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Seasonal variation in organic and inorganic phosphorus fractions of temperate-climate sandy soils

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Abstract

Soils from an arable plot, a grassland plot and pasture plot were sampled over an 18-month period. Inorganic (P_i) and organic (P_o) soil phosphorus fractions were extracted sequentially with resin, $NaHCO_3$, and NaOH. Soil solution was sampled on the arable plot and pasture plot during 12 months with teflon suction cups, and the contents of P_i and P_o were determined.

The patterns of the variation for all soil fractions were similar for the three plots. All soil P_i fractions were at minimum in the cool moist winter period. The soil P_o fractions varied less systematically than P_i fractions. The sum of P_o fractions had a winter maximum and a spring minimum. For all soil P fractions temporal variation was highly significant ($p < 0.0001$). The magnitude of change in P_i and P_o soil fractions was 4–40 times greater than what would be expected from the magnitude of new N mineralization.

The content of P in the inorganic soil P fractions was negatively correlated with soil moisture. The variation in organic soil P could not be explained by any single factor, but it is suggested that the variation is caused by changes in solubility rather than by biological transformations. Thus, physico-chemical processes masked the impact of biological transformations on the temporal variation of soil phosphorus fractions.

Both soil solution P_i and P_o varied significantly with time on field scale. In contrast to soil P_i fractions, solution P_i was initially low in the early autumn, increased by a factor 4 during the following 6 weeks, and thereafter decreased to a low level by the end of the sampling period. Soil solution P_o had several fluctuations during the sampling period.

Introduction

Phosphorus (P) taking part in the biological cycle is usually a small fraction of the total P content of a soil. It has been proposed that soil organic P (P_o) plays an important role as a source and sink of biologically available P (Chauhan et al., 1979; Halm et al., 1972; McGill and Cole, 1981). Tarafdar and Jungk (1987) found considerable depletion of soil P_o in the rhizosphere of germinating spring barley plants. Gahoonia and Nielsen (1992) found considerable depletion of P_o in the rhizosphere of rape seedlings. Knowledge of seasonal variation in the sizes of phosphorus fractions in soil is important for our understanding of phosphorus dynamics in the soil, and our evaluation of soil tests for plant-available phosphorus.

Several field studies on temperate-climate-zone soils have shown a considerable seasonal variation of P_i. Smith (1959) reported a threefold increase in extractable P_i during warm summers, on an unfertilized plot in Berwickshire. Similarly, Garbouchev (1966) found a summer maximum and winter minimum in resin-extractable P on unfertilized plots from Woburn, the difference being 0.8 μmoles P g^{-1} soil. Weaver et al. (1988) observed the same trend in water-soluble P on sandy soils. In contrast, Sharpley (1985) found that Bray-1-P in the top 5 cm of an unfertilized grass plot was 2.4 μmol g^{-1} higher in winter than in summer. Tate et al. (1991a) found no significant variation in resin-extractable P_i, but bicarbonate-extractable P_i showed a winter maximum and a summer minimum. Felleca et al. (1983) reported monthly changes in soluble P_i (Truog's method) of approximately 0.5 μmol P g^{-1} soil in several pot experiments, and Saunders and Metson (1971) found monthly changes in resin-extractable P_i of 0.7 μmol g^{-1} soil.

Few studies have focused on changes in P_o fractions. Sharpley (1985) found that total organic P on an unfertilized grass plot increased 2.3 μmol P g^{-1} soil from summer to winter and decreased 2.6 μmol P g^{-1} during the following summer. Dormaar (1972) also found a winter maximum of organic P in an Ap horizon of a dark-brown chernozem, and reported seasonal changes of similar magnitude.

Considering the normal crop uptake of 20 to 40 kg P ha^{-1} in a growing season (Wild, 1988), as well as estimates of annual cycling of P through microbial biomass of 5 to 40 kg P ha^{-1} (Brookes et al., 1982) the cited reports of seasonal variation seem high. Taken from a 20-cm plowlayer (density 1.3 g cm^{-3}), crop uptake should deplete P_i pools by less than 0.5 μmol g^{-1} soil on average, and microbial cycling over the year should be less than 0.5 μmol P g^{-1} soil.

The present work examines the extent of seasonal variation of soil phosphorus fractions extracted sequentially with anion exchange resin, $NaHCO_3$, and NaOH, and of soil solution P_i and P_o on a sandy soil site. The aims were to gain understanding of the field situation on sandy soils, under different vegetation, and to assess the applicability of the methods for growing-season studies.

Materials and methods

Soils

The fields were located at St. Lyngby, North Eastern Zealand, Denmark. The soil had developed from windblown sand, on top of alternating layers of diluvial sand and silt. Three adjacent plots were selected: a) an arable plot with winter barley in both years, b) an ungrazed pasture plot with grass and a sparse population of legumes (pasture established in 1987, 100 kg fertilizer N), and c) a 20-year-old grassland plot.

Sampling of soil

In order to minimize the impact of spatial variation, 3 sampling patterns (replicates) were outlined, each consisting of 50 randomly generated points to be resampled to approximately 20-cm depth with a 2.5-cm auger, on each sampling date. Soil from one sampling pattern made up one of the three replicates. The soils were sampled monthly from March 1989 to August 1990.

Sampling of soil solution

After the study of soil fractions had begun, teflon suction cells (Prenart, Denmark), were installed at 30-cm depth according to Rhoades and Oster (1986), and each cell was connected to a 1-L borosilicate flask. Suction was applied to the flasks until they reached a pressure of approximately 0.3 bars, and the cells were left for 2 weeks before sampling. Ten cells were installed on the arable plot and ten on the pasture plot. The suction cells were sampled from November 1989 to November 1990.

Methods of analysis

Inorganic P in the extracts and soil solutions was determined as molybdate-reactive P in the extracts following the method of Murphy and Riley (1962) using a spectrophotometer fitted with a 5-cm flowthrough cuvette. The detection limit for orthophosphate was 0.06 μM. Soil solutions were filtered (0.22 μm) before determination of P_i was performed. Total P in solution was determined after oxidation by autoclaving the sam-

Table 1. Selected properties of the soils

Plot	Clay (%)	Silt (%)	Sand (%)	Fe[a]	Al	pH H_2O	C (%)	N (%)	C/N	Exch. acid.[b]	Ca	Base sat. pH 7.0
Arable	3.6	2.9	92.6	4.9	5.9	6.7	0.5	0.046	10	12	40.5	0.78
Grassland	4.7	3.9	89.9	6.4	7.1	5.0	0.7	0.066	11	37	12.8	0.32

[a] Extractable Fe and Al oxides are expressed as μmoles g^{-1} soil.
[b] Exchangeable acidity and Ca are expressed as μ-equivalents g^{-1} soil.

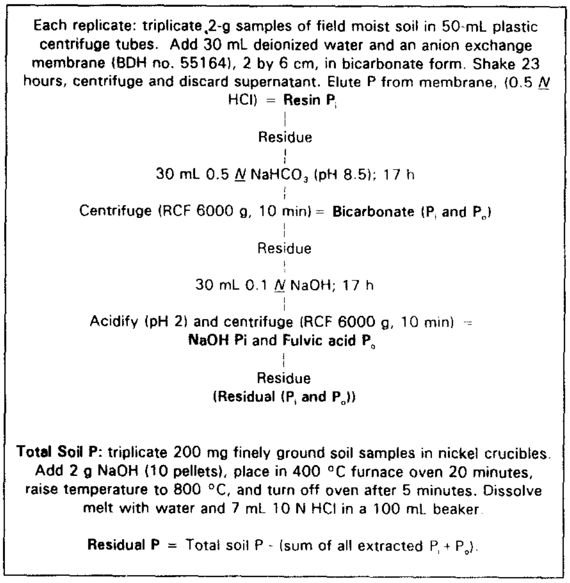
ples (140°C, 50 minutes) with a mixture of $K_2S_2O_8$ and NaOH following the procedure of Ebina et al. (1983). Organic P in the soil extracts and soil solutions was then calculated as the difference between total P and P_i. Total soil P was determined using a NaOH fusion method described by Smith and Bain (1982). Chemical and physical analysis of the soils (Table 1) included: NH_4-acetate-exchangeable Ca, Na, K and Mg, exchangeable acidity according to Thomas (1982), texture, pH and oxalate-extractable Fe and Al by extraction in darkness during 4 hours at pH 3 (McKeague and Day, 1966). Total soil carbon and nitrogen, was measured on a Carlo Erba Elemental analysis system.

Soil pretreatment

The soil samples were mixed by crushing and shaking in the incoming sample bags. A subsample was taken by coning and quartering, and sieved through a 2-mm sieve, while still in moist condition. Gravimetric water content was determined by oven-drying a sample at 105°C overnight. The soil temperature in the plow layer was estimated on the basis of air temperature, using an empirical relation derived from analysis of climatic data from a nearby meteorological station (Hansen et al., 1981).

Phosphorus fractionation

The fractionation procedure used (Fig. 1) is a modification of a sequential fractionation method suggested by Hedley et al. (1982) for extraction of decreasingly soluble P forms. Based on this scheme, Tiessen et al. (1984) characterized 168 USDA benchmark soils from 8 soil orders of the Soil Taxonomy system, and found that the distribution of phosphorus forms as defined by this method were indicative of pedological development. The method has also provided useful in elucidating long-term effects of cultivation, and changes occurring during laboratory incubations (Tiessen et al., 1982, 1983). According to Hedley et al. (1982), the resin treatment reduces the P_i concentrations in subsequent extractions, and thus reduces the risks of reprecipitation under alkaline conditions. Resin P_i as well as bicarbonate P_i are often used as indicators of plant-available P (Olsen et al., 1954; Sibbesen, 1983). Bicarbonate also extracts the most labile forms of P_o (Bowman and Cole, 1978). The NaOH solution desorbs P_i from iron oxide surfaces, dissolves aluminium oxides and a considerable amount of organic matter. Acidification of this extract leaves the fulvic acid fraction that contains moderately labile organic matter (Tiessen et al., 1984).



Each replicate: triplicate, 2-g samples of field moist soil in 50-mL plastic centrifuge tubes. Add 30 mL deionized water and an anion exchange membrane (BDH no. 55164), 2 by 6 cm, in bicarbonate form. Shake 23 hours, centrifuge and discard supernatant. Elute P from membrane, (0.5 N HCl) = **Resin P_i**

Residue

30 mL 0.5 N $NaHCO_3$ (pH 8.5); 17 h

Centrifuge (RCF 6000 g, 10 min) = **Bicarbonate (P_i and P_o)**

Residue

30 mL 0.1 N NaOH; 17 h

Acidify (pH 2) and centrifuge (RCF 6000 g, 10 min) = **NaOH Pi and Fulvic acid P_o**

Residue
(Residual (P_i and P_o))

Total Soil P: triplicate 200 mg finely ground soil samples in nickel crucibles. Add 2 g NaOH (10 pellets), place in 400 °C furnace oven 20 minutes, raise temperature to 800 °C, and turn off oven after 5 minutes. Dissolve melt with water and 7 mL 10 N HCl in a 100 mL beaker.

Residual P = Total soil P - (sum of all extracted $P_i + P_o$).

Fig. 1. Fractionation of soil inorganic P (P_i) and organic P (P_o).

To assess the effects of varying room temperature on extraction a crude test was performed. During one night, soil was extracted with resin, bicarbonate and NaOH solution (non-consecutive) at room temperature (20°C). The following day the extraction apparatus was moved into a cold room (4°C), and the procedure was repeated. The observed differences are taken to represent the effect of room temperature on extraction (Table 2).

A standard air-dry soil was included in the period from January 1990 to August 1990. The variation of the standard soil is taken solely as repeatability error. Based on this assumption a correction for repeatability or 'laboratory bias' was made for each fraction on each data:

$$f_{ci} = f_{ui} * \bar{f}_s / f_{si}$$

where f_{ci} is the corrected value for fraction 'f' on date 'i', f_{ui} is the measured value for fraction 'f' on date 'i', and $\bar{f}_s/f_{si}$ is a correction factor yielding the quotient of the mean value of fraction f from a standard soil over the particular value obtained from the standard soil on date 'i'.

The following phosphorus fractions are considered from the sequential extraction procedure:

Resin P_i

Sum of resin P_i and bicarbonate P_i

The study was initiated without the resin fraction, and in order to include data from the first months these fractions must be considered jointly. That this pooling is actually feasible was assessed by controls in the first four months of using the resin membranes.

Total extracted P_i

The sum of resin P_i, bicarbonate P_i and NaOH P_i.

Bicarbonate P_o

The difference between total and P_i in the bicarbonate extract.

Fulvic acid P_o

The difference between total and P_i in the acidified NaOH extract.

Total extracted P_o

The sum of bicarbonate Po and fulvic acid Po.

Analysis of variance

Analysis of variance was performed on the soil fractionation data with the SAS GLM procedure using two models:

$$Y_{ijk} = \mu + A_i + B_{ij} + \varepsilon_{ijk} \tag{1}$$

where A is the field variability, B is the variability from subsamples and ε is the variability of measurements, in a hierarchical analysis.

$$Y_{ijk} = \mu + A_i + B_j + (AB)_{ij} + \varepsilon_{ijk} \tag{2}$$

where A is the temporal variability, B is the field variability, (AB) is the interaction between temporal and field variability, and ε is the subsample variability.

Results

As the soil fractionation data for the pasture plot and the arable plot were similar, results from the pasture plot has been excluded in subsequent figures.

Statistical analysis

The initial characterization of the plots was based on soil sampled in a 5-meter grid over an area of 15 by 30 meters. Inorganic P (P_i) and organic P (P_o) was extracted by the bicarbonate method of Olsen et al. (1954) (Fig. 2). On all three plots P_i was not correlated with P_o and neither was P_o correlated with P_i. Both P_i and P_o varied systematically over the area.

The soil fractions from the standard soil used to evaluate laboratory bias during the last 6 months had the following coefficients of varia-

Table 2. Amounts of P (μmol P g^{-1} soil) extracted in various fractions at differing room temperature

T	Resin Pi	Bicarb. Pi	NaOH Pi	Bicarb. Po	Fulvic Po
4°C	0.85	0.81	2.16	0.27	0.49
20°C	0.77	1.53	2.45	0.52	0.87
Signif.[a]	*	* * *	* * *	* * *	* * *

[a]Significant differences are described as: $* = p < 0.05$, $** = p < 0.001$, $*** = p < 0.0001$.

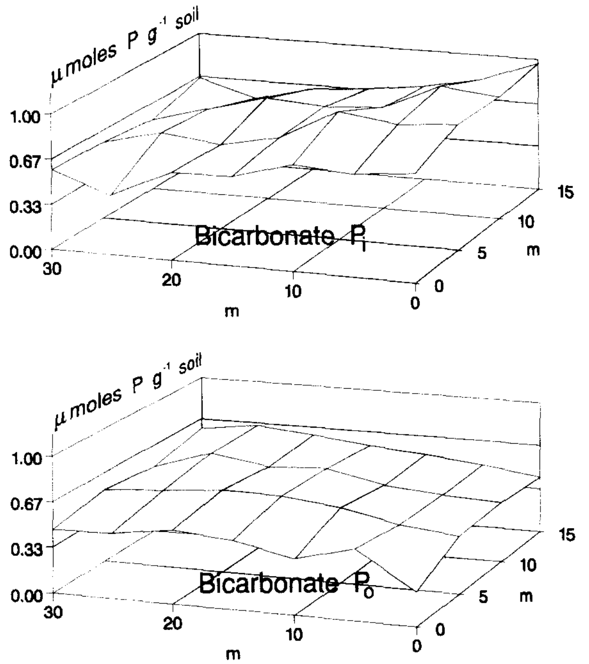


Fig. 2. Spatial variation on the grassland plot in bicarbonate P_i and P_o, as extracted by the method of Olsen et al. (1954).

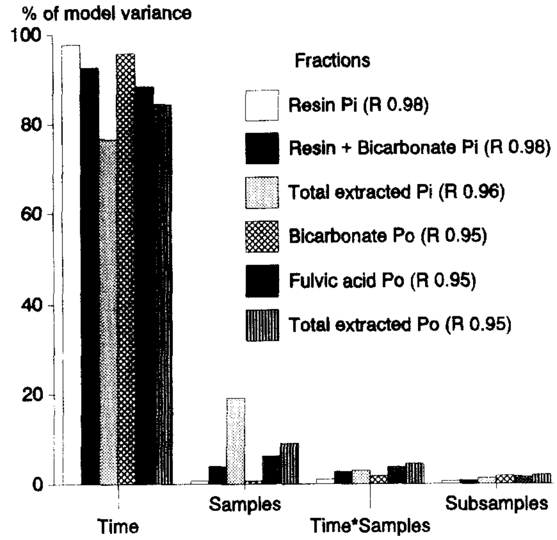


Fig. 3. The magnitude of variance components, expressed as % of total mean square estimates, from analysis of variance of data from the arable plot.

tions: 'Resin P_i', 6%; 'Sum of resin P_i and bicarbonate P_i', 10%; 'Total extracted P_i', 1%; 'Bicarbonate P_o', 36%; 'Fulvic acid P_o', 21%; 'Total extracted P_o', 2%. Apart from having the largest variability, the 'Bicarbonate P_o' was the only fraction in which corrections for laboratory bias systematically cancelled the temporal variability of field estimates.

showed that the different sources of variation contributed to the total variation in the following order: apparatus error < variance of extraction- ≪ variance between replicates of the plot. Figure 3 shows the results of applying an analysis of variance (GLM) testing the effect of 'time', 'samples', 'subsamples' and 'interactions between time and samples' on the data collected from the arable plot (model 2). Correlation coefficients were high, ranging from 0.95–0.98. It may be seen that 'time' is the main factor, explaining 77–98% of the model variance. In most cases the variance introduced from the samples was significantly greater than that from the subsamples. However only in the case of 'Total extracted P_i' was the sample variance significantly greater than the interactions between time and samples. Thus the interaction between time and samples (i.e. sampling strategy) generally overshadowed the effect of systematic sampling.

Analysis of the soil solution data showed that the variation between suction cups accounted for more than 50% of the total variance of P_i concentrations, but less than 15% of total variance of the P_o concentrations. Thus the spatial variation between samplers was dominant for soil solution P_i but not for soil solution P_o. The pasture plot had significantly higher concentrations of P_i and P_o than the arable plot. Analysis of the temporal variation showed that P_o concentrations on both the arable and pasture plot varied considerably ($p < 0.0001$, R^2 0.34–0.44). The variation of field estimates for P_i concentrations was also significant with time ($p < 0.05$, R^2 0.20).

Temporal variations

Soil moisture and temperature

As the plots are adjacent, they followed the same pattern with regard to temperature and moisture content (Fig. 4). However, the grassland plot contained systematically higher amounts of soil moisture throughout the study

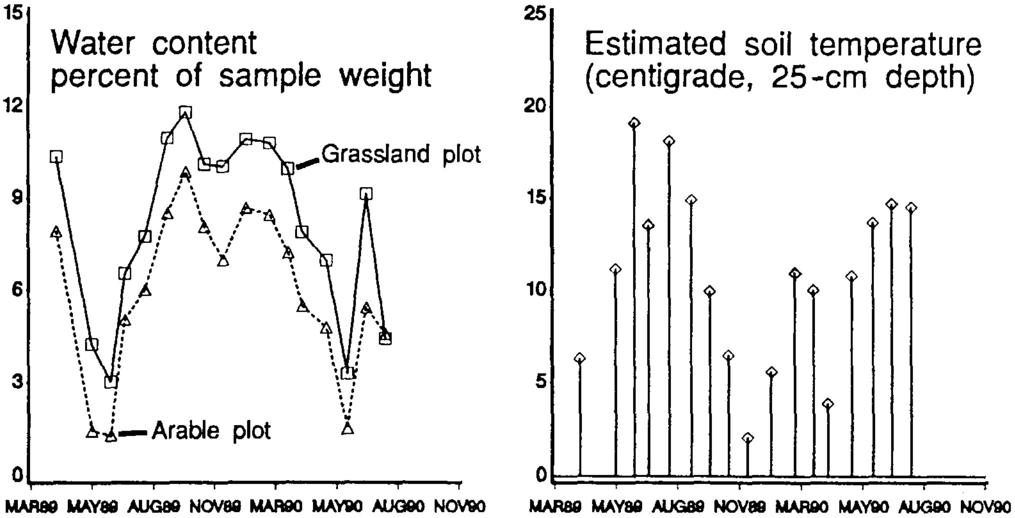


Fig. 4. Temporal variation in moisture content and soil temperature estimated from air temperature (Hansen et al., 1981).

period. This may be due to higher content of organic matter. The soils became very dry in the summer period, with water contents below 3% by weight. The estimated soil temperature varied between 2°C and 19°C.

Total P

Total P data, given in Figure 5, are seen to be approximately constant over the whole period, as the variability encountered was within the limits of the uncertainty of total P determinations. This indicates that the repeatibility of soil sampling was satisfactory. Total P was systematically slightly lower on the arable plot (1 μmol g^{-1} soil).

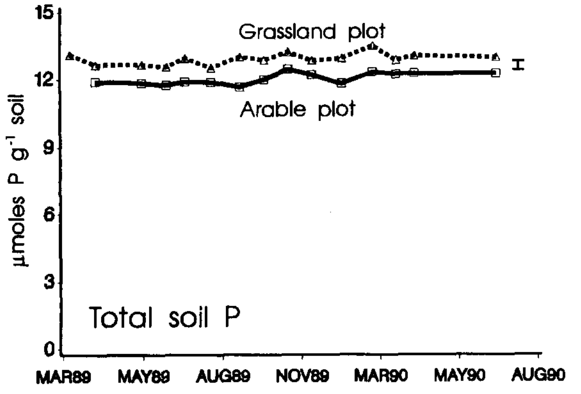


Fig. 5. Total P content of the samples, the error bar represents the mean value of the standard error for the plots.

Soil inorganic P

Figure 6 shows the variation of P_i fractions on the arable and grassland plots. As the correction for laboratory bias did not seriously change the pattern of variation in any of these fractions, it is assumed that the changes observed reflected changes in the field, and the corrected estimates have been left out of the graph. The field estimates of 'Resin P_i' followed a sinusoidal pattern, decreasing in autumn and winter, and increasing in spring. The largest span was approximately 0.4 μmol P g^{-1} soil. The 'Sum of resin P_i and bicarbonate P_i', approximately doubled relative to that of 'Resin P_i' alone, but the pattern remained the same. The largest span was 0.7–0.8 μmol g^{-1} soil. The level of 'Total extracted P_i' was twice that of 'Sum of resin P_i and bicarbonate P_i', the largest span being 1.1–1.2 μmoles g^{-1} soil. Although the curves are less smooth, they have a sinusoidal shape synchronous with the other fractions.

Soil organic P

The organic P fractions are shown in Figure 7. The 'Bicarbonate P_o' was quite variable over time, the pattern less systematic than the easily soluble inorganic fractions. Corrections of field estimates for laboratory bias cancelled most of the temporal variation of 'Bicarbonate P_O' on all plots. 'Fulvic acid P_o' was less variable, but there

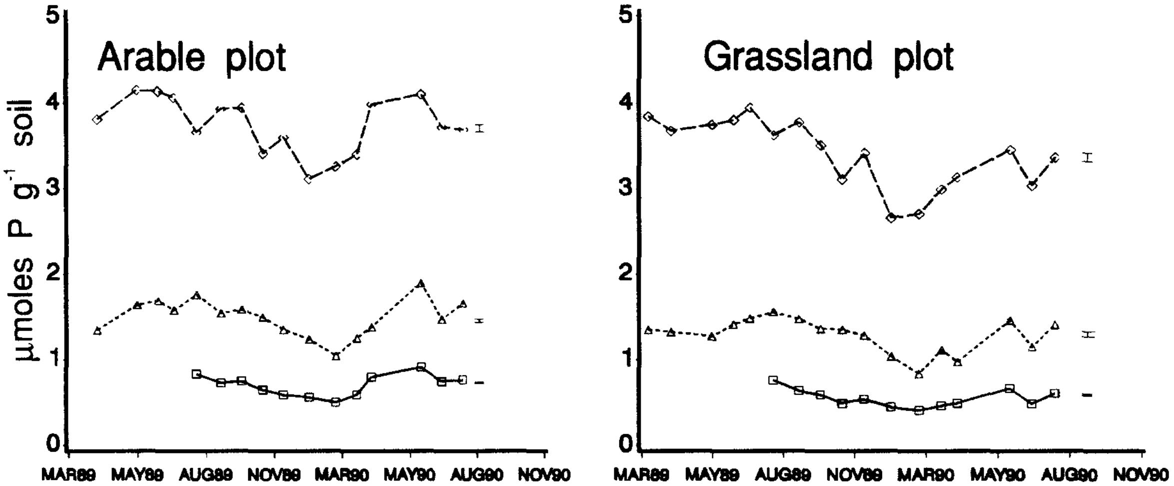


Fig. 6. Soil inorganic phosphorus fractions, sampled from the 0–20 cm layer of the arable plot and the grassland plot. Observed data: □ 'Resin P_i', △ 'Sum of resin P_i and bicarbonate P_i', ◇ 'Total extracted P_i'. Error bars represent the mean value of the standard error for the various fractions.

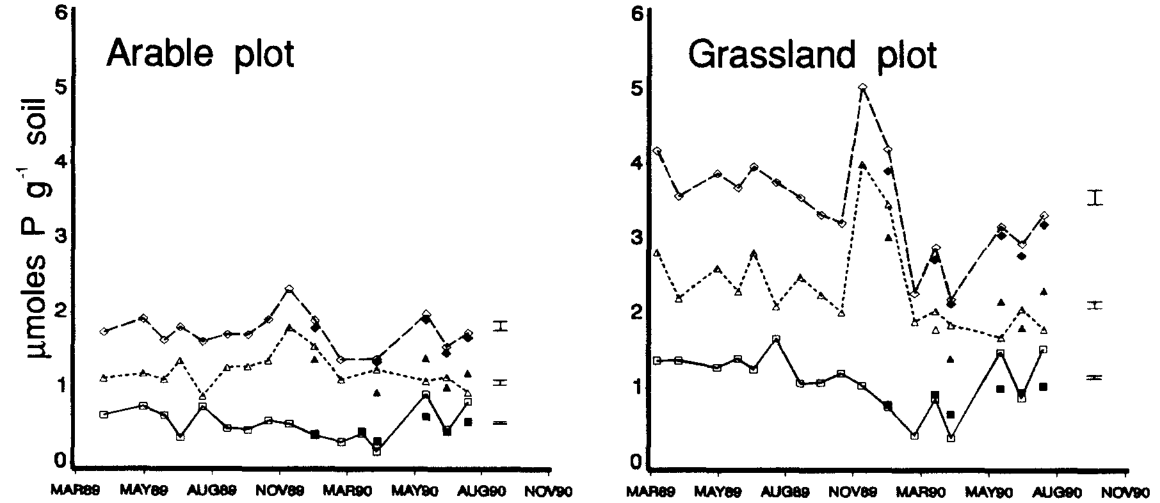


Fig. 7. Soil organic phosphorus fractions, sampled from the 0–20 cm layer of the arable plot and the grassland plot. Observed data: opens symbols are field estimates, solid symbols have been corrected for laboratory bias. □/■ 'Bicarbonate P_o', △/▲ 'Fulvic acid P_o', ◇/◆ 'Total extracted P_o'. Error bars represent the mean value of the standard error for the various fractions.

was a characteristic peak in the winter. The span from the highest to lowest estimate was 2.4 μmol g^{-1} soil in the grassland plot and 0.8 μmol g^{-1} soil in the other plots. The correction for laboratory bias increased the temporal variation. The pattern of variation of 'Total extracted P_o' was more smooth than 'Bicarbonate P_o' and 'Fulvic acid P_o', and the deviations between corrected and uncorrected estimates were small. The correction for laboratory bias seriously affected both 'Bicarbonate P_o' and 'Fulvic acid P_o', but the effect was minimal on the sum of these fractions. Therefore the changes in 'Total extracted P_o' are assumed to reflect changes in the field. The corrected values have been included in Figure 7. There was a shift in the general level of

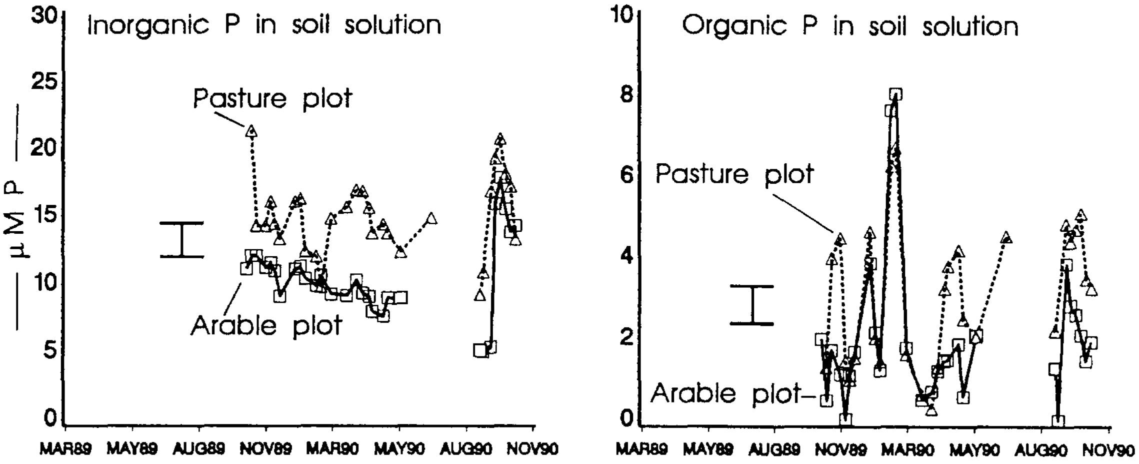


Fig. 8. Soil solution concentrations of inorganic and organic phosphorus, sampled with teflon suction cells at 30 cm depth. Observed data; □ arable plot, △ pasture plot.

extractable P_o, that was lower in the spring of 1990 than in that of 1989. This was especially marked on the grassland plot.

Soil solution P

Soil solution P_i and P_o concentrations are shown in Figure 8. P_o concentrations vary in a similar way in the two plots, showing frequent fluctuations in the sampling period. P_i concentrations are less variable. In the second sampling period all plots behave similarly with regard to P_i and P_o, showing an initial increase during 6 weeks, and a subsequent decrease in soil solution P_i and P_o concentrations.

Discussion

The data on spatial variation (Fig. 2) show that it is important to take spatial variation into consideration in the sampling strategy. If the sampling had been made in varying patterns from one date to another, considerable spatial variation could be superimposed on the temporal changes. From the statistical analysis it may be seen that a significant part of the variability could be explained by the samples, but also that there was a significant interaction between sampling and time (Fig. 3). Plots of values for each sample against time showed that there was a systematic difference between samples throughout the sampling period, but also that the samples sometimes changed with respect to which pattern gave the highest or lowest value.

The temporal variability of the soil phosphorus fractions forms patterns in which often more than three points define the peaks and valleys. However, the scale of variation is beyond what can be understood solely in terms of biological processes, which may be illustrated in the following reasoning. Christensen et al. (1990) determined the net N-mineralization in the top 20 cm of various subplots of the St. Lyngby site. They concluded that it ranged from 60–100 kg N ha^{-1} yr^{-1}. The change in resin P_i is approximately 0.4 μmol^{-1} from winter to summer corresponding to a change of 40 kg $P_i ha^{-1}$ in the fraction. It seems unlikely that all mineralized P should be recovered in the resin P fraction. Therefore, the real mineralized amount of P should supposedly be higher than 40 kg P_i ha^{-1} and therefore the ratio of mineralized $N:P<2$. Other P fractions have even higher amplitudes, particularly 'Total extracted P_i' and 'Total extracted P_o' (1.1–2.8 μmoles P g^{-1} soil). Elliott (1986) found rather narrow N:P ratios in a loam soil, ranging from 9 to 12 depending on aggregate size. Thus, if the mean N:P ratio of the mineralized material was 10, the expected mineralization should be 6–10 kg, which is 4–40 times less than the changes observed in the various fractions.

The changes in inorganic fractions follow the changes in soil moisture content inversely. Regressions between estimates for the inorganic fractions and the moisture content on the day of sampling gave highly significant ($p < 0.0001$) negative correlation coefficients (R−0.58 to −0.56). If biological turnover had been a major cause for the observed variation, this should have been reflected in the effect of temperature, and especially the interactions between moisture and temperature. Effects of soil temperature were not significant, although interactions between temperature and moisture were significant in accounting for variance in 'Total inorganic P_i'.

Dehydration of soil occurring during air-drying has been shown to have a profound effect on desorption of phosphate in soil (Barrow and Shaw, 1980; Bartlett and James, 1980; Haynes and Swift, 1984; Olsen and Court, 1983). Olsen and Court (1983) suggested that rewetting dry soil exposed new surfaces containing both native P and unreacted adsorption sites. They found that this effect was reversible upon prolonged moist storage. There have been reports of increases in $NaHCO_3$-extractable P in drying soils, thought to be derived from microorganisms killed in the drying process (Brookes et al., 1982; McLaughlin et al., 1988; Sparling et al., 1987). However, as the drying of the soils in the actual field situation occurred rather slowly, the microbial biomass should have had time to adapt to changes in moisture conditions. Therefore, physical changes in the soil are more likely to be the main cause than microbial death. This assumption is supported by unpublished data showing that the effect of drying St. Lyngby soil sampled from 30–60 cm and 60–90 cm is comparable to the effect of drying the plow layer soil. Measurements of seasonal variations in soil microbial biomass on two pastures (Tate et al., 1991b), showed no significant changes.

The changes in P_o fractions are difficult to explain. Changes in the fulvic-acid P of 2 μmol g^{-1} soil on the grassland plot amount to more than 180 kg P ha^{-1}. Although it cannot be explained on the basis of other observations, these changes must be attributed to changes in solubility of soil P_o. Statistical analysis showed significant interactions between soil moisture and temperature in the extractability of 'Total P_o', being high in cool and moist months.

Opposed to the soil fractions, P_i in soil solution did not vary very smoothly with time. In the second sampling period following the dry summer there was a marked increase in P_i concentration during the first 6 weeks in autumn in all plots, and P_o follows the pattern of P_i rather closely in this period. This might be related to a microbial flush following the rewetting of dry soil (Hunt et al., 1989). Cole et al. (1978) showed that upon addition of glucose to soil, bicarbonate-extractable P_i decreased, whereas microbial P increased. The observed low initial P_i and P_o contents of soil solution could therefore be consistent with an expected high microbiological activity following the rewetting of dry warm soil, resulting in initial immobilization of phosphate in solution. The subsequent increase in P_i and P_o in soil solution could be a result of microbial death. Organic P in soil solution fluctuated several times during the winter period, and there was a marked synchronism between the plots. The magnitude of these changes is compatible with current biological processes in the cycling of organic matter, as a change of 1 μmole P L^{-1} solution is less than 30 g P ha^{-1} in the 0–30 cm layer. The changes in solution P_i or P_o bear no marked resemblance with such changes in soil fractions.

The use of extraction-based methods more or less defeats the purpose of studying short-term biological transformations in these sandy soils. The lack of stability of even the least soluble soil fractions is striking. This also raises the question whether extraction procedures normally applied to estimate soil fertility are reliable enough to give consistent results over time. Different soils respond differently to drying (Olsen and Court, 1983), and as plants do not take up phosphorus from dry soil, it may be argued that the practice of using air-dry soil for analysis introduces an inappropriate bias to the estimate of plant-available P, even though air-drying the soils may remove some of the variation in inorganic P. However, Garbouchev (1966) found a considerable seasonal variation in resin P_i extracted from air-dried soils. The winter minimum–summer maximum cycle may be particular for coarse-textured soils in which the larger part of the soil volume becomes dry during dry warm periods. For fine-textured soils one might expect temporal increases in phosphate released, as ferric minerals may be reduced during the wet season in smaller or larger parts of biologically active soil. This is in agreement with Tate et al. (1991) and Sharpley (1985). Thereby, the biological cycling may be completely masked by physicochemical processes connected with changes in soil moisture.

Conclusions

The soil phosphorus fractions defined by the current fractionation method was found to vary 4–40 times more than what had been expected from biological considerations. The amounts of inorganic P in the extractable fractions varied inversely with changes in soil moisture content, which may be explained by physical changes in soil structure, and by effects of drying on the soil microbial biomass. The changes in organic fractions cannot be explained, but it seems likely that they reflect changes in solubility of organic matter, rather than biological turnover of organic matter.

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