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Variable response to phosphorus mitigation measures across the nutrient transfer continuum in a dairy grassland catchment

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ABSTRACT

Phosphorus (P) loss from soils to water can be a major pressure on freshwater quality and dairy farming, with higher animal stocking rates, may lead to potentially greater nutrient source pressures. In many countries with intensive agriculture, regulation of P management aims to minimise these losses. This study examined the P transfer continuum, from source to impact, in a dairy-dominated, highly stocked, grassland catchment with free-draining soils over three years. The aim was to measure the effects of P source management and regulation on P transfer across the nutrient transfer continuum and subsequent water quality and agro-economic impacts. Reduced P source pressure was indicated by: (a) lower average farm-gate P balances (2.4 kg ha^{-1} yr^{-1}), higher P use efficiencies (89%) and lower inorganic fertilizer P use (5.2 kg ha^{-1} yr^{-1}) relative to previous studies; (b) almost no recorded P application during the winter closed period, when applications were prohibited, to avoid incidental transfers; and (c) decreased proportions of soils with excessive P concentrations (32–24%). Concurrently, production and profitability remained comparable with the top 10% of dairy farmers nationally with milk outputs of 14,585 l ha^{-1}, and gross margins of € 3130 ha^{-1}. Whilst there was some indication of a response in P delivery in surface water with declines in quick flow and interflow pathway P concentrations during the winter closed period for P application, delayed baseflows in the wetter third year resulted in elevated P concentrations for long durations and there were no clear trends of improving stream biological quality. This suggests a variable response to policy measures between P source pressure and delivery/impact where the strength of any observable trend is greater closer to the source end of the nutrient transfer continuum and a time lag occurs at the other end. Policy monitoring and assessment efforts will need to be cognisant of this.

1. Introduction

The driver of food needs and the pressure (DPSIR framework; EEA, 1999) of intensive agriculture may impact water quality, particularly via nutrient loss from land to water, causing eutrophication (Sharpley and Rekolainen, 1997). The EU policy response is the nitrates directive (ND) (OJEC, 1991) and consequent Nitrates Action Programmes (NAPs) to manage the risks of such losses. In the Republic of Ireland, the NAP (SI 31, 2014) includes measures for both N and P, as P is an important trophic pressure in freshwaters (EPA, 2012). Reviews of the NAP follow a four-year cycle and are contingent, amongst other things, on water quality status and the agricultural contribution to the pressure.

Dairy farming is a key sector of Irish agriculture and operates a relatively low cost, efficient and profitable system based on maximizing grazed grass in the cow's diet (Ryan et al., 2011). However, dairy farms also tend to be more intensive with higher stocking rates than other grass-based systems, supported by higher P applications to grassland and higher farm P imports in

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feed and fertilizer, potentially creating a greater nutrient source pressure.

Under the NAP, P inputs and management are constrained by measures intended to improve P use efficiency (PUE) and minimise P loss risks (Table 1), such as a winter closed period for spreading fertilisers and maximum field-level P application rates based on crop type and soil P concentration (Morgan P) (Wall et al., 2013). Application of P to soils with excessive P is prohibited in most scenarios, the intention being that, with continued P offtake by crops, concentrations will decline to optimum and reduce the environmental risk. Previous research to gauge the effectiveness of NAP measures has focused on the time required to decline to optimum (e.g., 2–20 years in Wall et al., 2013), including modeling (Schulte et al., 2010) and plot scale monitoring (e.g., Dodd et al., 2012; Blake et al., 2003; Burkitt et al., 2002). However, few studies have examined soil P changes over time in whole farm systems and less so on a catchment or watershed scale – the scale of the farming landscape as it interacts with hydrological processes. Wall et al. (2011) proposed that monitoring of policy impacts be cognisant of the nutrient transfer continuum (Lemunyon and Gilbert, 1993; Haygarth et al., 2005), or nutrient cascade (Smith et al., 2013), from source to impact, including nutrient changes and attenuation along pathways and their influence on ecological impacts.

Ultimately, optimising agronomic output and lowering environmental risk is the policy goal (Buckley and Carney, 2013) but discrete monitoring programs report on national scale pressures and states separately and few consider the links between these two. Biophysical processes, such as variable climatic processes (Mellander et al., 2014) and non-agricultural pressures (Withers et al., 2013), can lead to lag effects between changes in nutrient source pressure and water quality impact (Sharpley et al., 2013). Positive river water quality responses to agricultural practice change in meso-catchments (1–100 km^2) may commonly take up to 10 years to occur, and even longer to measure (Melland et al., 2014). The time-scale of affecting change may not, therefore, match the expectations of policy makers and this may have consequences for DPSIR reviews of policy effectiveness. Furthermore, the water framework directive (WFD; OJEC, 2000) makes explicit comment on the economic consequences of such policy measures (Martin-Ortega, 2012), which, at the farm scale, is the impact on productivity and profitability. These considerations are increasingly embedded in catchment management reviews (e.g., Kragt et al., 2011; Roberts et al., 2012).

The advantage of examining the P cascade in catchments is that the integrated effect of farm management practices and environmental processes, that both generate and attenuate P loss in the landscape, are captured (Sharpley et al., 2013). This study examined farm-level P balances and use efficiencies, field-level P inputs, management and soil P status, P pathways and losses to water, stream biological quality and farm agro-economics in a dairy-dominated catchment with free-draining soils over three years. The P cascade elements were measured to gauge the effects of the NAP measures on P source pressure and subsequent water quality and agro-economic impacts.

2. Materials and methods

2.1. Study area

This study took place in south-west Ireland, in a 7.6 km^2 catchment (Fig. 1) with mostly well-drained Brown Earth soils (Cambisols) (85%) with lesser areas of more poorly drained surface-water gleys and gleyic alluvial soils (stagnosols) and peats (histosols). Bedrock geology consists mostly of Devonian (old red sandstone) interbedded sandstones, mudstones and siltstones and upper Devonian–Carboniferous sandstones and mudstones (Sleeman and Pracht, 1994). The climate is cool temperate oceanic with a mean annual rainfall of 1207 mm (Table 1). The catchment area is ca. 90% agricultural, dominated by grassland (79% in 2010 and 70% in 2011) used for dairy production in a system based on grazed grass that is characteristic of the more intensive dairy production systems in southern Ireland. The remainder is in arable crops; principally maize, spring barley and spring wheat. There are 42 land owners in the catchment with 15–20 accounting for most of the agricultural area. Twelve farms (34% of the catchment area) have stocking rate derogation. The catchment has an overall

Table 1
Characteristics of the study catchment, including nutrient loss mitigation measures under the NAP (AF = all farms, DF = derogation farms, NDF = non derogation farms).

Physical			
Climate	Cool temperate oceanic	Elevation (m AOL)	17–127
Topography	Rolling to flat	Mean annual temperature[a] (C)	9.4
Mean annual rainfall[a] (mm)	1207	Mean winter (Nov–Jan) rainfall[a] (mm)	394
Mean summer (May–Jul) rainfall[a] (mm)	217		
Mean annual catchment rainfall 2010–2013 (mm)	1144	Mean annual stream runoff 2010–13 (mm)	563
Mean annual runoff coefficient 2010–2013	0.48		
Dominant soil type	Well-drained brown earth (Brunisol)	Bedrock geology	Devonian sandstones and mudstones
Unconsolidated sediments	Fluvial and glacial deposits	Stream order	3
Land use			
Total area (km^2)	7.6	Grassland area (%)	75
Agricultural area (%)	90	Arable area (%)	15
Livestock density (LU ha^{-1})	1.94	Other area (%)	10

Mitigation measures			
Organic N limit 170 kg ha^{-1}	NDF	Organic N limit 250 kg ha^{-1}	DF
Organic fertiliser closed period (15 Oct –12 Jan)	AF	Inorganic fertiliser closed period (15 Sep–12 Jan)	AF
16 weeks manure storage facilities	AF	Max field N and P rates	AF
Ploughing restrictions (1 July –15 Jan) and green cover requirements	AF	Limits on farm P import	AF
Soil sampling and analysis at least every 4 years	DF	Nutrient management plan	DF
No fertilizer close to streams, rivers, lakes or groundwater sources	AF	No fertilizer on waterlogged, frozen or steep ground or when heavy rain is forecast	AF
Soiled water storage facilities for 10 days	AF	Good yard facilities and management	AF

[a] 30 year average (1962–1991) from nearest synoptic station (Cork Airport).