputs at farm level.

Contrary to slurry, manure application has a positive impact on P fertilizer amount, increasing it by 17.5% for each increase of manure input by 1 tonne. This finding is seemingly peculiar; however the reasons behind it can be traced in the specific nature of manure-based fertilising strategies. Indeed, in most cases manure is used as a source of nitrogen and P needs of crops are sometimes neglected or not accurately estimated or accounted for. Lory and Massey (2006) revealed that the use of manure as fertiliser depends on a variety of factors, some of which are the type of crop, environmental concerns, crop rotation etc. The N to P removal ratio is an indicator demonstrating the efficiency of manure fertilization for each crop type. Especially when it comes to the environment, the authors stated that specific strategies are required in order to achieve a sustainable level of P use in the long run.

Nitrogen and Potassium chemical fertilizer total farm input both have a significant and positive impact on P chemical fertilizer applied on farm. This is an expected result according to the follow-up discussions with experts and farmers as fertilizers are generally utilized to cover for the overall needs of crops. Even though these variables were not found to demonstrate statistically significant correlation with soil tests, it is general practice to utilize chemical fertilizers also containing units of Nitrogen and Potassium.

The variable “soil type” is significantly and positively correlated with the amount of P chemical fertilizer used by farms. This result shows that the use of P chemical fertilizers increases for areas with low land use potential. This result can be attributed to two factors: firstly, as explained by extension agents who commented on this result, there might be a tendency to apply more chemical P on poorly drained soils, as the poor production potential is often misinterpreted by farmers as lack of nutrients in the soil. Secondly, as also is implied by Lory and Massey (2006), farmers prefer not to use organic sources of P (especially manure) in land with high drainage and prefer more precise applications with chemical fertilizers, increasing this way the amount used.

Finally, an interesting finding lies in the positive correlation between part-time farming and higher use of P chemical fertilizers. There are two possible explanations for this result: firstly, assuming that part-time farming indicates having an off-farm job, this may result in a positive wealth effect, which enables farmers to purchase more fertilizer (Breen et al, 2012); secondly, it could be due to the fact that grassland management is, generally, time consuming and thus not-appropriate for farmers who only have part of their time available for farming. As reported by Gladwin (1989) and later by Hara (2001) farmers tend to reduce the use of organic fertilizers and increase chemical inputs when they face time constraints. Other explanatory factors could potentially be related to the specific profile of part-time farmers i.e. level of farm education, years of experience, environmental awareness etc.

## **Conclusions, recommendations and further research**

The analysis in this study provided some insights about the factors affecting the intensity of use P chemical fertilizers by the Irish dairy producers. It was demonstrated that the decision to utilize more or less P chemical fertilizer is subject to farm- and farmer-specific characteristics and have confirmed the hypothesis that soil testing is associated with reducing P fertilizer use intensity. The results reported here could be useful for the design of strategies to support better and more efficient use of P fertilizers in order to achieve farm productivity objectives combined with environmental efficiency. As farmers and advisors have explained, having soil tested the farm as an overall process leads farmers to make more accurate decisions, which eventually results in reduced fertilizer amounts; this is partly because a soil test can provide the exact amount of fertilizer needed, and partly because the process itself psychologically influences the farmers to become more cautious on fertilizer use.

A major policy implications arising from the result of this analysis regarding soils testing is the importance of the perceived cost-benefit relation between soils testing and reduction of chemical P fertilizer. Soil testing is proven to reduce chemical P fertilizer application; however, farmers have explained in extended discussions that they often do not consider soil testing to be cost-efficient as by itself it does not provide sufficient information for more efficient fertilizer allocation and has to be combined with costly nutrient management advice by the extension agents. This however increases the advisory cost beyond what farmers are willing to spend. Indeed, studies have indicated that farmers' main concern, when it comes to adopting voluntarily tools for more environmentally friendly fertiliser allocation decisions, is finance related (Doody et al., 2012; Micha et al., 2017). A potential policy recommendation to overcome this caveat would be the inclusion in the soil testing service of follow up advice for fertilizer allocation, that would help farmers make better actual use of the results. For example, Byrne et al. (2009) had suggested in the past the provision of these combined services (soil testing & nutrient management advice) without a fee for a few pilot years – particularly in sensitive areas such as agricultural catchments – in order to raise awareness and gradually shift farmers perception of the cost-effectiveness of the tool towards a more positive view.

Furthermore, although it could be expected that soil tests could provide farmers and extension agents with more detailed and accurate information regarding the efficient and precise utilization of chemical fertilizers in order to cover the needs of grass, other methods may also be needed. For example, better results could be achieved through the more widespread utilization of Precision Agriculture (PA) methods, such as Variable-Rate Application systems (Grisso et al., 2011; Zhang et al., 2010). The feasibility of these methods in the Irish dairy sector is under constant examination.

In general, the conclusions derived from this study also show that farmers need to have access to better, systematic and integrated information regarding the requirements of their farms in P-fertilization. Some other necessary information would potentially include analysis of the slurry and manure they use, alongside additional support for the adoption of integrated fertilization strategies which would ensure sustainability in the long run. Furthermore, the results of this paper could be of greater importance for policy making if they were analyzed under the light of the general farm management decisions that farmers adopt (e.g. their grazing periods and rotation systems) and the environmental risks involved (e.g. existence of critical source areas on farm). These factors, could provide much more insight regarding the use of P fertilisers and the design of proper policies and strategies to simultaneously achieve economic and environmental sustainability of the sector.

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