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Phosphorus levels in croplands of the European Union with implications for P fertilizer use☆

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ABSTRACT

In the frame of the Land Use/Land Cover Area Frame Survey sampling of topsoil was carried out on around 22,000 points in 25 EU Member States in 2009 and in additional 2 Member States in 2012. Besides other basic soil properties soil phosphorus (P) content of the samples were also measured in a single laboratory in both years. Based on the results of the LUCAS topsoil survey we performed an assessment of plant available P status of European croplands. Higher P levels can be observed in regions where higher crop yields can be expected and where high fertilizer P inputs are reported. Plant available phosphorus levels were determined using two selected fertilizer recommendation systems: one from Hungary and one from the United Kingdom. The fertilizer recommendation system of the UK does not recommend additional fertilizer use on croplands with highest P supply, which covers regions mostly in Belgium and the Netherlands. According to a Hungarian advisory system there is a need for fertilizer P input in all regions of the EU. We established a P fertilizer need map based on integrating results from the two systems. Based on data from 2009 and 2012, P input demand of croplands in the European Union was estimated to $3,849,873\ \mathrm{tons}_{(P_2O_5)}$/year. Meanwhile we found disparities of calculated input need and reported fertilizer statistics both on local (country) scale and EU level. The first ever uniform topsoil P survey of the EU highlights the contradictions between soil P management of different countries of the Union and the inconsistencies between reported P fertilizer consumption and advised P doses. Our analysis shows a status of a baseline period of the years 2009 and 2012, while a repeated LUCAS topsoil survey can be a useful tool to monitor future changes of nutrient levels, including P in soils of the EU.

1. Introduction

Soil represents a temporary reservoir for phosphorus (P) in which its availability affects plant growth and biological processes (Lair et al., 2009). Soil phosphorus (P) is an essential element for plant growth but is often slowly available to plants within the soil environment. This is mainly due to soil P being sorbed to the soil reactive clay surfaces, Al and Fe oxides, carbonates, organic matter. The soil pH then determines the chemical complexion of P (Torrent, 1997; Borggaard et al., 2004). At a soil pH above 5.5 most soil phosphate reacts with calcium and at a pH below 5.5 it will react with Al and Fe oxides leaving P only slowly available to plants. Historically crop production did rely on natural availabilities of soil phosphorus (P) and input from organic manure. However with the increased food demand, improved agrotechnology and availability of mineral P forms in the 20th and 21st centuries, fertilizer P application became the substantial source of soil P (Cordell et al., 2009). In developed countries P accumulation took place in the past decades, due to high doses of P fertilization (Lemercier et al., 2008). Although the impact of P input to soils had a positive impact on crop production the impact on the environment such as eutrophication has become a problem within Europe (Csathó et al., 2011). Additionally the world's P supply is both finite and non-renewable (Jordan-Meille et al., 2012) which has caused tension within global P markets (IFA, 2012). Hence, P fertilizer usage must be carried out to secure a sustainable environment and best possible utilization by crops.

To meet these challenges fertilizers recommendations to farmers become a common practice worldwide generally optimizing fertilizer doses to sustain a desired yield without a load to the environment. Consequently, soil P recommendation systems are widely used around the world to ensure good soil management and nutrient efficiency promoting agricultural sustainability. However recommendation systems differ considerably among countries. Not

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many systems can be found as peer reviewed literature; however a brief overview on those available is hereby given. Phosphorus recommendation systems are commonly used in Brazil, in a country where soils are generally nutrient poor. The Brazilian recommendation systems are based on quantitative analyses of soil input variables. The input variable consists of the following factors; cation exchange capacity (CEC), base saturation (BS), base sum, exchangeable aluminium (Al), calcium/magnesium (Ca/Mg), potassium (K) and P levels, sodium (Na) saturation and electrical conductivity. The output variable of the system is the amount of fertilizer to be applied. This is mainly based on 4 classes, low, medium, high to very high (Palhares et al., 2001). While Brazil follows a detailed set of variables when recommending P fertilizer levels, the agronomists at Kansas University – who, among other land grant Universities in the United States, provide single rate recommendation for nutrients such as P – are developing a fertilizer recommendation system that gives growers the flexibility to choose a soil management practice suitable for their needs. This flexibility included choosing from 2 systems, the "nutrient sufficiency recommendation system" which is developed to provide a 90–95% maximum yield for the year, and the "build maintenance fertility program" based soil test values over a planned period of time, usually 4–8 years, for both immediate crop needs and build up levels to a non-limiting value (Leikam et al., 2003). In West Africa, a framework to optimize soil fertility management in rice production is in use were the yield potential is estimated by an ecophysiological model based on weather conditions, cultivar species and sowing date. This yield potential is used as an input into a static model together with field specific data such as recovery efficiency of applied N, P and K, indigenous NPK supply and maximum NPK accumulation. Outputs of the framework include, required fertilizer doses to obtain different yield targets depending on yield potential and the soil nutrient supply (Haefele et al., 2003).

Sims (1992) conducted a study assessing different P tests for fertilizer recommendations used in Europe and confirmed their effectiveness. The amount of P extracted did however differ, with different extraction methods. Jordan-Meille et al. (2012) published an overview of fertilizer P recommendation systems in Europe where fertilizer recommendation systems from 18 countries were compared were data on different fertilization systems was obtained from the peer reviewed literature, personal contact and the "grey literature". In Europe P recommendation systems are mainly based on 3 steps. The first step includes soil testing to approximate the crop available P pool in soil. The second test involves relating results from the before mentioned soil tests to yield response (correlations between soil P tests and field trials) to account, similarly to already mentioned Brazilian system, for a 90% maximum yield per year. Based on these results, threshold values are often developed to divide soils into 3 different categories, "low", "medium", "high" and sometimes "excessive". From these categories the third step takes place, that is, the actual P recommendation is calculated. According to the review conducted by Jordan-Meille et al. (2012), the main difference between P recommendation systems in European countries was the chemical method used to extract P during the soil P test. Some use strong extractants which dissolved strongly bound P and hence does not necessarily represent the actual labile pool of P in soils and others use week extractants like water or week acids which might underestimate available soil P (Neyroud and Lischer, 2003). Moreover about half of the recommendation systems used in Europe take into account other factors such as crop characteristic (Belgium, Hungary, Sweden, Denmark, England, France, Germany and Switzerland) and soil characteristics such as soil texture, clay and organic matter content, soil pH, carbonate content and soil type (France, Italy, Switzerland and the Netherlands) (Jordan-Meille et al., 2012).

In the frame of the Land Use/Land Cover Area Frame Survey (LUCAS, Eurostat, 2013a) sampling of topsoil (upper 20 cm) was carried out on around 22,000 points in 25 EU Member States in 2009 (Tóth et al., 2013a) and in other 2 Member States – Bulgaria and Romania – in 2012 (Tóth et al., 2013c). Beside other basic soil properties soil nutrient (N, P, K) content of these samples were measured in a single laboratory using standard determination method (ISO, 1994) which is based on the method of Olsen et al. (1954). Results of the LUCAS topsoil survey and laboratory analysis allows an assessment of nutrient status of croplands at a European scale. As no coherent figures from EU Member States were available to date – mainly due to data accessibility problems or lack of data – the LUCAS topsoil survey provides a unique opportunity for a European overview of this issue. The LUCAS topsoil P data can help to refine and update incomplete or outdated national spatial phosphorus datasets or just provide an independent set of data for cross-comparison for countries where soil P data is available, such as the UK (Emmett et al., 2010) or France (Huyghe, 2013).

The aim of our current study was to make a comparative assessment of plant-available phosphorus levels of croplands in regions of the European Union using the data from the LUCAS topsoil survey. Plant available phosphorus levels were determined using two selected fertilizer recommendation systems: one from Hungary (Antal et al., 1979) one from the United Kingdom (DEFRA, 2010). These two systems were chosen as they are developed for two contrasting agro-ecologic regions of Europe, did not include site specific criteria which were not adaptable in other parts of the EU and hence were easily applicable to a large Pan European dataset such as the hereby presented LUCAS soil dataset.

Further to the determination and comparison of plant available phosphorus levels we made an attempt for a general estimation of P demand of croplands in the European Union, based on yield statistics and the data from the LUCAS topsoil survey.

2. Materials and methods

2.1. Databases used

2.1.1. The LUCAS topsoil database

Approximately 22,000 topsoil (upper 20 cm) samples with unique georeferenced location were collected in 2009 from 25 European Union (EU) Member States (EU-27 except Bulgaria and Romania) and in 2012 in Bulgaria and Romania with the aim to produce the first coherent baseline topsoil database for continental scale monitoring (Tóth et al., 2013a,b,c). The soil sampling was undertaken within the frame of the Land Use/Land Cover Area Frame Survey (LUCAS), a EU wide project to monitor changes in the management and character of the land surface (Eurostat, 2013a). Based on a stratified sampling scheme samples were taken from all land cover classes, with systematically higher proportions from arable and grasslands (Tóth et al., 2013a). Soil samples have been analysed for basic soil properties such as particle size distribution, pH, organic carbon, carbonates, NPK, cation exchange capacity (CEC) and multispectral signatures. Analysis of soil parameters followed standard procedures. Tóth et al. (2013a) provided detailed description on the methodology and data of the LUCAS topsoil survey. Analysis of the P amount was carried out with spectrometric determination of phosphorus soluble in sodium hydrogen carbonate solution (ISO, 1994). Results of P measurement of samples from the LUCAS topsoil survey were used in our assessment. Fig. 1a shows the spatial representation of measured phosphorus content at the LUCAS sampling sites (Hermann, 2013).