Geoderma 237–238 (2015) 325–335

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Phosphate saturation degree and accumulation of phosphate in various soil types in The Netherlands

O.F. Schoumans *, W.J. Chardon

Alterra, part of Wageningen UR, PO Box 47, 6700 AA Wageningen, The Netherlands

ARTICLE INFO

Article history:
Received 11 December 2013
Received in revised form 1 August 2014
Accepted 22 August 2014
Available online 2 October 2014

Keywords:
Phosphate
Phosphate accumulation
Phosphate sorption capacity
Phosphate saturation degree
Phosphate saturated area
Sand
Peat and clay

ABSTRACT

Objective: The objective of this study is to quantify the potential risk of P leaching to groundwater in characteristic soil types in The Netherlands. In areas with shallow groundwater P losses via groundwater to surface waters is an important pathway.

Methods: The risk of P leaching to groundwater can be assessed by means of the phosphate saturation degree (PSD) methodology. The PSD is an index of the actual phosphate accumulation in the soil (P_{act}) in relation to the maximum phosphate sorption capacity (PSC_m) of the soil to a reference depth. To assess the risk of P leaching the actual PSD of soils has to be compared to the critical PSD (PSD_{crit}) of the soil type. The critical PSD is determined for characteristic soil types based on phosphate sorption and desorption characteristics, and a reference depth (L_{ref}) where a defined P concentration (C_p) in solution may not be exceeded. A stratified soil survey is used to determine the actual PSD of the soils.

Results: The critical phosphate saturation degree we determined for the main Dutch soil types varies from 5%–78%. The average P accumulation in agricultural soils in The Netherlands is about 2050 kg P ha^{-1} (4700 kg P_2O_5 ha^{-1}) and the 5‰ and 95‰ are approximately 850 and 4500 kg P ha^{-1}. Since maize can tolerate high manure application rates, more phosphate has been applied on maize in the past, and high P accumulations are measured. In about 43% of the agricultural land in The Netherlands the critical PSD value for the given soil type is exceeded.

Practice: Consequently, a large area of agricultural land contributes, or is expected to contribute to the P pollution of surface water in the nearby future. Especially from fields with a high PSD severe P losses can occur due to the convex relationship between the PSD and the P concentrations in soil solution.

Implementation: Strategies and additional measures are needed for fields with a high PSD in order to substantially reduce the P losses from agricultural land to surface waters within a catchment.

1. Introduction

In the mid-20th century, agricultural production in Europe was stimulated and intensified. As a result the national phosphorus (P) balance increased (OECD, 2008), since the amount of phosphorus imported in fertilizer and fodder became much higher than the amount exported in products (crops, dairy and meat). Manure production increased, especially in areas with high livestock densities, and consequently the manure application rates on agricultural land rose to levels far above plant requirements for phosphorus, and a potential environmental risk was born (Smit and Dijkman, 1987).

As phosphate accumulated in soil, emissions of phosphate to surface water increased and agriculture became a major source of nutrient enrichment of such waters (Lee, 1973; Vollenweider, 1968). Phosphorus loss from agricultural land in flat areas such as The Netherlands is mainly determined by the phosphate accumulation in soils in relation to the phosphate sorption capacity and hydrological conditions. Based on studies of the phosphate sorption capacity of sandy soil types (Schoumans et al., 1987; Van der Zee and Van Riemsdijk, 1986) and a simple regional phosphorus transport model (Schoumans et al., 1986), the first estimations of phosphate saturation of soils in The Netherlands were made for areas with non-calcareous sandy soils and high livestock densities (Breeuwsma and Schoumans, 1987).

In the early 1990s, a straightforward approach for non-calcareous sandy soils was developed to determine a critical value for the degree of phosphate saturation (known as phosphate saturation degree, abbreviated as PSD) in The Netherlands (Van der Zee et al., 1990a,b). The criteria required, namely the acceptable P concentration and reference soil depth that should be protected, were defined by a technical committee (TCB, 1990). As acceptable P concentration the natural background concentration was chosen (0.1 mg L^{-1} ortho-P) and as reference depth, the mean highest water level (MHW). In lowland countries like The Netherlands the groundwater is shallow and fluctuates during the year. In the summer period the lowest groundwater levels and during the winter period (autumn–spring) the highest groundwater levels are

* Corresponding author.
E-mail address: oscar.schoumans@wur.nl (O.F. Schoumans).

http://dx.doi.org/10.1016/j.geoderma.2014.08.015
0016-7061/

reached. In The Netherlands the mean highest and lowest groundwater level (MHW and MLW respectively) are defined as resp. the average of the three highest or lowest groundwater levels during a period of 8 successive years. In the wet areas the MHW varies between 0 and 0.4 m and the MLW between 0.6 and 1.4 m. During the year the groundwater levels can be above or below this level for a short period (<2 months). Using these criteria and the phosphate kinetics of non-calcareous sandy soils, a critical PSD of 25% was calculated, which means that the actual phosphate accumulation in the soil should be less than 25% of the total phosphate sorption capacity of the soil between the soil surface and the MHW. When this critical value for non-calcareous sandy soils was used in a modeling application it was found that about 70% of the agricultural land in non-calcareous sandy soils in areas with intensive husbandry in The Netherlands exceeded the defined critical PSD (Breeuwsma and Silva, 1992). At that stage it was not possible to define a critical value for the other soils in The Netherlands because no information was available on the phosphate sorption and desorption parameters and, moreover, the reference criteria had not been defined. Since then, the sorption and desorption processes in other Dutch soil types have been studied (Schoumans, in press; Van Beek et al., 2003) and the phosphate accumulation has been determined by measurements (Finke et al., 2001). The main aim of this paper is to derive indicative critical values of phosphate saturation for different soil types and estimate the phosphate-saturated area and phosphate accumulation in The Netherlands.

2. Materials and methods

The dataset of the national stratified soil survey (Finke et al., 2001) was used to estimate the degree of phosphate saturation of the Dutch soil types. The locations had been selected randomly within 95 strata (combinations of soil type and groundwater regime) that are presented in Fig. 1. The red area in Fig. 1 represents the location of one of the 95 strata: calcareous silty clay soils with a MHW between 0.4 and 0.8 m. This stratum, like other strata, is situated in different parts of The Netherlands. For the soil survey, the soil samples were collected from 1992 to 1998 by sampling the horizons of the soil to a depth of 1.20 m at about 1400 locations. If a horizon layer was thicker than 0.25 m, the horizon was subsampled in layers less than 20 cm each. The soil profiles were described and all horizons were sampled and their chemical characteristics were determined (pH, oxalate-extractable P, Al and Fe, for example). At each location the land use of the field and the mean highest water level (MHW) and mean lowest water level (MLW) were also determined.

Table 1 gives the number of locations sampled (n) and the area represented for combinations of soil type and land use. The average density is approximately one sampled location per 2000 ha agricultural land. Although the sample density is not high, it is the only statistical database available for the entire country that includes the parameters needed to determine the PSD. For each stratum the PSD of each location was calculated in order to produce a map of the average degree of phosphate

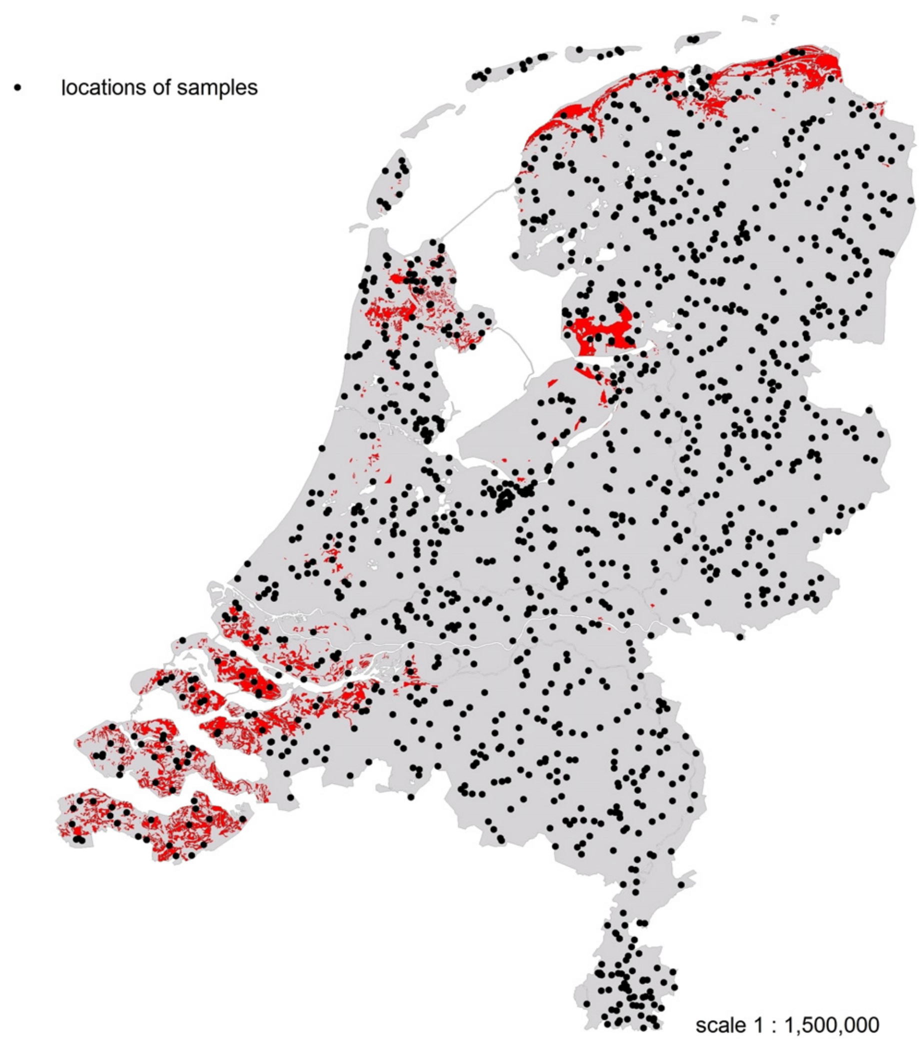

Fig. 1. Locations of the national stratified soil survey sampling (Finke et al., 2001). The red area is an example of the location of one of the 95 strata (calcareous silty clay soils with a MHW between 0.4 and 0.8 m) that is distinguished in the national stratified soil survey.