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Frameworks for variable rate application of manure

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Abstract.

Worldwide, nitrogen (N) and phosphorus (P) losses from agriculture are main contributors to eutrophication of water bodies so that forceful agro-technical measures are required to reduce their diffuse discharge to the environment. With view to worldwide finite mineral rock phosphates efficient standards are required to close the agricultural P cycle. In intensive agricultural livestock production manure is often treated as a waste problem rather than an organic fertilizer and source of nutrients. Consequently, application rates of manure are not based on a documented demand of nutrients, but fully exhaust the maximum legal output quantity. However, even if maximum manure loads will not exceed an upper limit of 170 kg/ha N, its use is not sustainable as it exceeds the mean P off-take of 22 kg/ha P by agricultural crops with harvest products by 95% to >120% if pig and poultry manure are applied. A solution to the problem offers the limitation of manure rates on basis of P loads that equal the off-take. This simple math stresses the urgent need to revise current practices of manure application and to focus on innovations in the production and recycling chain of manure and slurries. In general, the implementation of Codes of Good Agricultural Practice (GAP) on farms is recommended to reduce the pollution from agricultural activities. Variable rate application of fertilizers complies with GAP codes as it matches the small-scale variation of plant available nutrients in soils with the nutrient demand of crops. It is intrinsic that such site-specific nutrient management complies with a sustainable input of resources that favors crop growth and minimizes negative impacts on the environment. Algorithms for the continuous variable rate input of straight and compound mineral fertilizers, and farmyard manure have been developed. The present contribution demonstrates the problem of P accumulation in soils of livestock farms, addresses the spatial variation of plant available P in soils, and provides algorithms for a balanced, variable rate fertilization of manure.

Keywords. *B7alanced fertilization, eutrophication, livestock density, nitrogen, phosphorus, variable rate fertilization.*

Introduction

Sustainability is a buzzword commonly used, however, often exploited thoughtlessly. Its implications go far beyond assets in the present and profit being named regularly as an indicator for sustainability. The chief constraint of sustainable development is that it requires investments for future generations, which are usually not paying off in the present. Today's agriculture and its prospected future development are far away from being sustainable. In particular, fertilization requires substantial advancement towards sustainability. Major concerns are the loss of nutrients from agro-ecosystems resulting in eutrophication of water bodies, the waste of the non-renewable resource phosphorus (P), the charging of soils with heavy metals and radioactivity by P fertilizers, and the contamination of soils with organic compounds, pharmaceutical residues and infectivity by organic, waste-derived fertilizers (Schnug and De Kok 2016).

Non-point N and P losses from agriculture – the ultimate threat for water quality

Carpenter et al. (1998) described now 20 years ago the *status quo* of diffuse nitrogen (N) and P losses from agriculture precisely: “at regional and global scales, the causes and consequences of non-point pollution are clear.” Fact is that since then no progress has been made towards a reduction of nutrient discharges from agriculture to water bodies, which suggests that scientific solutions to tackle the problem have not been implemented on farms on a voluntary basis. The contamination of drinking water with nitrate is a worldwide problem. Non-point N losses from agriculture are closely linked to the fertilization intensity, particularly on livestock farms. Nitrate is quickly translocated in soils into groundwater and underground aquifers, thus contaminating well water (DVGW 2018). In Germany, in 2012-2014 the nitrate concentration in about 50% of all groundwater control points was elevated, in 28% of all samples the limit value of 50 mg/L NO_3 was exceeded (Anonymous 2018a). Unlike N, P from agricultural sources is not subjected to a European regulatory approach (Ekardt et al. 2016). European and German fertilizer and soil regulations are too weak to oppose pollution trends in agriculture (Ekardt et al. 2016). On European level, a precautionary concept, which relates to environmental issues, is largely inexistent. Legislation in the field of soil protection, water quality, fertilizers and wastes is usually based on orders and prohibitions (command and control), but Ekardt et al. (2016) evaluate the success of such administrative legal systems as minor, mainly because an area-wide control system is simply not feasible (Ekardt et al. 2016). Yet, another risk is the relocation of nutrient surplus problems to other countries and to safeguard an absolute quantity reduction of P applications in agriculture on a global scale. Current regulations lack concreteness and real enforcement (Ekardt et al. 2016). The authors see a global approach for closed agricultural P cycles including GAP codes and legal regulations as the only chance to maintain food security, to preserve geological P reserves and to reduce P losses to water bodies.

It is known since long that intensive livestock enterprises are hot spots for diffuse N and P losses (Carpenter et al. 1998). Though the major problem, which is an imbalance of N and P input and off-take by plant and animal products has been identified, no measurable progress towards a balanced nutrient input has been made within the past 25 years (Carpenter 1998, Haneklaus et al. 2016). And the process of nutrient accumulation in soils and N and P losses by leaching, erosion and run-off will continue if no legal action is taken in Europe as the voluntary commitment of farmers proved to be without results (Ekardt et al. 2016). The current limitation of manure and slurry inputs to a rate which equals 170 kg/ha N is not sufficient to solve the problem as it causes coherently P surpluses in case of pig and poultry manure. Another problem is that farmers are permitted to use mineral in addition to organic fertilizers. A first important step to reduce nutrient surpluses would be to limit the overall N and P inputs by manure/slurry and mineral fertilizers based on the farm-gate balances for both nutrients. For the majority of big livestock farms such restrictions imply that either the stocking density must be reduced in order to comply with the guidelines, or the acreage of farmland increased. Alternately, recycling chains for manure-based fertilizer products need to be implemented.

While it is feasible to control point losses of P, it is a major challenge to efficiently reduce the discharge of diffuse losses from agriculture. A simple reduction of P fertilizer rates will not reduce ecological problems as soils are neither static, nor homogenous in space and time so that the standard approach of a reduced uniform application rate will still result in a side by side of over- and under-supply. The phenomenon of the spatial variability of soil features which is closely linked to nutrient utilization is the major bottleneck for reducing non-point nutrient surpluses on field scale. The mean nutrient surplus of a field is the result of a higher number of individual events which in the case of N can easily vary by 100% from the average. Thus it is not satisfying to address a field as the smallest operational unit for applying balanced fertilization (Haneklaus and Schnug 2006). The smallest operational unit, the pedon, has to be defined as that area which is homogenous in terms of soil factors influencing the nutrient balance. Precision Agriculture technologies and concepts including directed sampling approaches for data collection and monitoring of spatio-temporal changes of soil characteristics and crop productivity in so-called monitor pedo cells have been developed and enable the transformation of knowledge about the spatial variability of these particular soil characteristics into VR fertilizer applications which balance the nutrient input of all minerals applied on an annual basis or within the crop rotation (Haneklaus and Schnug 1999, Haneklaus et al. 2000).

It is intrinsic that a site-specific nutrient management employing precision agriculture technologies improves the nutrient efficiency as it matches the P off-take by harvest products with P fertilizer rates. In addition, geomorphological specifications such as slope have a major impact on nutrient losses and VR application of NPK fertilizers was shown to reduce significantly surface run-off of N and P species (Saleem et al. 2014). Algorithms for the VR input of straight and compound mineral fertilizers, and manure and slurry have been developed which yield a balanced nutrient input (Haneklaus and Schnug 1999, Haneklaus et al. 2016). On intensive livestock farms the implementation of precision agriculture technology will enforce the problem of manure production that cannot be utilized on the farm. Alternatively, processing of manure, e.g. by employing methods which extract P need to be employed. Compared to precipitation the advantage of this procedure is the preservation of P solubility (Cicek 2003). For this purpose organic matter with soluble inorganic P is filtrated from liquids employing ceramic membranes (Cicek 2003). By means of ion exchange and reverse osmosis P is concentrated in the final product (Cicek 2003). Additional value could be added to this basic application by documenting and controlling the whereabouts of manure and recycled wastes, both from animal production and industry outside agriculture (Haneklaus and Schnug 2006).

What shall we do with the overly manure? Lessons learned from a case study in the Baltic Sea Region

The Baltic Sea is one of the most polluted marine bodies worldwide. It was the aim of the partly EU-funded flagship project *Baltic Manure* to develop sustainable strategies for P management which aim at closing anthropogenic and agronomic P cycles, thus strictly limiting the use of finite mineral P sources. Research focused amongst others on a balanced nutrient input on livestock farms and options for recycling of manure (Baltic Manure 2014). In the Baltic Sea region about 981,000 t of N and 281,000 t of P incur annually in the form of manure (Baltic Manure 2014). Here, liquid manure or slurry needs to be distinguished from solid manure: the first contains 90-96% water, while the latter less than 90% (Derikx et al. 1997, Popovic 2012).

There is a linear relationship between dissolved P content in soils and the amount of P lost to surface waters; even more P is transported in particulate form (Carpenter et al. 1998, Sims et al. 2000). In a long-term field experiment with sugarcane on Mauritius Mardamootoo et al. (2013) showed that an excessive P input increased the P losses to surface waters. Nutrient flows to aquatic ecosystems are directly linked to stocking densities and regularly manure production exceeds the nutrient demand of the crops (Carpenter et al. 1998). The reduction of P is the key for lakes and estuaries to recover from eutrophication, a process which will take decades (Schindler 2012). Important in this context is the fact that the shift from turbid to clear state occurs at lower P concentrations than from clear to turbid (Jeppesen et al. 2007). Water transparency is expressed as secchi-depth. Secchi-depth observations have been collected in the Baltic Sea since 1903 (Aarup 2002). In the Baltic Proper the secchi-depth decreased from the Second World War until the late 1990s by -0.05m/yr (Sandén and Håkansson 1996). According to the Helsinki Commission (HELCOM), “the Baltic Sea ecosystem has degraded to such an extent that its capacity to deliver goods and services to humans living in the nine coastal states has been hampered” (HELCOM, 2010). To improve the condition of this unique ecosystem and its valuable resources, sustainability in word and deed must be obligatory for all sectors and at all scales. A transdisciplinary assessment of the significance of P management in the Baltic Sea Region outlines cornerstones for a sustainable use of the resource (Perspectives Agriculture, 2011). Expectedly, N and P losses from agriculture have a strong impact on the highly sensitive ecosystem (Corell 1998, Schnug et al. 2001, Granstedt et al., 2008). On November 15, 2007 the member states of the Helsinki Convention (HELCOM) for protecting the Baltic Sea decided in Krakow on a Baltic Sea Action Plan for reducing nutrient inputs into the Baltic Sea, which implies among others the distribution of country-wise quota for upper nutrient loads (HELCOM 2007, Elofsson 2010, Ahvenharju et al. 2010). This is now 10 years ago, but obviously without any positive effect on the water quality of the Baltic Sea.

Once upon a time a big pile of manure in front of the farmhouse was a sign of wealth, nowadays oversize slurry containers are a sign of a hot spot and indicator of pollution. GAP codes have been developed, ultimately aiming at reducing nutrient losses to the environment (Perspectives Agriculture 2011). For example, the risk of surface run-off after application of manure can be reduced significantly by timing the application in a period with no rainfall (Smith et al. 2007), or by removing cattle from grassland (Line et al. 2000). Though such measures are principally praiseworthy, they will not achieve a breakthrough in reducing the discharge of nutrients into water bodies for the following reasons. Firstly, application rates of manure are commonly not based on a documented demand of nutrients, but fully exhaust the maximum legal input. Secondly, a truly balanced nutrient input based on the small-scale spatial variability of landscape, soil and crop characteristics will reduce the output volumes of manure drastically on livestock enterprises. Thus advanced PA technologies are likely to be objected by farmers as they demand changes in the production and recycling chain of liquid and solid manure.

The problem – soils overloaded with P

Many soils of livestock farms are already overloaded with P (see Figure 1). A comparison of the soil P status along transects of neighboring fields in different countries of the Baltic Sea Region that received historically either mineral fertilizers or manure showed that the P supply was regularly higher on livestock farms (Haneklaus et al. 2016).

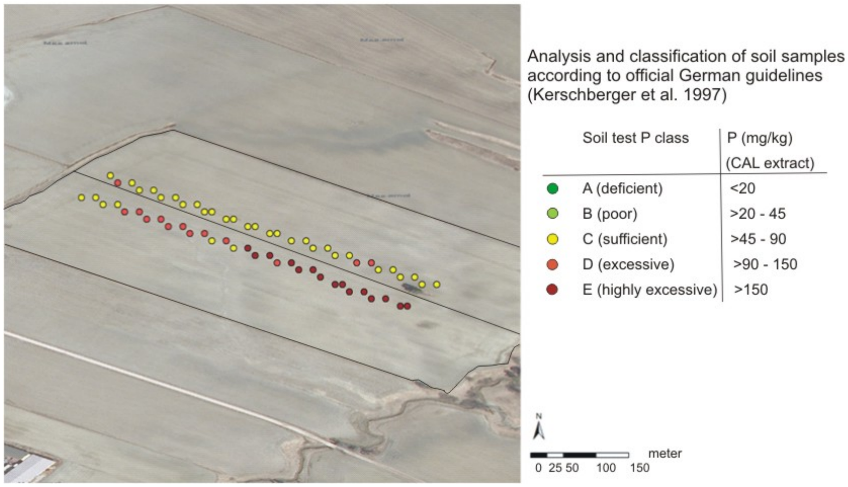

Figure 1. Categorized P content along transects of neighboring fields (the northerly field received exclusively mineral fertilizers and the southerly field exclusively chicken manure as P supply in the past; adapted from Haneklaus et al. 2014).

Grid distances of 30 to 50 meter may be required in order to accurately determine the spatial variation of soil crop features and to produce representative fertilizer application maps (Haneklaus and Schnug 2006). In the study of Haneklaus et al. (2016) samples were taken along transects in order to assess the small-scale variation of the soil P content in different riparian states of the Baltic Sea. Variogram analysis of in total 86 transects in Estonia, Finland, Germany and Poland showed that suitable variograms could be adapted for nearly all fields (Table 1; Figure 2).

Table 1. Examples for results from semi-variogram analysis of plant available P_{CAL} content in soils along transects on arable and livestock farms in four countries of the Baltic Sea Region (extracted from Haneklaus et al. 2016).

Farm ID	No of lags	Model Type	Range	Nugget	Partial Sill	Root-Mean-Square Error	Mean Standardized Error	Root-Mean-Square Standardized Error	Average Standard Error
Range: 20-30 m									
EE9	10	Stable	22	33	123	9.10	0.01	0.88	10.51
FI10	7	Stable	25	423	1116	33.34	-0.08	1.00	32.86
DE7	12	Exponential	23	258	381	30.45	-0.04	1.12	26.59
PL4	10	Stable	28	87	3314	25.82	-0.03	0.97	28.03
Range: 30.1-55 m									
EE11	11	Exponential	50	0	473	17.50	-0.05	1.01	16.51
FI2	11	Circular	48	0	37	3.36	0.02	0.99	3.44
DE1	12	Exponential	57	0	124	7.35	-0.03	0.91	7.78
PL5	10	Spherical	44	314	1733	31.91	0.00	0.95	33.75
Range: 55.1-90 m									
EE7	12	Spherical	71	143	1598	23.09	-0.02	0.97	23.89
FI1	11	Stable	68	108	1427	11.82	0.01	0.88	13.90
DE11	11	Gaussian	78	38	95	9.34	-0.08	1.19	7.28
PL10	12	Stable	83	0	28350	69.43	-0.03	0.89	80.68
Range: 90.1-220 m									
EE5	15	Circular	142	91	313	14.46	-0.04	1.14	12.13
FI16	17	Spherical	160	6	274	6.48	0.01	0.99	6.24
DE9	12	Stable	132	104	0	11.28	-0.05	1.06	10.61
PL8	15	Stable	135	304	87	18.55	-0.03	1.00	18.57
note: country code: EE – Estonia, FI – Finland, DE – Germany, PL - Poland									

The range of the model variogram is a measure for the distance up to which samples exhibit a spatial correlation. Ranges of 20-30 m, 30.1-55 m, 55.1-90 m and 90.1 m - 220 m were determined for the studied fields at equal percentages of 25%. No correlation was found between range and country, fertilizer type or validation errors.

The way out – balanced, variable rate application of manure

A basic rule of balanced fertilization is that the nutrient input matches the demand in order to avoid equally surpluses and undersupply. The VR application of manure is an important step towards a targeted input of nutrients. Modern spreading machines automatically control manure application on a volumetric basis so that the nutrient output can be adjusted (Saeys et al. 2008). Studies of Eghball et al. (2005) showed that already in the first year of application P accessibility can be as high as 100%. Thus it is fair to assume that the entire P in manure is plant available on a long-term basis which makes it an ideal P source.

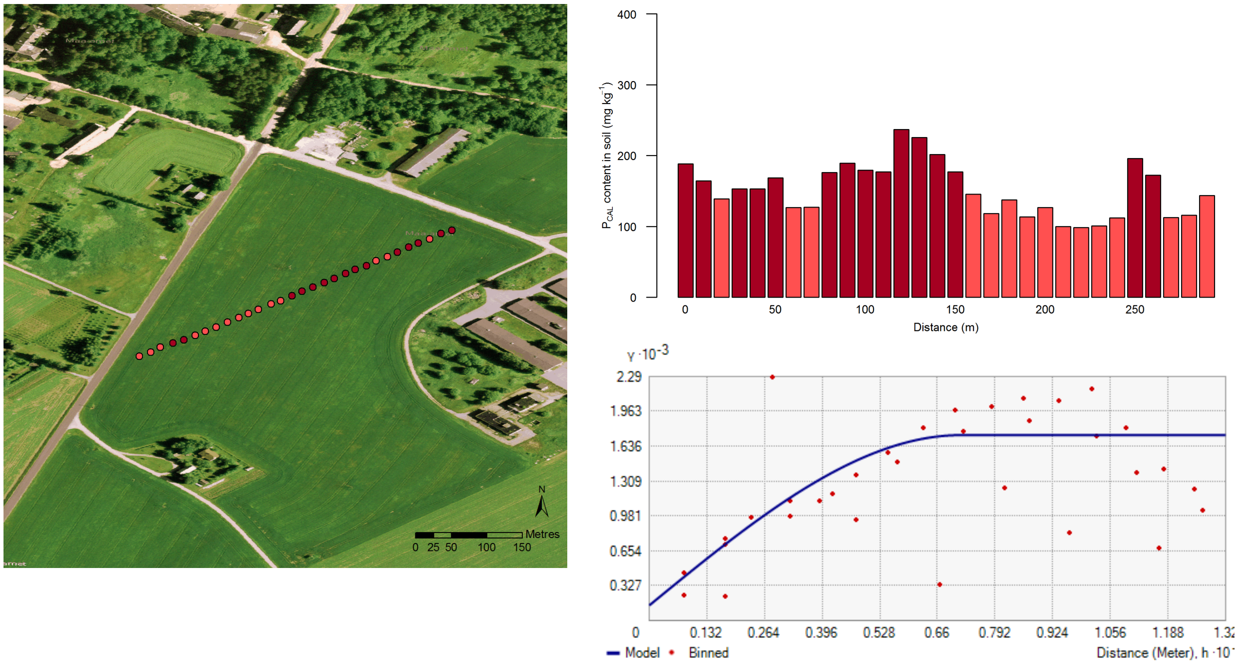

Figure 2. Sampling locations in transect of field EE7 classified (left), variation of plant available PCAL content at sampling points (top right) and semi-variogram where sampling points were binned in groups and the curve reflecting the theoretical semi-variogram (for details see Table 1; adapted from Haneklaus et al. 2014).

With a view to the N:P ratio in manure of about 6.4:1in cattle, 4:1 in pig and 3.5:1 in poultry manure this implies that maximum loads must be based on the P rather than the N content of manure. Then, with 22 kg/ha P (mean P off-take), on an average 141, 88 and 77 kg/ha N would be applied with cattle, pig and poultry manure, respectively. In contrast, maximum application rates of manure equaling 170 kg/ha N (as commonly practiced) exceed the mean P off-take of agricultural crops by 95% to >120% if pig and poultry manure is used. If cattle manure is applied the surplus is minor with approximately 2%. An N- and P-based regulation of manure rates is the only option for a sustainable use of manure and reduction of nutrient losses to water bodies. A mandatory limitation of the P input to 22 kg/ha P as practiced in Sweden implies that alternative ways for the utilization of manure are required or livestock densities must be reduced. The first involves for example co-fermentation in biogas plants, technological separation and processing of liquid and solid phases in order to preserve the fertilizer value of the product (Popovic 2012). The extension of the acreage where manure is applied is another option (Powers and van Horn 2001).

Accuracy of methods for assessing the soil P status and reliability of recommended fertilizer input

For maximum utilization of manure VRs usually follow the spatial variability of the plant available P content in soils as an indicator for the P demand of crops. The problem is that not only the band widths, which characterize different levels of the soil P status proved to be not congruent in different countries of the Baltic Sea region, but also recommended fertilizer rates based on soil analytical data deviated highly (Haneklaus et al. 2016). The data from soil test P employing the same method in one laboratory revealed that in 37% of all samples the P supply was not sufficiently high employing the German classification system (data shown in Shwiekh et al. 2015). If the Swedish or Estonian classification system had been applied this value was significantly lower with 9 and 5%, respectively (Shwiekh et al. 2015). The data showed that in 85% of all tested samples the Swedish soil analysis and classification system delivered categories denoting a higher P supply by one and two categories when compared to the German system. For Estonia the corresponding share of samples was 38% (Shwiekh et al. 2015). These findings stress that the continuation of current, official recommendations will further aggravate the problem of undesired nutrient surpluses.

In addition to the diverging evaluation of the soil P status the recommended fertilizer rates may deviate by up to 28% for grain crops and 37% for sugar beet if the soil P status had been rated optimum in Sweden and Germany. In the worst case, three and four times higher application rates to sugar beet and cereals would have been recommended to German farmers (Haneklaus et al. 2016). Tóth et al. (2014) compared the P fertilizer recommendation systems in the UK and Hungary with distinct disparities in the advised fertilizer doses, too. These findings stress the urgent need for a harmonization of analytical methods, interpretation and recommendation procedures. The solution to overcome the previously mentioned problems is on-farm experimentation (Haneklaus and Schnug 2006). Farmers can assess truly site-specific threshold values for soil and plant analytical data and establish site-specific response curves to fertilizer input by implementing Precision Agriculture technologies (Haneklaus and Schnug 2006). Then, data about the spatial variation of soil and crop characteristics can be transcribed together with critical nutrient values and site-specific fertilizer rates into algorithms for VR applications of mineral and organic fertilizers (Haneklaus and Schnug 2006).

At this point a brief retrospective of the adoption of soil analysis in agriculture as control quantity for fertilization seems appropriate. Soil analysis, which is meanwhile the standard method in agriculture, faced unanimous skepticism at the start of 20th century (Uekötter 2006). This early mistrust gradually faded away though the uncertainties of the method did not disappear (Uekötter 2006). The causes of error and imprecision are numerous and the spatial variability of soil features is definitively one major factor while many other components contribute to the inaccuracy (Uekötter 2006).

Algorithms for a balanced, variable rate application of manure

The ideal P supply is given if P rates equal the off-take by harvest products and the P source is fully plant available because only then P utilization is 100% on a long-term basis (Schnug and De Kok, 2016). Such approach is applicable on soils which are sufficiently supplied with P and if P in the fertilizer product is fully plant available as then the apparent, long-term P utilization will be 100% (Schnug and Haneklaus 2016). Djodijic et al. (2005) came to the same conclusion as a result of a long-term field experiment in Sweden. In case of manure P is fully plant available (Hansen 2006). Here, recycled P fertilizer products and rock phosphates have to be evaluated critically as a significant amount of P will not take place in the soil P cycle and thus will not contribute to the P nutrition of agricultural crops (Schick 2010).

The following conditions were defined for adopting general algorithms for VR application of manure (Table 2): no manure is applied if the soil P status exceeds the sufficiency range, the N:P:K ratio in manure is constant, the N, P and K content is analyzed prior to fertilization to follow up any changes in livestock management, and the minimum N demand is 170 kg/ha N. This implies that the algorithms need to be adjusted if the feeding regime is modified on a farm. It is recommended to identify so-called monitor pedo cells in order to follow up spatio-temporal changes in the nutrient stock and nutrient availability in soils and crop productivity, respectively (Haneklaus et al. 2000).

Ideally, manure is applied at rates which match the lowest N, P or K demand and respective deficits of N, P and/or K are balanced either by mineral fertilizers within one year (Table 2), or by manure together with mineral fertilizers in subsequent years on a crop rotation basis. The spatial variation of the P and K off-take can be established easily by yield maps if the technology is available (Haneklaus and Schnug 2006). With respect to N, annual rates need to match the spatial variation of the crop demand. A suitable approach to assess the site-specific N demand is for example by adjusting rates based on the spatial variation of the clay and organic matter content, and geomorphological features (Haneklaus et al. 1999, Haneklaus and Schnug 2006).

Table 2. Algorithms for variable rate (VR) application of manure targeting a balanced input of N, P and K (extracted from Haneklaus et al. (2016).

Cattle manure (N:P = 6.4:1 and P:K = 1:6.4)				
	Variable P rate as manure (kg/ha)			
Soil test P class[1]	P rate (kg/ha)	If soil test P (mg/kg)	then N rate (kg/ha)	then K rate (kg/ha)
A, B[2]	$Y = -0.880X + 61.4$	$X > 41$	≤ 170	≤ 177[3]
C	22 or [3]$VR_{off\text{-}take}$		141	147[3]
	Variable, mineral P fertilizer rate (kg/ha)		*N rate*	*K rate*
	$P_{VR} = P_{demand} - P_{manure}$, if $X \le 41$		$N_VR = N_{demand} - N_{manure}$	-
Pig manure (N:P = 4:1 and P:K = 1:3.9)				
	Variable P rate as manure (kg/ha)			
	P rate (kg/ha)	If soil test P (mg/kg)	then N rate (kg/ha)	then K rate (kg/ha)
A, B[2]	$Y = -0.880X + 61.4$	$X > 21.5$	≤ 170	≤ 142[4]
C	22 or [3]$VR_{off\text{-}take}$		88	73
	Variable, mineral P fertilizer rate (kg/ha)		*N rate*	*K rate*
	$P_{VR} = P_{demand} - P_{manure}$, if $X \le 21.5$		$N_{VR} = N_{demand} - N_{manure}$	$K_{VR} = K_{demand} - K_{manure}$ or [5]$VR_{off\text{-}take}$ if $\le K_{VR}$
Poultry manure (N:P = 3.5:1 and P:K = 1:1.5)				
	Variable P rate as manure (kg/ha)			
	P rate (kg/ha)	If soil test P (mg/kg)	then N rate (kg/ha)	then K rate (kg/ha)
A, B[2]	$Y = -0.880X + 61.4$	$X < 45$	< 77	≤ 32
C	22 or [3]$VR_{off\text{-}take}$		77	32
	Variable, mineral P fertilizer rate (kg/ha)		*N rate*	*K rate*
	$P_{VR} = P_{demand} - P_{manure}$, if $X \le 45$		$N_{VR} = N_{demand} - N_{manure}$	$K_{VR} = K_{demand} - K_{manure}$ or [5]$VR_{off\text{-}take}$ if $\le K_{VR}$

notes: [1]for details see Figure 1;[2]1.5 and 2-fold P rate in soil test class A and B; [3]geo-coded nutrient off-take data from yield mapping; [4]K input needs to be balanced:

$$\sum_{i=1}^{n} K_{rates}\,(yr_1 + yr2 + ... + yr_n) = \sum_{i=1}^{n} K_{offtake}\,(yr_1 + yr2 + ... + yr_n)$$

with view to the N:P and P:K ratios in manure in case of cattle manure this is only possible if the K demand is accordingly high as for instance in sugar beet/cereals crop rotations if straw is removed and on high yielding intensive grassland; from case to case manure rates need to follow K supply; [5]rate equals difference of summated K off-take by crop rotation.

It has been mentioned above that a P-based manure application will limit its utilization on livestock farms. However, it is not only P, but a balanced input of K may further decrease the manure quantity applied, particularly in case of cattle and pig manure (Table 2). As a rule of thumb cereal grains and oilseed rape remove about 40 kg/ha, sugar beets 100 kg/ha and intensive grassland 120 kg/ha K (Anonymous 1993). Thus a balanced K management is only feasible in sugar beet/cereal crop rotations where straw is harvested and conditionally on intensive grassland (Table 2). Following these basic rules that ensure a balanced N, P and K input, it is evident that the recycling of manure is compulsory in order handle incoming quantities of manure.

Conclusions

Science produced comprehensive GAP codes with respect to mineral and organic N and P fertilization which have the potential to tackle the problem of non-point pollution. So, why doesn’t it work? The two main reasons are that legally permitted manure rates in the EU are based on a maximum N input of 170 kg/ha N so that an overload with P is inevitable. Secondly, the regular application of manure (and mineral P fertilizers) on soils with excessively high soil P contents will aggravate the discharge of P into water bodies. It is time to realize that it is five to midnight and action needed on a global scale as the following example shall emphasize. New Zealand enjoys the image of a natural, unspoiled island. In contrast to the Baltic Sea region where about 85 million people discharge nutrients, the total number of inhabitants is only 4.6 million in New Zealand, which is about the same size, but surrounded by vast water masses. Though stocking densities are as high as 7 livestock units and N surpluses as high as 1000 kg/ha N, the problem of eutrophication of lakes, rivers and sea was only minor 15 years ago (Schnug 2010). Nowadays, severe eutrophication of lakes and streams is a serious, omnipresent problem, closely linked to livestock densities, while eutrophication is at the moment less critical in marine waters due to dilution (Cornelisen 2013).

Summarizing the state of the art of science, a 5-point plan has been extracted which is suggested to be expedient to reduce nutrient losses to water bodies:

1. The EU needs to pass a new law which limits the use of mineral and organic P in agriculture. P rates must not exceed the off-take by harvest-products on sufficiently supplied soils which is on an average 22 kg/ha P. On soils with excessively high P content, no P must be applied until the status decreases to the sufficiency range.

2. It needs to be obligatory for livestock farmers to register the whereabouts of manure.

3. Implementation of Precision Agriculture technologies for on-farm experimentation (including geo-coded sampling, deduction of critical nutrient values in soils and plants, creation of response curves, monitoring of crop productivity) and adjustment of algorithms for VR application of mineral and organic fertilizers must be mandatory and is in return acknowledged as a greening component according to EU policy (Anonymous 2018b) in order to compensate farmers for investments and ongoing expenses. The socio-ecological benefit of truly site-specific VR fertilization is almost certainly an improved water quality on the long run. Positive effects will only unfold if PA is implemented area-wide and after a time lag of at least 10 years.

4. Farm-gate balances must be established by employing agricultural GIS systems on pedon scale which represents the smallest operational unit which is homogenous in terms of soil factors influencing the nutrient balance (Schumann et al. 1997, Haneklaus and Schnug 2006).

5. Official advisory services for farmers with respect to fertilizer planning and data management including the preparation of farm-gate balance statements will be extended.

Such rigid measures are required in order to make real progress in reducing non-point losses of N and P and finally to improve water quality.

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