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Phosphorus offtake and optimal phosphorus fertilisation rate of some fodder crops and potatoes in temperate regions

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Introduction

Phosphorus (P) is a major factor in eutrophication of surface waters as P is typically the limiting factor for algal blooming in freshwater systems (STERNER, 2008). Negative environmental effects are the reduced biodiversity of aquatic ecosystems and the decline in water quality. The algae produce toxic substances that kill fish and cause diseases in animals and humans.

In some European countries agriculture has become the main P source in water bodies (KRONVANG et al., 2005). In Flanders, the share of agriculture in total P load to ground- and surface waters was estimated to be 44% in 2011 (ANONYMOUS, 2015c). The attention of the Manure Action Plan (MAP) legislation is shifting from nitrate to P, as the average ortho-P concentration in the MAP network surface water is about 0.4 mg ortho-P·l^{-1} (PEETERS, 2014) which is about four times higher than the environmental limit of 0.07–0.14 mg ortho-P·l^{-1}, depending on the type of watercourse (ANONYMOUS, 2010).

The diffuse P losses into ground- and surface water from agriculture in northwest Europe are caused by the historically large P fertiliser additions resulting in a large acreage of soils with a high P content (KRONVANG et al., 2005). As P fertilisation rates affect the soil P content, one of the most commonly followed strategies to reduce P losses from agricultural soils is a rational P fertilisation rate. Fertilisation advice should envisage an equilibrium maintenance P fertilisation rate for fields with optimal soil P content, with differentiation for other fields taking into account the soil P content. Phosphorus fertility categories, as a function of soil P values, are used in 25 European regions, studied by JORDAN–MEILLE et al. (2012).

In this paper, up-to-date information is given on the phosphate (P_2O_5) removed by cut grassland without clover, silage maize or potatoes and this is confronted with the maximum allowed P fertilisation rates in Flanders' new MAP in the framework of the implementation of the Nitrates Directive and Water Framework Directive.

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Furthermore, P concentration, P offtake and maximum allowed P fertilisation rates are compared to data from northwest European countries with a similar climate.

Material and methods

According to the Köppen classification Flanders has a temperate Cfb climate (without dry season and with a warm summer) (PEEL et al., 2007) which is favourable for high crop yields. A re-analysis was made of 13, 26 and 7 nitrogen (N) fertilisation experiments on cut grassland without clover (*Poaceae*) (1997–2008), on silage maize (*Zea mays*) (1996–2013) and on table potatoes (*Solanum tuberosum*) (2004–2012), respectively, at different locations where P concentration of exported plant parts was measured. Phosphorus fertilisation rates were often based on a P fertilisation recommendation dependent on the expected yield. For cut grassland and silage maize, experiments were available from two decades and the effect of e.g. optimised fertilisation or newer crop varieties could be evaluated.

Total fresh and dry matter (FM and DM) yields were determined. The dry matter content of grass and silage maize was measured by drying, while that of potatoes was indirectly assessed according to the method of WIERSEMA (1993).

The P concentration of the harvested plant parts was measured colorimetrically after digestion and acid decomposition. The soil P content of the upper soil layer was determined with ammonium lactate (P-AL method) (EGNÈR et al., 1960). Only plots given the maximum N fertilisation rate allowed in MAP IV and V (2011–2018) ±25% were included in the analysis of the P concentration of exported plant parts and in the calculation of P offtake by the crops, in order to preclude the effect of the N amount applied. This corresponds to plots fertilised with 225–375, 100–200 and 140–260 kg effective $N \cdot ha^{-1}$ for cut grassland, silage maize and potatoes, respectively (ANONYMOUS, 2011b; 2015a; d).

Results

Fig. 1 shows the DM yield and P offtake of all plots of cut grassland, silage maize and potato fields as a function of applied effective N. The grey area indicates the range of applied effective N which was used in the analysis of P concentration and P offtake. Phosphorus offtake followed the same trend as DM yield.

In Fig. 2 only plots given the maximum allowed N fertilisation rate ±25% are included (ANONYMOUS, 2011b; 2015a; d). The phosphorus fertilisation rate and P offtake are given as a function of the four P soil classes of MAP V (Table 1). The P availability in Class I soils is below the target range (Class II soils), which should normally be offset by P fertilisation rates above crop P offtakes. The P availability in Class III and IV soils are above the target zone and P fertilisation rates should normally result in P mining (ANONYMOUS, 2015a). Fig. 2 shows that a lower P-AL content in the soil was linked with a higher P fertilisation rate for silage maize and potatoes, which was not the case for cut grassland in these experiments.

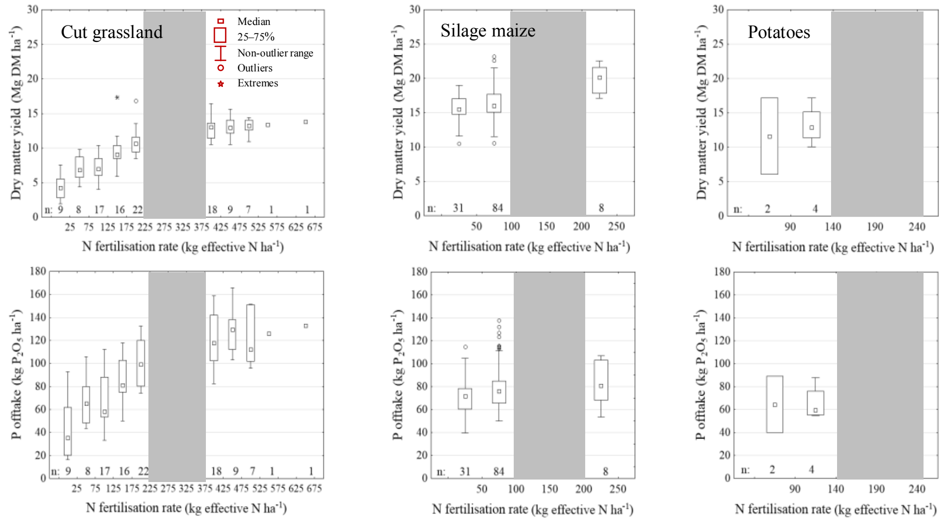

Fig. 1

Dry matter yield (Mg DM·ha^{-1}) and phosphorus offtake (kg P_2O_5 ha^{-1}) of cut grassland (left), silage maize (middle) and potatoes (right) in Flanders as a function of nitrogen fertilisation rate (kg effective N·ha^{-1}) (n = # plots)

Table 1

Phosphorus (P) content, percentage of acreage (Flanders, 2008–2011) measured by Soil Service of Belgium and maximum P fertilisation rate of the four P soil classes in MAP V for grassland, silage maize and potatoes (ANONYMOUS, 2015a; d)

Crop (depth)	Characteristic	Unit	Class I (low)	Class II (target)	Class III (moderate)	Class IV (high)
Grassland (0–6 cm)	Class boundaries	mg P-AL·100 g^{-1} soil	< 19	19–25	26–50	> 51
	Acreage	%	22	21	48	9
	Maximum P fertilisation rate for grassland	kg P_2O_5·ha^{-1}	115	95	90	70
Arable crop (0–23 or 30 cm)	Class boundaries	mg P-AL·100 g^{-1} soil	< 12	12–18	19–40	> 41
	Acreage	%	5	16	58	21
	Maximum P fertilisation rate for silage maize	kg P_2O_5·ha^{-1}	100	80	70	55
	Maximum P fertilisation rate for potatoes	kg P_2O_5·ha^{-1}	95	75	70	55

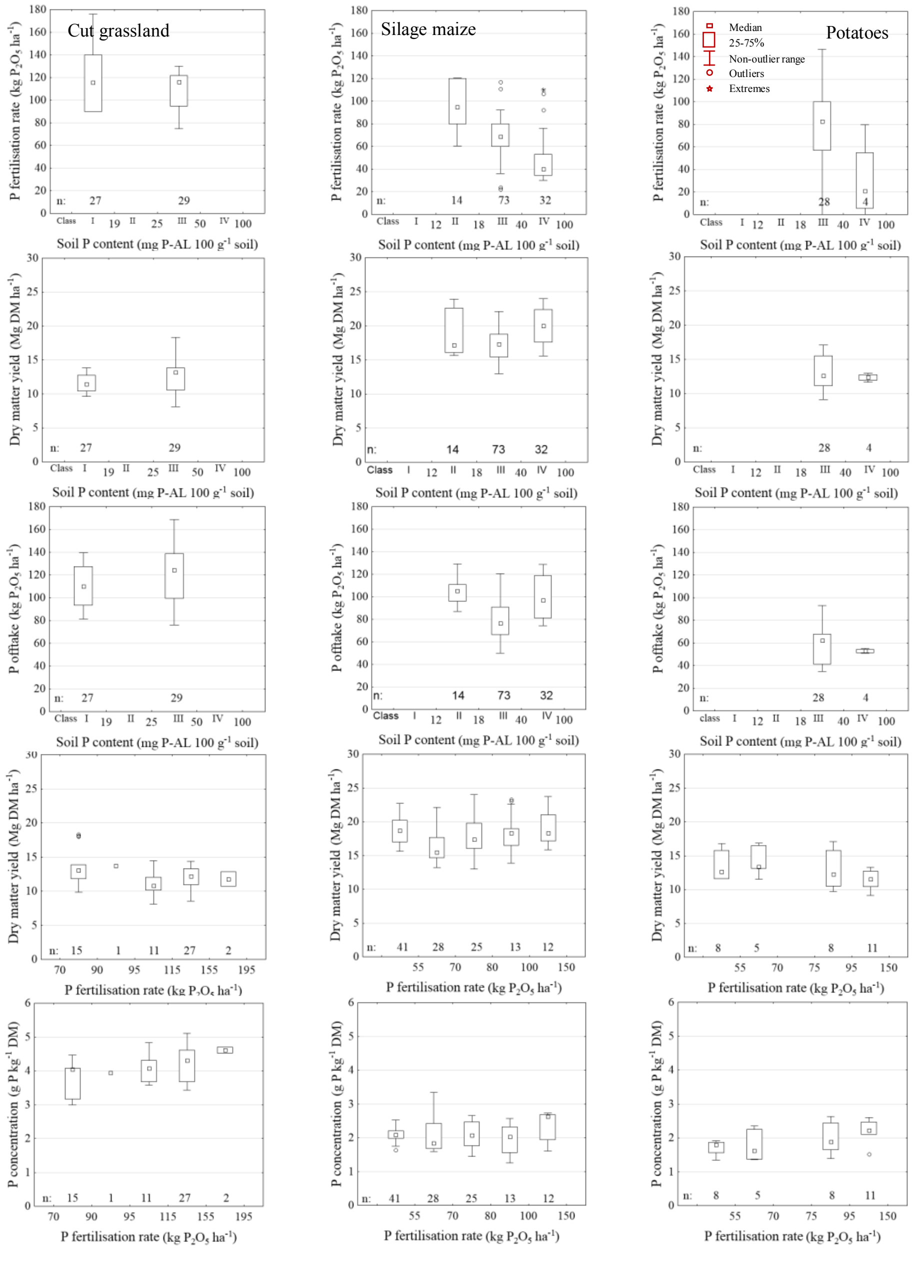

Fig. 2

Phosphorus (P) fertilisation rate (kg $P_2O_5 \cdot ha^{-1}$), dry matter (DM) yield (Mg $DM \cdot ha^{-1}$) and P offtake (kg $P_2O_5 \cdot ha^{-1}$) of cut grassland (left), silage maize (middle) and potatoes (right) as a function of soil P content (mg P-AL·100 g^{-1} soil) and DM yield (Mg $DM \cdot ha^{-1}$) and P concentration (g $P \cdot kg^{-1}$ DM) as a function of P fertilisation rate (kg $P_2O_5 \cdot ha^{-1}$) (based on P soil classes in MAP V (ANONYMOUS, 2015a; d)) (n = # plots)

Fig. 2 indicates that there was no significant difference in P offtake as a function of P soil content, although P offtake tended to be higher for cut grassland. There was also no trend of DM yield in response to P fertilisation rate (divided in maximum P fertilisation rates of the different soil P classes of MAP V (ANONYMOUS, 2015a; d). Mean P concentrations were the highest (although not significant) for P fertilisation above the current maximum P fertilisation rates currently allowed.

Table 2

Average (Av.), median (Med.) and standard deviation (Std.) of phosphorus (P) and effective nitrogen fertilisation rate, P content in the soil (0–6 cm), dry matter yield, P concentration and P offtake by cut grassland in Flanders*

Characteristic	Unit	56 plots (1997–2008)			44 plots (1997–1998)			12 plots (2003–2008)		
		Av.	Med.	Std.	Av.	Med.	Std.	Av.	Med.	Std.
P fertilisation rate	kg $P_2O_5 \cdot ha^{-1}$	114	116	24	119	116	23	98	90	20
N fertilisation rate	kg effective $N \cdot ha^{-1}$	289	296	42	296	300	43	262	250	24
P content soil	mg P-AL·100 g^{-1} soil	28	27	11	29	37	12	23	22	8
Dry matter yield	Mg $DM \cdot ha^{-1}$	12.0	11.9	2.1	11.8	11.9	1.5	12.9	12.3	3.5
P concentration	g $P \cdot kg^{-1}$ DM	4.0	4.1	0.6	4.1	4.2	0.6	3.7	3.9	0.4
P offtake	kg $P_2O_5 \cdot ha^{-1}$	111	111	26	111	111	27	110	109	21

Remark: *only plots given 225 to 375 kg effective $N \cdot ha^{-1}$ were included in the analysis

Table 3

Average (Av.), median (Med.) and standard deviation (Std.) of phosphorus (P) and effective nitrogen fertilisation rate, P content in the soil (0–23 or 30 cm), dry matter yield, P concentration and P by silage maize in Flanders*

Characteristic	Unit	119 plots (1996–2013)			73 plots (1996–1997)			46 plots (2003–2013)		
		Av.	Med.	Std.	Av.	Med.	Std.	Av.	Med.	Std.
P fertilsation rate	kg $P_2O_5 \cdot ha^{-1}$	67	65	25	66	69	21	67	60	30
N fertilisation rate	kg effective $N \cdot ha^{-1}$	140	138	26	141	138	28	138	135	22
P content soil	mg P-AL· 100 g^{-1} soil	34	30	15	35	33	11	32	29	21
Dry matter yield	Mg $DM \cdot ha^{-1}$	18.1	17.7	2.7	17.4	16.8	2.6	19.3	18.9	2.5
P concentration	g $P \cdot kg^{-1}$ DM	2.1	2.1	0.4	2.1	2.1	0.4	2.1	2.1	0.3
P offtake	kg $P_2O_5 \cdot ha^{-1}$	87	86	21	83	78	23	95	94	14

Remark: *only plots given 100 to 200 kg effective $N \cdot ha^{-1}$ were included in the analysis

The median P removed by Flemish cut grassland (1997–2008, 225–375 kg effective N·ha^{-1}) was about 110 kg P_2O_5·ha^{-1} with a median P concentration of 4.1 g P·kg^{-1} DM (Table 2). However, the median P concentration decreased from 4.2 g P·kg^{-1} DM in 1997–1998 to 3.9 g P·kg^{-1} DM in 2003–2008.

The P_2O_5 removed by silage maize in Flanders (1996–2013, 100–200 kg effective N·ha^{-1}) had a median of 86 kg P_2O_5·ha^{-1} with a median of 0.7 and 2.1 g P·kg^{-1} on a FM and DM basis, respectively (Table 3).

The median P removed by potato tubers (2004–2012, 140–260 kg effective N·ha^{-1}) was the lowest for the studied crops i.e. 59 kg P_2O_5·ha^{-1} with a median P concentration of 0.46 g P·kg^{-1} FM or 1.9 g P·kg^{-1} DM (Table 4).

Table 4

Average (Av.), median (Med.) and standard deviation (Std.) of phosphorus (P) and effective nitrogen fertilisation rate, P content in the soil (0–23 or 30 cm), fresh and dry matter yield, P concentration and P offtake by potatoes in Flanders*

Characteristic	Unit	36 plots (2004–2012)		
		Av.	Med.	Std.
P fertilisation rate	kg P_2O_5·ha^{-1}	75	80	35
N fertilisation rate	kg effective N·ha^{-1}	188	187	32
P content soil	mg P-AL·100 g^{-1} soil	28	25	9
Fresh matter yield	Mg FM·ha^{-1}	60.4	58.5	8.9
Dry matter yield	Mg DM·ha^{-1}	12.9	12.6	2.3
P concentration fresh matter	g P·kg^{-1} FM	0.42	0.46	0.09
P concentration dry matter	g P·kg^{-1} DM	2.0	1.9	0.4
P offtake	kg P_2O_5·ha^{-1}	58	59	16

Remark: *only plots given 140 to 260 kg effective N·ha^{-1} were included in the analysis

Discussion and conclusions

Yield

To calculate the P offtake, which is the basis for the maximum P fertilisation rates as a function of soil P availability, knowledge about the mean or median DM yields is necessary.

The median yield of *cut grassland* in Flanders went up to > 13 Mg DM·ha^{-1} (> 500 kg effective N·ha^{-1}) (Fig. 1). For the maximum allowed N fertilisation rate in MAP V ±25% (225–375 kg effective N·ha^{-1}), the median DM yield of all the trials was 11.9 Mg DM·ha^{-1} which is about 0.7 Mg DM·ha^{-1} higher than the data used in the legislation, which was 11.2 Mg DM·ha^{-1} (ANONYMOUS, 2011a). These yields are high compared to most other regions under a temperate Cfb climate, but comparable to Ireland (SMIT et al., 2008). Relatively high yields were also estimated by SMIT et al. (2008) for the Netherlands, Northern Ireland and the UK.

The median *silage maize* yield was 18.9 Mg DM·ha^{-1} (>150 kg effective N·ha^{-1}) (Fig. 1). This yield is about 0.9 Mg DM·ha^{-1} higher than the data used in the legislation (18.0 Mg DM·ha^{-1}) (ANONYMOUS, 2011a). D'HAENE et al. (2014) calculated with a logistic model a maximum yield of 20.1±0.6 Mg DM·ha^{-1} for Flanders. The yield of Belgian variety trials varied between 19.7 and 21.7 (average 20.3) Mg DM·ha^{-1} (PANNECOUCQUE et al., 2014), which is about 2.3 Mg DM·ha^{-1} higher than the data used in the legislation. The yield in Flanders is higher than in other regions with a temperate Cfb climate. The average yield of Irish variety trials of silage maize was between 15.5 (depending on variety 14.3–16.3) and 18.1 (depending on variety 17.9–19.0) Mg DM·ha^{-1} for uncovered and covered fields, respectively (ANONYMOUS, 2015e).

SCHRÖDER et al. (2013) measured from about 9 (±75 kg applied total N·ha^{-1}) to about 15 Mg DM·ha^{-1} (±175 kg applied total N·ha^{-1}) on a sandy experimental field in the Netherlands.

The median yield of *potato tubers* was 62.7 Mg FM·ha^{-1} or 13.2 Mg DM·ha^{-1} with > 190 kg effective N·ha^{-1} (Fig. 1), which is about 1.1 Mg DM·ha^{-1} higher than the data used in the legislation (12.1 Mg DM·ha^{-1}) (ANONYMOUS, 2011a). A comparison of tuber yields of farmers' fields in Europe in 2000–2005 showed that the highest yields were harvested in Belgium (Flanders + Wallonia) followed by the Netherlands and France. Also high potato yields were also found in Germany and the UK (ANONYMOUS, 2007).

Dry matter yields do not seem to be influenced by P availability or by P fertilisation rate. This is not surprising because most of the fields were in at least Class II and the P fertilisation rate was adapted to this P availability (except for grassland). In many years of field trials in the Netherlands on P needy crops such as potatoes, it was found that a low soil P status and a high P fertilisation rate did not achieve the same yield level as a high soil P status with a low P fertilisation rate (DEKKER & POSTMA, 2008). This could not be detected in these field trials because P availability in most of the potato fields was situated in Class III.

Phosphorus concentration

The P concentration of *cut grassland* in Flanders (median of 4.1 g P·kg^{-1} DM (Table 2)) (225–375 kg effective N·ha^{-1}) falls within the range of measurements from intensively managed grassland under a temperate Cfb climate i.e. 3.0 to 4.5 g P·kg^{-1} DM (FOTYMA & SHEPHERD, 2001; AARTS et al., 2008; EHLERT et al., 2009; MATHOT et al., 2009; DEFRA, 2010; EGERT, 2014).

Fig. 2 shows that the average P concentration of the grass was higher when the P fertilisation rate was higher (high P availability was not compensated by a lower P fertilisation rate). The limited data from recent years suggest that the lower P fertilisation rate (90 compared to 116 kg P_2O_5·ha^{-1}) has resulted in an insignificant decrease in the average P concentration (p = 0.06 T-test). This could be a direct effect of the lower P fertilisation rate or the indirect effect of the lower P soil content.

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 lower P fertilisation rate due to stricter legislation (AARTS et al., 2008). No decreasing trend was seen for P offtake (Table 2), suggesting that P concentration is affected faster by fertilisation rate than grass yield, as was observed in the Netherlands (AARTS et al., 2008). As the critical value of P concentration in the feed of highly productive dairy cows is 3.0 to 3.5 g P·kg^{-1} DM (DE BRABANDER et al., 2011; MIHAILESCU et al., 2015), the lower P concentration may have a negative effect on the nutritional value of grass for dairy cattle, resulting in the need for P supplementation, although there is no danger for this scenario at the moment.

The P concentration of *silage maize* (median of 2.1 g P·kg^{-1} DM – Table 3) (100–200 kg effective N·ha^{-1}) in Flanders is comparable to that in other temperate regions i.e. 1.8 to 2.3 g P·kg^{-1} DM (FOTYMA & SHEPHERD, 2001; EHLERT et al., 2009; GLORIA, 2012; EGERT, 2014). The median P concentrations of the ears and stover, measured at 16 plots, were 2.5 and 0.6 g P·kg^{-1} DM, respectively. The high P concentration in ears can be explained by the fact that grain nutrient concentration plays a key role in seed quality, as it relates to reserves required for germination.

The P concentration of *potato tubers* (median of 0.46 g P·kg^{-1} FM or 1.9 g P·kg^{-1} DM – Table 4) (140–260 kg effective N·ha^{-1}) also fell within the range of other countries with a temperate Cfb climate i.e. 0.4–0.6 g P·kg^{-1} FM (SCHRÖDER et al., 1996; FOTYMA & SHEPHERD, 2001; DEFRA, 2010) or 1.3–2.9 g P·kg^{-1} DM (KOLBE, 1997; EHLERT et al., 2009; WHITE et al., 2009). On 11 plots fertilisation above the maximum P fertilisation rate (> 95 kg P_2O_5·ha^{-1}) resulted in a higher P concentration (median of 2.2 g P·kg^{-1} DM) (Fig. 2).

Phosphorus offtake

The median Flemish P offtake by *cut grassland* (225–375 kg effective N·ha^{-1}) in the field trials remained about 110 kg P_2O_5·ha^{-1} (1997–1998 versus 2003–2008) (Table 2). In England and Wales, maintenance fertilisation advice is 90 kg P_2O_5·ha^{-1} (DEFRA, 2010). AARTS et al. (2008) calculated an average P offtake of 89 kg P_2O_5·ha^{-1} from fields of Dutch dairy farms (1998–2006). According to EHLERT et al. (2009) average P offtake for experimental fields with an optimal soil P content in the Netherlands was 95 kg P_2O_5·ha^{-1}. They estimated that the offtake could be 12 to 20 kg P_2O_5·ha^{-1} higher for fields with a high soil P content.

The median P offtake by *silage maize* (100–200 kg effective N·ha^{-1}) increased significantly from 78 in 1996–1997 to 94 kg P_2O_5·ha^{-1} in 2003–2013 ($p < 0.001$ Mann-Witney U-test) (Table 3). The increase of the median P offtake can be explained by the higher yield in the period 2003–2013 compared to 1996–1997, as the P concentration did not change. The median Flemish P offtake over the last two decades (86 kg P_2O_5·ha^{-1}) is higher than in other temperate regions. In France fertilisation advice is based on an offtake of 60 kg P_2O_5·ha^{-1} (GLORIA, 2012). In the UK, maintenance P fertilisation advice is 55 kg P_2O_5·ha^{-1} (DEFRA, 2010). AARTS et al. (2008) calculated an average offtake of 69 kg P_2O_5·ha^{-1} from fields of Dutch dairy farms (1998–2006) based on an average 2.0 g P·kg^{-1} DM measured by BLGG.

EHLERT et al. (2009) computed an average offtake of 64 kg $P_2O_5 \cdot ha^{-1}$ in the Netherlands for experimental fields with an optimal soil P content. They assessed that P offtake may be somewhat higher for fields with a high soil P content.

The median P removed by Flemish *potato tubers* (140–260 kg effective $N \cdot ha^{-1}$) was 59 kg $P_2O_5 \cdot ha^{-1}$ (Table 4). The median Flemish P offtake is comparable to that in other temperate regions e.g. EHLERT et al. (2009) calculated an average offtake of 55 kg $P_2O_5 \cdot ha^{-1}$ in the Netherlands for soils with an optimal P content, but assessed that the P offtake could be 8 kg $P_2O_5 \cdot ha^{-1}$ higher for soils with a high P content (EHLERT et al., 2009). In the UK and Germany average P offtake is estimated at 50 and 56 kg $P_2O_5 \cdot ha^{-1}$, respectively (NITSCH, 2003; DEFRA, 2010).

Phosphorus fertilisation and soil quality

In Flanders P is mainly applied with *organic fertilisers* (LENDERS et al., 2012). As a consequence of stricter maximum P fertilisation rates, extra attention has to be given to soil organic matter (SOM) to avoid a decrease in soil quality. During the MAP IV and V periods Flanders aims to stimulate the use of fertiliser types that contribute substantially to the maintenance and increase of SOM and at the same time pose a low risk for N and P losses (ANONYMOUS, 2011b; 2015a).

During MAP IV (2011–2014) the possibility of accounting only 50% of P from certified compost (i.e. green or vegetable fruit garden (VFG) compost) was foreseen for all soils (ANONYMOUS, 2011b). This was extended in MAP V (2015–2018) to other types of compost and farm yard manure (FYM) for P Class I and II soils. There will also be soils with low SOM in P Class III and IV soils. Although these would undoubtedly benefit from an increased gift of uncertified compost or FYM in order to increase their SOM, the P soil status does not seem to justify the increased P input (ANONYMOUS, 2015a). Furthermore, VANDEN NEST et al. (2014) showed that the risk of P leaching after the application of FYM might be higher than after certified compost. In the Netherlands, too, only 50% of P applied via compost is taken into account by legislation because compost has a considerable soil fraction. The upper limit of this exemption is 3.5 g $P_2O_5 \cdot kg^{-1}$ DM compost. In Ireland, only 50% of P in organic fertilisers must be taken into account on soils with low P value (Class I to III soils). In Finland, not all P from manure, sludge and compost has to be taken into account (AMERY & SCHOUMANS, 2014; ANONYMOUS, 2015f).

Stricter maximum P fertilisation rates might stimulate *manure processing i.e. separation and mixing*. It is important that the N:P ratio of fertilisers should be consistent with the N:P ratio of plants. The average N:P ratio of manure often varies between 2 and 4. Since the N:P ratio of the most important cereals is on average 5.6 with a standard error of 0.2 (SADRAS, 2006), too much P is often applied, resulting in a P increase in the soil. Due to the altered N:P ratio, the products arising after separation or mixing of manure are potentially more interesting as fertiliser (SCHOUMANS et al., 2014). Through co-composting, too, the N:P ratio of composted manure can be better tuned to crop needs (VANDECASTEELE et al., 2014). Manure processing is mainly interesting for derogation fields where N application of above 170 kg $N \cdot ha^{-1}$ is allowed from manure. After the separation of manure a liquid fraction with a high N:P ratio and a solid fraction with a low N:P ratio are obtained. The solid fraction with low N:P ratio but high organic matter (OM) content is rarely applied to Flemish soils. Therefore, after manure separation less OM is applied compared to unprocessed manure. The mixing of manure result in a fertiliser composition that more closely matches the crop needs and allows higher application rates of manure, OM and nutrients compared to unprocessed manure. The further reduction in P input into the soil in MAP V will *reduce soil P status*, but this will have little or no direct effect on yield in the short and mid-term. On the other hand, it will take a long time before P losses from drainage will change, which makes it difficult to convince farmers of the need for lower P inputs. As the P chemistry in soils is complicated, P management is complex and requires an understanding of the dominating processes at both field and landscape level. Management techniques could retain certain P forms (i.e. accumulation of particulate P), while simultaneously creating conditions that release other P forms (e.g. reduction of iron and P desorption) (KRONVANG et al., 2005). Due to the slow effect of soil mining on soil P content, mitigation measures at field, farm, catchment or ecosystem level might be needed or be more cost-effective (SCHOUMANS et al., 2014).

Maximum phosphorus fertilisation rates taking into account soil phosphorus values

Maximum P fertilisation rates differentiated for four *classes of P availability* were introduced in Flanders in MAP V (Table 1) (ANONYMOUS, 2015a, d). The maximum P fertilisation rates should be at the level of the crops offtake in the target zone Class II soils (except for potatoes), somewhat higher for a low soil P availability (Class I soils) and lower for higher soil P availabilities (Class III and IV soils). In MAP V, the P offtake for grassland is based on a mean attainable yield of 11.2 Mg $DM \cdot ha^{-1}$ (cut grassland) and 10.5 Mg $DM \cdot ha^{-1}$ (for a combination of grazed and cut grassland) and a mean P concentration of 3.8 g $P \cdot kg^{-1}$ DM grass. For silage maize, a mean yield of 18 Mg $DM \cdot ha^{-1}$ with a P concentration of 2.0 g $P \cdot kg^{-1}$ DM has been used. These data correspond to a P offtake of 97, 91 and 83 kg $P_2O_5 \cdot ha^{-1}$ for cut grassland, grazed + cut grassland and silage maize (ANONYMOUS, 2011a). The data of the fertilisation trials show a P offtake on optimally N fertilised fields which is on average ±15 kg $P_2O_5 \cdot ha^{-1}$ higher for cut grassland and ±5 kg P_2O_5 ha^{-1} for silage maize (or even 15 kg $P_2O_5 \cdot ha^{-1}$ higher in more recent trials) than that is used in the legislation (Tables 2, 3 and 4). This is linked to both somewhat higher yields and higher P concentrations, and means that the maximum P fertilisation rates are rather strict for Class II soils and that there will certainly no further accumulation of P in the soils. Soil P mining will definitely occur in Class III and especially Class IV soils (67 and 79% of grassland and arable soils, respectively) with even lower maximum P fertilisation rates (Table 1) (ANONYMOUS, 2015a).

Due to the sparse and shallow root system of potatoes combined with the low mobility of P, *potatoes* are *very sensitive to P fertilisation rate*. Phosphorus promotes rapid canopy development, root cell division, tuber set, and starch synthesis in potatoes. Adequate available P is essential for optimising tuber yield, nutritional quality and resistance to some diseases (DEKKER & POSTMA, 2008; ROSEN et al., 2014). In most European regions with a temperate climate, the high P sensitivity of potatoes has been taken into consideration when putting forward maximum allowed P fertilisation rates (Table 5). Therefore, the maximum P fertilisation rates for Class II soils in Flanders are 15 to 20 kg $P_2O_5 \cdot ha^{-1}$ higher than the P offtake. Maximum P fertilisation rates at optimal soil P values are much higher than P offtake in Ireland and Northern Ireland (Table 5). However, control of P fertilisation rate is done at farm level in Flanders, allowing farmers to apply more P on potato fields if compensated at other fields in the same year. In Germany the P sensitivity of potatoes is taken into account by the fact that the P balances are calculated for six years allowing higher P fertilisation rates for P sensitive crops (WENDLAND et al., 2012; AMERY & SCHOUMANS, 2014). In the Netherlands the maximum P fertilisation rate is calculated per farm and a farmer can apply a maximum of 20 kg $P_2O_5 \cdot (ha \cdot y)^{-1}$ above this limit, providing that this surplus is compensated for by lower P application rate(s) in the next year (AMERY & SCHOUMANS, 2014; ANONYMOUS, 2015f). Outside northwest Europe, Estonia and Quebec (Canada) have a high maximum P fertilisation rate for potatoes at optimal soil P values (Mehlich III P extraction). In Estonia 57 (from organic manure) + 126–149 kg $P_2O_5 \cdot ha^{-1}$ (depending on yields of between 20 to 30 Mg $FM \cdot ha^{-1}$) can be applied while in Quebec a maximum P fertilisation rate of 140 kg $P_2O_5 \cdot ha^{-1}$ is allowed (AMERY & SCHOUMANS, 2014; ANONYMOUS, 2015b). A variation in maximum P fertilisation rates taking into account P soil values has also been introduced in the legislation of other regions with a temperate Cfb climate e.g. Germany, Ireland, Northern Ireland and the Netherlands, in order to stimulate the P soil mining of fields with a high soil P content (Table 5) (HOFMAN et al., 2013; AMERY & SCHOUMANS, 2014). However, it is hard to compare the P value of the class defined as optimal because different sampling depths and extraction methods are used (Table 5). There are some conversion factors between two extraction methods, but such conversion factors have to be used with caution due to the fact that they are chemical and empirical approximations of available P, tested on only a few soil types (JORDAN-MEILLE et al., 2012). The difference in maximum P fertilisation rates at optimal soil P value mainly depends on estimated crop yield. The maximum P fertilisation rates depend on the P offtake of average fixed crop yield in Flanders and Ireland, but have to be calculated based on actual crop yields in Germany and Northern Ireland (WENDLAND et al., 2012; ANONYMOUS, 2014a; b; 2015a).

Differences can be observed between European countries in the *variation* between the *lowest and highest* maximum P fertilisation rates, as a function of soil P content (Table 5). This does not seem to have a real scientific basis. The differences in maximum P fertilisation rates are high in Northern Ireland and Ireland and fairly small in Flanders and the Netherlands. Farmers are reluctant to decrease P fertilisation rates below P offtake because they fear that yield might be reduced, although none or only minimal crop yield reductions are expected within 10 years if P inputs are smaller than P offtake, given the large soil P reserves in northwest Europe. Effects occur faster for grasslands, especially for P concentrations, and for P sensitive crops e.g. potatoes (DEKKER & POSTMA, 2008; EHLERT et al., 2008).

Table 5

Extraction method, soil sampling depth (cm) and maximum (max.) phosphorus (P) fertilisation rates (kg $P_2O_5 \cdot ha^{-1}$) (taking into account soil P value) in European regions with a temperate Cfb climate. Italics indicate that the maximum P fertilisation rate depends on crop yield (Based on WENDLAND et al., 2012; AMERY & SCHOUMANS, 2014; ANONYMOUS, 2014a; b; 2015a; d; f).

	Grassland			Silage maize	Potatoes
Germany (5 soil P classes)					
Extraction method	_Calcium acetate lactate_				
Soil sampling depth	0–10			0–15 to 20	
Max. P fertilisation					
highest soil P	_Offtake (10–120) + 20*_			_FM x 1.6–2.0 + 20*_	_FM x 1.4 + 20*_
optimal soil P	_Offtake (10–120) + 20* + A**_			_FM x 1.6–2.0 + 20* + A**_	_FM x 1.4 + 20* + A**_
lowest soil P	_Offtake (10–120) + 20* + A**_			_FM x 1.6–2.0 + 20* + A**_	_FM x 1.4 + 20* + A**_
Northern Ireland (5 soil P classes)					
Extraction method	_Olsen_				
Soil sampling depth	0–7.5			0–15	
	Grazed	Silage	New		
Max. P fertilisation					
highest soil P	0	0	0	0	0
optimal soil P	_20_†	_90_†	_50_†	_55_†	170†
lowest soil P	_80_†	_150_†	_120_†	_115_†	250†
Ireland (4 soil P classes)					
Extraction method	_Morgan's test_				
Soil sampling depth	0–10			0–10	
	Grazed	Cut grassland			
		First cut	Other		
Max. P fertilisation					
highest soil P	0	0	0	46	115
optimal soil P	25–71††	46	23	92	172
lowest soil P	71–117††	92	23	160	286

Note: see next page

Table 5 Contd.

	Grassland	Silage maize	Potatoes
Flanders (4 soil P classes + phosphate saturated soils)			
Extraction method	*Ammonium lactate*		
Soil sampling depth	0–6	0–23 or 30	
Max. P fertilisation			
highest soil P	70 (40[‡])	55 (40[‡])	55 (40[‡])
optimal soil P	95	80	75
lowest soil P	115	100	95
the Netherlands (3 soil P classes + P poor or fixating soil)			
Extraction method	*Ammonium lactate*	*water*	
Soil sampling depth	0–10	0–10 or 25	
Max. P fertilisation			
high soil P	80	50	50
optimal soil P	90	60	60
low soil P	100 (120[‡‡])	75 (120[‡‡])	75 (120[‡‡])
France – Brittany	80–95[#] or *offtake +10%*		
Scotland	*Offtake*		
Denmark	P balance for specific animal farms		
Luxembourg	in agri-environmental programs depending on P soil content		
England and Wales	no maximum P fertilisation rates		
Wallonia	no maximum P fertilisation rates		

Notes: *: The soil P balance must not exceed 20 kg $P_2O_5 \cdot (ha \cdot y)^{-1}$ as a 6 year average. The P output can be calculated by official P crop contents and crop yield. Grassland P offtake depends on yield, field quality and intensity (dry matter (DM) yield: 3–12 Mg DM·ha^{-1} & P_2O_5 offtake: 10–120 $P_2O_5 \cdot ha^{-1}$). For silage maize the factor is 1.6, 1.8 and 2.0 for crops with 28, 32 and 35% DM, respectively. Mean fresh matter (FM) yield is 55 and 40 Mg FM·ha^{-1} for silage maize and potatoes, respectively

**: In addition to the balance limit of 20 kg $P_2O_5 \cdot (ha \cdot y)^{-1}$, the "soil need" has to be based on a fertilisation advice. As the P fertilisation rate must correspond to the crop and soil needs, the soil P value has to be determined at least every 6 years.

†: Only restriction of mineral fertilisers taking into consideration the P already available from the soil and organic manures. The values given are for average yields (average 40 and 50 Mg FM·ha^{-1} for silage maize and potatoes, respectively) but have to be adapted based on crop requirement for lower or higher yields, except for potatoes.

††: Depending on grassland stocking rate - for fields with a stocking rate with a total annual nitrogen (N) excreted by grazing livestock averaged over the eligible grassland area (grazing and silage area) < 170 kg N·$(ha \cdot y)^{-1}$ an additional 34 kg $P_2O_5 \cdot ha^{-1}$ may be applied for each hectare of pasture establishment undertaken.

‡: only 40 kg $P_2O_5 \cdot ha^{-1}$ is allowed for phosphate saturated soils

‡‡: 120 kg $P_2O_5 \cdot ha^{-1}$ is allowed for P poor or P fixating soils

#: for small or not new farms

There are no maximum P fertilisation rates for Wallonia, England and Wales. There is only an indirect P limitation from manure in Nitrate Vulnerable Zones by the limit of 170 kg $N \cdot (ha \cdot y)^{-1}$. In Luxembourg the P fertilisation rates in agri-environmental programmes depend on P soil value. Danish animal farms that 1) want to expand or change their production unit, 2) drain into Natura 2000 areas overloaded with P, or 3) fall under P class 1–3 have additional restrictions for the manure P surplus depending on the soil type and P status (AMERY & SCHOUMANS, 2014). In north, south and east European countries P fertilisation legislation is limited. In Estonia maximum P fertilisation rates depend on P soil content. In Norway, a general maximum fertilisation rate of 80 kg $P_2O_5 \cdot ha^{-1}$ from manure is dictated. In Sweden and Slovenia maximum fertilisation rates of 50 (5 year average) and 120 kg $P_2O_5 \cdot ha^{-1}$ from organic fertilisers are imposed, respectively. In Finland the P fertilisation rates in agri-environmental programmes take soil P values into account. There are no maximum P fertilisation rates in Austria, Czech Republic, Greece, Hungary, Italy, Lithuania, Latvia, Poland, Spain or Switzerland (MIHELIČ et al., 2006; ANONYMOUS, 2011c; HOFMAN et al., 2013; AMERY & SCHOUMANS, 2014).

Conclusions

In this paper, the P concentration and P offtake by cut grassland, silage maize and potatoes are confronted with the maximum P fertilisation rates in Flanders' new MAP. The P offtake by cut grassland and silage maize from the field trials was somewhat higher than the maximum allowed P fertilisation rate at optimal soil P value. As a consequence there is already a small negative P balance and soil P mining. On the other hand, as in some other countries, the maximum P fertilisation rate for potatoes, a highly P-sensitive crop, is higher than P offtake.

The aim of various P inputs is to bring the soil P reserves to an optimal level for crop growth and at the same time to reduce possible P losses from soils with high P levels. Some other countries in northwest Europe have also introduced maximum P fertilisation rates as a function of soil P availability while others have no limits on it. Variations between the lowest and highest maximum allowed P fertilisation rates as a function of available soil P are high between countries and does not seem to have a real scientific basis. Limitations on P fertilisation rates may have a negative influence on soil quality, especially SOM content, because inputs of OM with high P contents will be drastically reduced.

Summary

Algal blooming caused by phosphorus (P) losses from agriculture is a major problem in northwest Europe. In order to obtain optimal yields while taking into consideration the environmental impact, legislation and phosphate (P_2O_5) fertilisation recommendations should consider an equilibrium P fertilisation rate for fields with optimal soil P value, with differentiation for other fields taking into account the soil P value.

In this paper, P offtake by cut grassland (*Poaceae*), silage maize (*Zea mays*) and potatoes (*Solanum tuberosum*) is presented and confronted with the stricter maximum P fertilisation rate in Flanders' new Manure Action Plan (MAP). Phosphorus offtake by cut grassland and silage maize in field trials was higher than the maximum P fertilisation rate at optimal P soil value. The median P offtake by cut grassland was about 110 kg $P_2O_5 \cdot ha^{-1}$ (1997–2008) and thus ±15 kg $P_2O_5 \cdot ha^{-1}$ higher than the maximum P fertilisation rate for Class II soils (target Class). More recent trials show a decrease in P concentration of grass. Although there is certainly no problem at the moment, the P concentration in grass should be monitored, because if P concentrations are too low, this could have a negative effect on the nutritional value. The median P offtake by silage maize has increased significantly from 78 kg $P_2O_5 \cdot ha^{-1}$ in the last decade of the 20th century to 94 kg $P_2O_5 \cdot ha^{-1}$ in recent years due to the higher yield. This means that even for Class II soils (maximum 80 kg $P_2O_5 \cdot ha^{-1}$), there should be a small negative P balance and soil P mining. The maximum P fertilisation rate for potatoes (75 kg $P_2O_5 \cdot ha^{-1}$ for fields with optimal P soil content) is higher than P offtake (median of 59 kg $P_2O_5 \cdot ha^{-1}$ in the field trials and 58 kg $P_2O_5 \cdot ha^{-1}$ used in the legislation). As in other countries, this is linked with their high P sensitivy.

There are large differences in P legislation between European countries, ranging from detailed maximum P fertilisation rates as a function of soil P availablity to no restriction on P inputs. The limited soil P input due to stricter maximum P fertilisation rates will reduce the soil P status and will be critical for reducing P losses in the long term. This is the main reason for the strict P legislation in Flanders. However, soil organic matter content and soil quality can be reduced by this legislation, because inputs of organic material, sometimes containing high amounts of P, are reduced. The stricter maximum P fertilisation rates might stimulate manure separation and mixing. Due to the altered nitrogen to P ratio, the products obtained after separating or mixing manure are potentially more interesting as fertilisers.

Keywords: phosphate offtake, maximum phosphorus fertilisation rate, soil quality

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