Use of the DPS indicator for risk assessment of phosphorus losses in surface runoff: evaluation of the method and application to the Baltic Commune of Puck

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Abstract

Background. Risk assessment of phosphorus (P) losses in surface runoff from agricultural land is a basic measure that should be included in action plans to counteract eutrophication in watercourses and water reservoirs. To assess this risk, a new method has been recently developed based on estimation of degree of P saturation (DPS) on the grounds of P concentration of water extract (water-soluble P – WSP).

Methods. Based on the DPS method, the risk of P losses in surface runoff from agricultural land in Puck Commune (Baltic Sea Coast) was assessed and compared to an agronomic interpretation of soil test P concentration (STP). The research was conducted on mineral and organic soils from 50 and 11 separate agricultural plots with a total area of 133.82 and 37.23 ha, respectively. In the collected soil samples, P was extracted using distilled water (all soil samples), acid ammonium lactate (mineral soils) and extract of 0.5 mol $HCl \cdot dm^{-3}$ (organic soils). The organic matter content and pH values were also determined. The results of P content in water extract from soils was converted into DPS values, which were classified by appropriate limit intervals.

Results & Discussion. It was found that there was a high risk of P losses from soil via surface runoff transport in 96.7% of the tested agricultural parcels (96% plots with mineral soils and 100% plots with organic soils). Simultaneously, a large deficiency of plant available P was found in soils from 62% of agricultural plots. These data indicate that the assessment of P

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concentration in soils made on the basis of an environmental soil P test conflicts with this kind of assessment based on STP (the assessment results create cognitive dissonance). It should be recognized that the risk level of P losses in surface runoff from the analyzed plots determined by the DPS indicator is uncertain. This uncertainty is increased by the lack of linking the DPS index with other significant factors in P runoff losses such as type of crop and area inclination.

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Introduction

The Baltic Sea is a basin affected by strong eutrophication (*Andersen et al., 2011; HELCOM, 2018b*) which results in many adverse changes in the marine flora and fauna (*Ojaveer et al., 2010*) and in turn leads to large social and economic losses (*Ahtiainen et al., 2014*). One of the main reasons for eutrophication of the Baltic Sea waters is the excessive river inflow of phosphorus (P). The inflow from the entire Baltic basin is estimated at 29.3 tons per year, of which 35.7% comes from dispersed sources, mainly from agriculture (*HELCOM, 2018a*). About 12.7 tons of P are brought from Poland to the Baltic Sea by river waters (*HELCOM, 2018a*), including 21 or 33% from the agricultural sector depending on the method of assessment (*NWMB, 2016a*). In order to counteract the eutrophication of the Baltic Sea, various initiatives and actions have been taken for many years, both at the regional and national level, aimed at limiting the supply of P to the waters of the Baltic Sea. Particularly important arrangements have been recently made at the Conference of Ministers for the

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Environment of the HELCOM countries held on 3rd October 2013 in Copenhagen. It was specified, among others, expected degrees of reduction of total P loads discharged by the HELCOM Member States to the Baltic Sea (Reference is need). According to them, Poland should reduce the P inflow to the Baltic Sea by 51%, respectively, compared to the reference period 1997-2003 (*NWMB*, *2016a*). Poland approved this level of reduction as a rough indication, stating that it will adopt a final position after conducting relevant analyses. Regardless of their result, Polish agriculture is expected to face a major challenge to significantly reduce its pressure on the Baltic Sea in terms of P. There is a need to seek and implement effective solutions to reduce P loss from agricultural sources to waters considering Conferences provisions as well economic factors and prevention from eutrophication of inland surface waters (according to polish monitoring data, in 2012-2015 eutrophication parameters (nutrient and chlorophyll-a concentration, water transparency) were exceeded by 42% for sites located on flowing waters (rivers) and by 66% for stands on stagnant waters (lakes/water reservoirs) (*NWMB*, *2016b*)). The list of measures should include tools and procedures for controlling agricultural land soils in case of P loss in surface runoff. Thanks to the results of such a control it is possible to manage agricultural land so as to minimize the threat posed by excess P in aquatic ecosystems. In this context, it should be stated that the problem of diagnosing threats to rivers and reservoirs by P loss from agricultural soils is by no means new and has been of interest to many researchers for years. This problem is most commonly considered in terms of interactions between the content of plant available P in soil

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(determined by various methods, for example Mehlich 3, Olsen, Egner-Riehm), and P saturation in runoff water. Using this approach, it was proved that as P content in soil increases, its amount increases along with surface runoff (*Pole et al., 1996; Torbert et al., 2002; Sharpley & Kleinman, 2003; Pietrzak, Wesołowski & Brysiewicz, 2017*), yet the system of cultivation of plants and the type of soil have an impact, too (*Gaj, 2008 after: Sharpley et al., 1981*). It should be emphasized that the existing P agrochemical tests are not equally useful for testing all soil types – which is a factor limiting their use.

Another applied approach to assessing P loss from agricultural soils via rainwater and the risk of surface waters eutrophication is based on the determination of the degree of P saturation (DPS) (*Alleoni, Fernandes & de Campos, 2014*). The DPS in its classical formula is expressed in percentage relation of the P content in the soil extract to the P sorption capacity of soil, wherein various approaches are used for determination of the components in this formula (*Nair et al., 2004; Casson et al., 2006*). The procedure for determining the DPS index according to this formula is unique for different types of soil, which can create specific methodological problems and limit the possibilities of its wider use (*Sapek, 2007*). Pöthig et al. (*2010*) have recently developed a different method for determining this index according to which the only factor from which the DPS indicator depends is the P content in soil determined with the use of distilled water – WSP (water-soluble P). This method is attractive because it is simpler and has the potential of being applicable to different soil types. In the MONERIS model (Modelling Nutrient Emissions into River Systems), developed for

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The aim of this work is two-fold: (1) estimate the risk of P loss in surface runoff from agricultural soils in the conditions of the Puck Commune using the DPS indicator determined on the basis of WSP, and (2) identify the practical utility of this index.

Material & Methods

This research was conducted in the Puck Commune. It is located in Poland, in the north-eastern region of the Pomeranian Voivodeship, on the western shore of the Puck Bay, which is part of the Baltic Sea. The land use structure in Puck Commune is dominated by agricultural land (57.3% of the total area of the commune), the vast majority of which is characterized by high yield potential. The area is largely undulating, with land falls up to approx. 9% (5.14°). Such landform features increase the risk of P loss in surface runoff. The study presented in this paper is a part of the project "Modelling of the impact of the agricultural holdings and land use structure on the quality of inland and coastal waters of Baltic Sea set up on the examples of the Municipality of Puck region – Integrated info-prediction Web Service WaterPUCK" (*Dzierzbicka-Głowacka et al., 2019*).

In the spring of 2018, soil samples from 61 agricultural plots from 22 farms were taken for chemical analysis based on the guidelines included in the PN-R-04031:1997 standard. An

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overall (aggregate) sample was created by combining and thoroughly mixing a set of primary (individual) samples of up to 20 items. In the overall samples, in laboratory, the organic matter content in the layer of 0-5 cm, pH in the layer 0-30 cm, the concentration of plant available P in layers 0-5 and 0-30 cm and the content of WSP in the layer of 0-5 cm (WSP_w1) were determined. In this regard:

(1) fraction content below 0.02 mm was determined by the sedimentation (pipette) method according to PN-EN ISO 17892-4:2016 standard;

(2) organic matter content was determined as a loss on ignition at 550°C by the weight method according to PN-EN 12879:2004 standard;

(3) pH measurement of soil was conducted in 1N suspension of KCl solution by potentiometric method according to PN-ISO 10390:1997 standard (pH_{KCl});

(4) the concentration of available P forms (in agronomic soil P test – STP) in mineral soils was determined in acid ammonium lactate (pH ~ 3.55) according to PN-R-04023:1996 standard (P_{AL}) and in organic soils – in the extract of 0.5 mol HCl·dm^{-3} according to PN-R-04024:1997 standard (P_{HCl}); the content of WSP (in environmental soil P test), in mg P·kg^{-1} of soil, was determined by the method of Inductively Coupled Plasma Optical Emission Spectroscopy ICP-OES after stages involving drying soil samples in the air and sieving them (through the sieve <2 mm), preparing a suspension in the ratio: 1 g of soil in 50 ml of distilled water, agitation for 2 hours, filtration through a 0.45 μm filter.

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The of analysis of soil samples were ordered and evaluated according to the following criteria:

(1) Based on the soil organic matter (SOM) content, the soils were divided into mineral and organic. With the SOM content of more than 10% (threshold value between mineral and organic soils) organic soil was classified as organic (on the basis of: *Szymanowski, 1995; PN-R-04024:1997*).

(2) According to the accepted standards, the assessment of soil acidification was conducted, defining their reaction classes: very acidic, acidic, slightly acidic, neutral and alkaline under conditions where their measured pH was in the following ranges: ≤4.5; (4.5-5.5]; (5.5-6.5]; (6.5-7.2] and >7.2.

(3) An assessment of P content in soil was conducted with respect to threshold values given in the following standards: PN-PN-R-04023:1996 and PN-R-04024:1997, for the following abundance classes: very low, low, medium, high and very high – Table 1. The basis for the assessment was the percentage share of the soil samples tested in individual concentration classes.

(4) Based on the results of the P content determination in soil using water extract, DPS, in %, indices were calculated using the equation (*Pöthig et al., 2010*):

$$DPS(\%) = \{1/[1 + (1.25 \cdot WSP^{-0.75})]\} \cdot 100$$

where: WSP – is the content of water soluble P, mg P·kg^{-1} of soil.

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On the basis of the determined P saturation indices, the risk of P loss by surface runoff was assessed using the limit intervals specified by Pöthig et al. (*2010*) – Fig. 1. It was assumed that if the DPS value exceeds 80%, there is a high risk of P loss from the soil by surface runoff, DPS values lower than 70% were considered as safe, and values between 70 and 80% as tolerable.

The results of laboratory tests were also scrutinized statistically determining the basic parameters of descriptive statistics and correlations between the analyzed soil indices. The statistics of the results were prepared with the use of a program designed for statistical data analysis – the Statistica 6 (*STATISTICA Help*).

Irrespectively of the DSP-index analysis, interviews with farmers and indoor work were conducted aimed at determining the consumption of P fertilizers in 22 farms selected for this research, area and type of development of agricultural plots, recognizing the categories, and soil types and subtypes as well as inclination of slopes in the research area. In these works the following were used: specially prepared questionnaires filled by farmers, the results of own terrain observations, a soil agricultural map of the Puck Commune in a vector format (*IUNG-PIB*) and maps of selected agricultural plots acquired with the use of Google Earth Pro.

Results

The research covered soils taken from 61 separate agricultural plots with a total area of 171.05 ha. 50 plots with a total area of 133.82 ha were agricultural lands (AL) made from

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mineral-derived soils (with an organic matter content of 2.53-7.01%), and 11 plots with a total area of 37.23 ha were AL made from organic soils (characterized by organic matter content at the level of 25.60- 68.17%). Given the genetic criteria, the following types and subtypes of soils occurred in the research area in the given proportions (constituting the share in the area): brown soils – 61.9%, brown soils, lessive soils, podzolic soils and rusty soils made from gravel and sands – 10.2%, lessive soils – 3.7%, black soils – 2.4%, peat and muck-peat soils – 21.8%. Among mineral soils, medium soils (21-35% content of particles with diameter less than 0.02 mm) dominated, covering 49.7% of their area, followed by very light (to 10% content) and light soils (11-20% content), whose share in the mineral soil area was 39.1 and 11.2%, respectively. On most plots with mineral soils, grains were grown, while most of the plots with organic soils were covered with permanent grassland. The area of these plots was largely undulating – Fig. 2, with landfalls of up to approx. 9% (5.14°). Such landform features increased the danger of P loss in surface runoff.

On farms in which the agricultural plots were located, the average consumption of P fertilizers in 2017 was 11.1 kg $P \cdot ha^{-1}$ of agricultural land (AL) with a range of 0-24.9 kg $P \cdot ha^{-1}$ AL on the individual farms. This type of fertilizers most often – in over 54% of agricultural holdings, was used in doses of 5-10 and 10-15 kg $P \cdot ha^{-1}$ AL – Table 2.

The analyzed soils in the 0-30 cm layer – which is treated as a diagnostic layer in the analysis of agrochemical properties of soils for the needs of fertilizer consultancy, were characterized by a pH_{KCl} within 4.2-7.2 (average 5.4) – 4.2-7.2 (average 5.4) and 4.9-6.3 (average 5.5) in

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case of mineral and organic soils, respectively. The available P forms concentration in the 0-30 cm layer of analyzed soils reached values from 3.6 to 66.5 mg P_{AL}·kg^{-1} (average 33.3 mg P_{AL}·kg^{-1}) in case of mineral soils and from 171.0 to 707.0 mg P_{HCl}·kg^{-1} (average 340.6 P_{HCl}·kg^{-1}) in case of organic soils. Within individual categories of mineral soils, the highest amounts of P were found in light soils (average 42.2 mg P_{AL}·kg^{-1}) while in very light and medium soils the P content was on a similar level (25.6 and 25.8 mg P_{AL}·kg^{-1}). In the soil layer of 0-5 cm – treated as a standard in environmental research on establishing relationships between the quantitative state of P in soil and surface runoff (*Sharpley et al., 1985; Schindler, German & Gelderman, 2002; Schierer, Davis & Zumbrunnen, 2006; Hansen et al., 2012*), the P concentration ranged from 3.6 to 68.8 mg P_{AL}·kg^{-1} (average 35.4 mg P_{AL}·kg^{-1}) in mineral soils and from 136.0 to 526.0 mg P_{HCl}·kg^{-1} (average 284.6 P_{HCl}·kg^{-1}) in organic soils. In this layer, the P concentration in mineral soils was on average 6.5% higher than in layer 0-30 cm while in organic ones – 16.6% lower. In turn, the WSP_w1 content in the tested mineral and organic soils was determined in water extract was in the range of 2.2-58.5 mg WSP·kg^{-1} (average 24.6 mg WSP·kg^{-1}) and 13.7-79.5 mg WSP·kg^{-1} (average 40.3 mg WSP·kg^{-1}), respectively. At this level of mineral soils there was on average 39.0% less P than in organic ones. In mineral soils the content of WSP_w1 was variable depending on their type – on average it was 20.0, 32.8 and 17.0 mg WSP·kg^{-1} in very light, light and medium soils.

Discussion

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One of the most important factors determining the physical, chemical and biological soil properties is pH. It affects the availability of P accumulated in soil for plants and the P loss to the environment (*von Tucher, Hörndl & Schmidhalter, 2018*). The soil acidity test showed that 62.3% of plots were characterized by a very acidic and acidic reaction, 31.1% of plots slightly acidic, and 6.6% neutral, whereby the share of mineral and organic soils in individual reaction classes was varied – Fig. 3. These conditions are common in Puck Commune where 13% and 54% of the soils are considered very acidic and acidic, respectively, (*Puck Commune Office, 2016*) and much worse than in the Pomeranian Voivodeship and Poland where these fractions reduce to 10, 31% and 12, 25%, respectively (*GUS, 2018*). In the range of the optimum pH value – which can be assumed at 5.6 to 7.0 for mineral soils (for the majority of cultivated species of plants in Poland) (*Kocoń, 2014*) and at 4.5 to 5.5 for organic soils (*Barszczewski, Jankowska-Huflejt & Mendra, 2015 after: Moraczewski, 1996*), there were soils covering 34.4% of plots, including 30% plots with mineral soils and 54.5% plots with organic soils. These data indicate that on more than 1/3 of the soil pH from research area was very unfavorable from an agronomic and environmental point of view.

Results of STP showed also that in about 62.3% of plots the P content was „very low" and „low", compared to 32.8% „medium" – Fig. 4. In 4.9% of all plots, soil fertility in P was „high" and „very high". In comparison with mineral soils, the share of organic soils was much smaller in the abundance classes „very low" and „low", and much higher in the classes „medium" and „very high". Soils with high P deficiencies (very low and low P content)

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In the spatial arrangement the distribution of soil pH and available P forms concentration in individual classes had a rather irregular character – Fig. 5. Very low or low P content in the 0-30 cm layer of soil with very acidic and acidic reaction was particularly often noticeable.

Calculated on the basis of WSP in the analyzed soils, their DPS index was in the range of 59.1-95.5% (average 88.4%) – Table 3. It should be noted that organic soils were characterized by higher DPS values than mineral ones.

For soils from 59 plots, including 48 with mineral soils and 11 organic soils, the DPS values were set at 80% and higher – Table 4. There was a high risk of P losses from these soils to water following the approach to determining this risk suggested by Pöthig et al. (*2010*). The legitimacy of such evaluating would require verification by additional studies determining a relationship between WSP/DPS and P concentration in surface runoff. Previously conducted in north-western Poland (53°16’2.46”N, 14°46’9.42”E) this type of studies showed that the

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soluble phosphates concentration (P-PO_4) in surface runoff from mineral soils with a P content of 10.3-86.1 mg WSP·kg^{-1} (average 23.2 mg WSP·kg^{-1}) ranged from 0.34 to 17.89 mg·dm^{-3} (average 3.11 mg·dm^{-3}) (*Pietrzak, Majewska & Wesołowski, 2016*). It follows that from studied mineral soils in which the average WSP content was 24.6 mg·kg^{-1} significant amounts of P-PO_4 in surface runoff could be obtained under certain conditions.

The high DPS values observed for almost the entire research area suggest that for environmental reasons P fertilization should be limited. This is an opposite conclusion in relation to the one which results from the STP. To resolve the observed conflict between the results of P soil tests obtained on the basis of agronomic and environmental test methods further research is needed. Indirectly, some light on these antagonistic assessments is cast by the results of research on soil sorption properties in a place located in close proximity to the research area – Table 5, obtained as a part of the arable soils chemism monitoring in Poland. They indicate among others that this soil was characterized by a relatively low cation exchange capacity (CEC), and thus a low soil buffering capacity, as well as the content of exchangeable aluminum (ExAl). Typical CEC and ExAl values for similar soils in Poland are from 7.18 to 10.38 and from 0.33 to 0.41 cmol(+)·kg^{-1}, respectively (*Fotyma & Mercik, 1995*). A small ExAl content in the monitored soil could have been caused by the applied P fertilization which results the reduction of free Al^{3+} ions (*Filipek, 1989; Brzeziński & Barszczak, 2009*) due to the precipitation of insoluble aluminum phosphates. In the soils on the majority of research plots the Al^{3+} content level was also probably low which in part may explain large P (available for plants uptake) deficiencies established by STP. In this context it seems that more reliable results of P content assessment in the tested soils were obtained by agronomic test method compared to the environmental one.

Notwithstanding of the above, there were numerous interactions between the analyzed soil indices. First of all, they occurred between indices describing mineral soils. In this case, each parameter analyzed was correlated with all others (according to the peer-to-peer mechanism) – Table 6. These were positive and mostly strong or very strong dependencies.

There was a relatively low correlation between the pH_{KCl} value of the soil and its P_{AL} content determined both in the layer up to 5 and 30 cm. However, this correlation indicates that by reducing the acidity of soils plant available P would increase to a certain extent. It is worth emphasizing that the pH_{KCl} of soil is one of the factors that have the greatest direct impact on the P availability. In acid soils, a large part of this component is immobilized by manganese (Mn), iron (Fe) or aluminium (Al) compounds. The use of liming on such soils increases the amount P available for plants uptake.

The P_{AL}_w2 and P_{AL}_w1 contents were most strongly correlated with each other which indicate that P was quite uniformly accumulated in the topsoil (0-30 cm). Hence, the data regarding P state may prove equally useful to quantify P loss in surface runoff from agricultural land at each of mentioned levels. The possibility of using soil samples from more than 5 cm level to assess the risk of P losses in surface runoff is also suggested by Fischer's et al. studies (*2018*) conducted in Brazil which involve the use of P determinations results in the

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0-20 cm layer using the Mehlich-1P test (M1P) to calculate the DPS indicator values on the basis of M1P-WSP correlation determined on a set of soil samples.

There were fairly strong correlations between WSP_w1 and P_{AL} content. Similarly strong relationships were found between WSP and P_{AL} content in Brazilian and German soils defined by M1P and CAL (calcium-acetate-lactate) methods based on the P-extraction by a mixture of calcium lactate and calcium acetate (*Fischer, 2018*). In case of such correlations, it is possible to convert the results obtained with one method to another with great accuracy. As DPS is a function of WSP_w1 (R=1), then in a view of a relatively strong relationship between WSP_w1 and P_{AL}_w2 and P_{AL}_w1, the latter two indices also remained in a strong relationship with DPS indicator. While all the analyzed indices in mineral soils were correlated, in case of organic soils only P_{HCl}_w1 and P_{HCl}_w2 were statistically correlated, with the moderate degree of this correlation – Table 7, ignoring the natural relationship between DPS and WSP_w1. The correlation between the P_{HCl} contents in soil profiles 0-5 and 0-30 cm of organic soils was less stronger than in mineral soils which may result from the fact that they were not usually mixed when used (mainly for grasslands) and therefore did not favour homogenisation of their top layer composition – including P content. The lack of correlation between WSP_w1, P_{HCl}_w2 and P_{HCl}_w1 indicates that P transfers from soil to water and 0.5 mol HCl extracts in a different way and in disproportionate amounts due to their different extraction possibilities.

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In the light of presented research results and analyses as well as the purpose of the work, it should be stated that the risk of P loss to waters based on the DPS is arguable. As established, the share of agricultural plots with soils at high risk of P loss by surface runoff (DPS ≥ 80) was 96.7%, with 96% plots with mineral soils and 100% plots with organic soils. The obtained results indicate that soils practically in the whole analyzed area of agricultural lands were overly supplied with P, and suggest that measures need to be taken in this area to prevent its outflow to waters, e.g. by decreasing phosphate fertilizers application. However, the results of STPs revealed that in order to obtain satisfactory crops, the P content in assessed soils should be significantly increased rather than decreased (therefore, in terms of soil P management various or even contradictory conclusions emerge from environmental and agronomic assessments). They were indeed largely characterized by very low or low level of P – in case of plots with mineral soils, 72% of them were affected by this problem. It should be emphasized that in case of serious P deficiencies in soil (as identified in the research area), relatively small amounts of this component are found in surface runoff (*Pietrzak, Wesołowski & Brysiewicz, 2017*), which, given the episodic character of the formation of runoffs, indicates that the risk of surface water quality under these conditions should not be overestimated. Perhaps the reason why the results of STP and environmental soil P test yielded opposite assessments is negligible soils' P retention capacity. Such soils may be marked by low P content determined by agronomic test method and a high risk of P release (*Nair & Harris, 2004; Nair et al., 2010*).

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With regard to the STP, it is worth adding that from an agronomic point of view the vast majority of analyzed soils requires not only increased application of phosphate fertilization, but also liming in order to optimize their pH. This treatment would increase the solubility of bound (immobilized) form of P in the soil and thus increase resources of plant available P and would be productively justified, yet it could be considered unnecessary in terms of WSP analysis.

Doubts over the adequacy of determining the risk of P loss from soils to waters by means of DPS threshold values are increased by the results of the assessment conducted with respect to all analyzed organic soils, which were mainly under grasslands. DPS for these soils exceeded 80% each time so the risk of P loss to waters was high. However, it is difficult to take it as a deciding conclusion as grassland is a biological filter that protects against the release of pollutants into waters. The fact that this approach overlooks the aspect of landform features contributes to the uncertainty as to the risk of P loss in surface runoff from agricultural land soils to waters determined by DPS index. In these assessments, the inclination factor should be taken into account as it contributes to the risk of surface runoff – Table 8. In the research area there were sometimes significant landfalls which undoubtedly affected the dynamics of P outflow to waters. In addition, it should be considered that the outflow was shaped by a number of other factors, such as: physical and chemical soil properties (including pH and organic matter content), soil and plants cultivation, atmospheric conditions (*Ulen, 2013; Sapek, 2014)*. Such factors in the identifying of areas particularly exposed to P losses should

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be considered on a comprehensive approach. This approach is contained in a "P index" (*Lemunyon & Gilbert, 1993; Sharpley et al., 2003*). It is a measure of soil vulnerability to P movement from the field site to waters which consults the P sources and transport conditions. The "P index" is a widely used tool in the USA and Europe to assess the risk of P losses from agricultural landscape to surface water (*Buczko & Kuchenbuch, 2007*).

As indicated above, the problem of determining the risk of P loss in surface runoff from agricultural soils to waters is complex. The assessment of such a risk should by no means depend solely on the value of DPS index. Therefore, it is justified that DPS indicator should be considered not alone but in conjunction with a set of various parameters characterizing the possibility of P losses from agriculturally used soils to watercourses and water reservoirs.

Conclusion

The research was conducted on a typical undulating area of agricultural land in the Puck Commune, 78.2% of which consisted of arable land and 21.8% of grassland. In terms of mechanical composition, agricultural land soils were predominantly medium and light, whereas alluvial soils were entirely of organic origin. Most of them were characterized by high acidity (on more than 62% of agricultural plots the soils had a very acidic and acid reaction) and deficiency of plant available P. In the latter case, over 62% of the analysed soils – including 72% of mineral soils and over 18% of organic soils – were characterized by very low and low content of the mentioned component. The DPS (determined on the basis of P content extracted in the water extract) in almost all of the assessed soils exceeded 80%. Hence, taking into account the existing criterion of DPS index assessment, there was a high risk of P loss in surface runoff to water. It seems, however, that this assessment should be approached cautiously as it does not correspond to the results of the agronomic assessment of the P content in soil (conducted in terms of requirements for application of phosphate fertilization). It also disregards other factors affecting P loss in runoff, such as the type of crop or area inclination.

In the light of the above, it can be concluded that the problem of determining the risk of P loss in surface runoff from agricultural land to water is still open. There is a need for further work on its solution.

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