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SHORT COMMUNICATION

Microbial biomass phosphorus contributions to phosphorus solubility in riparian vegetated buffer strip soils

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Abstract This study tests the hypothesis that microbial biomass phosphorus (P) makes a significant contribution to P solubility in riparian buffer strip soils. In 36 soils collected from buffer strips within three UK soil associations, water-extractable inorganic P solubility was most strongly related to $NaHCO_3$ extractable inorganic P. However, within individual soil associations where soil pedological properties and management were similar, water-extractable inorganic P was most strongly related to microbial biomass P. These results highlight the difficulty in predicting dissolved P leaching risk based on agronomic soil P tests alone and the dissolved P leaching risk presented by having soils high in organic matter and microbial biomass P in close proximity to surface waters.

Keywords Phosphorus solubility · Organic matter · Microbial biomass phosphorus · Microbial turnover · Riparian vegetated buffer strip

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Introduction

Laboratory scale studies have demonstrated that turnover of microbial biomass phosphorus (P) can increase soil P solubility and leaching therefore increasing the potential for dissolved P delivery to surface waters (Seeling and Zasoski 1993; Blackwell et al. 2013). It is much less clear that the microbial biomass contributes to soil P solubility at larger spatial scales because under natural field conditions many additional factors affect P solubility, for example geochemical solubility controls. Riparian vegetated buffer strips present an opportunity to study P solubility in soils of increased organic matter contents but otherwise similar pedological properties compared with adjacent upslope arable field soils. Because microbial concentrations of P have been shown to be strongly correlated with soil organic matter (Joergensen et al. 1995), studying otherwise similar soils but with varying concentrations of organic matter may give insight into the contribution of microbial biomass P to P solubility. The aim of this study was to test the hypothesis that microbial biomass P makes a significant contribution to P solubility in riparian buffer strip soils.

Material and methods

Soil samples were collected from existing buffer strips established on three UK soil associations of differing characteristics within the national Demonstration Test Catchments (Table 1). The buffer strips were established on arable land under either Countryside Stewardship or Environmental Stewardship agri-environment schemes. At four buffer strips on each soil, five soil cores (0–7 cm depth) were collected and bulked from positions within the upslope arable field and 2 and 4 m within the buffer strip from the upslope edge during January 2011.

Table 1 Description of the location, climate, geology and vegetation characteristics of the three study soils (Collins et al. 2012; Soil survey of England and Wales 1983)

Soil association	County, river catchment	Average annual rainfall (mm)	Geology	Soil description	Percentage sand, silt and clay	Field crop	Riparian vegetation characteristics
Ardington	Hampshire, Avon	749 (Boscombe down)	Cretaceous; glauconitic sand, loam and clay	Deep, well drained, sandy silt loamy glauconitic soils	32, 57, 11	Wheat, fodder beans, winter barley and oats	Tall vegetation with moderate % cover of perennial forbs, low perennial flower numbers and low grass cover
Clifton	Cumbria, Eden	947 (Penrith)	Reddish till	Deep, slowly permeable, seasonally slightly waterlogged, sandy silt loamy soils	25, 58, 17	Oats, spring barley, oil seed rape and wheat	Species rich, dense vegetation with high % cover of perennial forbs and high perennial flower numbers and moderate grass cover
Burlingham	Norfolk, Wensum	653 (Marham)	Chalky till and glaciofluvial drift	Deep, slowly permeable, seasonally slightly waterlogged, sandy silt loamy soils	28, 58, 14	Spring barley, oil seed rape and wheat	Short vegetation with moderate % cover of perennial forbs, moderate perennial flower numbers and moderate grass cover

With the exception of soil total P, sample analyses were carried out in triplicate on field moist soils that were sieved to <2 mm. Soil samples were assayed for basal soil respiration to infer microbial activity and glucose substrate induced soil respiration to approximate microbial biomass size (Campbell et al. 2003). Microbial biomass P was determined to quantify concentrations of P held within the soil microbial biomass (Brookes et al. 1982). Total soil P was measured using an Accuris inductively coupled plasma optical emission spectrometer (ARL/Fisons, Eclubens, Switzerland) after aqua regia acid digestion of air dried soils that were sieved to <2 mm. An agronomic soil test, $NaHCO_3$ extractable inorganic P, originally designed to estimate plant available P but commonly used for determining P leaching risk, was conducted on samples according to the methods of Olsen and Sommers (1982). Phosphorus solubility was determined by extracting 5 g (dry weight equivalent) of soil with 25 ml of deionised water and shaking end-over-end for 1 h before filtration through a 0.45-μm membrane. The concentrations of total P in potassium persulphate-digested filtrates and the concentrations of inorganic P in undigested filtrates were determined by ammonium molybdate colourimetry. Organic P was calculated as the difference between inorganic P and total P concentration.

The variance of transformed data was analysed by linear modelling to determine significant differences between group means and significant relationships between variables (R statistical software version 2.14.1). Sample populations were analysed on the basis of a 'position' factor indicating whether samples were from the arable field or positions within the buffer strip and a 'soil' factor indicating significance between different soil associations.

Results and discussion

Mean concentrations of determinants within groups and significant differences in means between groups are presented in Table 2. Organic matter and microbial biomass P concentrations were significantly related ($R^2=0.80$, $p\leq0.001$) and means were significantly higher in the 2- and 4-m position groups compared with the field group (Table 2). Mean concentration of water-extractable inorganic P was significantly higher in the 2-m position group compared to the field group and was also increased in the 4-m group (Table 2). In the data as a whole, incorporating variation in soil pedological properties and management caused by the soil factor, water-extractable inorganic P concentration was most strongly related to $NaHCO_3$ extractable inorganic P ($R^2=0.58$, $p\leq0.001$). Within individual position groups, the slopes of this relationship were greater in the two buffer strip position groups compared to the field group (Fig. 1) which confirmed that other factors were

Table 2 Means and standard errors of determinants measured within soil and position factor groups with overall factor significance

	Soil			Position			Overall significance	
	Ardington ($n=12$)	Clifton ($n=12$)	Burlingham ($n=12$)	Field ($n=12$)	2-m ($n=12$)	4-m ($n=12$)	Soil	Position
pH	5.97a	5.89ab	5.46a	5.88	5.7	5.61	$p=0.009$	$p=0.759$
Soil moisture (g kg^{-1})	308±14a	278±16ab	238±30b	230±18a	289±24ab	304±20b	$p=0.011$	$p=0.019$
Organic matter (g kg^{-1})	55±4	66±5	67±15	41±4a	73±10b	75±9b	$p=0.338$	$p\leq0.001$
Basal soil respiration (µg C g^{-1} h^{-1})	0.32±0.05	0.27±0.03	0.40±0.07	0.20±0.03a	0.35±0.06b	0.43±0.05b	$p=0.199$	$p=0.002$
Glucose SIR (µg C g^{-1} h^{-1})	1.55±0.36	1.53±0.34	1.27±0.35	0.27±0.09a	1.35±0.21b	2.73±0.21c	$p=0.174$	$p\leq0.001$
Microbial biomass P (mg P kg^{-1})	50.6±7.8	51.4±7.9	64.2±20.0	23.6±2.4a	73.8±16.1b	68.7±11.5b	$p=0.857$	$p\leq0.001$
Total P (mg P kg^{-1})	683±83ab	806±89a	550±31b	559±73	730±77	751±74	$p=0.048$	$p=0.119$
NaHCO$_3$ extractable inorganic P (mg P kg^{-1})	54.4±10.7a	24.8±2.6b	22.5±3.6b	23.1±3.1	36.0±8.0	42.7±10.0	$p=0.002$	$p=0.111$
Water-extractable total P (mg P kg^{-1})	4.47±0.65a	1.07±0.16b	1.14±0.32b	1.18±0.27a	2.87±0.63b	2.64±0.78ab	$p\leq0.001$	$p=0.008$
Water-extractable inorganic P (mg P kg^{-1})	3.41±0.54a	0.57±0.08b	0.57±0.15b	0.84±0.23a	1.89±0.57b	1.82±0.62ab	$p\leq0.001$	$p=0.022$
Water-extractable organic P (mg P kg^{-1})	1.01±0.28	0.58±0.09	0.58±0.17	0.38±0.10a	0.97±0.20b	0.81±0.25ab	$p=0.426$	$p=0.026$

Different letters between groups within factors denote groups are significantly different at the $p<0.05$ significance level as determined by linear modelling

SIR substrate-induced respiration

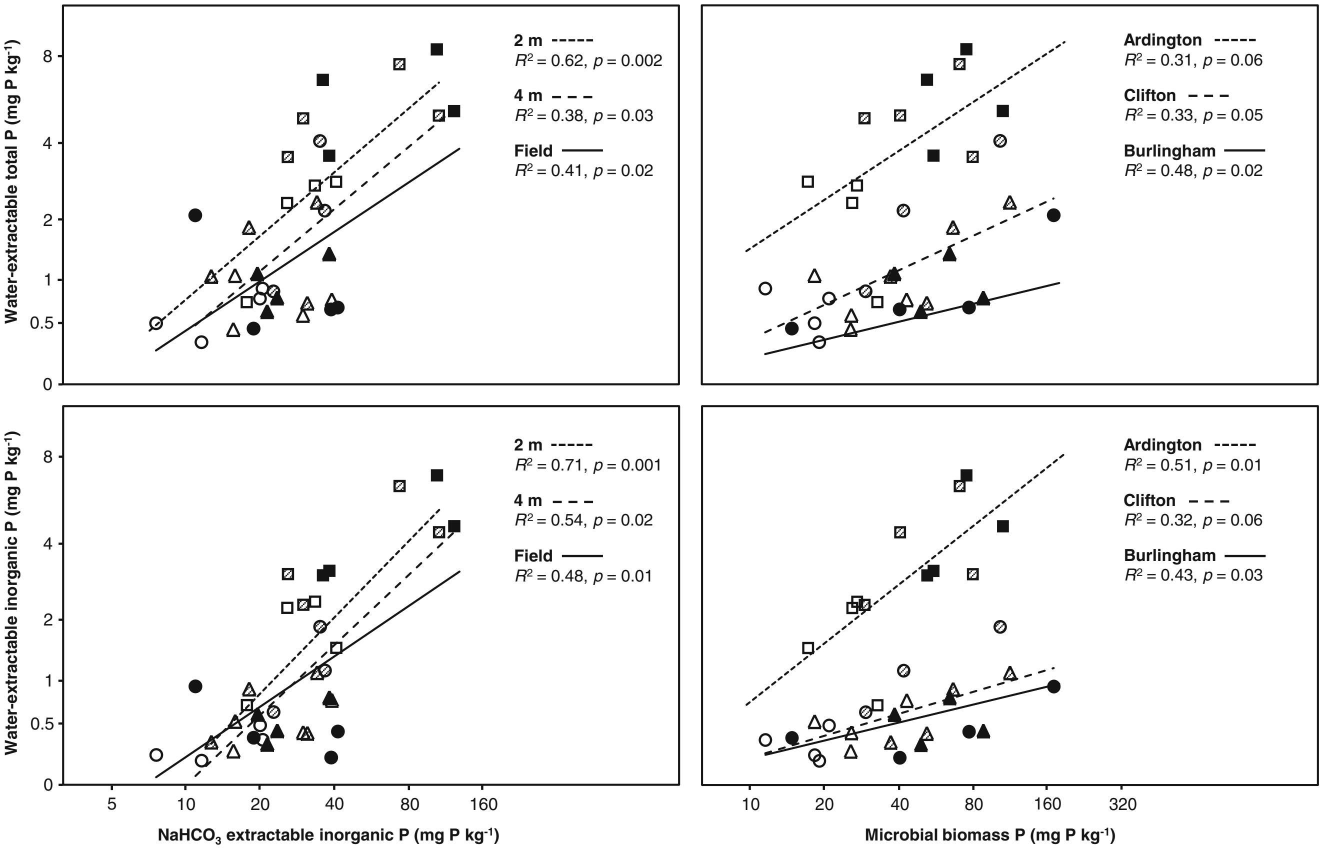

Fig. 1 Relationships between water-extractable P fractions and NaHCO$_3$ extractable inorganic P within individual position groups and relationships between water-extractable P fractions and microbial biomass P within individual soil groups. *Shapes* indicate that groups are from within the soil factor where *squares*, *circles* and *triangles* denote samples from the Ardington, Burlingham and Clifton soil association groups, respectively. *Shading within shapes* indicates that groups are from within the position factor where *transparency, hatching and opacity* denote samples from field, 2- and 4-m position groups, respectively

contributing to P solubility within the buffer strip soils. Inclusion of microbial biomass P and water-extractable organic P in the statistical model increased R^2 to 0.65. The variation caused by the soil factor was removed by investigating relationships within individual soil groups where water-extractable inorganic P was found to be most strongly related to microbial biomass P (Fig. 1). Therefore, by incorporating soil as a factor in the statistical model for the data as a whole, microbial biomass P was responsible for a significant ($p=0.01$) amount of variation in water-extractable inorganic P.

The significant relationships between $NaHCO_3$ extractable inorganic P and water-extractable inorganic P concurs with the findings of previous studies on the relationship between such agronomic soil P tests and P concentrations in more soluble fractions (Pote et al. 1996) and suggests saturation and subsequent desorption of P. However, the combination of $NaHCO_3$ extractable inorganic P, microbial biomass P and water-extractable organic P explained a greater amount of variation in inorganic P solubility. As well as desorption, inorganic P released from the microbial biomass and mineralisation of soluble organic P both also contribute to the soluble inorganic P pool. The significant relationships between water-extractable inorganic P and microbial biomass P within the soil groups shows how, when soil pedological properties and management are held relatively constant, variations in microbial biomass P concentrations can be directly responsible for significant variations in soil P solubility. Both of these findings suggest that the soluble inorganic P pool is partially independent of soil P determined by agronomic soil P tests which may not be sensitive to small but environmentally significant changes in P solubility. Mobilisation of P from the microbial biomass could therefore be responsible for previously reported variations in P solubility and leaching from soils with similar agronomic soil P concentrations but different concentrations of organic matter (Stutter et al. 2009; McDowell and Sharpley 2001). Elucidating the exact mobilisation mechanisms by which microbial biomass P contributes to P solubility will require targeted approaches and the novel experimental design will guide these future studies. Given the stable temperatures and soil moisture conditions during the period of sampling, the increased solubility is most likely due to microbial turnover of P during basal mineralisation at stable respiration rates. Under stable soil conditions, the soluble organic and inorganic P pools would be constantly maintained by microbial turnover as a consequence of microbial death and P mobilisation coupled with simultaneous multiplication and P immobilisation (Oberson and Joner 2005). Subsequent biological or biochemical mineralisation of soluble organic P would also contribute to the soluble inorganic P pool. Phosphorus turnover would also be enhanced during unstable soil conditions such as soil drying or freezing where large quantities of P could be mobilised in riparian buffer strip soils, due to microbial cell lysis and subsequent release of P (Blackwell et al. 2010).

Microbial biomass P contributed to variation in P solubility within the data as a whole and within data for the individual soil associations tested. Phosphorus solubility is therefore partially independent of agronomic soil P concentrations and depends on a range of processes which suggests that agronomic soil P testing alone will not accurately predict dissolved P leaching risk. Combining these soil tests with simple analyses for example, organic matter, clay mineral contents and water-extractable P, would greatly aid the prediction of P leaching risk at appropriate catchment management scales. While the variation in organic matter provided by the experimental system served well to study the microbial driver of P solubility, this variation also has implications for P delivery to surface waters. Riparian buffer strip and other riparian agricultural soils showing increased organic matter and microbial turnover of P may bring a dissolved P leaching risk at a critical landscape location due to increased soil P solubility. In order to reduce this risk, management of P mobilisation may be required and in the case of riparian vegetated buffer strips, occasional vegetation removal and/or tillage could help to slow organic matter build up. A better understanding of these processes and their contribution to P solubility and delivery at larger spatial scales will facilitate the development of these management strategies.

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