NJF seminar 401

Phosphorus management in Nordic-Baltic agriculture
– reconciling productivity
and environmental protection

Uppsala, Sweden – 22-23 September 2008

nJf
Nordic Association of Agricultural Scientists

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Book of abstracts
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Estimating bioavailable reserves and potential leaching of soil P by simple chemical tests

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Introduction

An acid ammonium acetate method, modified from the better-known Morgan test, has been used in routine soil testing in Finland since the 1950s. If calibrated for different soil types, the acetate method (P_{Ac}) has shown to a reliable indicator of phosphorus (P) needs of crops (Saarela *et al.*, 2006a, 2006b). Nowadays the soil test is used in the Agri-Environmental Program, but it has not been properly evaluated and calibrated for different soils as an estimate of the leaching losses of soil P and the release of P to water from eroded soil material.

The slowly available reserves of potassium were successfully estimated with cold 2 M HCl (Saarela *et al.*, 2003). Even if a strong acid is theoretically less suitable for P, the HCl-extracts of the soils used in both studies were analysed for P and the P_{HCl} values included in the variables studied. Sippola & Saarela (1992) calibrated the P_{Ac} values preliminary as indicators of potential P leaching on the basis of equilibrium phosphate concentration (EPC) in 0.005 M $CaCl_2$. Uusitalo & Jansson (2002) obtained a close correlation between P_{Ac} and water-extractable P (P_W) and suggested to use the corresponding DRP/P_{Ac} slope to calculate P leaching as done by Ekholm *et al.* (2005).

Material and methods

The bioavailable reserves of P in 56 soils representing the whole agricultural area of Finland were exhausted with grasses and cereals grown successively for 3 to 6 seasons and the relationships of the total uptakes of P with the P_{Ac} values and other soil parameters were studied. For estimating the leaching losses (dissolved reactive P, DRP) from different soils, the corresponding EPC/P_{Ac} relationships of 154 heavily enriched soils reported by Sippola & Saarela (1992) were recalculated and compared to the DRP/P_{Ac} slopes obtained by simulated rain (Uusitalo and Aura, 2005) and by some field studies in Finland and Ireland.

Assessing bioavailable P reserves by simple extraction tests

The mean P_{Ac} value of the 56 soils was 15.5 mg dm^{-3} (range 3.0—74.1) and the mean total uptake of P 126 (5—278) mg dm^{-3} soil or 8.1-fold the former. The extracted amount (15.5 mg dm^{-3}) corresponds approximately 1.2% of total P. At the medium level of P_{Ac}, the uptakes were tenfold the amount measured by the soil test. For all 56 soils, R^2 was 0.69 and for 50 normal soils, without tree poor sands (BD >1,35), two peats (OM >40%) and a calcareous sand from Åland (pH >7,5), R^2 was 0.81.

The acetate test has been interpreted by soil type since the 1950s because the optimal P_{Ac} value is lower in clay soils than in coarser-textured soils (Saarela *et al.*, 2006a, 2006b). The P uptakes confirmed the increasing supply of P with clay content (Figure 1). Including the clay% (mean 22, range 0−69) in the regression equation increased the R^2 value to 0.78 (all 56 soils) or to 0.87 (50 normal soils).
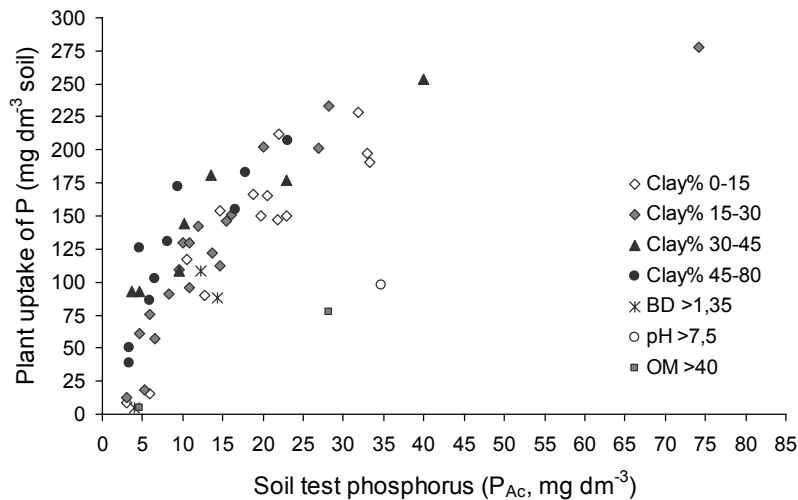

Figure 1. Dependence of the amounts of soil P taken up by plants in 3 to 6 seasons on the concentration of soil P extracted by the Finnish ammonium acetate method (0.5 M acid, 0.5 M acetate, pH 4,65, soil to solution ratio (v/v) 1:10 for 1 h).

Additional improvements were obtained by inserting the pH (mean 6.07, range 5.12−7.11, except 7.69 for one soil) and the P_{HCl} values (mean 665, range 32−1620 mg dm^{-3}) in the equation (Figure 2). The R^2 value was 0.93 for all 56 soils and 0.945 for the 50 normal soils. In respect to pH, the parabolic equation had a maximum at 6.05. The percentage of organic matter (mean 10.3, range 1.1−78%) was insignificant. The significant effect of P_{HCl} suggests that these values vary largely with the secondary P reserves bound to aluminium and iron and less with the poorly available apatitic P that is easily dissolved with a strong acid.
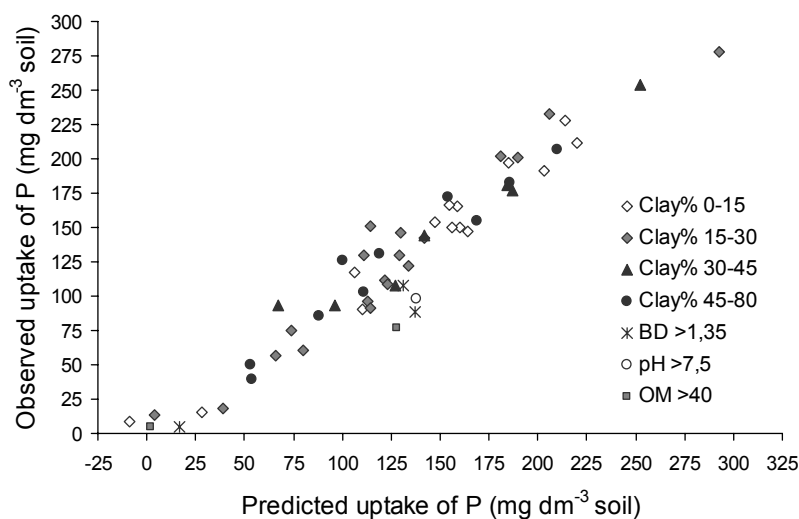
Predicted uptake of P = 66.20 * log(P_{Ac}) +0.0669 * P_{HCl} +1.088 * clay%

+287.22 * pH -23.74 * pH*pH −963.5. All terms are significant,

P = 0.0013 (pH), 0.0004 (intercept) and <0.0001 (others), R^2 = 0,945

Figure 2. Correlation between predicted and observed plant uptakes of P. The equation was calculated for 50 normal soils. 3 poor sands (BD >1,35, 2 peats (OM >40) and a calcareous soil (pH >7,5) were excluded but are plotted.

Leaching of P from different soils in relation to P_{Ac} and pH

The EPC value of 0.5 mg dm^{-3} corresponding to 1 kg P ha^{-1} in 200 mm runoff was reached at P_{Ac} 70 mg dm^{-3} in clay soils, at 53 mg dm^{-3} in coarser mineral soils and at 14 mg dm^{-3} in organic soils (Sippola & Saarela, 1992). Recalculations showed that the EPC values of heavily enriched soils increase with decreasing pH (Figure 3). The effect of soil texture was small, but the EPC values were lower in subsoil than in topsoil. A similar pH effect was obtained by recalculating the results from simulated rain (Figure 3). Only 15 soils were tested, but a R^2 value as high as 0.99 means reliable results. At low pH the DRP values were similar to those obtained from Irish grasslands (Tunney, 2002): DRP = 0.002 * Morgan P^2. As P_{Ac} = 1.4 * Morgan P, the equation equals to 0.001 * P_{Ac}^2, and to P_{Ac}^2 when DRP is in µg dm^{-3}.

The EPC/P_{Ac} slopes were much higher in organic soils than in mineral soils, and a wide variation was obtained even between and within different types of organic soil (Figure 4). In peat subsoil the slope was about 100 times higher than in mineral subsoil. As the P_{Ac} values of peat subsoil are frequently rather high, the EPC values suggest even 1000 times higher leaching losses from deep peat soils than from mineral soils. The DRP concentrations of Finnish field studies conducted on weakly

acid clay soils were calculated from the amounts on runoff and DRP transported by it (data not shown). The DRP values were closely correlated with P_{Ac} and the linear DRP/P_{Ac} slope had a coefficient of about 0.01. This agreed with the EPC/P_{Ac} slopes of laboratory studies and the DRP/P_{Ac} slopes obtained by simulated rain.
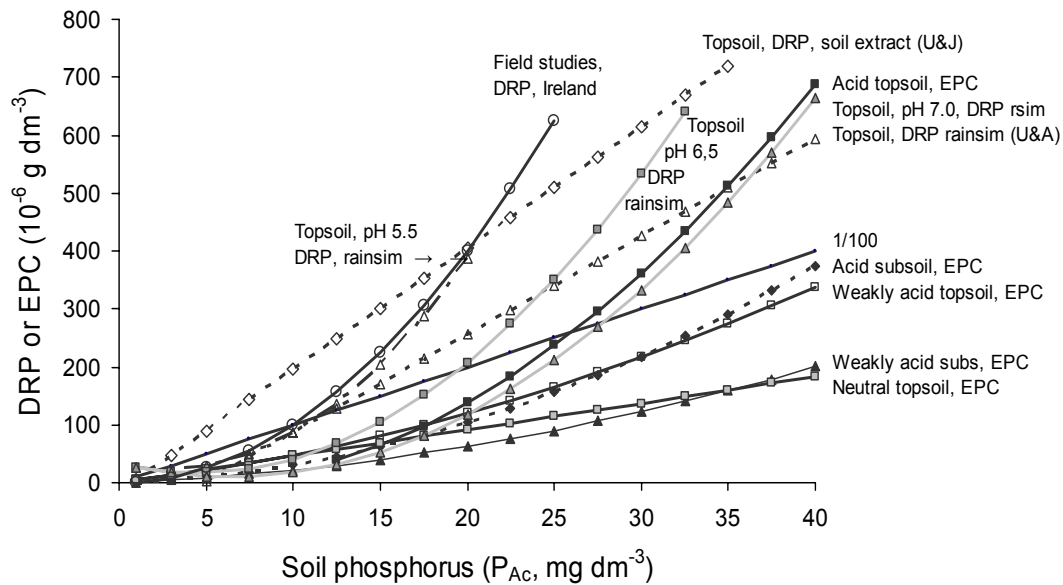

Figure 3. Relationships of the concentration of dissolved phosphate in water and soil test P in mineral soils as recalculated from published studies (Sippola & Saarela, 1992 (EPC), Uusitalo & Aura, 2005 (DRP) or according to the original equations (Uusitalo & Jansson, 2002 (U&J), Tunney, 2002, Uusitalo & Aura, 2005 (U&A).
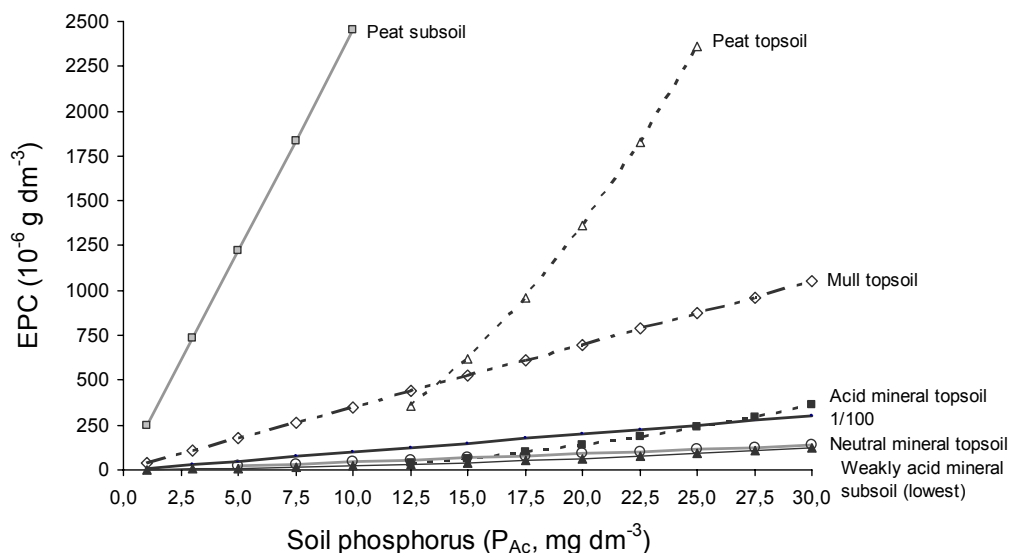

Figure 4. Relationships of equilibrium phosphate concentration (EPC) in 0.005 M $CaCl^2$ and soil test P value in organic soils compared to mineral soils (Sippola & Saarela, 1992, recalculated).

Conclusions

The amounts of P extracted with acid ammonium acetate are significantly correlated with the bioavailable P reserves of Finnish soils. Together with clay percentage the simple extraction method is fairly reliable. In routine soil testing clay% can be estimated visually. Additional improvement in accuracy is possible by extraction with a strong acid. Leaching losses of P are also significantly correlated with acetate-extractable soil P, but the concentration of dissolved phosphate at a certain soil test P value varies with other soil properties and increases with decreasing pH. Potential leaching losses are by far the highest in deep peat soils. Some applied leaching models over-estimate the losses significantly in most soils and many times in the heavily limed soils where high soil test P values are common.

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