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Phosphate acceptance map: A novel approach to match phosphorus content of biosolids with land and crop requirements

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ABSTRACT

Phosphorus is a key irreplaceable nutrient that plays a major role in crop nutrition. The mineral form of phosphorus fertiliser is a mined resource and its supply comes predominantly from geopolitically sensitive parts of the world. A renewable source of phosphorus such as biosolids therefore offers a sustainable option. Nevertheless, continuous application of biosolids needs to be managed to ensure that soil is not saturated with nutrients which can then become a cause for concern in terms of enrichment of water bodies in the event of an erosion. Existing field trials have demonstrated the efficacy of biosolids as phosphorus fertiliser to meet crop demand whilst maintaining an environmentally safe amount in the soil. However, field trials are expensive, and an alternative would be a geospatial tool that builds on such information to act as a decision support tool to determine suitability of land to receive biosolids whilst ensuring that phosphorus levels are in environmentally safe limits.

Thus, a novel and evidence-based decision support method for assessing land suitability for biosolids application at a national scale known as the Phosphate Acceptance Map (PAM) is described here. It provides a sound basis for addressing this need, layering over the model the means to capture a range of realistic scenarios, developed with industry practitioners, to allow exploration of the consequences of different land management strategies. The research method has involved the development and application of a modelling approach for phosphate acceptance, drawing from a collation of the core geographical and descriptive data themes required. These data describe both the environmental characteristics of the land under assessment, as well as the expression of nominal stakeholder values and protected areas.

In considering the methods, it may be noted that the modelling drew upon key empirical data themes as a pragmatic approach. A number of key national datasets have been utilised such as the National Soil Map (Natmap), the 'National Soil Inventory' (NSI), geology and land use, as well as topography and prevailing climatic data. Demographic data was used to calculate potential arising nationally which was coupled together in the context of fertiliser recommendations. The issues addressed in the PAM modelling span borders and thus, where the data required is forthcoming, the methods demonstrated also have the potential to support wider application in other national contexts.

1. Introduction

Phosphorus (P) supply is a key macro nutrient for crops. The majority of P supply in agriculture in its mineral form is derived from phosphate rock. Approximately 40 million tons of phosphate rock (P_2O_5 equivalent) is mined annually, of which 80–90% is used in fertilisers (Defra, 2009). There is information on the global scarcity of P which has implications for food security (Cordell et al., 2009). The greatest reserve globally for phosphate rock is assigned to Morocco (Jasinski, 2011) and whilst reserves remain available, the cost of extraction is increasing, affecting fertiliser prices; volatility of supply for any reason could affect UK food security. A sustainable way forward will be to utilise renewable sources of P such as biosolids (also associated with increasing population), so reducing reliance on finite, mined rock phosphate.

The quantity of biosolids that is recycled to agriculture has increased since the implementation of various European directives, such as The Sewage Sludge Directive 86/278/EEC. In the UK, the GB Fertiliser Regulation is currently considering renewable sources of P, but discussions are still in their infancy. > 10 million tonnes (dry solids) of biosolids is now produced annually in the EU (Laturnus et al., 2007) and 12.8 million tonnes by 2020 (WRc (Water Research Centre),

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2010). The quantity of biosolids recycled to agriculture varies considerably between EU member states with the UK recycling approximately 80% (Smith, 2008).

The agricultural benefits of biosolids are widely recognised. However, application rates based on crop nitrogen requirements may lead to a build-up of soil P (Antille, 2011). A single application of dewatered biosolids will supply adequate phosphate for most 3–4 year crop rotations (Smith, 2008). Thereby application of phosphorus at rates greater than required by the crop represents a wasted resource and potential environmental hazard. More information is required regarding the long-term fate and release of P in biosolids treated agricultural soils to assess the efficiency of crop P utilisation (Smith, 2008). According to Cogger et al. (2013), repeated application of biosolids leads to accumulation of soil P when applied at rates to meet crop N needs. Previous work to-date on the nutrient value of biosolids has tended to concentrate on its value as a source of Nitrogen, with added phosphorus viewed as a "bonus". Loading soils with sufficient biosolids to meet the crop need for N will always over-apply P, which is not only inefficient and ineffective (economically and environmentally) but leads to an increased risk of leaching and eutrophication of adjacent water bodies.

In the UK, there will be a continued supply of biosolids, rich in phosphorus (P) (up to 5% dry matter) (Antille et al., 2013a, 2013b). It is accepted that recycling provides a more advantageous outcome than landfill or incineration (close to 80% of biosolids are recycled to agriculture in the UK - Smith, 2008). Several field-scale studies on the efficacy of biosolids as a fertiliser (Deeks et al., 2013; Pawlett et al., 2015; Antille et al., 2017) have shown that P is available to crops without increasing the soil P index, at least in sandy loam soils established with grass and major combinable crops. Whilst this provides valuable data, the cost of these trials is expensive. Consequently, to balance cost implications of field trials but without compromising on the application of biosolids to land, a geospatial approach is sought that can assist land owners to target application of biosolids, whilst maintaining suitable soil phosphorus levels to meet crop demand.

One reported project using such a geospatial approach is the Geographical Information System (GIS)-based ALOWANCE model (Agricultural Landbank, Organic 'Waste', A National Capacity Estimator) (Nicholson et al., 2012). ALOWANCE models the agricultural value of Nitrogen, considering this input from all sources of organic material based on data from the agricultural census. Two versions are reported, a commercial and an open tool. Both the public and restricted versions of ALOWANCE operate on a 10 km^2 grid and, although it is noted that future versions may include models of phosphorus, this is currently included only as background information. ALOWANCE is used in the consultancy sector, particularly with a focus on the water utilities in the UK.

The objective of this paper is to utilise geospatial analysis building on experimental data and substantive national datasets using a Big Data approach to produce the Phosphate Acceptance Map (PAM) to assess land suitability to receive biosolids application without compromising soil P levels and crop needs. This work also covers aspects related to interaction with relevant stakeholders and their perception on the use of PAM.

2. Materials and methods

In this paper, biosolids refer to pelletised materials which are granular between 2 and 5 mm and have an addition of urea and potash as a source of nitrogen and potassium respectively to make a balanced

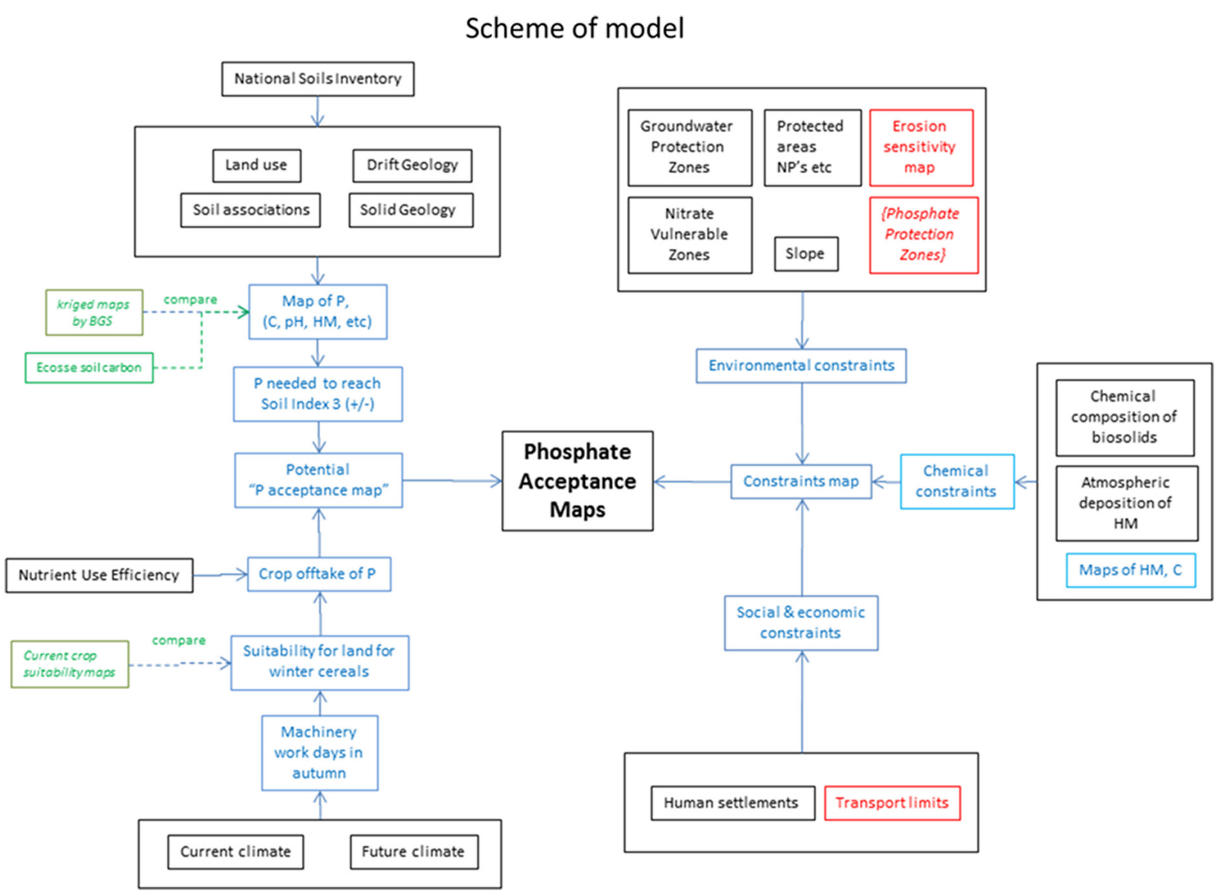

Fig. 1. Schematic of data flows in producing Phosphate Acceptance Maps. (Note, black outer text denotes specific data sources; red text denotes threshold limits; blue text denotes derivations made or modelling processes undertaken). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)