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Changes of yield responses and soil test values in Finnish soils in relation to cumulative phosphorus and potassium balances

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Agro-environmental soil testing by acid ammonium acetate extraction

An acid ammonium acetate method has been used in Finland since the early 1950s. The soil test phosphorus values (STP) determined by this method (P_{Ac}) are closely correlated with Morgan P: P_{Ac} = 1.4 * Morgan P (and P_{Ac}, mg dm^{-3}, ~ P_{Al}, mg 100 g^{-1}). The potassium values of this method (K_{Ac}, STK) represent the quickly exchangeable pool of K^+ cations (~ 85% of total exchangeable). Current interpretations of the test values are mainly based on the long-term field experiments carried out at 24 sites in 1977-1994. The amounts of P allowed by the Agro-Environmental program are slightly below the long-term agricultural optimum.

Sippola and Saarela (1992) determined the limits of excessively high STP values on the basis of the equilibrium concentration of P in 0.005 M $CaCl_2$ suspension (EPC, estimate of DRP) and found that the critical EPC value of 0.5 mg dm^{-3} corresponded to the STP values of 14, 53 and 70 mg dm^{-3} in organic soils, coarse mineral soils and clay soils, respectively. According to the amounts of DRP leaching, water flow and STP measured in Finnish fields (Saarela, 2007, unpublished calculations), the DRP/STP slope of 0.5/50 or 0.01 is typical for weakly acid mineral soils. The equation derived from chemical extractions by Uusitalo and Jansson (2002), DRP = 0.021 * STP – 0.015, and applied to estimate the losses of DRP from agricultural soils (Ekholm et al., 2005) gives too high estimates of DRP leaching.

Yield responses to P fertilisation increased from year to year

Field experiments with five rates of annual P fertilisation were carried out at 24 sites in Finland in 1977-1994 (Saarela et al., 1995, 2004, 2006a,b). A summary of the yield results was calculated on the basis of the amounts of P recommended to cereals according to STP in early 1990s (Saarela et al., 1995): 20 kg P ha^{-1} in the STP class satisfactory (8-16 mg P dm^{-3}), 30 kg ha^{-1} in the class fair (4-8 mg dm^{-3}) and 40 kg P ha^{-1} in poorer classes. The actual limits of the classes differed by soil type. The yields obtained with these and 10 kg ha^{-1} larger or 10-30 kg ha^{-1} smaller amounts of P (-30 only in a part of the sites) were related to the yields produced with the highest rate of P, 60 or 45 kg ha^{-1} (Fig. 1).

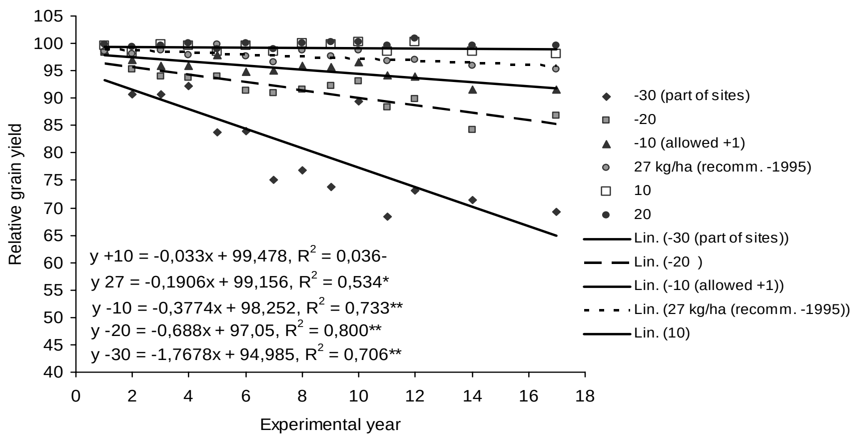

Figure 1. Relative grain yields at 1992-1995 recommended P rates (mean 27 kg/ha) and lower or higher rates of P. 227 harvest years, STP 0-16 mg dm^{-3} (Saarela et al., 1995).

The statistically significant equations (Fig 1) show that the difference to the maximal yield increased even by applying the amounts of P recommended in the early 1990s. The efficiency of repeated P fertilisation increased from year to year because the control yield and even the yield obtained with the smallest amount of P, 15 kg ha^{-1}, decreased in many soils. The improved supply of P from the soil by the highest rates also increased the responses. Even if the P fertiliser was applied by the placement method, its P was utilised rather inefficiently.

The amounts of P allowed to be used by the Finnish Agri-Environmental Program, which are about 10 kg ha^{-1} less than recommended in the early 1990s, decreased the yields by five per cent in ten years. The changes appear less dramatic when calculated as relative yields. The value of the -10 line is 97.8% in year 1 and 92.5% in year 15, while the difference from the maximum was 2.2% in year 1 and 7.5% in year 15. The amounts of grain corresponding to these relative values were 80 kg ha^{-1} for the initial 2.2% and 270 kg ha^{-1} for the final 7.5%.

Examination of the results showed that the supply of P to cereal crops during the most critical stages of development in the early summer was sensitive to the physical conditions of the soil. Unstable silty soils, from silty clay to silty fine sand, which were compacted by showers, dried by evaporation and rooted poorly, required large rates of P to produce good grain yields (Saarela et al., 2006a,b). In the sandy soils prevailing in the inland regions of Finland the concentration of water-extractable P was low in relation to acetate-extractable P. The low water-solubility or low intensity of soil P appeared to be caused by high concentrations of sorption active aluminium in relation to iron. In the poorest soils the physical properties of silty soils were combined with the poor chemistry of coarse-textured acid soils. In the glacial clays prevailing in the southern coastal regions the main sorption agent of P was iron and the supply of P in relation to acetate-extractable P was better.

Changes of STP values with time and P balance

The changes of STP at the zero balance and the surpluses required to maintain the initial value were statistically calculated from the relationships of the initial and final values (Saarela et al., 2004). For this presentation the STP values corresponding to the zero balance of the 4 to 6 samplings of each experiment were determined and regressed against the experimental years. The results are presented as relative changes in Fig. 2.

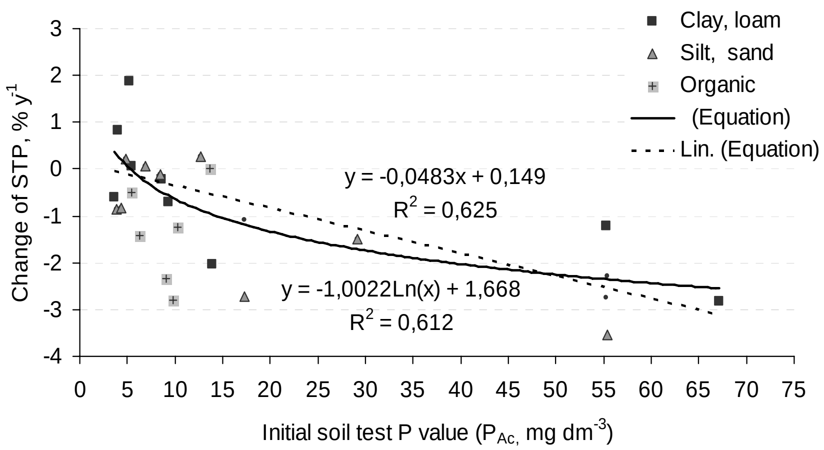

Figure 2. Annual changes of STP values at 24 sites in Finland at the P balance zero.

According to the logarithmic curve (Fig. 2), the STP value remained at the initial level at 5 mg dm^{-3} and decreased 0.82% annually at 12 mg dm^{-3}. As one unit of STP corresponded to 67 kg P ha^{-1} in the P balance at STP 12 mg dm^{-3} (and 256, 133 and 41 kg ha^{-1} at STP 2, 5 and 25, Saarela et al., 2004), the initial STP value 12 mg dm^{-3} was maintained with the annual balance surplus of 6.6 kg P ha^{-1}. This is slightly less than the earlier estimation by Saarela et al. (2004) and substantially less than the corresponding value by the equation of Ekholm et al. (2005) used to predict the changes of STP at the national level (Uusitalo et al., 2007).

P balance and changes of STP in Finnish soils from the 1950s

The amounts of P applied in manure and fertilisers have been larger than the amount removed in crops since the late 1940s, but the countrywide mean of the STP values begun to increase not until in the late 1960s (Kähäri et al., 1987). The delay was certainly a result of an increase of the volume of fertilised soil both in the horizontal and vertical directions. The mean depth of the ploughed topsoil was 17 cm in the 1950s (Juusela and Wäre, 1956), approximately 15 cm in the 1940s and 22 to 25 cm since the late 1970s. The weight of the ploughed layer of typical mineral soil has been about 1500 tonnes ha^{-1} in the 1940s and about 2300 to 2600 tonnes or 70 % more since the late 1970s. Surface soils have extended over the open ditches of subdrained fields and to the swamps and forests cleared for cultivation.

The quick increase of the amount of fertilised soil from the 1940s to the 1960s is a key factor to understand the dissimilar changes of the mean STP value of Finnish soils in relation to the P balance until the middle 1960s and since that turning point. The strong apparent fixation of soluble P during the 1950s and early 1960s was largely caused by the mixing of the thin layer of surface soil with large proportions of infertile subsurface soil. In some experiments suggesting a strong continuous fixation of extractable soil P the initial value may have been inexact (Larpes, 1981) or the depth of the fertilised soil was still increasing (Yli-Halla, 1989, Saarela et al., 2004). The STP values decrease steeply with pH at the level from 7.3 to 6.0 (Lakanen and Vuorinen, 1963), which is an obvious reason for a quick drop of STP values observed in some soils in Finland.

Freshly applied P becomes less and less extractable from year to year, but a major part of the residual P of Finnish soils has aged for decades and is changing slowly now. Increases of the easily extractable pool of P in Finnish mineral soils are efficiently buffered because of fixation, but that does not necessarily mean any continuous losses at the zero balance.

Grain yields decreased little with STK values

The effects of repeated K fertilisation were studied at 21 sites in 1977-1994, (Saarela et al., 1778). The yield responses remained small because the K reserves of the soils together with the returned straw maintained a relatively good supply of K from the soil. The changes of the STK values at the zero balance were calculated from the initial and final values (Fig. 3). High STK values of coarse-textured soils decreased quickly in the first six years but slowly or not at all between the last samplings (Saarela et al., 1998). Then a relatively small pool of soil K, not only in the surface layer but deeper, was probably used repeatedly by successive crops.

The STK values responded to the cumulative K balances most quantitatively in light clay soils. The large quickly-exchangeable pools of K in the heavy clay soils were probably efficiently buffered by the slowly exchangeable reserves of interlayer K. In coarse-textured mineral soils the leaching losses of extractable soil K increased so steeply with the balance surpluses that he differences in the STK value remained small. In several soils the final STK values were below the earlier target levels by all treatments, but even a small rate of K, 20-40 kg ha^{-1} seemed to be sufficient for sustainable and efficient grain production. The rates earlier recommended for cereals were optimal or slightly excessive for barley and considerably over the optimum for other cereals.

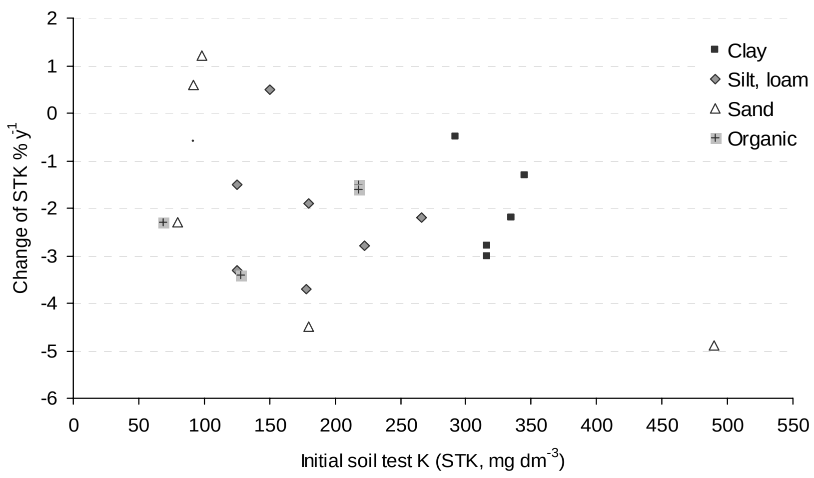

Figure 3. Annual changes of STK values at 21 sites in Finland at the K balance zero.

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