Nutrient management planning and water protection efficiency: examining the farmers' attitudes towards using soil testing as a nutrient management tool

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Abstract: *Phosphorus (P) is an important agricultural input, but also responsible for significant deterioration of water quality in agricultural catchments. EU member states are required to maintain water quality and integrate science, technology and practice under the Water Framework Directive (WFD), but Ireland is currently in breach of this directive due to a decline in the number of catchments of high status, thought to be primarily due to agricultural activity. Improved nutrient management is suggested as a means by which farmers can minimise the risk of pollution to water bodies by increasing the efficiency of inputs. This paper demonstrates differences in the risk of P losses to water between farms by comparing P balances for a number of farms in a selected catchment in the South-West of Ireland. P balances were derived by subtracting P outputs (agricultural production) from P inputs (seeds, organic and mineral fertilisers). The estimated P balances were then compared between farms to identify to what extent those farms with a lower risk of aqueous pollution followed extension advice or employed science-based nutrient management planning. Qualitative interviews were conducted with farmers and extension agents to investigate the motivations in communicating agronomic advisory information and illustrate some of the successes and challenges in the current agricultural advisory services. The study can inform policy design by demonstrating beneficial and practical advice for farmers, and help extension services by highlighting the most successful means of communicating this advice.*

Keywords: *Phosphorus, water quality, agricultural catchments, environment, farm management*

Introduction

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).

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.

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. **Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.** 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 (kg/ha)	Average allowed rates (kg/ha)
1	0.0 - 3.0	Very low	Definite	20	39
2	3.1 - 5.0	Low	Likely	10	29
3	5.1 - 8.0	Adequate	Unlikely	0	19
4	Above 8.0	Excess	None	0	0

As seen in **Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.** 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 wish to avail of derogation regulations[1] and of rural development subsidy schemes (GLAS) 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 that 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.

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 Läpple and Kelley (2013). Regarding particularly soil testing,

[1] 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.

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 paper is to explore the impact of soil testing on farm nutrient balances and profitability in south-western Irish dairy farm using farm acountancy data, illustrated by farmer interviews on the use of soil testing.

Methods

Farm management and economic data

Farm agricultural output, management and economic data were obtained from the 2015 Teagasc National Farm Survey (NFS, Hennessy and Moran, 2016). The Teagasc NFS collects farm management and microeconomic data for a representative sample of approximately 900 Irish farms annually, and is part of the EU Farm Accountancy Data Network (FADN). In recent years the Teagasc NFS data collection has been expanded to cover a number of environmental impact and farm sustainability topics in addition to farm economic performance (Dillon *et al.*, 2016; Lynch *et al.*, 2016; Ryan *et al.*, 2016).

Data were obtained for 96 dairy farms from the south-west of Ireland (counties Cork and Kerry), of which 81 had performed soil tests within the last 5 years, and 15 had not. This geographic restriction was used so that study farms would be comparable with those where interviews were held.

Phosphorus balances

Annual farm phosphorus balances were calculated following Buckley *et al.* (2015). The phosphorus content of all farm exports (milk, livestock and crops) was subtracted from the phosphorus content of farm imports (fertilisers, imported livestock and feeds) in order to indicate the potential phosphorus surplus applied. Fertiliser phosphorus was obtained directly from the NFS, where fertiliser applications are directly recorded. Other imports and exports used standard coefficients to estimate the phosphorus content from the total weight of each item (further details in Buckley *et al.*, 2015).

Farm production and profitability

Milk output and composition recorded at creamery was obtained from the NFS and expressed as fat and protein corrected milk (FPCM) standardised to 4% fat and 3.3% protein following the equation below (IDF, 2015):

$$FPCM = milk\,production\,(kg) \times (0.1226 \times fat\% + 0.776 \times protein\% + 0.2354)$$

Market based gross margin per hectare of utilised agricultural area was used as a measure of farm profitability, with market gross margin calculated as gross output less direct costs, grants and subsidies using NFS data.

Statistical analyses

Mann-Whitney tests were used to compare farm phosphorus balance per hectare, profitability and kg surplus phosphorus per kg FPCM produced for farms that did and did not soil test. All analyses were performed in R (R Core Team, 2016). The Mann-Whitney test was chosen as a most appropriate method instead of the normal T-test for te group differences mainly beacuae the sample was not normally distributed.

Interviews

Qualitative interviews took place with farmers in the south west of Ireland. In total 5 dairy farmers were interviewed that covered farmers in derogation (see introduction), farmers that soil test their farms volunarily and farmers that have not soil tested their farms at all in the past 5 years. The bdistribution of interviewees to each group is:

- 1 in derogation & rural development schemes (GLAS)
- 2 in derogation
- 1 non-derogation farmer woh has soil tested
- 1 farmer who has never soil tested

A larger number of farmers were contacted to investigate willignress to aprticipate in the interview and 5 responded positively. The number was accepted as satisfactory, as the participants would represent the all bahaviours towards soil testing in Ireland. This decision was based on the assumptions that farmers in Ireland share common views and opinions and this representation can capture the wider beliefs.

The purpose of the inteviews was to identify and explore the views and opinions of dairy farmers regarding soil testing, in order to provide a more in depth interpretation of the results of the statistical analysis. The area where the interviews were held was chosen as the region with the highest desnsity of dairy farms in Ireland (Teagasc NFS, 2015).

Interviews followed a semistructured protocol, during which the interveiwes provided general framework questions to the participant and recorder their answer, supporting the conversation with follow-up question to facilitate and ansure the the sustainable continuation of the conversation. The inteviewes were transcibed and analysed using the contect analysis method as a guideline.

Results and discussion

Phosphorus balance per hectare was not significantly different between farms that did (median = 6.02 kg ha^{-1}) and did not (mdn = 6.50 kg ha^{-1}) perform soil tests (U = 596, p = 0.91), indicating that soil testing results were not used to minimise phosphorus surpluses.

Farms that soil tested were more profitable than farms that did not (U = 947, $p < 0.001$), with a median market gross margin per hectare of €1744.71 for soil-testing farms compared with €1194.26 for non soil-testers. This profitability did not appear to be driven by phosphorus use efficiency however, as soil testing farms did not show a lower phosphorus surplus per kg FPCM sold (soil testers median = 11.47 g surplus P per kg FPCM; non soil-testers mdn = 17.9 g surplus P kg^{-1} FPCM;U = 459, p = 0.14).

Although soil testing was associated with increased profitability, it did not appear to have a clear impact on efficiency of phosphorus use in milk production (inferred through the P surplus per unit milk production) or risk of environmental losses (inferred through P balances per hectare). It may be that soil testing is sufficiently widespread that this group captures a range of outlooks and approaches to nutrient management strategy, as indicated by the greater number of farms from the sample who did undertake soil testing compared to those that did not. This range of views among soil testing farmers was reflected in interviews. Some farmers indicated that they found soil testing very beneficial in improve nutrient management and efficiency, stating, for example, “Soil testing can help reduce input costs – less fertiliser costs,” “It helps avoid unnecessary fertilising – the surplus is not used by the plants,” And “Helps make better decision on chemical fertiliser to be used – it’s always good to know your soils.” Other soil-testing farmers, however, expressed scepticism or a negative opinion on soil-testing, with statements such as: “I don’t think they are accurate” And “There is no point doing it, the fertilizers I put are the same with and without it.”

Interpreting the results is also complicated by the fact that soil-testing is a requirement for nitrates derogation (see introduction for details). Larger, more intensive and more profitable dairy farms are more likely to require nitrates derogation, and so this may explain the link between soil testing and profitability, rather than a direct impact of soil-testing. A number of farmers also raised this point in interviews, suggesting that “The more profitable farms are in derogation, they have to…,” “only the more profitable can afford to,” and “No one I know has ever done it voluntarily”.

Several quotes suggested there may be practical issues preventing soil test results being used to their best effect, even where they are undertaken. According to the interview participants the main reason a soilt est is not able to reduce the p surpuses on farm is because, in reality, it is not being approriately used. Presentation of the soil test results is not friedly to the farmers and does not lead to a clear explanation of how P should be managed on farm. Also, soil testing is a process that takes lace in a laboratory, and the farmer has no control over the process and the timing of the results. In addition, soil testing is a process that is beyod tha farmers control and often does not align with the farmers‘ timing of making management decisions.

These issues are reflected on the interviewees ansewers, for example “I don’t understand the information it provides – it’s not useful without the extra advisory services,” “nobody has told us why we should do it – there is not enough information on how and where we basically have to find the info ourselves,” “…not good understanding of soil types.” And “results came in too late, fertiliser purchases had already been made.”

AS farmers have noted, soil tsting alone is not considered a useful tool if not combined with costly Nutirent management planning advice, that derive from it. Depending on the farmers intention to invest on precise fartilizer allocation, there is a high possibility that farmers are not willing to cover the extra cost of receiving that advice if they are not obliged to and allocate theri fertilizersa based on other criteria, such as their own judgement and assumptions or their existing history of P application.

It should also be noted that while the farm gate phosphorus balances used in this study can provide a useful indicator of risk of environmental loss, they may omit important details. Farmers may be using the results of their soil-tests to apply fertilisers in a more targeted manner and/or with a greater awareness of where mitigations or more careful fertiliser application is required due to an increased risk of losses. This was supported by some farmers in interviews, with suggestions that “helps protect environment – understanding of runoff” and “balance inputs between fields”.

Conclusion

Soil testing has the potential to benefit farmers and minimise the risk of environmental losses. At present, however, there are barriers to achieving this. 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,

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.

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