A PHOSPHORUS INDEX FOR NORWAY: JUSTIFICATION OF FACTORS

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ABSTRACT
Loss of phosphorus (P) from agricultural areas is undesirable in terms of wasted soil fertility resources and environmental impacts. The P Index is a simple approach used to rank the potential for P loss from agricultural fields. The P Index identifies areas where P source (soil P content and P application, including rate, method and time of application) and its risk of transport (soil erosion, surface runoff, subsurface runoff and contributing distance) coincide. Factors included in the P Index, developed for Pennsylvania, were justified in relation to Norwegian conditions and some changes were suggested. P application rate was modified by P removal. A factor for P release by freezing of plant residues and a factor for annual precipitation were suggested. The suggested P Index for organic soils reflects the low P sorption of these soils. Management practices in the Index were adjusted to reflect the effect of time and method of P application on P loss in Norway as well as to Norwegian erosion control measures. To conclude, the framework of the Pennsylvanian P Index seems to be suitable for development of a Norwegian P Index. Further development of calculation routines and calibration is of great importance for future use of the P Index.

KEYWORDS: Diffuse pollution, eutrophication, losses from soil, Norway, phosphorus, P Index.

INTRODUCTION
Eutrophication is a problem for lakes with anthropogenic influence in U.S.A and in Norway (USEPA, 1996; SFT, 2003). Eutrophication of most freshwaters around the world is accelerated by P inputs (Carpenter et al., 1998; Withers and Lord, 2002). In Norwegian surface waters, 45% of the anthropogenic P inputs originate from agricultural areas (Borgvang et al., 2002), while agricultural areas contribute 61% of P in the Chesapeake Bay (on the northeastern U.S.A. coast) (Chesapeake Bay Program, 1995). There is a need for improved efforts to control P loss from non-point sources. In the U.S.A., one method of targeting best management practices (BMP) to critical areas of P loss is by using the P Index to identify areas in a catchment most vulnerable to P loss. The Index ranks source and transport factors controlling P loss at field and catchment scale (Gburek et al., 2000; Lemunyon and Gilbert, 1993). The framework of the P Index is empirical but considers the general processes of diffuse P loss. The approach has received great attention, but has only been used in a few European countries (Heathwaite et al., 2003). The advantage of the P Index is that it is based on easily available input data and much research has gone into defining and quantifying the various source and transport effects on P loss for the P Index in the U.S.A. (Eghball and Gilley, 2001; Sharpley et al., 2001). However, little information is available on the relevancy of the various source and transport factors in the P Index for Norway.

FRAMEWORK FOR P INDEX
The premise for the P Index is the observation that generally, most P from agricultural catchments comes from only a small but well defined area of the landscape, where area of runoff-generation coincide with a high soil P (Gburek and Sharpley, 1998). Similar results were obtained for Nordic countries when Ulén et al. (2001) measured runoff from fields and found that 4 of the 15 fields accounted for 74 % of the total P transport within a catchment.

The framework of the P Index consist of transport factors (e.g. soil erosion, surface runoff, subsurface drainage, contributing distance and connectivity) and source factors (e.g. soil test P, fertilizer and manure P rate, fertilizer and manure P application method and manure P availability) (Table 1). The transport and source factors are multiplied to obtain a site rating of the risk of P loss, which need to be reflected in the P Index (Weld et al., 2001). Between regions, the differences in importance of factors related to P loss may be related to soil, geography, climate and management practice (Sharpley et al., 2003). Based on the Pennsylvanian P Index (Pennsylvanian Phosphorus Index group, 2002), factors and weightings for the development of a Norwegian P Index are suggested in Table 1.

Source factors

Soil test P
McDowell and Sharpley (2001) documented the relationship between soil test P (Mehlich-3 P) and the potential surface runoff concentration of dissolved P (Figure 1). The standard soil test P in Norway is the Ammonium Lactate method (P-AL) by Egner et al. (1960). The relationship between Mehlich-3 P and P-AL shown in Figure 2, justify the change of soil test P factor from 0.20 in the Pennsylvanian P Index to 0.3 in the Norwegian P Index (Table 1). Øgaard (1995) showed in a linear regression analysis that P-AL explained 83% of the variation in total reactive P which was found to correlate very well with available P for blue-green algae (Krogstad and Løvstad, 1991).

Table 1. The Norwegian P Index. Suggested factors and weightings refer to the text.

Source factors					
Soil test P	**Soil test rating** = 0.30 * P-AL (mg kg^{-1})				
Fertilizer P rate	Fertilizer P (kg ha^{-1})				
Fertilizer application method	0.2 Placed or injected 5 cm or more deep	0.4 Incorporated < 18 hours following application	0.6 Incorp. > 18 hours or not incorporated following application in April – Aug.	0.8 Incorp. > 18 hours or not incorporated following application in Sept. – March	
	Fertilizer rating = Fertilizer P rate x method				
Manure P rate	Manure P (kg ha^{-1})				
Manure application method	0.2 Placed or injected 5 cm or more deep	0.4 Incorporated < 18 hours following application	0.6 Incorp. > 18 hours or not incorporated following application in April – Aug.	0.8 Incorp. > 18 hours or not incorporated following application in Sept. – March	
Manure P availability	0.5 Low–Treated manure/biosolids	0.8 Medium – Dairy	1.0 High – Poultry/Swine		
	Manure rating = Manure P rate x method x availability				
Plant residue P	P in plant residues left on ground during winter (kg ha^{-1})				
P removal	0.8 P removal > P application	1.0 P removal = P application	1.2 P removal < P application		
Source factor = ((Soil test rating + Fertilizer rating + Manure rating + Plant residues) x P removal) x (2 for organic soils)					
Transport factors					
Soil erosion	Soil loss (tonnes/ha) based on erosion risk maps corrected for management practice				
Surface runoff class	0 Very low	2 Low	4 Medium	6 High	8 Very high
Sub-surface drainage	0 Low		1 Single tile drains		2 Systematic tile drainage or rapid permeability soil near a stream
Contributing distance	0 >150 m	2 150 to 100 m	4 100 to 75 m	6 75 to 50 m	8 < 50 m
Transport factor = (Soil erosion + surface runoff + sub-surface runoff + contributing distance)					
Modified connectivity	0.7 Riparian buffer		1.0 Grassed waterway or inlet for surface runoff	1.1 Direct connection	
Annual precipitation	Precipitation weighting factor				
P Index value = Source factor x transport factor x modified connectivity x annual precipitation factor					

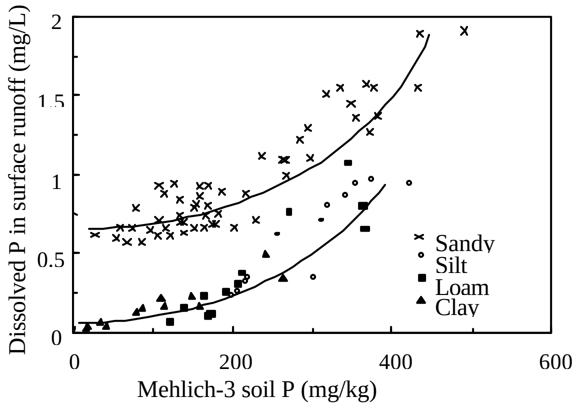

Figure 1. Relationship between the concentration of dissolved P in surface runoff and Mehlich-3 extract. soil P from the FD-36 watershed, U.S.A. (adapted from Sharpley et al., 2001).

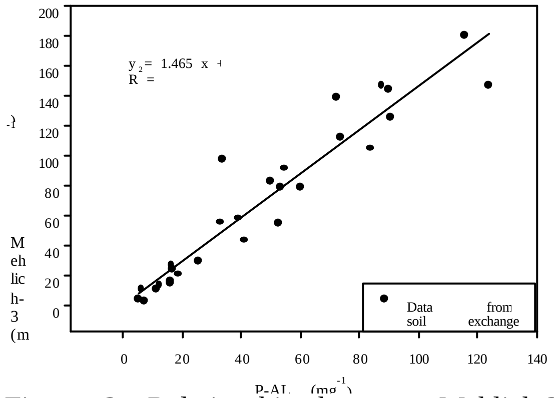

Figure 2. Relationship between Mehlich-3 P extractable soil P concentration and Ammonium Lactate extractable P (P-AL) in European surface soil with pH (water) less than 7 (COST832)

Fertilizer and manure: rate, application method and availability

Fertilizer and manure P rate are suggested equally weighted in the Norwegian P Index (Table 1). In Nordic studies Ulén (1998) found no significant difference between leaching of P from manure and from fertilizer. In Norway the rate of manure application are regulated at farm scale by limiting the number of livestock to 2.5 animal units ha^{-1} (Table 2). Despite these regulations, single fields may receive high amounts of P, especially from manure (Tveitnes, 1998). P application methods are adjusted to Norwegian regulations.

Table 2. Regulations for P application to agricultural land (LD, 2003).

Livestock density: max. 2.5 animal units/ha
After September 1st : incorporation of manure
November 1st – February 15th : no manure application
No manure application on frozen and snowcovered soil
Manure incorporation within 18 hours on arable land
Yearly nutrient management plan based on soil P test (4th to 8th year soil test)

In Europe, P balance has been suggested as an Index for P loss, where P is applied at different rates for different crops (Table 3;Tunney et al., 2003). Soil test P reflects the long-term P surplus, but as soil tests are only carried out every 4-8 year in Norway, a P removal factor is may be used to reflect the short time effect of P surplus on risk of P loss.

Table 3. P surplus for different crops in South Eastern Norway (Source: Hydro, Fertilizer Handbook, 2001).

	Yield, kg ha^{-1}	P applied, kg ha^{-1}	P in yield, kg ha^{-1}
Winter wheat	5500	26	22
Barley	4500	22	18
Grassland	7500	30	28
Potato	30000	45	18
Carrot	40000	50	22
Leek	25000	60	18

The P application method factor reflects the well-known fact that incorporation of P lowers the risk of being lost compared to surface application. Regulations in Norway require incorporation of manure on arable soil within 18 hours (Table 2), thus the limit for incorporation of manure were changed from 1 week to 18 hours. In Norwegian studies, P application in autumn has shown higher P loss compared to P application in spring, even with immediate ploughing after application (Eltun et al., 1996; Oskarsen et al., 1998). The definition of autumn months relates to length of growing season, and September 1st is used in Norwegian regulations (Table 2). The application of P on frozen or snow-covered soil introduces a high risk of P loss through surface runoff (Uhlen, 1989a). Norwegian national regulations prohibit P application on snow-covered or frozen ground, thus the class for P application on frozen soil was deleted in the suggested P Index for Norway (Table 2). Availability of P in types of manure is expected to show similar differences in Norway as shown for U.S.A. by Kleinman et al. (2002).

Plant residues

In cold areas freezing may create an additional source of P from plant residues. Studies on the effect of freezing have shown that concentration of P in runoff from areas with fertilised grass may increase significantly after the crop has been frozen (Uhlen, 1989b). In a laboratory study the total amount of P released from annual ryegrass increase with increasing number of freeze-thaw cycles (Figure 3). These results show that plant residues may release soluble P during the winter and is therefore suggested as a factor in a P Index for Norway.

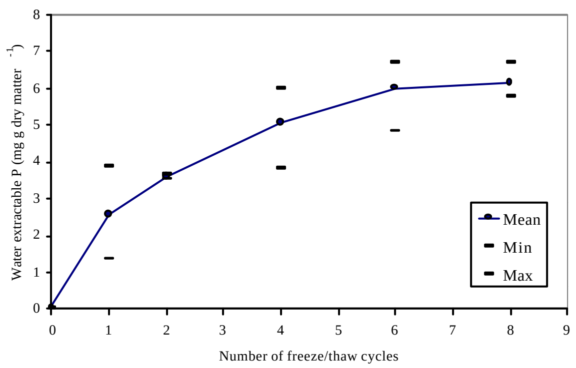

Figure 3. Water extractable P (mg g^{-1} dry matter) in cut-off plant residues as a function of number of freezing/thawing cycles. (Bechmann, unpublished).

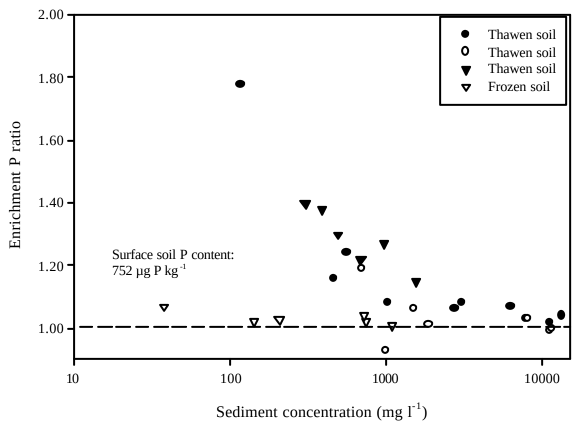

Figure 4. Enrichment ratio in surface runoff from a silt clay loam in 4 runoff events from a field in South-Eastern Norway (Krogstad, unpublished).

Organic soils

To include organic soils (>40% organic matter) in the P Index, an increased source factor reflects the increased availability of P in these soils (Sims et al. 1998). Yli-Halla (1998) showed the differences in relationship between degree of P saturation and equilibrium P concentration in mineral and organic soils. At a mean soil test P, equilibrium P concentration was 7 times higher for organic soil compared to mineral soil. In the P Index it is suggested to double the source factor for organic soil (Table 1). More specific data on the effect of soil type on risk of P leaching is however needed for further development of the P Index for organic soils in Norway.

Transport factors

Soil erosion

Erosion is an important P loss pathway in Norway (Øygarden, 2000; Lundekvam, 1998). For 6 Norwegian catchments with low livestock density (<1 animal unit ha^{-1}) the losses of P have shown good relationship with loss of suspended sediments (Bechmann and Våje, 2002). Eroded sediments in Norway as well as in other countries tend to have higher content of small particles and contain a higher amount of total P than the soil from which it originates (Øygarden, 2000). However, the higher the sediment transport is the lower the P enrichment of the sediment (Figure 4). Frozen soil tends to have a P enrichment ratio around one even at low sediment transport, indicating low selective particle erosion under frozen conditions. This relationship may be included in calculations of the erosion factor.

Soil type maps are available for 40% of the cultivated soil in Norway. Based on the map information the fields are classified into 4 erosion classes with 250, 1000, 5000 and 8000 kg soil loss ha^{-1} in the case of fall ploughing (worst case situation). Erosion risk for fall ploughing has to be adjusted to erosion risk for different management practices (Table 4).

Table 4. Soil loss reduction (%) in relation to fall ploughing as a consequence of erosion control techniques on arable land (Lundekvam, 2002).

Control techniques	Erosion classes 1 & 2	Erosion classes 3 & 4
Stubble field	60	80
Winter wheat, autumn plowing	8	10
Light harrowing	35	45
Winter wheat, direct drilling	55	70
Winter wheat, light harrowing autumn	30	40
Undersown catchcrop, in the main crop	65	85

Surface runoff and subsurface runoff

Surface loss of P constitutes in most studies in Norway more than 50 % of the P loss, including both particulate and dissolved P (Lundekvam, 1998). Dissolved P in surface runoff from grasslands constituted more than 75% of total P loss (Uhlen, 1989b). Fresh application of P may cause 'incidental' loss of dissolved and particulate P forms in land runoff when rainfall interacts directly with fertilizers and manures which are spread, or excreted, onto the soil surface. Incidental P loss, as described by Withers et al. (2003), may give a dominant (50-98%) contribution to measured P loads in runoff from field plots, though at catchment scale in Norway impacts were more difficult to quantify due to the difficulty in separating 'incidental' fromsoil P losses.

Subsurface runoff contributes more to P loss where soils are intensively drained, like most Norwegian soils. Loss of P from tile-drained soils include both particulate and dissolved P fractions transported from the soil surface through soil or macropores to the tile drainage system (Djodijk et al., 2000). Most soils in Norway are intensively drained and the effect of macropores on P loss needs further evaluation in a P Index for Norway.

Contributing distance and modified connectivity

Gburek et al. (2000) showed that, not all fields within a catchment have the same risk of actually causing pollution in the stream; i.e., distance from edge-of-field to stream. Thus, the catchment approach of the P Index includes connectivity of source to stream (Sharpley et al., 2001). For tile-drained areas there is a direct link of subsurface drainage from field to stream. This is accounted for in the Pennsylvanian P Index by adding a factor 2 for systematic tile drainage, which also is adapted in the suggested Norwegian P Index (Table 1). Connectivity is reduced by a factor 0.7 to reflect the effect of vegetated buffers on P loss. Syversen (2002) documented under Norwegian conditions, that vegetated buffer zones reduce surface runoff losses of P by 42-96% using buffer zones of 5-10m width.

Precipitation

In Norway annual precipitation may vary by a factor of more than 10 from the higher inland to the west coast. Precipitation is the driving force of P transport and is suggested as a factor in an Index for Norway. The approach of the Arkansas P index (Table 5) was applied to the Norwegian precipitation factor.

Table 5. Weighting of precipitation factor in the Arkansas P index (Weld, 2001).

Annual precipitation (mm)	Weighting factor
0 - 250	0.2
250 – 500	0.4
500 – 750	0.6
750 – 1000	0.8
1000 – 1250	1.0
1250 – 1500	1.2
> 1500	1.4

MANAGEMENT INTERPRETATION

Calculation of the P Index values in the Pennsylvanian P Index correspond to generalized management interpretations (Table 6). These measures describe reduction in the source factor. However, since erosion is an important P loss process in Norway, management recommendations should probably reflect erosion control measures together with source control. Djodjic (2001) used a decision support system for a Swedish catchment and found that high P level, excessive P fertilisation, stream proximity and subsurface drainage were probable causes for high P Indices. An interpretation table adjusted to Norwegian conditions has to be worked out.

Table 6. Generalised interpretation of the Pennsylvanian P Index (Pennsylvanian phosphorus Index group, 2001)

P Index	Interpretation of the Pennsylvanian P Index
Low < 60	Low potential for P loss. N based management
Medium 60 to 80	Medium potential for P loss. N based management
High 80 to 100	High potential for P loss. Manure limited to P removal
Very high >100	Very high potential for P loss. No manure applied

CONCLUSIONS

All individual factors in the Pennsylvanian P Index have been rigorously evaluated with much supporting research and data. Also, the relative importance of factors has been researched and supported in the Pennsylvanian P Index. The factors included in the Pennsylvanian P Index are important factors determining critical source areas for P loss also in Norway. The cold climate introduces an additional factor for plant release of P by freezing and there is a need to further develop the factors related to precipitation and snowmelt. P removal by crop is suggested to represent the effect of excess P fertilization. The high proportion of tile drained areas also creates a need for further evaluation to give subsurface drainage an appropriate representation in the P Index.

However, one of the main gaps and limitation at the moment for every P Index is showing that all these source and transport factors accurately describe the vulnerability of any given site within a catchment to loose P.

An objective for the future is to adjust the P Index more accurately to biological response in rivers and lakes, and to further develop the approach as we gain more knowledge and experience by using the Index.

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