Phosphorus concentration and export by silage maize and cut grassland under temperate climate

D'Haene K.[1], De Vliegher A.[1] and Hofman G.[2]
[1]*Institute for Agricultural and Fisheries Research (ILVO), Burg. Van Gansberghelaan 92, 9820 Merelbeke, Belgium;* [2]*Department of Soil Management, Faculty of Bioscience Engineering, Ghent University, Coupure Links 653, 9000 Ghent, Belgium*

Abstract

Algal blooming caused by phosphorus (P) losses from agricultural soils to ground- and surface water is a major problem as P is typically the limiting factor for eutrophication in freshwater systems. To fine-tune the advice on P fertilisation and increase P-use efficiency, it is important to have up to date information on amounts of phosphate (P_2O_5) exported by crops. We re-analysed Flemish nitrogen fertilisation experiments on silage maize (*Zea mays*) and cut grassland (*Poaceae*) to derive their quantities of exported P_2O_5. The median P_2O_5 export by silage maize increased significantly from 78 kg P_2O_5 ha^{-1} in the last decade of the 20th century to 94 kg P_2O_5 ha^{-1} in recent years (median of 2.1 g P kg^{-1} dry matter (DM)). This increase is due to the higher crop yields. The median P_2O_5 export for cut grassland remained at approximately 110 kg P_2O_5 ha^{-1} with a median of 4.1 g P kg^{-1} DM.

Keywords: phosphorus, export, fertilisation advice, best management practice

Introduction

Long term phosphorus (P) overfertilisation has resulted in a large acreage of P-saturated soils and increased P losses to ground- and surface waters. In some European countries agriculture has become the main P source in water bodies (Bogestrand *et al.*, 2005) and is a major factor in eutrophication of surface waters as P is typically the limiting factor for algal blooming in freshwater systems (Sterner, 2008). One of the most commonly followed strategies to reduce P losses from agricultural soils is a rational P-fertilisation rate. To fine-tune the P fertilisation advice, it is important to have up to date information of the phosphate (P_2O_5) export of silage maize (*Zea mays*) and cut grassland (*Poaceae*), as scientifically sound fertilisation advice takes both optimal crop yield and quality and environmental impact into account.

Material and methods

We re-analysed 26 and 14 Flemish nitrogen (N) fertilisation experiments (1996-2013) on silage maize and cut grassland without clover, respectively, to derive their P_2O_5 export. To preclude an effect of N fertilisation rate, only plots receiving the maximum allowed N fertilisation norm of the Flemish fertilisation legislation (MAP IV, 2011-2014) ±25%, meaning that plots with 100-200 and 225-375 kg of applied effective N ha^{-1} for silage maize and cut grassland, respectively, were included in the analysis (Anonymous, 2011). Phosphorus application rates were based on fertilisation advice dependent on the expected yield. Total fresh and dry matter (FM and DM) yields were determined and P concentration of harvested plant parts was measured colorimetrically after digestion and acid decomposition. Phosphorus content of the upper soil layer was determined with the ammonium lactate method (P-AL).

Results and discussion

The P_2O_5 export by silage maize in Flanders (1996-2013) had a median of 86 kg P_2O_5 ha^{-1} with a median 0.7 and 2.1 g P kg^{-1} on a FM and DM basis, respectively. Regression analysis showed no correlation between P_2O_5 export by silage maize and soil P-AL content and/or P_2O_5 fertilisation rate. There was a significant correlation (R^2=0.47) between P_2O_5 export and yield. The median P_2O_5 export by silage maize increased significantly (P<0.001 nonparametric Mann-Witney U-test). The increase of the median

P_2O_5 export from 78 in 1996-1997 to 94 kg P_2O_5 ha^{-1} in 2003-2013 can be explained by the higher yield (median of 16.8 and 18.9 Mg DM ha^{-1}, respectively) as the P concentration did not change (Table 1).

The P concentration in Flanders falls within the range of other temperate-climate areas, i.e. 1.8 g P kg^{-1} DM in the Netherlands and France (Ehlert *et al.*, 2009; Gloria, 2012) and 2.2-2.3 g P kg^{-1} DM (2008-2013) in northern Germany (Egert, 2014). Fotyma and Shepherd (2001) measured in northern and eastern Europe on average 0.6±0.009 g P kg^{-1} FM (or 2.0 g P kg^{-1} DM). The median Flemish P_2O_5 export (86 kg P_2O_5 ha^{-1}) is higher than in other regions under temperate climates. In France and Saskatchewan (Canada) fertilisation advice is based on an export of 60 (Gloria, 2012) and 64 to 78 kg P_2O_5 ha^{-1} (Anonymous, 2012), respectively. In the UK, the maintenance fertilisation advice is 55 kg P_2O_5 ha^{-1} (Defra, 2010). Aarts *et al.* (2008) calculated an average export of 69 kg P_2O_5 ha^{-1} from fields of representative Dutch dairy farms (1998-2006) based on an average 2.0 g P kg^{-1} DM measured by BLGG (http://blgg.agroxpertus.nl).

The median P_2O_5 export by Flemish cut grassland was about 110 kg P_2O_5 ha^{-1} with a median P concentration of 4.1 g P kg^{-1} DM (Table 1). Regression analysis showed no correlation between P_2O_5 export and soil P-AL content and/or P_2O_5 fertilisation rate. There was a significant correlation (R^2=0.50) between P_2O_5 export and yield. The limited data from recent years suggest that the lower P_2O_5 fertilisation rate (90 compared to 116 kg P_2O_5 ha^{-1}) has resulted in a non-significant decrease of the average P concentration (P=0.06 T-test). The median P concentration decreased from 4.2 g P kg^{-1} DM to 3.9 g P kg^{-1} DM. The average P concentrations of Dutch grass silage measured by BLGG decreased from 4.4 in 1998 to 4.0 g P kg^{-1} DM in 2007, which was also explained by the stricter legislation (Aarts *et al.*, 2008). Although the median N fertilisation rate was 50 kg of effective N ha^{-1} less in 2003-2008 than in 1997-1998, DM grass yield remained constant.

The Flemish P concentration is within the range of measurements from intensively managed grassland under temperate-climates: i.e. 3.3-3.6 g P kg^{-1} DM in northern Germany (2008-2013) (Egert, 2014),

Table 1. Average (av.), median (med.) and standard deviation (std.) of phosphorus and effective nitrogen fertilisation rate, phosphorus content in the soil, dry matter (DM) yield, phosphorus concentration and phosphorus export by silage maize and cut grassland in Flanders.

	Silage maize								
	119 plots (1996-2013)			73 plots (1996-1997)			46 plots (2003-2013)		
	Av.	Med.	Std.	Av.	Med.	Std.	Av.	Med.	Std.
P_2O_5 fertilisation (kg ha^{-1})	67	65	25	66	69	21	67	60	30
Effective N fertilisation (kg ha^{-1})	140	138	26	141	138	28	138	135	22
P-AL (mg $100g^{-1}$ soil)	34	30	15	35	33	11	32	29	21
DM yield (Mg ha^{-1})	18.1	17.7	2.7	17.4	16.8	2.6	19.3	18.9	2.5
Phosphorus (g kg^{-1} DM)	2.1	2.1	0.4	2.1	2.1	0.4	2.1	2.1	0.3
P_2O_5 export (kg ha^{-1})	87	86	21	83	78	23	95	94	14
	Cut grassland								
	56 plots (1997-2008)			44 plots (1997-1998)			12 plots (2003-2008)		
P_2O_5 fertilisation (kg ha^{-1})	114	116	24	119	116	23	98	90	20
Effective N fertilisation (kg ha^{-1})	289	296	42	296	300	43	262	250	24
P-AL (mg $100g^{-1}$ soil)	28	27	11	29	37	12	23	22	8
DM yield (Mg ha^{-1})	12.0	11.9	2.1	11.8	11.9	1.5	12.9	12.3	3.5
Phosphorus (g kg^{-1} DM)	4.0	4.1	0.6	4.1	4.2	0.6	3.7	3.9	0.4
P_2O_5 export (kg ha^{-1})	111	111	26	111	111	27	110	109	21

3.1-4.1 g P kg^{-1} DM in UK (Defra, 2010) and 3.5-4.4 g P kg^{-1} DM in the Netherlands (Aarts *et al.*, 2008; Ehlert *et al.*, 2009). Fotyma and Shepherd (2001) measured on average 0.6 g P kg^{-1} FM (or 3.0 g P kg^{-1} DM) in grassland with and without clover. The median Flemish P_2O_5 export is higher due to higher yields. In the UK, maintenance fertilisation advice is 90 kg P_2O_5 ha^{-1} (Defra, 2010). Aarts *et al.* (2008) calculated an average export of 89 kg P_2O_5 ha^{-1} from fields of representative dairy farms (1998-2006).

Conclusions

Phosphorus concentration of silage maize and cut grassland remained similar, independent of yield. The median P_2O_5 export by silage maize increased significantly from 78 kg P_2O_5 ha^{-1} in the last decade of the 20^{th} century to 94 kg P_2O_5 ha^{-1} in recent years (with a median of 2.1 g P kg^{-1} DM) due to the increased yield. The median P_2O_5 export by cut grassland was about 110 kg P_2O_5 ha^{-1} with a median of 4.1 g P kg^{-1} DM. In order to obtain optimal yield and taking into account the environmental impact, legislation and P_2O_5 fertilisation advice should envisage an equilibrium maintenance P_2O_5 fertilisation rate per crop for fields with an optimal soil P content, with differentiation for other fields depending on their soil P content.

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