The Concept of Phosphorus Index for Identification of Phosphorus Loss Risk
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Fosfora indekss fosfora noplūdes riska noteikšanai
I. Literatūras apskats

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Abstract. Phosphorus is the plant nutrient most often linked with impairment of surface water. The phosphorus index (PI) approach is developed and widely applied in the USA as well as it has been adopted in several European countries, especially in Scandinavia with main aim to estimate the risk of phosphorus loss from agricultural areas to surface waters. There is no "standard" PI, as a result scientists try to develop new versions of PI to account for specific regional conditions. Consequently, a great variety of different versions and modifications of phosphorus indices are presented. The aim of the paper is to provide an overview of the development of the risk identification tool (phosphorus index) to measure the risk of phosphorus losses from agriculture fields already at a farm level. The design of phosphorus index is based on the original PI and later versions of the model for prediction of the phosphorus load from agriculture field to nearest water body, taking into account findings in phosphorus research and local environmental experts' judgments.
Key words: phosphorus index, risk identification tool, phosphorus losses, surface water quality.

Introduction

The significance of phosphorus (P) pollution from agricultural sources to surface waters has been emphasized in a prominent number of scientific articles tended to advance research of P, because of the great ecological and agronomic significance of P, influencing both crop productivity and eutrophication (Sharpley, 1995). Phosphorus poses environmental problems due to its high contribution to eutrophication of fresh water bodies – undesirable growth of algae leading to low dissolved oxygen and degrading the water quality (Zaimes, Schultz, 2002). Phosphorus loss mostly is defined as a complex function that includes climate, soil type, land management, and other temporal and spatial factors that make influence on P transformations via P loss pathways to surface water bodies. Consequently, the primary objective of the article is to demonstrate the concept of P assessment tool that could be easily modified according to actual findings about relative importance of factors that accelerate potential of phosphorus loss. The aim of the work is not to suggest a new model, but to find the best way of integrating the existing P indexes.

Importance of Phosphorus in Environment and Agriculture

Phosphorous is naturally available in the ecosystem due to weathering of parent material and deposition in the soil by plants and animals. The phosphorus loss from agricultural areas to surface waters arises from the contribution of dissolved P (DP) and particulate P (PP) via different pathways as soil erosion and surface runoff, bank erosion, leaching, and tile drainage water (Kronvang, Bechmann et al., 2005). According to Haygarth and Sharpley (2000), dissolved and particulate phosphorus are differentiated by whether or not they pass through a 0.45 μm membrane filter. P fraction that passes through the membrane filter is defined as dissolved or soluble P, but P fraction that does not pass is called the particulate, sediment-bound, or suspended P. DP primarily consists of orthophosphate and it is immediately available for algae while PP is a long-term source of potentially bioavailable P. Particulate phosphorus may be associated with soil particles and minerals containing aluminium, iron, or calcium, or with organic matter. Loss of particulate phosphorus primarily is linked

Table 1

Phosphorus transport mechanisms
(Zaimes, Schultz, 2002)

Transport mechanisms	Description	Examples
Dissolution	Transport of P from the soil particle or adsorption site to the soil solution determined by chemistry refer to the movement of dissolved P (micro-scale process)	Leaching as the elluviation of solutes through soil
Physical	Primarily mechanism refers to the movement of particulate P (macro-scale process)	Soil erosion, displacement and entrainment of colloids
Incidental	Transport of P controlled by unique conditions as short-term transport of P fertilizer or manure after effective rainfall	Runoff

Table 2

Phosphorus transport pathways
(Zaimes, Schultz, 2002)

Type of flow	Details of flow	P transport details	Typical soils
Matrix flow	The downward (vertical) movement of water through the macro- and micro-pores of the soil	Little movement of P because the surface soil accumulates most of it (immobile and easily adsorbed)	Sandy, acid, organic soil with low P fixation (Djodjic, 2005)
Preferential flow	The downward movement of water in larger subsoil pathways (fissures, cracks, burrows, wormholes)	Greater transport of P because water moves faster with less chance of adsorption	Structured heavy soils, clay-rich soils (Heckrath, Bechmann et al., 2008)
Overland flow	Down-slope movement of water over the soil surface during heavy rainfall events	Traditionally considered as the major transport pathway for P in agricultural landscapes	Determined by soil physical properties, vegetation cover, and slope steepness
Interflow	Lateral movement of water in the soil	Provides the major proportion of flow in many streams, typically has low P concentrations	Sandy, poorly drained soils with high soil P levels; soil with a sandy A horizon and a heavy clay B horizon
Land drainage	Even if tile water has low P concentrations, it could be a major pathway, because of the large areas that have been tiled and contribute significant amounts of water to stream flow		

by soil erosion. Whereas dissolved phosphorus may result from leaching of fertilizer, crop residues, or human or animal wastes.

Phosphorus transport to surface waters is initiated by three main transport mechanisms (incidental, physical, dissolution) with hydrology as the main driving force (Table 1). The most important pathways moving P from agricultural landscapes are matrix flow, preferential flow, overland flow, interflow, and land drainage (Table 2, Fig. 1). These phosphorus pathways may interrelate. The concentration of P in overland and subsurface flow is related to the concentration and release rate of P in soil (McDowell, Sharpley, 2003). Matrix flow can be controlled by drainage in order to reduce discharge from arable fields during wet season, but preferential flow – by deep cultivation to destroy macropores and utilize subsoil sorption capacity. Overland flow can be diminished by (a) improving infiltration (proper tilling activities (tillage across slope, spring till instead autumn or no till (conservation tilling)); (b) reducing detachment (improved soil structure by liming, increasing content of organic matter, crop cover); (c) purifying overland flow (riparian buffers) (Bergström, Djodjic et al., 2007).

Calculations should account for P losses through flow types and take into consideration different

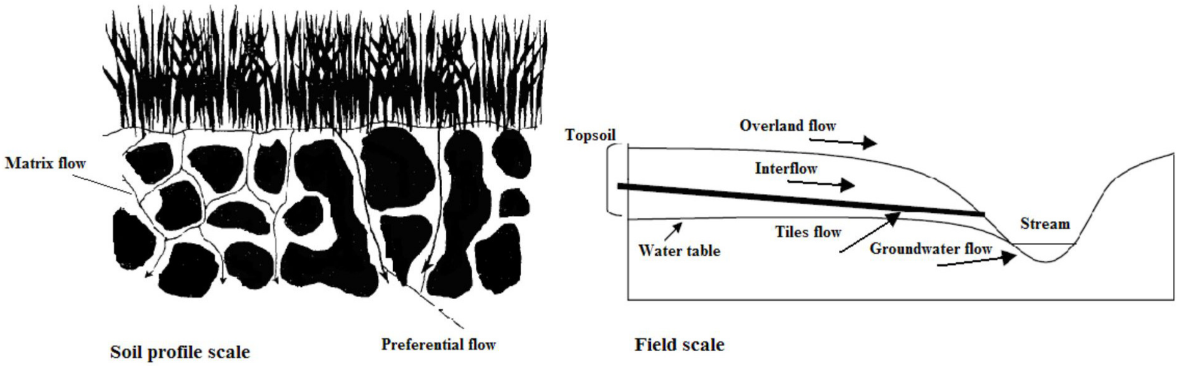

Fig. 1. Pathways for phosphorus transport (Zaimes, Schultz, 2002).

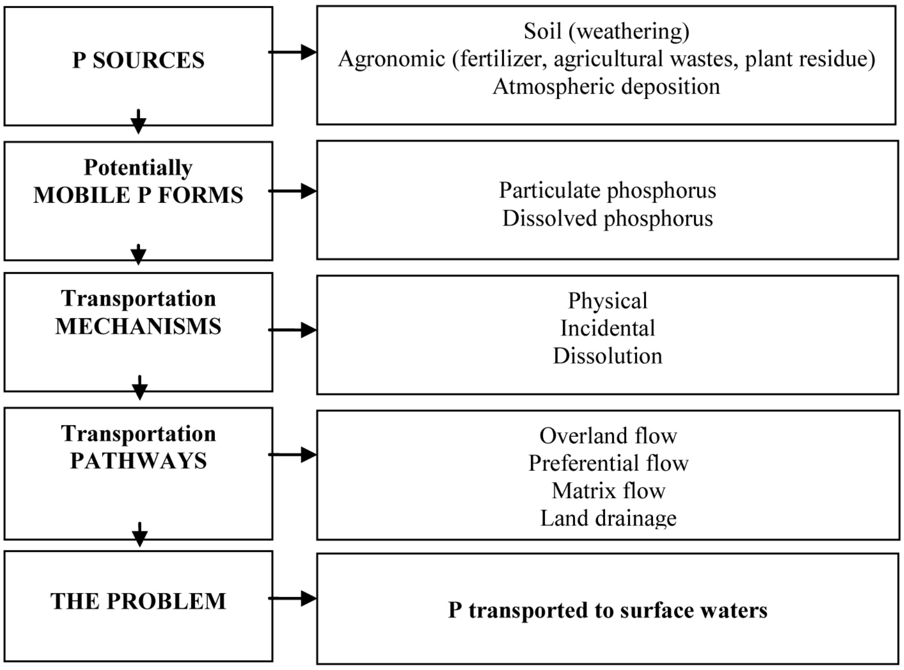

Fig. 2. Statement for PI development.

factors for each transport mechanism. According to Pautler and Sims (2000), soils have a defined capacity to adsorb P, and when a critical P sorption saturation level is reached, there is a probability of P loss to the surface water. For example, high soil P content in the topsoil may result in a high P loss risk value. However, this high potential for P losses is fulfilled only when the buffering capacity (the ability of soil to resist changes in pH) of the subsoil is either low or bypassed through surface runoff or preferential flow. Hence, the importance of some factors may be reduced or emphasized by other factors. Also, the significance of the buffering capacity of the subsoil is high if slow matrix flow is the dominant transport pathway, but it is negligible if interaction between percolating water is reduced because of rapid transport through macropores (Djodjic, Bergstrom, 2005). Consequently, all these considerations should be accounted to analyze problems linked to P loss and PI design (Fig. 2).

Phosphorus Index Approach to Estimate Relative Potential for Off-site Movement of Phosphorus

Modelling tools to predicting P losses from soil to water differ widely from complex approaches to simple indicators. However, in the case of the water management problem it is essential to work with methods that can provide results by taking into account data availability as a limiting factor

(Bechmann, Stalnacke, Kværnø, 2007; Lemunyon, Gilbert, 1993). The use of appropriate models can help to fill gaps in empirical data and predict P pollution pressures, as well to evaluate management alternatives in order to diminish the possible risk (Haygarth, Condron et al., 2005). Scientific literature offers different approaches to estimate the risk of nutrient losses from soil to water (Kovács, 2004; Vadas, Owens, Sharpley, 2008; Huttunen, Huttunen et al., 2007). Due to the previous statement, it is important to place emphasis on the strategy of the index tools. Index approach has been demonstrated according to the advantage of simple and immediate application that can give acceptable results with easy available input data (Leone, Ripa et al., 2008). The phosphorus index (PI) concept was at first developed in the United States of America (USA) and has been defined as a risk-assessment tool that combines phosphorus source factors, transport and management factors to rank the fields according to their risk of P losses or the vulnerability of fields to P losses in runoff (Lemunyon, Gilbert, 1993). The index outcome is the value for an individual field placed into a category (very low to very high risk of P loss) with associated interpretations and recommendations for nutrient management.

Original version of the PI developed by Lemunyon and Gilbert (1993) consists of matrix of 8 site characteristic parameters assigned to respective weighting values that present parameter effect on P loss (soil erosion (1.5); irrigation erosion (1.5); runoff loss (0.5); soil P test (1.0); fertilizer application rate (0.75); P fertilizer application method (0.5); organic P source application rate (1.0); organic P source application method (1.0)) and site characteristic parameters rating values for P loss risk identification. Rating values for each parameter of site characteristics show an association of P loss: very low (1), low (2), medium (4), high (6), and very high (8). The original PI is a sum of the product of the rating value and corresponding weighting value for each site characteristic (Birr, Mulla, 2001). Since, the PI has been widely modified. The most complicated task of PI modifying is to adjust weighting factors and coefficients of PI bringing them as close as possible to specific region conditions. In addition, some countries have involved very specific parameters in PI. For example, snowmelt is included in Norway PI to evaluate how it affects potential of P loss (Bechmann, 2005). The main advantages of earlier approaches to phosphorus indexing are simplicity and no need for assumptions about relationships between P source factor and P transport factor that advance movement of P. Later it was accepted that PI should focus on the so called critical source areas of P loss where source and transport conditions come together to favouring environmental problems. Sharpley (1995) declared that high P source with little opportunity for transport to surface water, like no P source and high transport potential may not constitute an environmental threat. Mallarino, Stewart et al. (2002) clarified this by an example showing that dissolved P in runoff or subsurface flow immediately after solid manure application may be lower than for liquid manure sources because of solid manure lower proportion of water soluble P, at the same time losses of soluble P in runoff may be lower for liquid manure than for solid manure because of greater infiltration and soil interaction when liquid manure is applied. Consequently, authors of later versions of PI modified the original approach for separate assess of source and transport factors before combining the integrated source and transport factors multiplicatively (Heckrath, Bechmann et al., 2008).

Most USA states and many European countries have adopted index approach and developed modified versions of PI to take into account local conditions by evolved PI from an additive to a multiplicative approach. In early PI versions (also original in PI), factors were additive. As explained before, this means that all factors were considered equivalent (with adjustments for variable weighting). A weighting coefficient was assigned to each factor to reflect its relative importance in contributing to P loss. The PI was calculated by multiplying each potential P loss rating by its corresponding weighting factor and summing the results. A modification introduced in recent indices mostly uses a multiplicative approach. The various PI factors are arranged into two distinct groups: phosphorus transport factors (for example, soil erosion, runoff class, and distance to a stream), and P source factors (P content in the soil, application of P chemical and organic fertilizer). The phosphorus source potential value is then multiplied by the P transport potential value. A detailed overview about PI development in USA and Europe is provided by Buczko and Kuchenbuch (2007). Despite the idea that PI is not a P loss quantification tool, but a P loss risk-assessment tool, designing of PI maximally appropriate for the specific conditions is the most complicated task of PI development and modification.

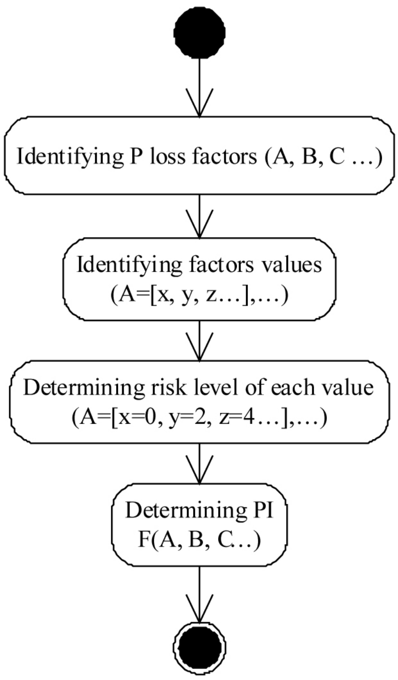

Fig. 3. Process of PI design.

Methodology of PI Development

Methodology of PI design for local conditions developed in the research consists of several steps. Step 1 includes identification of PI factors represented as index parameters that describe P loss. Parameters for PI design are adopted from P indexes already used in USA and Europe and are carefully selected for the best characterization of their influence on P availability, movement and management by taking into account data limitation for Latvia conditions. Following PI parameters were selected:

1) P source factors: soil P factor for representing the risk arising from processes of P loss resulting from high soil P content; P application factor for representing the risk of P loss arising due to an excessive and inappropriate application of phosphorus;
2) P transport factors: erosion, runoff, leaching, draining system, filter wells, and buffers.

Step 2 includes determination of PI parameters values. A rule is set that all values for each parameter must be qualitative to keep the original PI approach. Step 3 is devoted to ranking of parameter values and assigning them to P loss risk levels with a numerical value: very low (1), low (2), medium (4), high (6), and very high (8). It is one of the most important steps and requires use of expert systems. Expert system approaches usually are used to identify appropriate ratings and weightings for factors or indicators via the expert judgment if the data is limited or when the available data is incomplete as like as research data for specific conditions (Burgman, 2004; Linstone, Turoff, Helmer, 2002). Consequently, an expert system that relies on a panel of independent experts is applied to seek collective judgments about the rating of risk description for each parameter that explains a particular factor of P loss included in PI as possibly close to local conditions. For the agreed list of parameters and parameters values, experts' judgments are used to rate importance of each parameter with respect to the risk of nutrient loss from field to the wider environment. Experts' opinion is determined using rating scores from 1 (least important) to 8 (most important). For example, for the P leaching parameter experts suggested to use soil texture as risk estimator and made decision about soil textures that are most vulnerable to P leaching to soil textures that can not be considered with P leaching. Finally, all parameters values have two to five risk levels with assigned numerical values. The structure of PI is defined in step 4 (Fig. 3).

Finally, P management factors should be analyzed and evaluated with respect to notable role of the management to diminish the influence of P loss factors. These factors are defined as correction parameters and assigned to weights 0.2–1 and up. For solving the problem of PI outcome boundaries for all risk categories, multi-objective optimization methods and algorithms and multi-criteria decision making have been used (Berzina, Zujevs, 2008).

Parameters and Their Ratings Included in PI

Soil P component (SP) is the P source factor and includes soil testing results for P content in soil. Soil P status describes the natural background of the potential amount of P to be released. Pennsylvania PI and several PI's that are based on it use the soil test P number and multiply it by a fixed number. This number is decided by professionals on the field, as like as other weighting numbers. It should be noted that weighting factors are corrected in order to bring PI nearer to specific site conditions; however, like the original authors (Lemunyon, Gilbert, 1993) of the PI, other authors do not explain in their reports how these numbers are obtained. Consequently, soil P component is not presented as soil P testing result (suggested by Norwegian and Danish P indexes) (Heckrath, Bechmann et al., 2008). This component is developed based on research about P concentrations in Latvia soils (Timbare, Reinfelde, 2002). Soil P component categories as soil P content for PI calculation are set as follows: (a) less than 13 mg kg^{-1} (1 – very low risk); (b) 13–26 mg kg^{-1} (2 – low risk); (c) 27–52 mg kg^{-1} (4 – medium risk); (d) 53–109 mg kg^{-1} (6 – high risk); (e) over 109 mg kg^{-1} (8 – very high risk).

Application of P fertilizers (AP) component describes phosphorus application rate considering the total amount of P in manure and/or commercial fertilizer applied to a field for crop requirements. The application rate was based on generalized plant uptake requirements for commonly grown crops in the area. The higher are plant requirements, the higher is the risk of P loss because P fertilizer application arises. Phosphorus application parameter rates are placed in the following categories: no additional P (1 – very low risk), pastures (2 – low risk), winter and spring cereals, alfalfa, (4 – medium risk), rape, potatoes, beets (6 – high risk), and vegetables – cabbage, cucumbers, beans (8 – very high risk).

Erosion component (E) describes the loss of P as a product of the erosion rate and the P concentration of the eroded matter (Ekholm, Turtola et al., 2005). The output of the erosion component is an approximate estimate of the total amount of P delivered with sediment, excluding dissolved P in runoff. Several studies highlight the importance of soil erosion and physical transfer of P with soil particles from land to water. Even some episodes of water erosion occur during snowmelt and when frozen soil thaws may increase P losses (Djodjic, Bergstrom, 2005). Erosion is documented as the most important factor determining P transport in Norway and Sweden. However, soil erosion is not considered as major P loss pathway in Denmark due to topography and rainfall intensity (Heckrath, Bechmann et al., 2008). The transfer of particulate P in overland flow and erodibility is significantly affected by soil management (Bechmann, 2005). Usually soil erosion potential for PI is calculated using the Universal Soil Loss Equation (USLE), but there are some limitations while using the USLE to calculate soil loss in Latvia, because the USLE is calibrated for use in the USA. The represented PI model uses research about erosion processes in Latvia (Boruks, 2004). For parameter "erosion" , rating categories of P loss risk are determined using the following: (a) field slope – 0–5% (1 – very low risk); (b) field slope – 6–9% (2 – low risk); (c) field slope – 10–14% (4 – medium risk); (d) field slope – 15–20% (6 – high risk); (e) field slope >20% (8 – very high risk).

The surface runoff (R) component estimates the amount of both particulate and dissolved P (Hart, Quin, Nguyen, 2004). Runoff is highlighted as the major P transport pathway for most agricultural soils. Soil and plant material are significant sources of P to runoff, but their effect can be overwhelmed by P release from recently applied, inorganic fertilizers that are left unincorporated (Hart, Quin, Nguyen, 2004). Results from the research clearly show the influence of P sources and rainfall intensities on P concentration in surface runoff (Shigaki, Sharpley, Prochnow, 2007; Quinton, Catt, Hess, 2001). Vadas, Owens, and Sharpley (2008) present data that the amount of P fertilizer adsorbed by soil reaches a maximum at about 75% of that applied and remaining 25% of P fertilizer stay available to be leached by rain and transported in runoff. They also observed that adsorption of fertilizer P by soil decreased as the soil moisture or degree of contact between fertilizer and soil decreased (Vadas, Owens, Sharpley, 2008). Other studies (Kleinman, Sharpley et al., 2002; Kleinman, Srinivasan et al., 2006) show that dissolved P concentrations in runoff in the first storm after fertilizer application can be greater than P concentrations in runoff from unfertilized soils. Shigaki, Sharpley, and Prochnow (2007) reported an example that the effective depth of interaction between surface soil and runoff P increase with an increase of rainfall intensity and field slope. However, there is also evidence that high levels of P pollution can arise from grassland fields in pastoral

Table 3

Runoff evaluation classes

Slope, %	Soil texture classes		
	sand	loamy sand, sandy loam	clay
<0.5	1 (very low risk)	2 (low risk)	4 (medium risk)
0.6–3.0	2 (low risk)	4 (medium risk)	6 (high risk)
>3.0	4 (medium risk)	6 (high risk)	8 (very high risk)

farming areas. This appears to arise both during slurry spreading and during grazing. The occurrence of high levels of loss under wet conditions indicates environmental benefits from avoiding slurry spreading on wet soil or during rain (McGechan, Lewis, Hooda, 2005). Fresh application of P may be a significant reason for 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. Studies in Norway show that incidental P loss may give a dominant (50–98%) contribution to P loads in runoff (Bechmann, Krogstad, Sharpley, 2005). The review of Heckrath, Bechmann et al. (2008) also pays attention to soil type in the process of surface runoff evaluation. Runoff must be a particularly important PI parameter also for Latvia conditions (Dzalbe, Jansons et al., 2005). The presented PI model arranges risk classes for parameter "runoff" based on data about field slope and soil texture (Table 3). The background for this assumption is provided by Radcliffe and Nelson (2005) and Shkinkis (Шкинкис, 1981).

Leaching (L) as well as sub-surface drainage may be important pathways of P loss under certain conditions, particularly if the soil has a very high content of P. Sandy soils are tended to be particularly vulnerable since they have a very low adsorption capacity for phosphorus (Mainstone, Parr, 2002). High leaching losses have been documented from heavily fertilized sandy soils, particularly in combination with large phosphorus doses in the form of manure or artificial fertiliser (Djodjic, Bergstrom, 2005). Other soils are supposed to be less vulnerable, but still may be at risk due to macropore and fissure flow within the soil structure. Concentrations of P in leachate vary notably between soil textures. Fortune, Lu et al. (2005) have pointed out the change point concentration above which a significant quantity of P is available for leaching losses. Change point is the P concentrations in soils at which the rate of P leaching from soil suddenly increases. The frequent application of animal manures has been shown to promote the downward movement of P. The results suggest that despite the establishment of fast growing grass, P concentrations would not be mitigated in the short-term, due to the large contribution of P in subsurface pathways (McDowell, Sharpley, Folmar, 2001). Another option to reduce the risk of phosphorus leaching is to grow crops such as lucernes, which due to their deep root system have the capacity to take up large amounts of phosphorus from the soil. At harvest, the phosphorus is then removed from the field (Bergström, Djodjic et al., 2007). However, opinion about leaching varies, for example, loamy soils are attributed a higher weight in the Danish PI than sandy soils due to the risk of macropore flow. Danish studies also have shown large P losses from tile-drained organic soils. The phosphorus binding capacity of soils is almost exclusively associated to the mineral fraction. Thus, the P binding capacity of organic soils is normally very low. Consequently, organic soils are assigned the highest risk of P leaching in the Danish PI (Andersen, Heckrath et al., 2007). Organic soils often are represented as the ones with higher risk of P releases (Loeb, Lamers, Roelofs, 2008). This effect has also been shown in the Norwegian monitoring programme where P losses were highest from organic soils compared to other soil types (Heckrath, Bechmann et al., 2008). According to previous studies, P loss risk classes for parameter "leaching" are defined and rated as: (a) clay (1 – very low risk); (b) loam (2 – low risk); (c) sandy loam (4 – medium risk); (d) sand (6 – high risk); (e) peat (8 – very high risk).

Subsurface drainage component (D) estimates the amount of total dissolved P delivered to surface water resources through flow to tile lines (Mallarino, Stewart et al., 2002). The presence of tile drains leave impact on the natural flow of nutrients through the soil profile, as they are designed to move water quickly from the soil subsurface to recipient streams, and often they bypass any buffer zones which would otherwise prevent a nutrient loss to the waterway. The subsurface drainage component that describes the possibility that P may be delivered to surface water through drainage is necessary because of the vast area of land in Latvia that has been tiled. It has been believed that P is mainly lost from the field by surface runoff and soil erosion. However, recent studies have shown that a considerable portion of total P added to the field is lost through sub-surface runoff. As a result, it is considered that P transport through subsurface runoff is negligible. However, for the highly fertilized soils, any added P can exceed the P sorption capacity of the soil, causing P concentrations to increase in the soil solution (Sharpley, 1995; Nohra, Chandra et al., 2007).

Now it has been shown that a considerable percentage of P loads come from subsurface discharge of tile-drained fields (Nohra, Chandra et al., 2007). However, dissolved P tends to be higher in surface runoff than in drainage flow (Turtola, Jaakkola, 1995; Ekholm, Turtola et al., 2005). Tile drains and the presence of inlets for collection of surface runoff increase the field connectivity and thereby the risk for P losses. Recent research has shown that a considerable load of P in fresh water bodies is attributed to subsurface runoff from artificially drained fields (Kronvang, Bechmann et al., 2005; McGechan, Lewis, Hooda, 2005). There are also remarks that phosphorus moves readily through soil to field drains when macropores are water-filled, but in dry soil the P carrying colloids become trapped, so losses remain at a low level (McGechan, Lewis, Hooda, 2005). Loss of P from tile-drained soils includes both particulate and dissolved P fractions transported from the soil surface through soil or macropores to the tile drainage system. Consequently, sub-surface drainage and leaching may be important pathways under certain conditions, particularly if the soil has high content of P (Mainstone, Parr, 2002). Phosphorus losses in drainage dominate also on the tile-drained clay soils in the region around big lakes in south and central Sweden (Djodjic, Bergstrom, 2005). Loamy soils have been attributed a higher weight, i.e. a higher risk of P losses, in the Danish PI than sandy soils due to the risk of macropore flow and rapid transport of both particulate and dissolved P to drains. Some organic soils have a low P-binding capacity, therefore, typically tile-drained, organic soils tend to be particularly vulnerable to P losses (Heckrath, Bechmann et al., 2008). Djodjic and Bergstrom (2005) show that the main P transport mechanisms are surface runoff and subsurface drainage. Also in Denmark tile drains and leaching are considered major P loss pathways (Andersen, Kronvang, 2006). For tile drained areas there is a direct link of subsurface drainage from field to stream, consequently the risk class is higher for a field with drainage. The presence of tile drains should be an important factor in the transport and loss of P to the water body. When precipitation occurs in an area, which has drainage, the fine loose particles are the first to be flushed from the site during the initial rainfall activity (Sharpley, McDowell, Kleinman, 2001). Tile drainage and soil erosion is linked to increased volume of both dissolved phosphorus (DP) and particulate phosphorus (PP) entering in waterways. For the presented model, parameter "drainage" is placed in the following rating categories of P loss risk: (a) no drainage (1 – very low risk); (b) single tile drains (2 – low risk); (c) systematic tile drainage (4 – medium risk).

The presented index model considers identification of the presence or absence of surface runoff collectors on a field and uses it as **filter wells parameter (W)**. Filter wells as cylindrical artificial channels in the subsoil do function of temporary method of drainage and speed up surface runoff to drainage system or direct drain to surface water bodies. Filter wells decrease overland flow and P transport. As the spacing and the travel distance of the water increases, water reaching the filter wells has greater amounts of P. This parameter is ranked in fallowing categories: (a) no filter wells on field (1 – very low risk); (b) filter wells on field (2 – low risk). The **vegetative buffer factor (B)** accounts for the removal of finer particles that are transported in the eroded sediment (Zaimes, Schultz, 2002). A buffer zone is a varying width strip of uncultivated land, which runs alongside the water body. Its purpose is to act as a trap for sediments being transported down-slope towards the water body, as well as utilizing an area where soluble P can be adsorbed and/or utilized by the plant cover before it is lost to the stream (Zaimes, Schultz, 2002). Buffers at the stream can reduce the P load to streams, by stabilizing stream banks; however; the effects of established buffer strips along the streams on transport of the eroded material containing P from the edge of the fields to the watercourse are known to be extremely hard to estimate. Another positive effect of buffer strips is that ploughing and fertilizing close to the stream bank is avoided (Ulen, Kalisky, 2005). However, there are additions, for instance, that introduction of a buffer zone reduces losses of unreactive P, whereas it has a small impact on reactive P losses (Djodjic, Bergstrom, 2005). Unreactive P is generally considered to represent organic forms of P, although some condensed forms of P, such as polyphosphates. Soil tillage changes (no tillage in autumn) have been shown to be able to greatly reduce soil and P losses from high to medium risk arable fields, but the probability for sediment to escape through buffer zones receiving runoff water and soil material seems to be very dependent on the buffer zone width. However, experiments with 5 and 10 m wide vegetated buffer zones in Norway showed high removal efficiencies for both soil material and total P (>70%) (Kronvang, Bechmann et al., 2005). In numerous experiments it has been demonstrated that even small buffer strips between a field and receiving waters can effectively retain large amounts of total P being mobilized from the field by erosion or surface runoff. Danish field-based research (Kronvang, Bechmann et al., 2005) has shown that the risk of sediments passing through a buffer strip is a function partly of the width of the buffer strip and partly of the magnitude of the uphill erosion. It is documented under Norwegian conditions that vegetated buffer zones reduce surface runoff losses of P by 42–96% using buffer zones of 5–10 m width (Bechmann, Krogstad, Sharpley, 2005). The suggested PI model uses recommendations of Latvia Good Agriculture practice and sets the following risk classes for the parameter "buffers": (a) at least a 4 m wide buffer zone from the field edge (for draining-ditch) with perennial grassland (0 – very low risk); (b) at least an 1.5 m unploughed and grassed zone between the field and the draining ditch (2 – low risk); (c) no protective zone (4 – medium risk).

Moreover, there are a number of factors that could also be included in PI calculations to rise up or to bring down the value of PI. All factors that could diminish or, quite opposite, accelerate P loss or, in other words, factors that are consequent on Good Agriculture practice are called correction parameters. One of them – **contributing distance (C)** – is adapted in a number of index examples. The contributing distances refer to the distance of the field from the stream. As the distance increases, the risk of P pollution decreases. Gburek and Sharpley (1998) have showed that not all fields within a catchment have the same risk of actually causing pollution in the stream via distance from edge-of-field to stream. According to this it is suggested that areas greater than 50 m from the open stream are less important for nutrient transfer than near-stream zones. Similarly, several P indices call for screening tool that includes estimation of field distance to nearest water body. If the distance is grater than 45–50 m, PI calculation is stopped (The Pennsylvania …, 2006). Generally, the nearest water body is the water source where phosphorus enrichment could be a problem. For purposes of the PI, any permanent stream, lake or wetland, drainage ditch or other water course that is wet most of the year and eventually empties to a stream or a lake should be considered the nearest surface water (Minnesota Phosphorus …, 2006). Consequently, the study suggests using correction for P transport erosion and runoff parameters according to field distance to the nearest water body, multiplying the sum of these factors with the corresponding weights: (a) distance greater than 150 m – 0.2; (b) distance from 50 to 150 m – 0.6; (c) distance less than 50 m – 1.

Also results from the P research experiments strongly indicate that tillage practice, **fertilizer application type (FT)**, and soil management strongly affect erosion and losses of P via surface runoff (Ulen, Kalisky, 2005). It is a well known fact that incorporation of P lowers the risk of being lost compared to surface application. Regulation No. 531 of the Cabinet of Ministers of the Republic of Latvia, adopted on 18 December 2001, "Regulations regarding Protection of Water and Soil from Pollution with Nitrates Caused by Agricultural Sources" (MK noteikumi Nr. 531 ..., 2001) require incorporation of manure on arable soil within 24 hours (solid manure) or 18 hours (slurry) after application. Suggested time for application of organic fertilizers is from March 1 till November 15, but for chemical P fertilizers – until October 15. The application of P on frozen or snow-covered soil introduces a high risk of P loss through surface runoff, consequently Latvian national regulations prohibit P application on snow-covered or frozen ground, thus tending to assumption that P application on frozen soil has the highest risk value. Snow, snowmelt, soil freezing and thawing phenomena also are very important for the amount of P transferred in Norway. As research in Norway shows, P losses during snowmelt contribute on average 30% of the total annual P load in small agricultural catchments in south-eastern Norway (Heckrath, Bechmann et al., 2008). Based on local legislation stipulations (MK noteikumi Nr. 531 ..., 2001) there is proposed correction for parameter "P application factor" by using weights for fertilizer application type as follows: (a) incorporation of fertilizers into soil at least 5 cm deep directly after application – 0.2; (b) incorporation of manure into soil during 24 hours after application, and for slurry within 12 hours – 0.4; (c) incorporation of manure into soil later than in 24 hours during March 1 till November 15, and mineral fertilizers for grasslands till October 15 – 0.6; (d) incorporation of manure into soil later than in 24 hours during November 15 till March 1, and mineral fertilizers for grasslands later

Table 4

Site vulnerability rating (phosphorus hazard classes)

P risk class	Rating	Interpretation
Very low	0–70	If soil conservation and P management practices remain at current levels, impacts on surface water from P losses from the field will be considered to be small
Low	71–120	P delivery to surface water bodies is greater than from a field with a very low rating, current soil conservation and P management practices likely do not worsen the water quality
Medium	121–170	Impacts on surface water are considered to be higher than for a field with a low rating, P delivery potential does not significantly produce water quality impairment. However, consideration should be given to P management practices that could reduce the risk of P delivery
High	171–300	Impacts of surface water resources are considered to be high. Remedial action (soil and water conservation and/or P management practices) is required to reduce P movement to surface water bodies
Very high	>300	Impacts on surface water resources are extreme. Remedial action is required to reduce P movement such as all necessary soil and water conservation practices and P management plan

than October 15 – 0.8; (e) spreading of fertilizers on wet, frozen, snow covered soil or in territories under risk of flooding – 1.

Very important factors are not only timing and method of P application but also amount of P fertilizers applied and availability of P in different types of manure. For future development of PI it is advisable to use several additional correction parameters for P application factor as **fertilizing rate (FR):** (a) do not cover crop requirements for nutrients – 0.8; (b) cover cultivated plant requirements for a nutrient – 1; (c) exceed cultivated crop requirements for a nutrient – 1.2; as well as type of **organic fertilizer (OF)**: (a) no manure or compost – 0.2, (b) compost – 0.6; (c) cattle manure or slurry – 0.8; (d) pig slurry, manure or poultry manure – 1. However, it is necessary to carry out more observations and investigations about field distance to water body. The general conservation recommendations are based on the national legislation. Additional characteristics that have been considered are not used for tested fields because their contributions are not fully understood and they are considered difficult to obtain.

PI Calculation and Risk Class Identification

The designed PI is partly based on original PI and on the framework of the Pennsylvanian PI and its modifications – Norwegian and Danish PI. The basic PI calculation includes the multiplication of P source and transportation factor values:

$$PI = SF \times TF, \qquad (1)$$

where

SF – source factor;

TF – transportation factor.

Calculation of the source factor is suggested as follows:

$$SF = SP + AP, \qquad (2)$$

where

SP – soil P status;

AP – application of P fertilizers.

Recommended calculation of P transportation factor is described by formula:

$$TF = E + R + L + D + W + B, \qquad (3)$$

where

E – erosion component;

R – runoff;

L – leaching;

D – drainage;

W – filter wells;

B – buffers.

However, advanced model of PI asks to take into account also correction factors:

$$PI = (SP + (AP \times FR \times FT \times OF)) \times ((E+R) \times C) + L + D + W + B), \quad (4)$$

where

FR – fertilization rate;
FT – fertilizer application type;
OF – organic fertilizer type;
C – contributing distance.

The numerical values that correspond to the appropriate levels for each characteristic are preferable to multiply by the weighting factor to obtain the characteristic's rating (5). The rating system then can be changed to meet most localized conditions:

$$PI = \{[\Sigma (SF \times w) \times \Sigma (TF \times w)]\}, \quad (5)$$

where

w – weight factor.

The suggested risk class boundaries and risk class description for every field to loss of phosphorus are defined in Table 4 showing PI rating values for fields, based on the value that was calculated from PI. The higher the PI value, the more expected that the field is more vulnerable to phosphorus loss.

Conclusions

The results of this study suggest that, with certain limitations, the PI can be used at the field scale to prioritize P loss vulnerability using readily available data from a field. Further research should be done on the strengths and weaknesses of the approach in a certain site adjusting the PI more accurately to a particular region. Most important, PI cannot quantify P loss in waters because it is a qualitative tool that only predicts the potential P loss, and the development of adapted tools for European countries still is at an early stage. Therefore, the first adapted version of PI version must be validated in local conditions.

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Anotācija

ASV radītais un plaši izmantotais fosfora indekss ir rādītājs, ar kura palīdzību novērtē fosfora noplūdes riska iespējamību virszemes ūdenstilpēs un ūdenstecēs no lauksaimniecībā izmantojamām platībām. Indeksa oriģinālā versija pēdējos gados tiek modificēta un piemērota lietošanai vairākās Rietumeiropas un Skandināvijas valstīs

saistībā ar ūdeņu eitrofikācijas problēmu risinājumiem, savukārt fosfora nonākšana ūdens vidē tiek uzskatīta par vienu no eitrofikācijas cēloņiem.
Indekss kā riska modelēšanas instruments fosfora slodzes novērtēšanai uz ūdeņiem no minerālmēslu un citiem avotiem veidots izmantošanai zemnieku saimniecībā. Indeksā iekļautie fosfora avota (fosfora saturs augsnē, pielietotie minerālmēsli vai organiskie mēsli) un fosfora transportēšanās uz ūdens avotu sekmējošie faktori (erozija, notece, izskalošanās, drenāža) ļauj izvērtēt fosfora zudumu iespējamo daudzumu, fosfora zudumus veicinošos faktorus un lauku apsaimniekošanas praksi fosfora zudumu ierobežošanai. Fosfora indeksa rezultāts raksturo katru saimniecībā pētāmo lauku atbilstoši 5 riska klasēm: ļoti zems, zems, vidējs, augsts un ļoti augsts risks. Rakstā analizēti fosfora indeksā iekļautie parametri, parametru vērtību piesaiste riska klasēm un indeksa algoritma struktūra.