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EFFECTS OF TREES ON SOIL PROPERTIES, A RESAMPLING OF J D OVINGTON'S PLOTS AT ABBOTSWOOD

by

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1 INTRODUCTION

Because the United Kingdom imports about 92% of the timber that it uses, a considerable expansion of the afforested area appears to be inevitable (Centre for Agricultural Strategy 1980). A study of the effects of tree species on soils is therefore timely and of practical importance, because it is desirable to be forewarned of changes likely to result from the establishment of trees, so possibly being able to direct those changes by selecting the most suitable tree species for conserving and improving soil fertility, an aspect of particular importance to poor marginal land where most of the expansion is likely to occur.

In 1951, to gain an insight into the effects of trees on soils, J. D. Ovington sampled soils in plots of coniferous and deciduous species on 5 sites. His papers (Ovington 1953, 1954, 1955, 1956a, 1956b, 1958a, 1958b) did not present a statistical analysis of the data. In 1974, plots at Bedgebury, Abbotswood, and West Tofts which had not been felled and replanted were resampled by ITE and Forestry Commission staff to define changes in soil and litter chemical properties which might have occurred in the intervening period. None of the existing plots had fertilizer applied either on planting or subsequently, and none has had herbicide applications at any stage.

The 3 sites which were resampled differ in soil parent material and in the species planted. The results for *Pinus nigra* at all 3 sites and for the species at Bedgebury were given in Howard and Howard (1984 a,b). This paper presents the results for species planted at Abbotswood.

2 SITES AND SAMPLING PLOTS

The Abbotswood plots (Forest of Dean, Gloucestershire) are situated at about 107 m altitude along the eastern margin of forest on the relatively steep western slopes of a small north-to-south valley, on the rim outcrop of Old Red Sandstone. The soil is a fairly coarse sandy loam, generally becoming coarser down the profile, of average depth 80 cm. In some profiles, narrow bands of reddish clay occur. The soil is more or less stone-free, except for scattered pebbles, and is freely-drained, with no evidence of waterlogging. Ovington (1953) found the surface pH to be just over 4, increasing slowly with depth. There was no evidence of podzolization. This area is said to have carried previously a fairly uniform crop of mature beech standards, with a sprinkling of oak standards, probably planted in about 1806. There was a small relict woodland on the upper slopes (Ovington 1953).

The tree species and planting years of the resampled plots are given in Table 1. Full soil profile descriptions are given in Ovington (1953). Within each plot, 5 profiles were sampled. The sampling depths common to both years for the soil variables were 0-5, 5-10, 15-20, 25-30, 45-50 and 65-70 cm.

3 METHODS

3.1 Chemical analyses

The analyses which were common to both the 1951 and 1974 samplings were L and F/H layers: loss-on-ignition, total nitrogen, total sodium, potassium, calcium, magnesium, phosphorus. Soil: pH, loss-on-ignition, total nitrogen, extractable sodium, potassium, calcium, magnesium, phosphorus. There were some differences in the chemical methods used in 1951 and 1974, which made it necessary to apply conversion factors to some of the 1974 values to produce a 1951 equivalent (Appendix 1).

3.2 Statistical analyses

Ovington's plots were not part of a designed experiment, this was an opportunistic sampling of plots which had been planted for another purpose. Each species occurred only once at each site.

Analysis of variance: Ovington's papers did not give any indication of the variance within plots. In order to compare plot (ie species) means between years, we need an estimate of the within-plot variance. In the present work, the only course open to us was to assume that the within-plot variances in Ovington's samplings were the same as those in the 1974 samples, although this is not altogether satisfactory.

To obtain a pooled within-plots estimate of the variance, we did a one-way analysis of variance of the 1974 data for each soil depth (or L or F/H layer) and chemical element, separately. If there is heterogeneity of variance between plots (Bartlett's test), the pooled within-plots estimate of the variance cannot be used to compare between years. In such cases, transformation may remove heterogeneity. In cases where transformation was not effective, the means of individual plots in 1951 and 1974 were compared using Fisher's randomization test.

Where heterogeneity did not occur, or was removed by transformation, comparisons were made between the plot (species) means for the 1951 and 1974 samplings using Tukey's honestly significant difference. That test was also used to look for differences among plot (species) means in 1974. For the L and F/H layers, on the 1974 sampling; there were not always 5 replicates per plot, and so Dunnett's (1980) modification for unequal sample sizes was used. Scheffe's (1953) method was used to test for differences between means for broadleaves and conifers in 1974.

Principal component analysis: A principal component analysis was carried out on the correlation matrix of the data for the 7 chemical variables (means of plots) for both years for the L and F/H layers together. A similar analysis was carried out on the 8 chemical variables (means of plots) for both years for all the soil layers common to both samplings. A third set of analyses was carried out on the 1974 data alone, treating each layer separately. Components with eigenvalues greater than unity were accepted as being of practical importance. Eigenvector elements equal to, or greater than, 0.75 times the largest value (absolute) showed the variables which contributed most to the components. In each case the minimum spanning tree of the Pythagorean distances was computed from the components considered to be of practical importance.

4 RESULTS

Two complementary types of figure are used to present the results. One type illustrates the change of each variable with depth and the depths at which differences between years are significant. In the second type, for each soil depth, the mean values of the plots (species) are ordered on a single axis for each year. The second type illustrate more clearly than the first type the magnitudes of the differences between years, the relative values of the species in either year, and the significant differences, or lack of difference, between species in 1974.

4.1 L and F/H layers, analysis of variance

pH: Not measured on L and F/H in 1974.

Loss-on-ignition: *Larix decidua* litter had the lowest loss-on-ignition (greatest ash content) and *Pinus nigra* litter had the greatest loss-on-ignition (lowest ash content) in both 1951 and 1974 (cf *Pinus nigra* at Bedgebury, Howard & Howard 1984 a,b). In both years, *Abies grandis* F/H layer had the lowest loss-on-ignition. The only significant change from 1951 to 1974 was an increase in loss-on-ignition (decrease in ash content) in *Abies grandis* litter (Figure 4). The F/H layer under *Quercus robur* showed a significant decrease in loss-on-ignition (increase in ash content), while the opposite occurred under *Picea abies*. In both layers there was a narrowing in the range of loss-on-ignition values from 1951 to 1974, resulting in no significant differences between species in 1974.

Nitrogen (total): *Pinus nigra* litter had the lowest total nitrogen content in both years, in spite of a significant increase from 1951 to 1974 (Figure 6). *Abies grandis* litter also showed a significant increase, and had the greatest total nitrogen in 1974. In the F/H layers, there were significant decreases under *Castanea sativa*, *Quercus robur*, and *Larix decidua*, resulting in a narrowing of the range of values with no significant differences between species in 1974.

Sodium (total): *Pinus nigra* litter had the greatest total sodium content in 1951, but this decreased significantly to become the lowest in 1974 (Figure 8). There were no significant differences between plots in 1974. *Abies grandis* F/H layer had the greatest total sodium content in both years. In the F/H layer, *Abies grandis*, *Larix decidua*, and *Pinus nigra* showed significant increases in total sodium from 1951 to 1974.

Potassium (total): In 1974, the mean total potassium content of the litters of the hardwood species was significantly ($p < 0.01$) greater than that of the coniferous species. However, there was no significant difference between the individual species if the value for *Quercus robur* was removed (Figure 10). *Castanea sativa*, *Quercus robur*, *Abies grandis*, and *Pinus nigra* litters showed significant decreases from 1951 to 1974, while *Picea abies* litter showed a significant increase. The range of total potassium values in the litters decreased from 1951 to 1974. In the F/H layers, there were significant increases under *Quercus robur*, *Pinus nigra*, and *Larix decidua*.

Calcium (total): *Quercus robur* L and F/H layers had the greatest total calcium contents in both years. *Larix decidua* had the lowest total calcium in litter and *Picea abies* the lowest content in F/H. In 1974, the mean total calcium contents of the litter and F/H layers of the hardwood species were significantly ($p < 0.001$) greater than those of the coniferous species. However, comparing the individual species, litters of some coniferous species were not significantly different from those of some hardwood species. In the F/H layers, there was no significant difference between *Fagus sylvatica* and the coniferous species (Figure 12). There was a slight narrowing of the range of total calcium values in both L and F/H layers from 1951 to 1974. *Abies grandis* litter showed a significant decrease from 1951 to 1974, and *Picea abies* and *Larix decidua* litters showed significant increases.

Magnesium (total): In 1974, the mean total magnesium contents of the L and F/H layers of the hardwood species were significantly ($p < 0.001$) greater than those of the coniferous species. However, comparing the individual species, *Quercus robur* litter had a significantly greater total magnesium content than any other litter, and in both L and F/H layers some coniferous species were not significantly different from some hardwood species (Figure 14). *Castanea sativa* litter showed a large decrease in total magnesium, and *Pinus nigra* litter a small but significant decrease, from 1951 to 1974. The F/H layer under *Picea abies* showed a significant decrease in total magnesium, and that under *Quercus robur* a significant increase, from 1951 to 1974.

Phosphorus (total): *Castanea sativa* L and F/H layers had the greatest total phosphorus content in both years. *Pinus nigra* litter had the lowest total phosphorus content in both years, and its F/H layer had the lowest content in 1951, but in 1974 *Larix decidua* F/H had the lowest total phosphorus content. In 1974, the mean total phosphorus contents of the L and F/H layers of the hardwood species were significantly ($p < 0.01$) greater than those of the coniferous species. However, comparing the individual species, some coniferous species were not significantly different from some hardwood species (Figure 16). *Abies grandis*, *Picea abies*, *Larix decidua* and *Pinus nigra* litters and F/H layers showed significant increases from 1951 to 1974.

4.2 Soils, analysis of variance

pH: The mean values for each plot (species) are shown plotted against depth in Figure 1. In Figure 2, for each soil depth, the mean values of the plots (species) are ordered on a single axis for each year. In 1951, down to 25 cm depth, soils under the 3 hardwood species had the greatest pH values. In 1974, the mean pH of soil under the hardwoods was significantly ($p < 0.001$) greater than that under the coniferous species at all depths. However, there were not always significant differences between individual coniferous and hardwood species (Figure 2). Soil under *Castanea sativa* had the greatest, and under *Picea abies* the smallest, pH at all depths down to 50 cm. There was a significant decrease in pH at 0-5 cm depth under all species except *Pinus nigra*, and at 5-10 cm under all species except *P. nigra* and *Abies grandis*. Below 10 cm, there were some changes in pH, but they showed no clear trend. The largest decreases in pH were at 0-5 cm under *Quercus robur* (-0.77 units) and *Castanea sativa* (-0.53 units). All the other changes were less than 0.5 units.

Loss-on-ignition: The mean values for each plot (species) are shown plotted against depth in Figure 3. In Figure 4, for each soil depth, the mean values of the plots (species) are ordered on a single axis for each year. In 1974, at 0-5 cm, loss-on-ignition of soil under *Quercus robur* was not significantly different from that under *Picea abies*, *Larix decidua* and *Pinus nigra*, and loss-on-ignition of soil under *Abies grandis* was not significantly different from that under the 3 hardwood species. At all the other depths, soil under some individual coniferous and hardwood species did not have significantly different loss-on-ignition. From 1951 to 1974, at 0-5 cm depth, there was a significant increase in loss-on-ignition under *Picea abies* (from 7.5% to 10%), and at the same depth there was a significant decrease under *Abies grandis* (8.6% to 5.4%). Also at that depth, the range of loss-on-ignition values had increased by 1974 (cf Bedgebury, Howard & Howard 1984b). Smaller, but significant, decreases occurred at various depths under *Picea abies*, *Abies grandis*, *Fagus sylvatica*, *Quercus robur* and *Castanea sativa*.

Nitrogen (total): The mean values for each plot (species) are shown plotted against depth in Figure 5. In Figure 6, for each soil depth, the mean values of the plots (species) are ordered on a single axis for each year. In 1974, only at 5-10 cm was there any significant difference between plots in total nitrogen content. At that depth, soils under some of the coniferous species were not significantly different from those under some of the hardwood species. From 1951 to 1974, soils under all species except *Larix decidua* and *Picea abies* showed decreases in total nitrogen content at 0-5 cm, and there were decreases under all species at 5-10 cm and 15-20 cm. Under *Pinus nigra* there were significant decreases at all depths except 45-50 cm, and under *Abies grandis* down to 30 cm. There were also significant decreases at various depths under other species.

Sodium (extractable): The mean values for each plot (species) are shown plotted against depth in Figure 7. In Figure 8, for each soil depth, the mean values of the plots (species) are ordered on a single axis for each year. The mean extractable sodium contents of soils under the hardwood species were significantly ($p < 0.05$) smaller than those under the coniferous species at all depths except 25-30 cm. At all depths, soils under some individual hardwood and coniferous species were not significantly different. Soil under *Castanea sativa* had the lowest content of extractable sodium at all depths for both years down to 30 cm. From 1951 to 1974, there were significant decreases at 5-10 cm under all species except *Fagus sylvatica*. At greater depths some species showed no significant change, some showed gains and others losses.

Potassium (extractable): The mean values for each plot (species) are shown plotted against depth in Figure 9. In Figure 10, for each soil depth, the mean values of the plots (species) are ordered on a single axis for each year. Soil at 0-5 cm and 5-10 cm depth under *Quercus robur* had the greatest content of extractable potassium in 1974, but below 15 cm the content was greater under *Pinus nigra* in both years (cf Bedgebury, Howard & Howard 1984b). In 1974, the mean extractable potassium content of 0-5 cm soil under the hardwood species was significantly ($p < 0.01$) greater than that under the coniferous species. However, comparing the individual species, there was no significant difference between the remaining species if *Quercus robur* was removed. At 0-5 cm and 5-10 cm, soil under *Q. robur* had the greatest extractable potassium content in 1974, but below 15 cm the content was greater under *Pinus nigra* in both years (cf Bedgebury, Howard & Howard 1984b).

There was some evidence of an increase in extractable potassium from 1951 to 1974 at most depths under several of the species, and in many layers below 15 cm depth the increases were statistically significant (cf Bedgebury).

Calcium (extractable): The mean values for each plot (species) are shown plotted against depth in Figure 11. In Figure 12, for each soil depth, the mean values of the plots (species) are ordered on a single axis for each year. It is interesting that soil under *Pinus nigra* had a high extractable calcium content at most depths in both years, its content being the greatest at 5-10 cm in 1951, at 15-20 cm in 1974, at 25-30 cm in both years, at 45-50 cm in 1951, and at 65-70 cm in 1974. In 1974, the only significant difference between species with regard to soil extractable calcium content was at 65-70 cm depth, where soils under some of the coniferous species were not significantly different from soils under some of the hardwood species (Figure 12). Soils at 0-5 cm depth under *Abies grandis*, *Fagus sylvatica*, *Quercus robur* and *Castanea sativa* showed significant losses of extractable calcium between 1951 and 1974. Under all those species there were significant losses down to 20 cm except *F. sylvatica* 5-10 cm. Under *Castanea sativa* losses were significant down to 50 cm, and under *Picea abies* at all depths from 5 to 50 cm. Soil under all species except *Larix decidua* and *Quercus robur* showed losses at 45-50 cm. Under *Pinus nigra*, *Fagus sylvatica* and *Q. robur* there were significant increases at 65-70 cm.

Magnesium (extractable): The mean values for each plot (species) are shown plotted against depth in Figure 13. In Figure 14, for each soil depth, the mean values of the plots are ordered on a single axis for each year. Soil under *Castanea sativa* had the lowest extractable magnesium content at all depths below 5 cm in 1974, and at 5-10 cm and 15-20 cm in 1951. In 1974, the mean extractable magnesium content in the soils between 5 and 25 cm depth under the hardwood species was significantly ($p < 0.01$) smaller than that under the coniferous species. However, at most depths soils under some individual hardwood species were not significantly different from those under some coniferous species (Figure 14). There were significant decreases at all depths under all species except *Quercus robur* 45-50 cm and 65-70 cm, and under *Pinus nigra* and *Fagus sylvatica* at 65-70 cm. The magnitudes of the changes decreased with increasing depth.

Phosphorus (extractable): The mean values for each plot (species) are shown plotted against depth in Figure 15. In Figure 16, for each soil depth, the mean values of the plots are ordered on a single axis for each year. Soil under *Larix decidua* had an unusually large extractable phosphorus content at all depths in 1951, the amount increasing with depth. Soil under *Picea abies* had the greatest, and under *Fagus sylvatica* the smallest, extractable phosphorus content at all depths in 1974. At 0-5 cm the extractable phosphorus content of soil under *Picea abies* was significantly greater than that under any other species. In 1974, the mean extractable phosphorus content of soils under the hardwoods was significantly smaller than that under the conifers at 0-5 cm ($p < 0.001$), 5-10 cm ($p < 0.05$), 10-15 cm ($p < 0.01$), 15-20 cm ($p < 0.05$) and 25-30 cm ($p < 0.05$). However, taking the species individually, at all depths one (or more) hardwood species could be found which was not significantly different from one or more coniferous species. From 1951 to 1974 there were significant, and large, decreases in extractable phosphorus content at all depths under *Larix decidua*, related to its high content in 1951. There were significant increases at some depths under some species, but with no evidence of a clear trend.

4.3 L and F/H layers, principal component analysis, 1951 and 1974 data combined

Loss-on-ignition (CV 11%) and nitrogen (CV 18%) showed little variation, while total potassium (CV 53%) showed most variation. Nine of the 21 correlation coefficients are significant, the largest being between total potassium and magnesium ($r = 0.813$, $P < 0.001$). The pattern of significant correlations is different from that at Bedgebury (Howard & Howard 1984b). Total potassium, calcium, magnesium, and phosphorus are all intercorrelated at $p < 0.001$. Total nitrogen is correlated with total phosphorus at $p < 0.001$, and with calcium and magnesium at $p < 0.05$. Loss-on-ignition and total sodium were not correlated with any of the other variables.

The first 3 eigenvalues of the correlation matrix may be considered of practical importance, together they account for 83% of the total variance. The first component, accounting for 49% of the total variance, is chiefly a combination of total phosphorus, calcium, potassium, and magnesium. The second component accounts for 17% of the total variance, and is dominated by total sodium, here given a negative weighting. The third component, accounting for 17% of the total variance, is dominated by loss-on-ignition. These components are not the same as the first 3 components of the Bedgebury L and F/H layers (Howard & Howard 1984b). The first and second component values are plotted in Figure 17. Unlike the corresponding Bedgebury plot, this shows no division between L and F/H layers on the first component axis. *Castanea sativa* and *Quercus robur* litters, which have large positive first component values for 1951 (ie large values for one or more of total phosphorus, calcium, potassium, and magnesium), showed a decrease with time. On the other hand *Larix decidua* litter and *Pinus nigra* F/H layer, which had low first component values in 1951 (ie low values for one or more of calcium, potassium, and magnesium) showed an increase with time. Smaller increases were shown by *L. decidua* F/H, *P. nigra* litter, and both layers under *Picea abies*.

On the second component axis (Figure 17), L layers under *Picea abies*, *Fagus sylvatica*, and to some extent *Quercus robur*, show decreases in second component values (ie increases in total sodium) with time. The remaining litters show the reverse effect. *Pinus nigra* and *Abies grandis* litters show considerable increases in second component values with time. All the F/H layers, except that under *Picea abies*, show decreases in second component values with time, the largest decrease occurring under *Larix decidua*.

On the third component axis, there is a division between L layers, which have larger third component values (ie greater LOI and consequently lower ash), and F/H layers which have smaller or negative third component values (ie. lower LOI or greater ash content). All the L layers, except those under *Pinus nigra* and *Abies grandis*, show increases in third component value from 1951 to 1974. The largest increase in third component value is shown by *Picea abies* F/H, under *Quercus robur* there is a similarly large decrease.

4.4 L and F/H layers, principal component analysis, 1974 data only

As with the Bedgebury L layers (Howard & Howard 1984b), loss-on-ignition showed least variation (CV 3%) and total magnesium most (CV 37%). The pattern of significant correlations is different from that for the Bedgebury L layers, notably in the lower correlation between total phosphorus and potassium, and the greater correlations between total calcium and potassium, total nitrogen and magnesium, and nitrogen with potassium.

The first 2, possibly 3, eigenvalues of the correlation matrix for the L layers may be considered to be of practical importance. The first component, accounting for 56% of the total variance, is essentially a combination of total magnesium, phosphorus, potassium, and calcium. This differs from the first component of the Bedgebury L layer, mainly in giving a lower weighting to total nitrogen. The second component, accounting for 22% of the total variance, is mainly a contrast between loss-on-ignition and total sodium. The third component, accounting for about 12% of the total variance, is dominated by total nitrogen. The second and third components differ from those obtained from the Bedgebury L layer correlation matrix. The first and second component values are plotted in Figure 18, with the minimum spanning tree (3 dimensions) superimposed.

In the F/H layers, unlike the values for Bedgebury (Howard & Howard 1984b), total nitrogen shows least variation (CV 6%), but at both sites total magnesium shows most variation (CV 47% at Abbotswood). The pattern of significant correlations differs from that for the Bedgebury F/H layers, at Abbotswood there were significant positive inter-correlations between total potassium, calcium, magnesium, and phosphorus.

The first 3 eigenvalues of the correlation matrix for the F/H layers are of practical importance, together they account for 96% of the total variance. The first component, accounting for some 58% of the total variance, is essentially a combination of total potassium, magnesium, calcium, and phosphorus, these 4 variables account for about 83% of the variance in that component. The second component, accounting for nearly 23% of the total variance, is dominated by total sodium, which accounts for about 51% of the variance in that component. The third component is dominated by total nitrogen, which accounts for about 71% of the variance in that component. The first and second component values are plotted in Figure 19, with the minimum spanning tree in 3 dimensions superimposed.

4.5 Soils, principal component analysis, 1951 and 1974 data combined

The minima, maxima, means, standard deviations, and coefficients of variation of the variables are given in Table 2. As at Bedgebury (Howard & Howard 1984b), pH shows least variation (CV 5%), and extractable phosphorus and calcium are the most variable, with CV's of 119% and 80% respectively.

The correlation coefficients are given in Table 3. There are fewer significant correlations than with the Bedgebury soils, mainly because of the lack of significant correlations between extractable phosphorus and loss-on-ignition, total nitrogen, extractable sodium, potassium, calcium, and magnesium. Also, unlike Bedgebury, pH is not significantly correlated with total nitrogen. Extractable phosphorus is significantly correlated only wiht pH ($r = -0.292$, $p < 0.01$). Loss-on-ignition, total nitrogen, extractable sodium, calcium, and magnesium are all positively intercorrelated at $p < 0.001$.

The first 2, possible 3, eigenvalues of the correlation matrix (Table 4) may be considered to be of practical importance. The first component, accounting for 56% of the total variance, is essentially a combination of extractable calcium, loss-on-ignition, total nitrogen, extractable magnesium and sodium (Table 5). The second component, accounting for 18% of the total variance, is essentially a contrast between pH and extractable phosphorus, these 2 variables account for about 83% of the variance in this component. The third component, accounting for 11% of the total variance, is dominated by extractable potassium, which accounted for about 57% of the variance in this component.

The first and second component values are plotted in Figure 20. The soil layers are separated on the first axis, but some overlap is caused by time and species. Apart from *Picea abies* 0-5 cm, which showed a decrease in first component value with time, and *Larix decidua* 0-5 cm which showed little change, there is a general increase in first component values with time, ie a trend to lower loss-on-ignition, total nitrogen, extractable calcium, magnesium and sodium.

Most soils showed a small decrease in second component value with time, ie a trend to lower pH and greater extractable phosphorus, especially in the upper soil layers. In the lower layers there was mostly little change, or a small increase, notably under *Larix decidua*. Except for *Picea abies* 65-70 cm, there was a general decrease in third component value with time, ie a trend to lower content of extractable potassium. Soil layers under *Quercus robur* showed large decreases, especially at 0-5 cm.

For the 1974 data only, the orders of the species plots on the first components at the different depths are given in Table 6. The variables which make an important contribution to the first axis vary with depth, only loss-on-ignition and pH are constantly important at all depths. Extractable calcium, magnesium and phosphorus are important at all depths to 20 cm and extractable calcium and magnesium at 65-70 cm.

The first and second component values of the 1974 0-5 cm soil layer data are plotted in Figure 21. The first axis accounts for 77% of the total variation, and the order of the species plots summarizes their relative positions in a general way, although the second axis reveals a difference between *Quercus robur* and *Castanea sativa*.

5 DISCUSSION

The pH of surface layers of woodland soils is widely assumed to be strongly influenced by the nature of the leaf litter falling on them. In 1951, the most acid 0-5 cm soils occurred under *Larix decidua* (pH 4.1), *Pinus nigra* (pH 4.14), and *Picea abies* (pH 4.16). The least acid were under *Quercus robur* (pH 5.28) and *Castanea sativa* (pH 5.17). By 1974, the pH of the *Q. robur* 0-5 cm soil had fallen to 4.51, and to 3.82 under *Picea abies*. All the species except *Pinus nigra* showed a significant decrease in pH at 0-5 cm. The largest decrease was under *C. sativa* (0.53 units), the smallest significant decrease was under *L. decidua* (0.2 units). By contrast, at Bedgebury only *Quercus petraea* showed a significant change in pH at this depth, a small increase (Howard & Howard 1984b). Here, *Fagus sylvatica* showed a decrease in pH down to 15 cm, and *Picea abies* down to 20 cm and at 25-30 cm.

In 1974, the mean pH of soil under the hardwoods was significantly greater than that under the coniferous species at all depths. However, there were not always significant differences between individual coniferous and hardwood species. Also in 1974, under all species, there was a slightly increased acidity of soils down to 30 cm compared with those at greater depths. This effect was more pronounced than in 1951 (Ovington 1953). The smallest difference occurred under *Castanea sativa* (0.02 pH units) and the greatest under *Picea abies* (0.34 pH units).

In trying to find an ecological interpretation for these results, it is useful to recognize 2 groups of variables, (a) those concerned with the quality and quantity of soil organic matter (LOI, N, P) and with changes in them which are brought about by physiological activities of soil organisms, and (b) elements of the soil exchange complex (Na, K, Ca, Mg) which can be removed by leaching and can be replaced by weathering of soil minerals or, in the upper soil layers, by tree litterfall. pH is influenced by both (a) and (b).

In 1974 there was a significant difference between species in total nitrogen content only at 5-10 cm. From 1951 to 1974 there were significant decreases at 0-5 cm under *Quercus robur*, *Fagus sylvatica*, *Castanea sativa*, *Abies grandis* and *Pinus nigra*. By contrast, at Bedgebury at this depth the only significant change was a gain under *Larix eurolepis*. Other depths showed nitrogen losses of similar magnitudes at both sites.

In 1974, at 0-5 cm, there was no difference between species in extractable potassium except for *Quercus robur*. There was no difference between species at 5-10 cm. Below 10 cm, there was no difference between species except for *Pinus nigra*. From 1951 to 1974, extractable potassium showed significant increases between 15 cm and 50 cm under *Larix decidua*, *Picea abies*, *Pinus nigra* and *Quercus robur*, and there were increases at some other depths under other species. Changes were broadly similar at Abbotswood and Bedgebury and may result from increased mineral weathering.

Initial extractable calcium contents at Abbotswood (0-5 cm) were in the range 10.5 to 23.1. At Bedgebury, the range was 17.2 to 53.4. It is clear that, in general, the Bedgebury plots were higher in extractable calcium in 1951, especially under *Pinus nigra*. In deeper layers, the differences between the sites were less obvious, except for the *Pinus nigra* plot at Bedgebury. At Abbotswood there were significant losses of extractable calcium in the surface layers under most species, but *Larix decidua* showed a significant loss only at 15-20 cm.

At Abbotswood, as at Bedgebury, there were significant decreases in extractable magnesium under most species at most depths.

In 1951, extractable phosphorus contents at Abbotswood (0-5 cm) were in the range 0.48 (*Fagus sylvatica*) to 3.16 (*Larix decidua*). In 1974, the range was 0.36 (*Fagus sylvatica*) to 2.89 (*Picea abies*). By contrast, 0-5 cm soil at Bedgebury was generally poorer in extractable phosphorus, the range in 1951 being 0.20 (*Nothofagus obliqua*, *Larix eurolepis*) to 0.37 (*Chamaecyparis lawsoniana*), and in 1974, 0.39 (*Nothofagus obliqua*, *Quercus rubra*) to 0.67 (*Quercus petraea*). At all depths studied, soil at Abbotswood had a much greater content of extractable phosphorus than soil at Bedgebury, under all species.

Comparison between Abbotswood and Bedgebury is made difficult by the fact that the sites had only 2 tree species in common, *Pinus nigra* and *Picea abies*. Data for these 2 species at 0-5 cm are given in Table 7. Under both species at that depth, there was not much difference in 1951 between the 2 sites with respect to loss-on-ignition, total nitrogen, or extractable magnesium. At Abbotswood, 0-5 cm soils had slightly less extractable sodium, about half as much extractable potassium, and about 5 to 6 times as much extractable phosphorus.

Over the period 1951 to 1974, 0-5 cm soil under *Picea abies* showed a greater loss of extractable magnesium at Bedgebury than at Abbotswood, and a greater gain in extractable sodium and phosphorus. There was a slight (non-significant) gain in extractable calcium at Abbotswood as opposed to a small (non-significant) loss at Bedgebury. Under *Pinus nigra*, changes at Abbotswood and Bedgebury were of a similar order, leaving aside the anomalous calcium content at Bedgebury in 1951, except for a small but significant loss of extractable potassium at Bedgebury and a small but significant gain in extractable phosphorus.

As the first component is the axis of maximum variation, the species plots are arranged in the order of their first component values at the different depths in Table 6. The directions of the first component axes are influenced by high or low values for the listed variables, but these are trends only and not all will be expressed in any one species. The contributions of the variables to the first components were not the same as for the Bedgebury data, notably pH made a more important contribution at Abbotswood. Table 6 shows that at each depth at Abbotswood the 3 species plots with the largest first component values were all conifers, and down to 30 cm depth they included *Picea abies* and *Pinus nigra*. *Castanea sativa* had the lowest or second lowest first component value at all depths. If, as seems likely, any effect of species will be most pronounced at the surface, the order of the species on the first principal component axis at 0-5 cm in 1974 can be taken to indicate, in a general way, the relative effects of the species.

Taking the results of the principal component analysis and the analysis of variance together, the main changes at Abbotswood from 1951 to 1974 are summarized in Table 8. The species under which most leaching occurred are to the left of the table, although it is extremely difficult to put a strict order on the changes.

Although the results are not clearly defined, they suggest that soil under *Quercus robur* showed most leaching as well as the largest decrease in pH at 0-5 cm (0.77 units). This species has a deep tap-root and tends to have an above-average uptake of calcium, potassium, and phosphorus (Rennie 1955). Karkanis (1975) found that of 6 hardwood species studied, the soil phosphorus content increased most under *Q. robur*. The litter of this species seems to be relatively rapidly attached by soil animals and micro-organisms, Karkanis found that 73% of the litter disappeared in the first year. Here, *Q. robur* litter had the largest total calcium and magnesium contents in both years, and the largest potassium content and the second largest phosphorus content in 1974. In the soil, only extractable potassium increased from 1951 to 1974.

It is well known that the effect of *Fagus sylvatica* depends upon the site, forming mull on calcareous soils and mor on base-deficient soils (eg Brown 1953). At Abbotswood, *F. sylvatica* seems to have had a greater effect on soil leaching than did the 4 coniferous species.

Not much seems to be known about the effects of *Abies grandis* and *Castanea sativa*, although Gloaguen and Touffet (1976) found that *A. grandis* needles are fairly rich in calcium, potassium, magnesium, and phosphorus.

The position of *Pinus nigra* in Table 8 is not entirely consistent with its known properties. Its litter is poor in calcium, potassium, and phosphorus (Gloaguen & Touffet 1976), and Bonneau *et al.* (1979) found that on a sandy site it rapidly accelerated the loss of total soil elements, especially potassium, manganese, and sodium, and increased the organic nitrogen content. However, its effects on available elements were complicated. The position of *Pinus nigra* at Bedgebury (Howard & Howard 1984b) was also somewhat anomalous, but that plot was initially richer in calcium than any other at that site.

Picea abies is generally regarded as a soil-deteriorating species, and it is often found naturally on podzols with raw humus (Bonnevie-Svendson & Gjems 1957). However, this is not always the case. Von Miehlich (1971) found little evidence of soil compaction, nitrogen losses, or serious nutrient depletion in the soil of a 25 year-old second generation spruce stand on a loess-pseudogley, which had been under the species for 120 years, compared with the soil of a near-natural oak-beech stand. He concluded that at that site any effects on the nutrition of the spruce were small. At Bedgebury (Howard & Howard 1984b) the smallest losses of nitrogen and mineral elements occurred under *P. abies*. At Abbotswood, at 0-5 cm, there was a significant increase in loss-on-ignition (from 7.5 to 10%) and a decrease in pH (4.16 to 3.82) under *P. abies*, but in general this species appears to have had a smaller influence on leaching of soil minerals than did most of the other species. *P. abies* may be like *Fagus sylvatica* in that its effect on soils depends on the type of soil on which it grows.

Larch species have a mixed reputation concerning their effects on soil. Larch is often regarded as a beneficial type of tree with a nutrient-rich litter (Bonnevie-Svendson & Gjems 1957) or as a soil-deteriorating tree and a producer of poor humus (Viro 1956). The difference may be related to species (Schober 1953), or site, or both. More detailed studies are needed on larch species.

It is clear that different tree species have different effects on soils, and that for a given species the effects may depend on local conditions. Changes in the amounts of elements in soils serve to illustrate these effects in a general way, but are difficult to interpret. For the future, a greater emphasis on soil processes is needed.

6 SUMMARY

(i) Because there were no significant differences between years in the L layer total nitrogen contents of *Quercus robur*, *Castanea sativa* and *Larix decidua*, decreases in the total nitrogen contents of their F/H layers may reflect changes in biochemical activities in the forest floor.

(ii) From 1951 to 1974, the range of total potassium in the L layers narrowed, due chiefly to decreases in the larger values. The decreases were significant under *Castanea sativa*, *Q. robur*, *Abies grandis* and *Pinus nigra*. *Picea abies* litter showed a significant increase. In the F/H layers there were significant increases under *Q. robur*, *P. nigra*, and *Larix decidua*.

(iii) There was a slight narrowing of the range of total calcium in both the L and F/H layers from 1951 to 1974.

(iv) In both the L and F/H layers, the 4 coniferous species showed significant increases in total phosphorus from 1951 to 1974.

(v) In 1974, the mean total calcium, magnesium, and phosphorus contents of the hardwood L and F/H layers were significantly greater than those of the conifers. For total potassium this difference was significant only for the litters.

(vi) There was a significant decrease in pH in the 0-5 cm soil under all species except *Pinus nigra*, and at 5-10 cm under all species except *P. nigra* and *Abies grandis*. In 1974, at all depths, the mean pH of soil under the hardwoods was significantly greater than that under the conifers. However, there were not always significant differences between individual conifer and hardwood species. Also in 1974, under all species, the difference in acidity between the upper and lower mineral soils was more pronounced than in 1951. The smallest difference occurred under *Castanea sativa*, the greatest under *Picea abies*.

(vii) There were significant decreases in total nitrogen at 0-5 cm under all species except *Larix decidua* and *Picea abies*, under all species at 5-10 and 15-20 cm, and under some species at greater depths. Only at 5-10 cm was there a significant difference between species in 1974.

(viii) From 1951 to 1974 there were significant increases in extractable potassium under all species at 15-20 cm, and under *Larix decidua*, *Picea abies*, *Pinus nigra*, and *Quercus robur* at 25-30 cm and 45-50 cm. In 1974 there was no difference between species at 5-10 cm. At 0-5 cm there was no difference if *Q. robur* was excluded, below 10 cm there was no difference if *Pinus nigra* was excluded.

(ix) There were significant decreases in extractable calcium under all species at 15-20 cm and under many species at other depths. Only at 65-70 cm was there a significant difference between species in 1974.

(x) There were significant decreases in extractable magnesium under all species down to 30 cm and under most species below 45 cm.

(xi) As any effect of species is likely to be most pronounced at the surface, the order of the species on the first principal component axis at 0-5 cm in 1974 can be taken to indicate, in a general way, the relative effects of the species.

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REFERENCES

BONNEAU, M., BRETHES, A., LELONG, F., LEVY, G., NYS, C. & SOUCHIER, B. 1979. Effects de boisements résineux purs sur l'évolution de la fertilité du sol. Revue for. fr., 31, 198-207.

BONNEVIE-SVENDSON, C. & GJEMS, O. 1957. Amount and chemical composition of the litter from larch, beech, Norway spruce and Scots pine stands and its effect on the soil. Meddr. Norske SkogsforsVes, 14, 117-174.

BROWN, J.M.B. 1953. Studies on British beechwoods. Bull. For. Comm. (Lond.), No. 20, 100 pp.

CENTRE FOR AGRICULTURAL STRATEGY, 1980. A forestry strategy for the UK (CAS Report No. 6). Reading: Centre for Agricultural Strategy, University of Reading.

DUNNETT, C.W. 1980. Pairwise multiple comparisons in the homogeneous variance, unequal sample size case. J. Am. Statist. Ass., 75, 789-795.

GLOAGUEN, J.C. & TOUFFET, J. 1976. Production de litière et apport au sol d'éléments minéraux dans quelques peuplements résineux de Bretagne. Ann. Sci. for., 33, 87-107.

HOWARD, P.J.A. & HOWARD, D.M. 1984a. Effects of trees on soil properties, a resampling of J.D. Ovington's *Pinus nigra* var *maritima* plots at Bedgebury, Abbotswood, and West Tofts. (Merlewood research and development paper no. 97). Grange-over-Sands: Institute of Terrestrial Ecology.

HOWARD, P.J.A. & HOWARD, D.M. 1984b. Effects of trees on soil properties, a resampling of J.D. Ovington's plots at Bedgebury. (Merlewood research and development paper no. 100). Grange-over-Sands: Institute of Terrestrial Ecology.

KARKANIS, M. 1975. Decomposition of litter of various species of deciduous trees and its effect on soil environment. Fragm. flor. geobot., 21, 71-97.

OVINGTON, J.D. 1953. Studies of the development of woodland conditions under different trees. I. Soils pH. J. Ecol., 41, 13-34.

OVINGTON, J.D. 1954. II. The forest floor. J. Ecol., 42, 71-80.

OVINGTON, J.D. 1955. III. The ground flora. J. Ecol., 43, 1-21.

OVINGTON, J.D. 1956a. IV. The ignition loss, water, carbon and nitrogen content of the mineral soil. J. Ecol., 44, 171-179.

OVINGTON, J.D. 1956b. V. The mineral composition of the ground flora. J. Ecol., 44, 597-604.

OVINGTON, J.D. 1958a. VI. Soil sodium, potassium and phosphorus. J. Ecol., 46, 127-142.

OVINGTON, J.D. 1958b. VII. Soil calcium and magnesium. J. Ecol., 46, 391-405.

RENNIE, P.J. 1955. The uptake of nutrients by mature forest growth. Pl. Soil, 7, 49-95.

SCHEFFE, H. 1953. A method for judging all contrasts in the analysis of variance. Biometrika, 40, 87-104.

SCHOBER, R. 1953. Die japanische Lärche: eine biologischertrangskundliche Untersuchung. SchrReihe forstl. Fak. Univ. Göttingen, No. 7/8, 258 pp.

VIRO, P.J. 1956. The role of silica in the decomposition of forest humus. Trans. 6th int.Congr. Soil Sci., BII, 723-726.

VON MIEHLICH, G. 1971. Effect of spruce monoculture on pore-size distribution, pH, organic matter and nutrient content of a loess-pseudogley. Forstwiss. ZentBl., 90, 301-318.

Table 1 Ovington's sites resampled in 1974 at Abbotswood, Gloucestershire (Forest of Dean)

Species	Planted
Larix decidua Mill.	1906
Picea abies Karst	1905
Pinus nigra var *maritima* (Ait.) Melv	1906
Abies grandis Lindley	1928
Fagus sylvatica L.	1913
Quercus robur L.	1905
Castanea sativa Mill.	1905

Table 2. Minima, maxima, means, standard deviations, and coefficients of variation of the variables for the Abbotswood soils (1951 plus 1974).

	Min.	Max.	Mean	S.D.	C.V.%
pH	3.82	5.28	4.45	0.24	5
LOI % OD	1.00	10.00	3.88	2.08	54
Total N % OD	0.01	0.28	0.10	0.07	67
Extractable Na	0.20	2.00	0.83	0.34	41
Extractable K	1.90	12.04	4.66	2.23	48
Extractable Ca	1.00	23.10	5.90	4.74	80
Extractable Mg	0.50	10.50	2.95	2.31	78
Extractable P	0.07	7.63	1.10	1.32	119

Extractables are given as mg/100 g OD soil

Table 3 Correlation half-matrix for the Abbotswood soils (1951 plus 1974)

	pH	LOI	N	Na	K	Ca	Mg
pH	1						
LOI % OD	-.276 *	1					
Total N % OD	-.095	.931 ***	1				
Extractable Na	-.426 ***	.756 ***	.708 ***	1			
Extractable K	.054	.483 ***	.443 ***	.305 **	1		
Extractable Ca	-.081	.919 ***	.930 ***	.714 ***	.469 ***	1	
Extractable Mg	.044	.787 ***	.865 ***	.628 ***	.185	.886 ***	1
Extractable P	-.292 **	.019	-.071	.138	-.114	-.001	.016

* P < 0.05
** P < 0.01
*** P < 0.001

Table 4 Eigenvalues of the correlation matrix of the Abbotswood soil data (1951 plus 1974)

Component	Eigenvalue	Percentage of the variability Component	Cumulative
1	4.51	56.4	56.4
2	1.44	18.0	74.4
3	0.86	10.8	85.2
4	0.74	9.2	94.4
5	0.26	3.2	97.6
6	0.09	1.1	98.7
7	0.06	0.8	99.5
8	0.04	0.5	100.0

Table 5 Eigenvectors of the first three components of the correlation matrix of the Abbotswood soil data (1951 plus 1974)

Variable	Eigenvector for component 1	 2	 3
pH	0.10	0.68*	0.37
LOI % OD	-0.45*	-0.03	-0.07
Total N % OD	-0.45*	0.10	0.08
Extractable Na	-0.39*	-0.26	-0.08
Extractable K	-0.23	0.26	-0.75*
Extractable Ca	-0.45*	0.09	0.10
Extractable Mg	-0.41*	0.10	0.46
Extractable P	-0.01	-0.61*	0.23

*Absolute value greater than 0.75 times the largest absolute value

Table 6 The order of the Abbotswood species plots on the first components at the different depths, 1974

0-5 cm	5-10 cm	15-20 cm	25-30 cm	45-50 cm	65-70 cm
High LOI, Mg, Ca N, P Low pH	High LOI, N, Na, Ca, Mg, P Low pH	High LOI, Mg, P, Ca, Na Low pH	High LOI, Na, P Low pH	High Na, N, LOI Low pH	High LOI, Na, K Ca, Mg, N Low pH
Picea abies	*Larix decidua*	*Picea abies*	*Picea abies*	*Picea abies*	*Pinus nigra*
	Picea abies				
Larix decidua		*Pinus nigra*		*Larix decidua*	
			Abies grandis		*Abies grandis*
Pinus nigra	*Pinus nigra*	*Larix decidua*	*Pinus nigra*	*Abies grandis*	*Larix decidua*
Quercus robur	*Quercus robur*	*Fagus sylvatica*	*Fagus sylvatica*	*Fagus sylvatica*	*Fagus sylvatica*
Abies grandis	*Fagus sylvatica*		*Larix decidua*	*Pinus nigra*	*Picea abies*
		Abies grandis			
	Abies grandis			*Castanea sativa*	
Fagus sylvatica		*Quercus robur*	*Castanea sativa*		*Quercus robur*
Castanea sativa	*Castanea sativa*	*Castanea sativa*	*Quercus robur*	*Quercus robur*	*Castanea sativa*
Low LOI, Mg, Ca N P High pH	Low LOI, N, Na, Ca, Mg, P High pH	Low LOI, Mg, P, Ca, Na High pH	Low LOI, Na, P High pH	Low Na, N, LOI High pH	Low LOI, Na, K, Ca, Mg, N High pH

Table 7 Data for 0-5 cm soil under *Picea abies* and *Pinus nigra* at Abbotswood and Bedgebury, 1951 and 1974.

	pH	LOI	N	Na	K	Ca	Mg	P
P. abies, 1951								
Abbotswood	4.16	7.50	0.18	1.4	3.6	10.5	6.9	1.80
Bedgebury	3.94	8.44	0.18	1.9	6.2	17.1	5.9	0.28
P. abies, 1974								
Abbotswood	3.82	10.00	0.21	1.5	6.3	14.9	4.7	2.89
Bedgebury	3.99	11.00	0.20	3.2	5.6	13.7	0.6	0.55
P. abies, change								
Abbotswood	-0.34***	+2.5*	+0.03	+0.10	+2.7*	+4.4	-2.2**	+1.09*
Bedgebury	+0.05	+2.6**	+0.02	+1.30***	-0.6	-3.4	-5.3***	+0.27***
P. nigra, 1951								
Abbotswood	4.14	8.19	0.22	1.5	6.8	17.9	9.0	1.46
Bedgebury	4.43	9.54	0.25	2.6	12.7	53.4	9.7	0.24
P. nigra, 1974								
Abbotswood	4.05	7.50	0.17	1.2	7.8	14.8	3.3	1.07
Bedgebury	4.24	9.60	0.20	2.0	9.7	15.9	3.0	0.40
P. nigra, change								
Abbotswood	-0.09	-0.69	-0.05*	-0.3	+1.0	-3.1	-5.7***	-0.39
Bedgebury	-0.19	+0.06	-0.05	-0.6	-3.0*	-37.5***	-6.7***	+0.16*

Table 8 The main changes in the Abbotswood plots, 1951 to 1974.

Layer	*Quercus robur*	*Fagus sylvatica*	*Abies grandis*	*Castanea sativa*	*Pinus nigra*	*Picea abies*	*Larix decidua*
L	↓K		↑N P ↓K Ca	↓K Mg	↑N P ↓Na K Mg	↑K Ca P	↑Ca P
F/H	↑K Mg ↓N Ca		↑Na P	↓N	↑Na K P	↑P ↓Mg	↑Na K P ↓N
0-5cm	↓pH N Ca Mg	↓pH N Ca Mg	↓pH N Ca Mg	↓pH N Ca Mg	↓N Mg	↑K P ↓pH Mg	↓pH Mg P
5-10cm	↑K ↓pH N Na Ca Mg	↓pH N Mg	↓N Na Ca Mg	↓pH N Na Ca Mg	↓N Na Ca Mg	↓pH N Na Ca Mg	↓pH N Na Mg P
15-20cm	↑K ↓N Na Ca Mg	↑K ↓N Ca Mg	↑K ↓N Na Ca Mg	↑K P ↓N Ca Mg	↑K P ↓N Ca Mg	↑Na K P ↓pH N Ca Mg	↑K ↓N Ca Mg P
25-30cm	↑K ↓N Mg	↑Na ↓Mg	↑Na ↓N Mg	↑pH Na K P ↓Ca Mg	↑K P ↓N Mg	↑K P ↓pH Ca Mg	↑K ↓N Mg P
45-50cm	↑pH K	↑pH ↓Ca Mg	↓Ca Mg	↓Ca Mg	↑K ↓Na Ca Mg	↑K ↓Ca Mg	↑pH K ↓Mg P
65-70cm	↑pH Ca ↓N Na	↑Ca	↓Mg	↓N Na Mg	↑K Ca ↓N	↓Mg	↑pH ↓Na Mg P

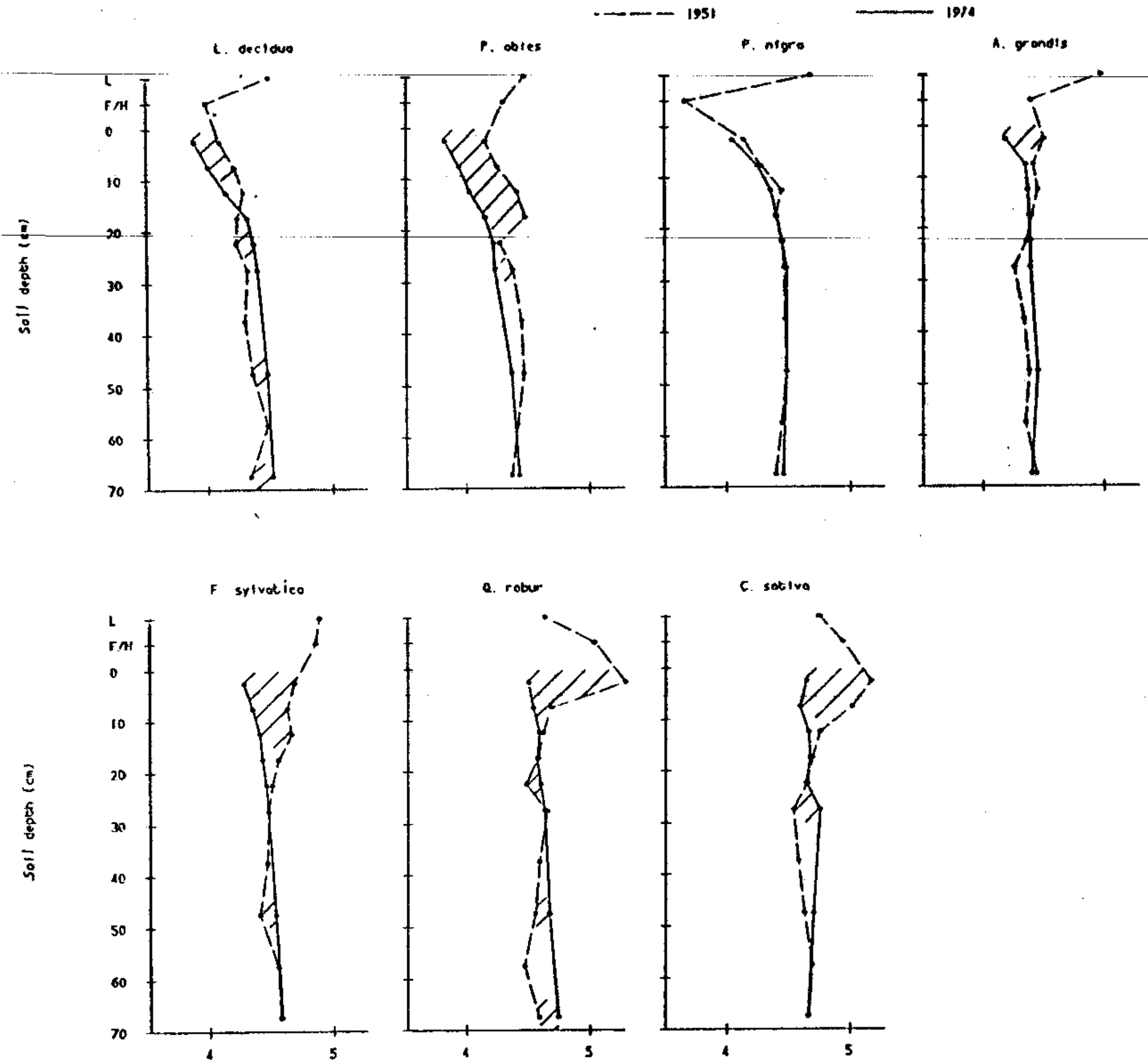


Figure 1. pH at different depths under different species in 1951 and 1974. Differences significant at $p < 0.05$ are hatched.

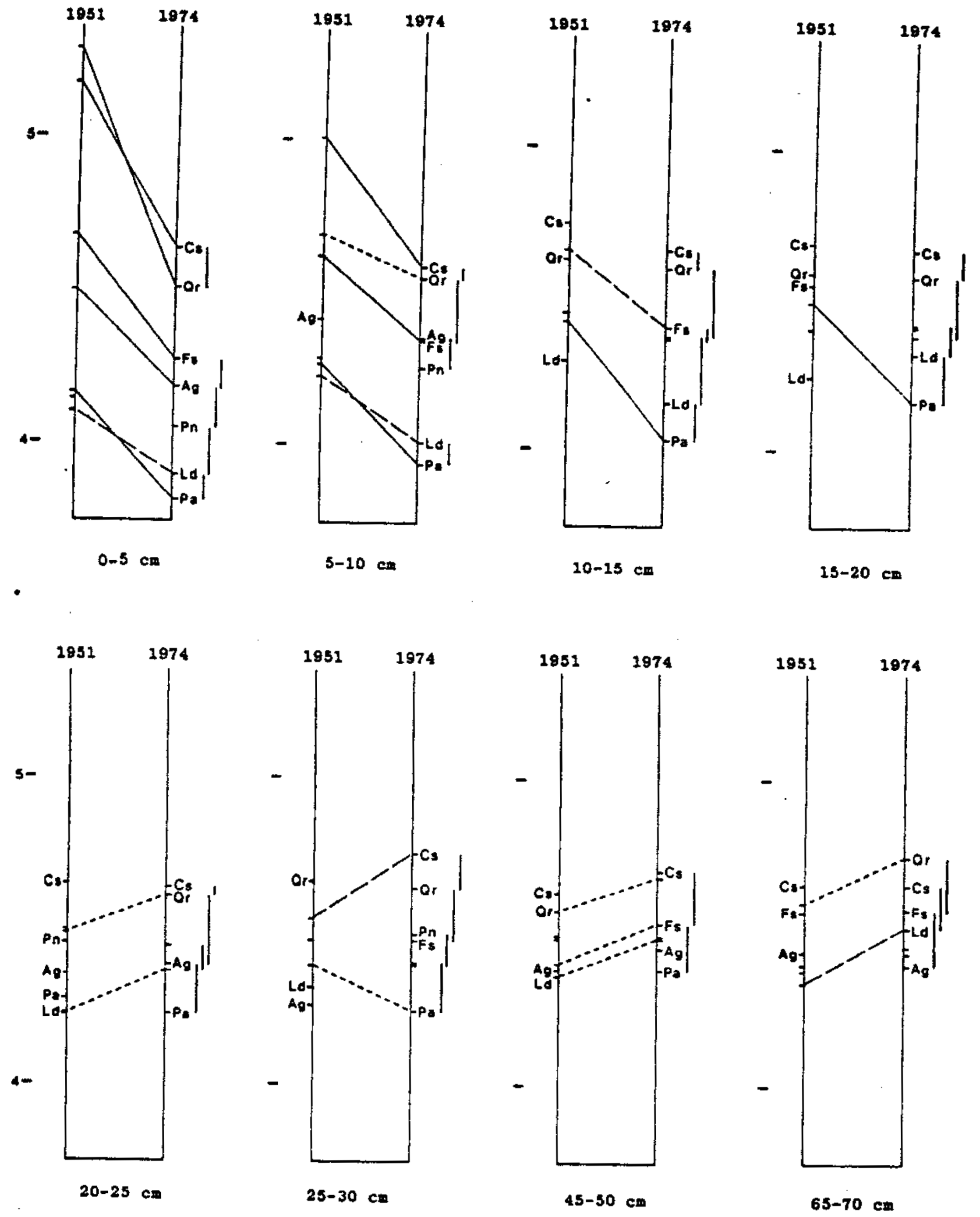


Figure 2. Changes in pH between 1951 and 1974 under different species (names abbreviated) at different depths, significant at $p < 0.05$ ----, $p < 0.01$ — —, $p < 0.001$ ———. The vertical lines link species not significantly different in 1974 (Tukey's HSD $p < 0.05$).

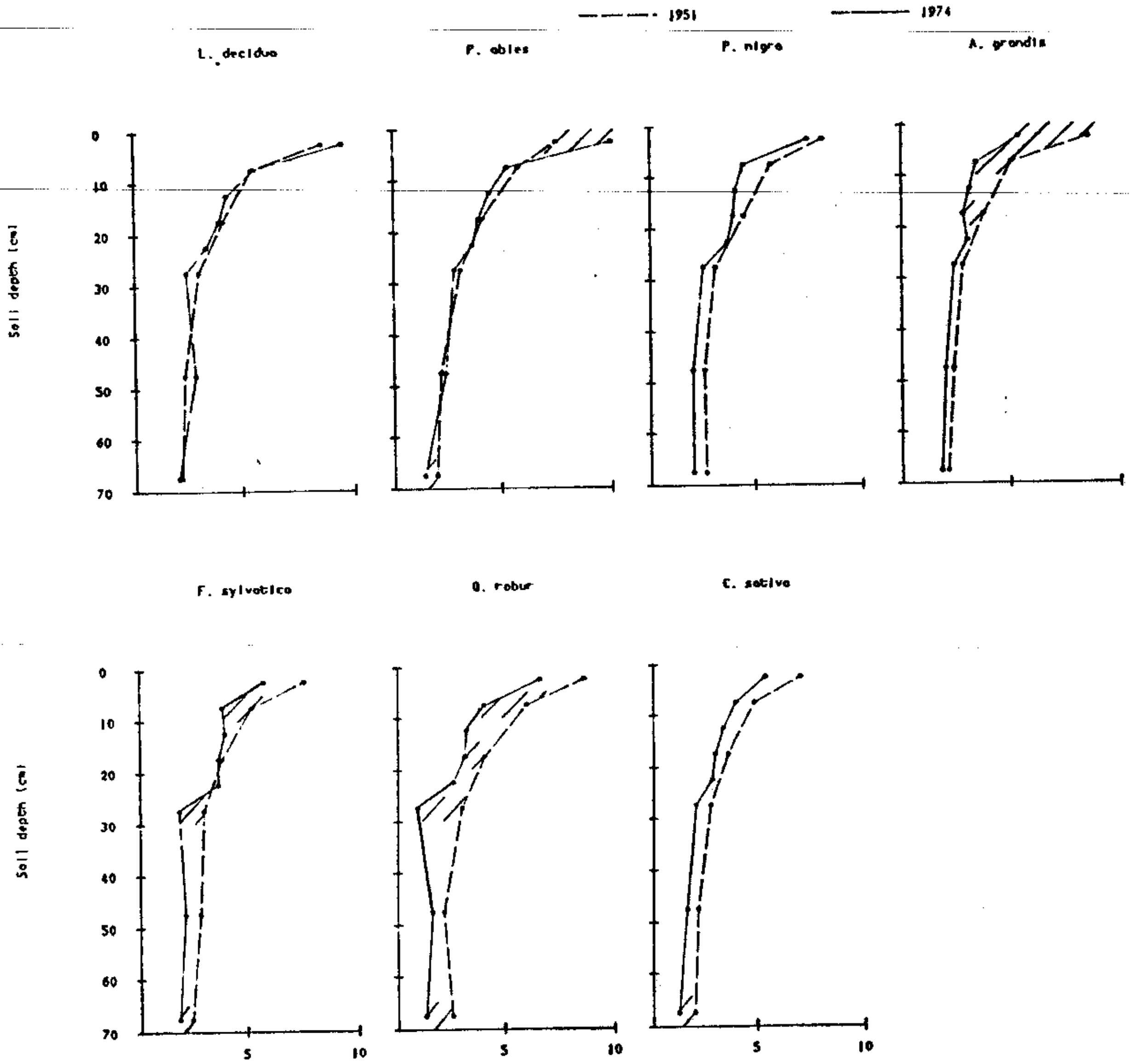
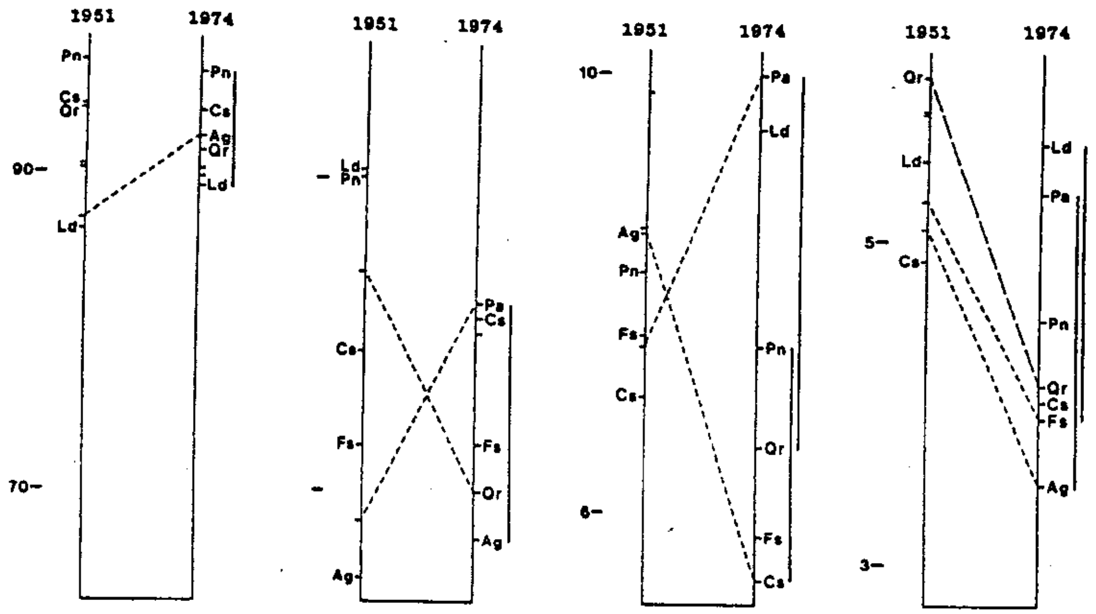
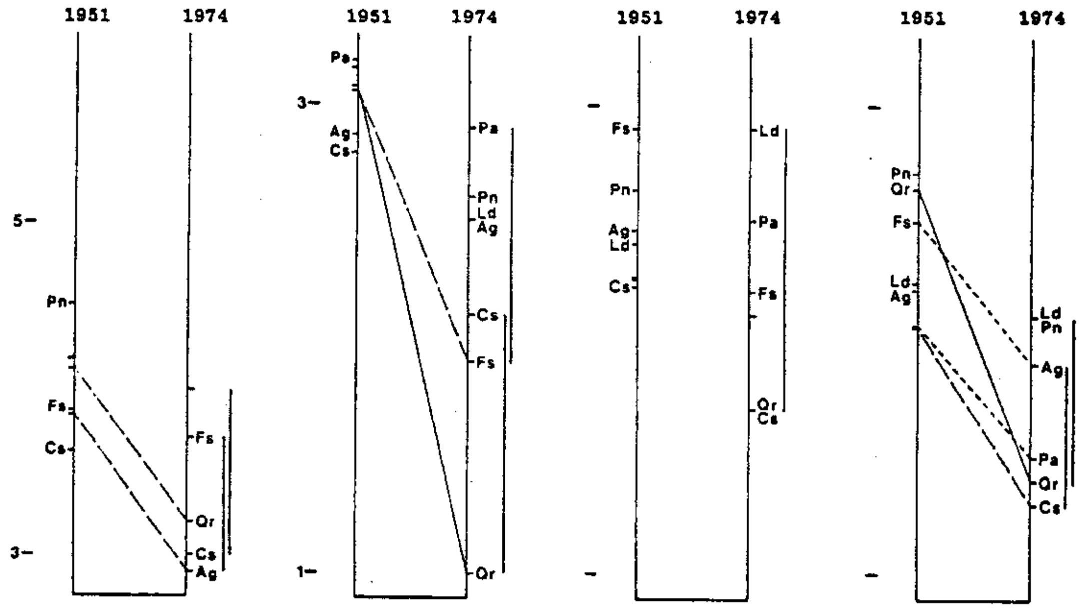


Figure 3. Loss-on-ignition at different depths under different species in 1951 and 1974. Differences significant at $p < 0.05$ are hatched.



Litter F/H 0-5 cm 5-10 cm



15-20 cm 25-30 cm 45-50 cm 65-70 cm

Figure 4. Changes in loss-on-ignition between 1951 and 1974 under different species (names abbreviated) at different depths, significant at $p < 0.05$ ----, $p < 0.01$ — —, $p < 0.001$ ———. The vertical lines link species not significantly different in 1974 (Tukey's HSD $p < 0.05$).

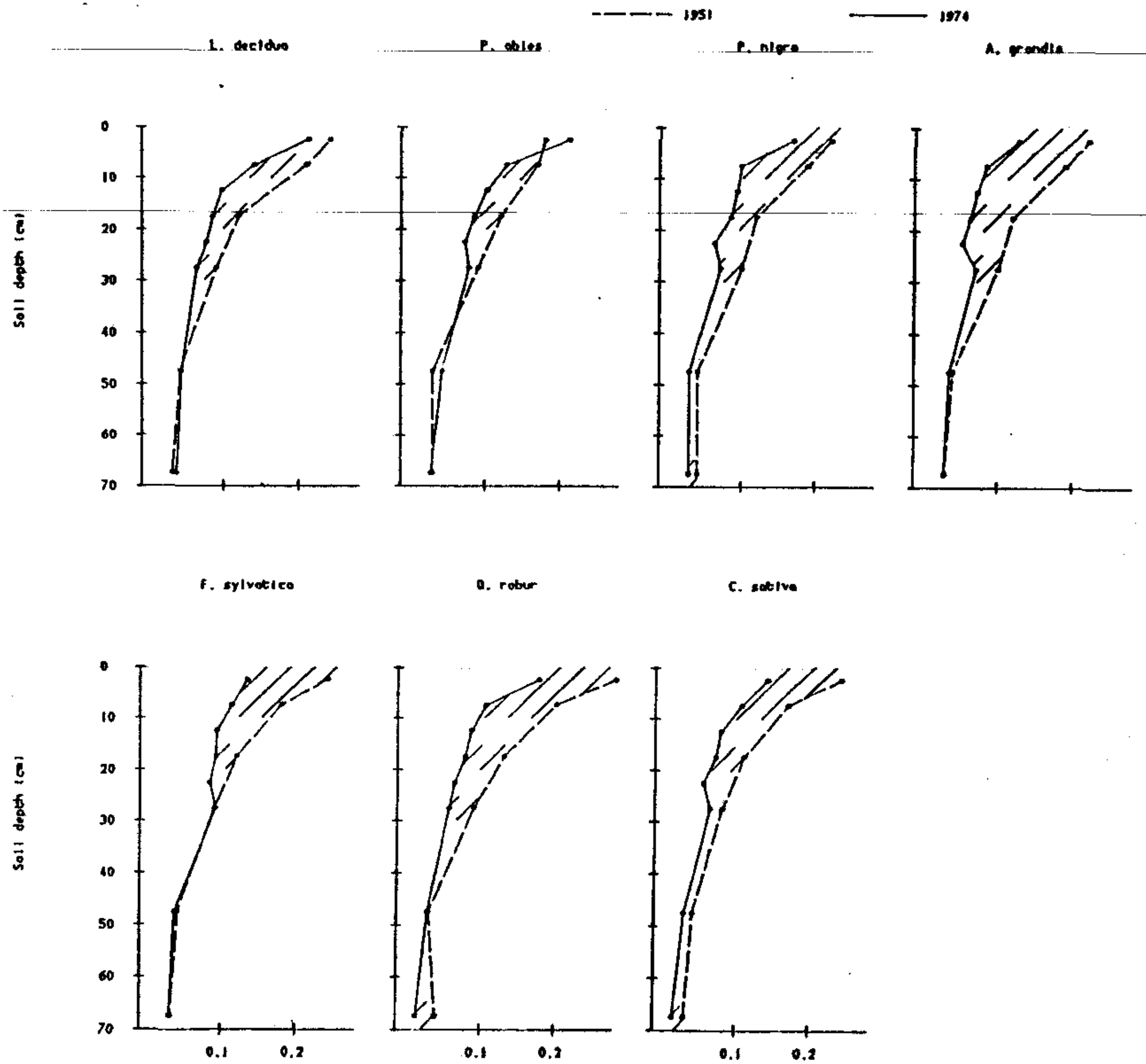
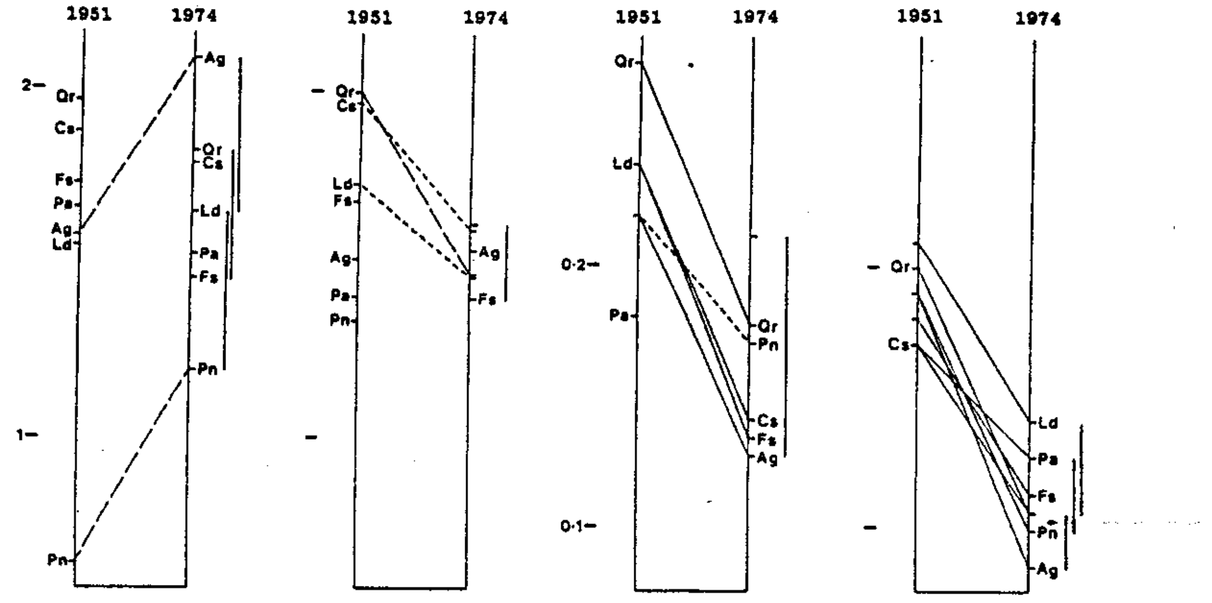
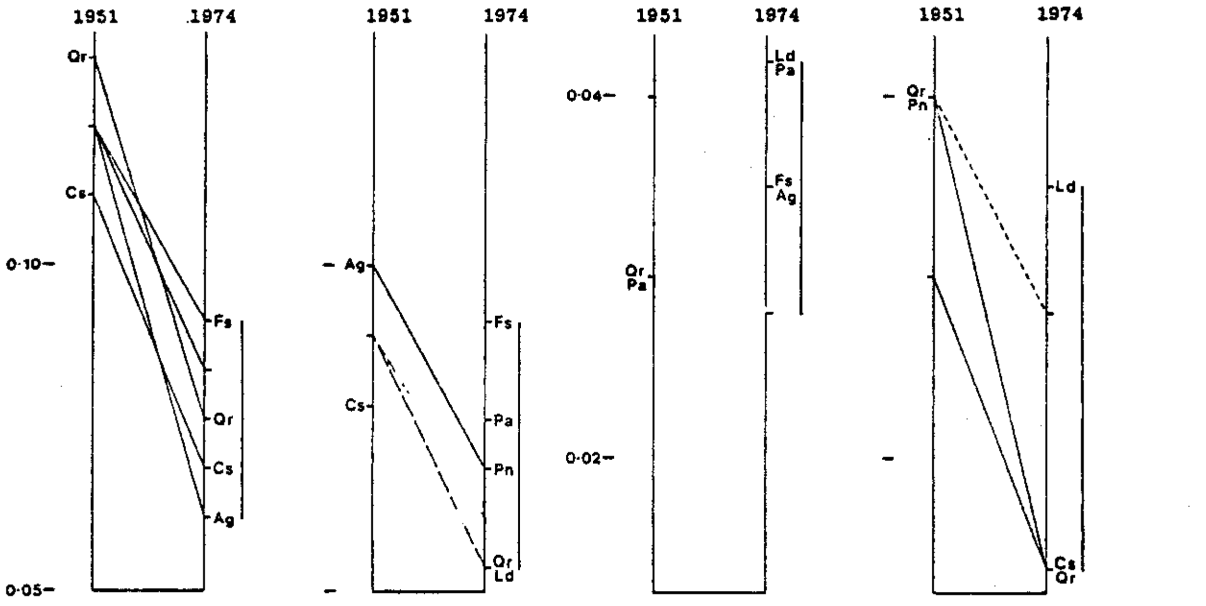


Figure 5. Total nitrogen at different depths under different species in 1951 and 1974. Differences significant at $p < 0.05$ are hatched.



Litter F/H 0-5 cm 5-10 cm



15-20 cm 25-30 cm 45-50 cm 65-70 cm

Figure 6. Changes in total nitrogen between 1951 and 1974 under different species (names abbreviated) at different depths, significant at $p < 0.05$ ----, $p < 0.01$ — —, $p < 0.001$ ——. The vertical lines link species not significantly different in 1974 (Tukey's HSD $p < 0.05$).

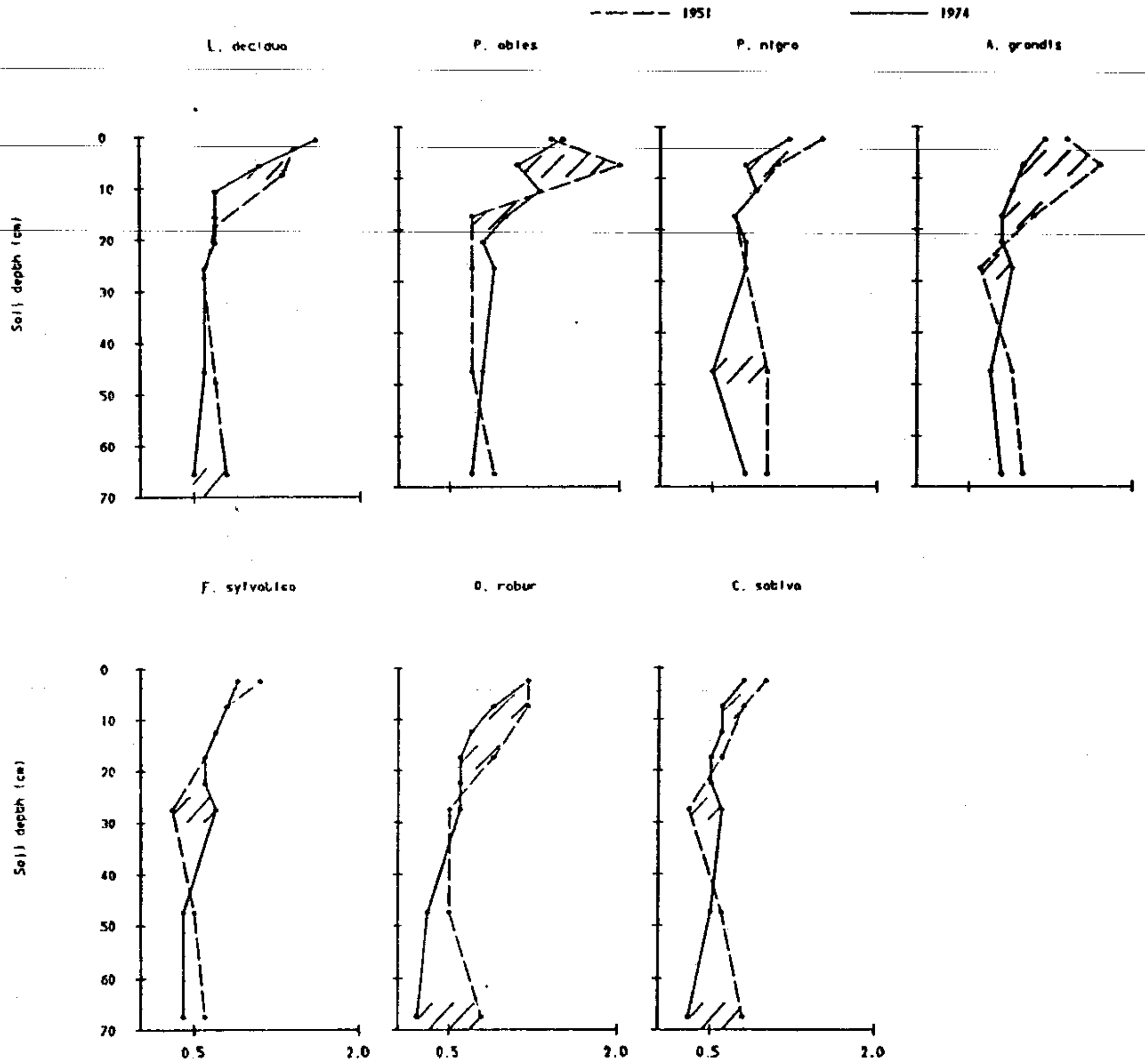


Figure 7. Extractable sodium at different depths under different species in 1951 and 1974. Differences significant at $p < 0.05$ are hatched.

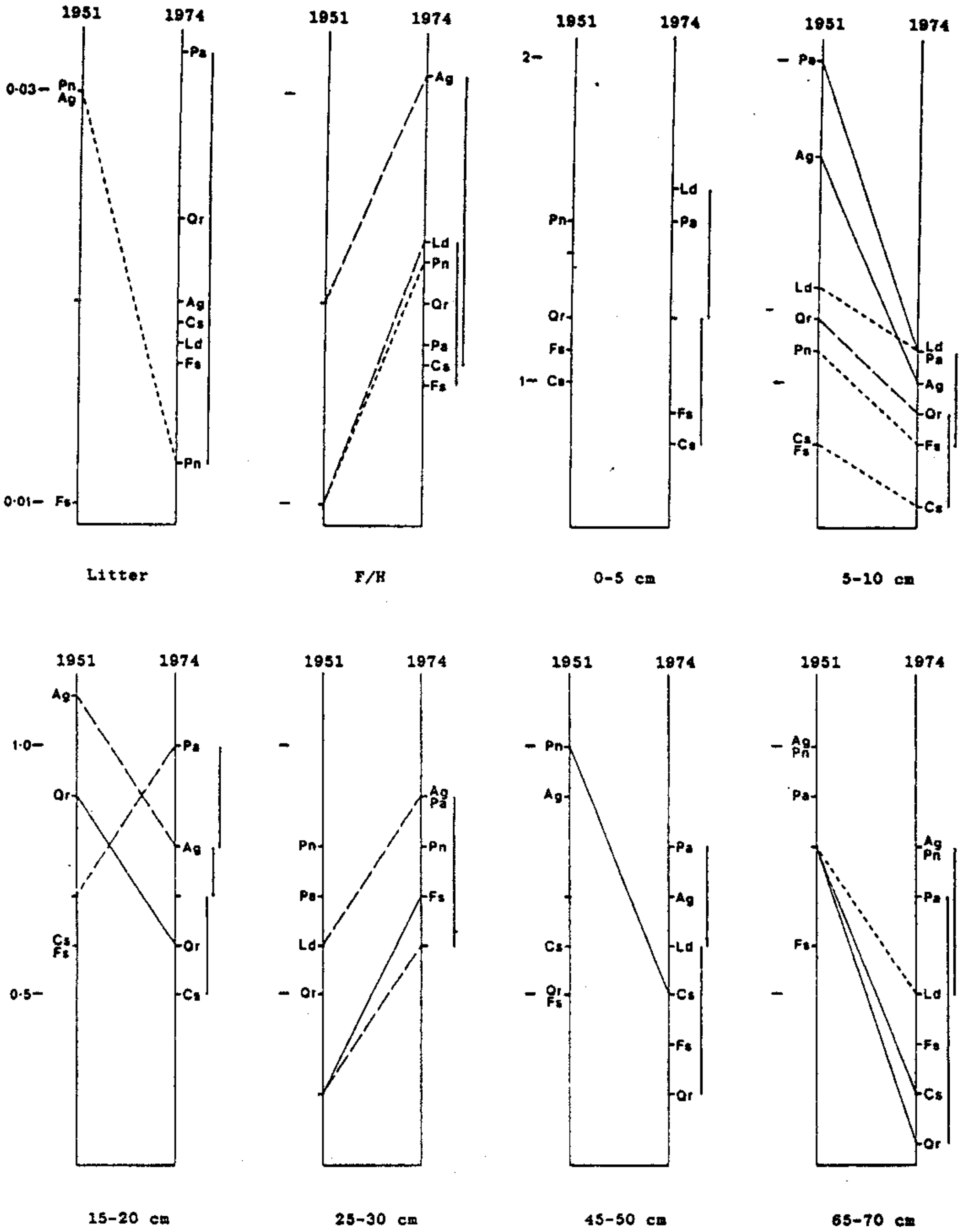


Figure 8. Changes in sodium between 1951 and 1974 under different species (names abbreviated) at different depths, significant at $p < 0.05$ ----, $p < 0.01$ — —, $p < 0.001$ ——. The vertical lines link species not significantly different in 1974 (Tukey's HSD $p < 0.05$).

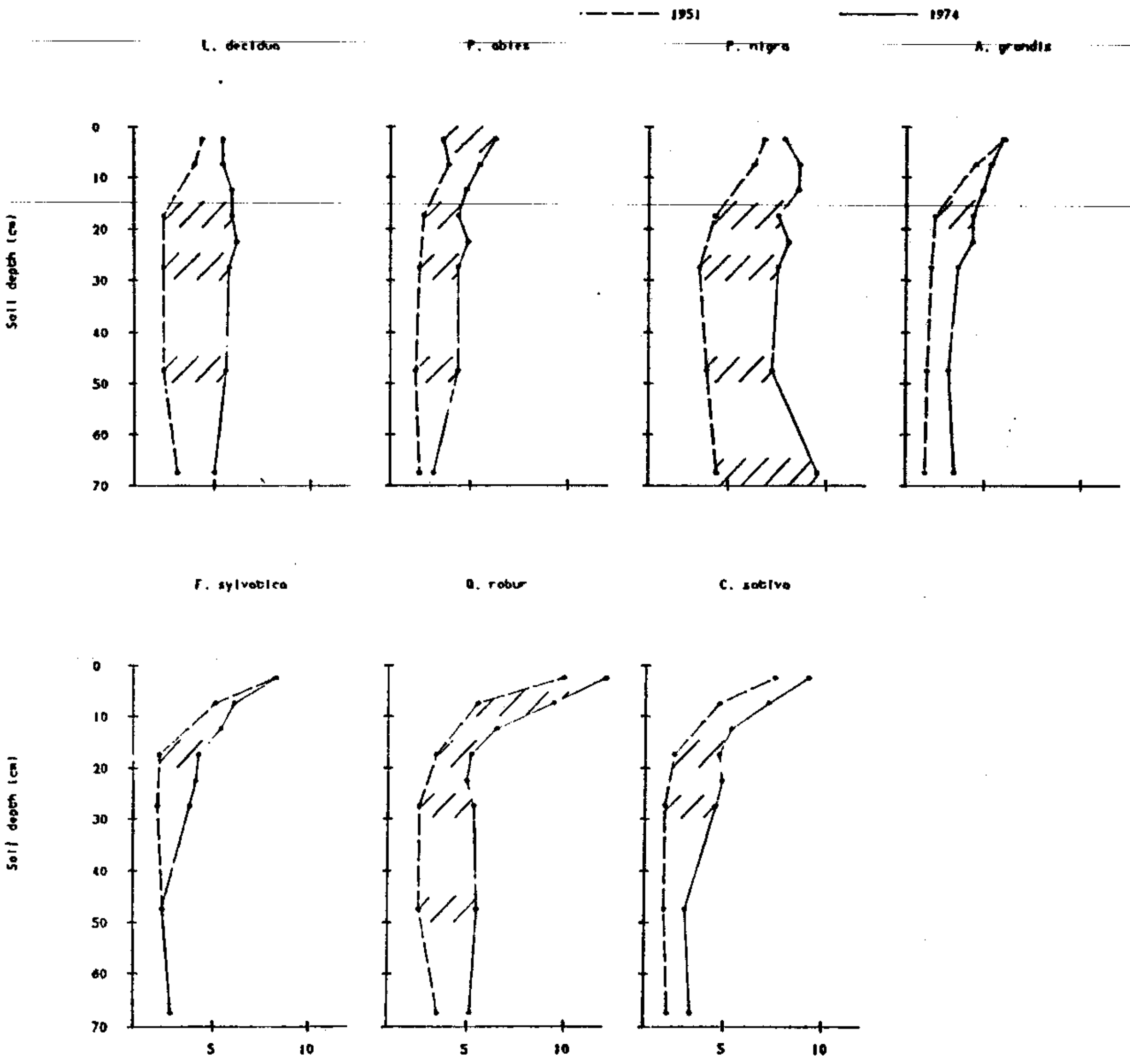


Figure 9. Extractable potassium at different depths under different species in 1951 and 1974. Differences significant at $p < 0.05$ are hatched.

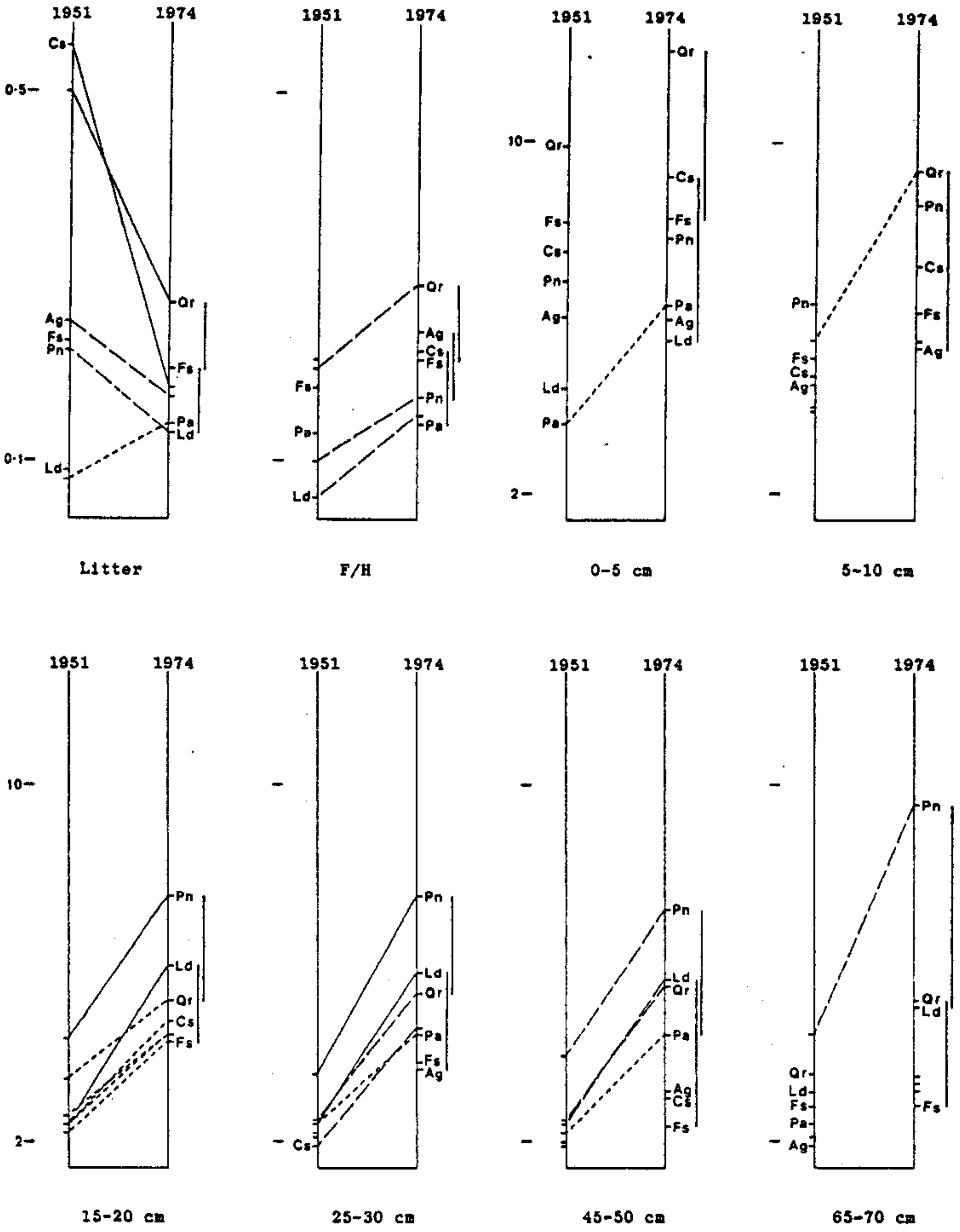


Figure 10. Changes in potassium between 1951 and 1974 under different species (names abbreviated) at different depths, significant at p <0.05 ----, p <0.01 — —, p <0.001 ———. The vertical lines link species not significantly different in 1974 (Tukey's HSD p <0.05).

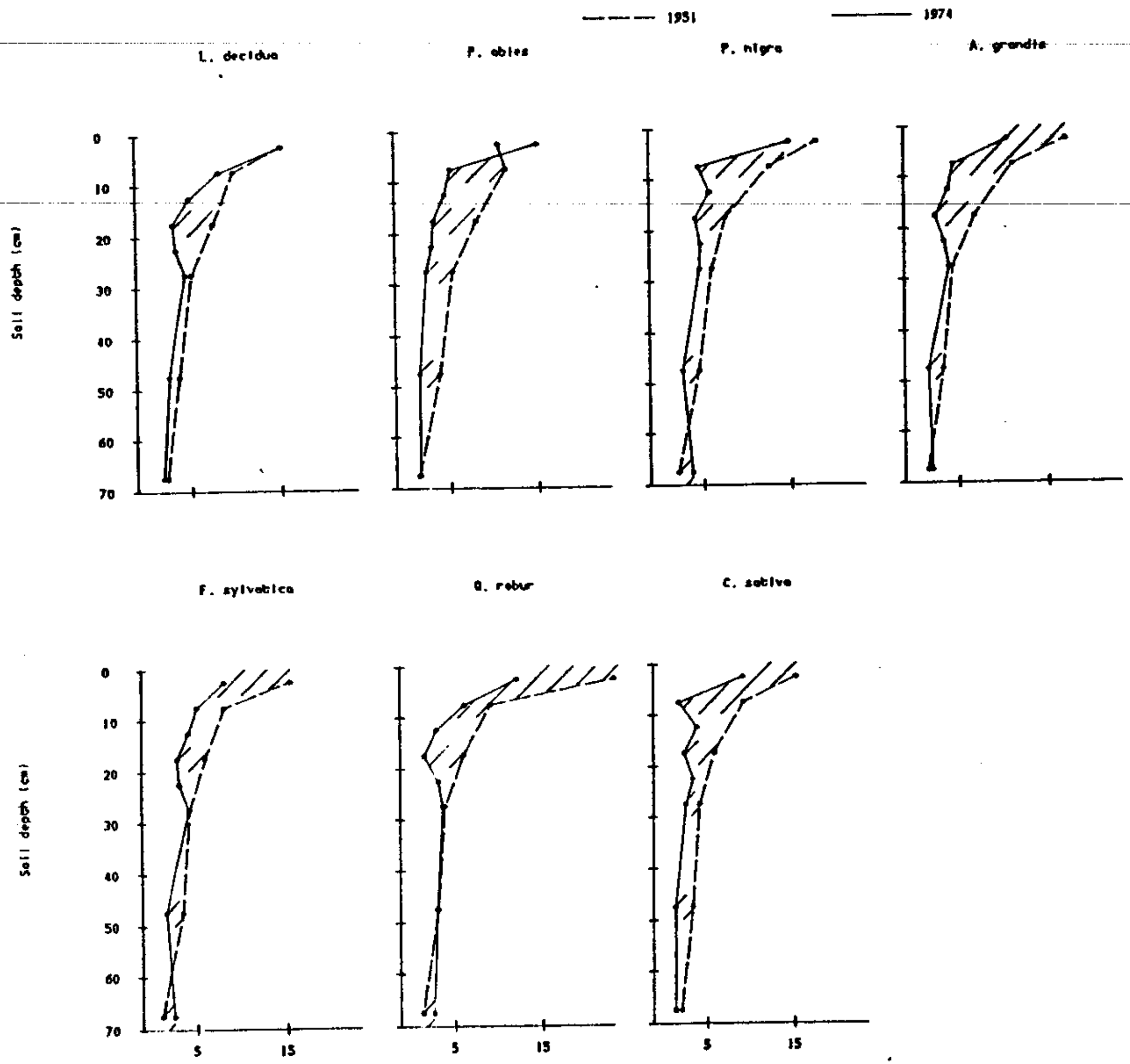
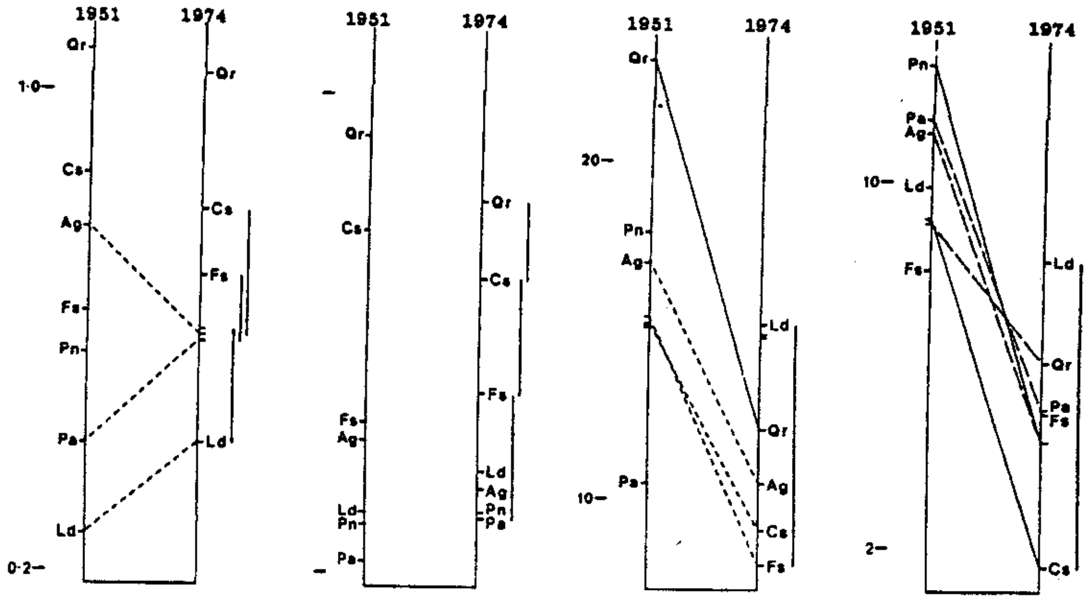
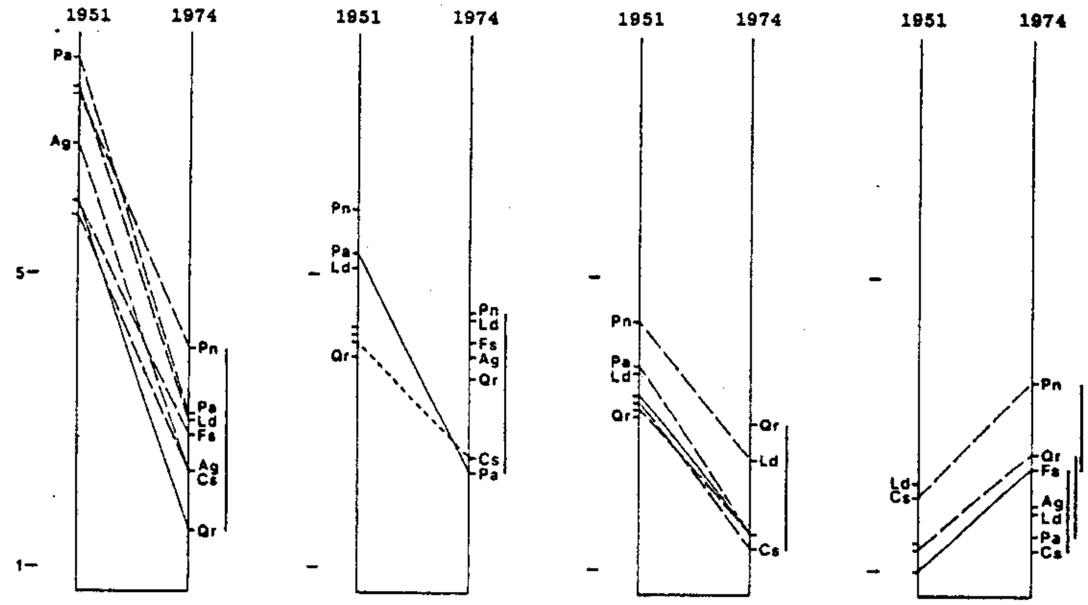


Figure 11. Extractable calcium at different depths under different species in 1951 and 1974. Differences significant at $p < 0.05$ are hatched.



Litter F/H 0-5 cm 5-10 cm



15-20 cm 25-30 cm 45-50 cm 65-70 cm

Figure 12. Changes in calcium between 1951 and 1974 under different species (names abbreviated) at different depths, significant at $p < 0.05$ ----, $p < 0.01$ — —, $p < 0.001$ ———. The vertical lines link species not significantly different in 1974 (Tukey's HSD $p < 0.05$).

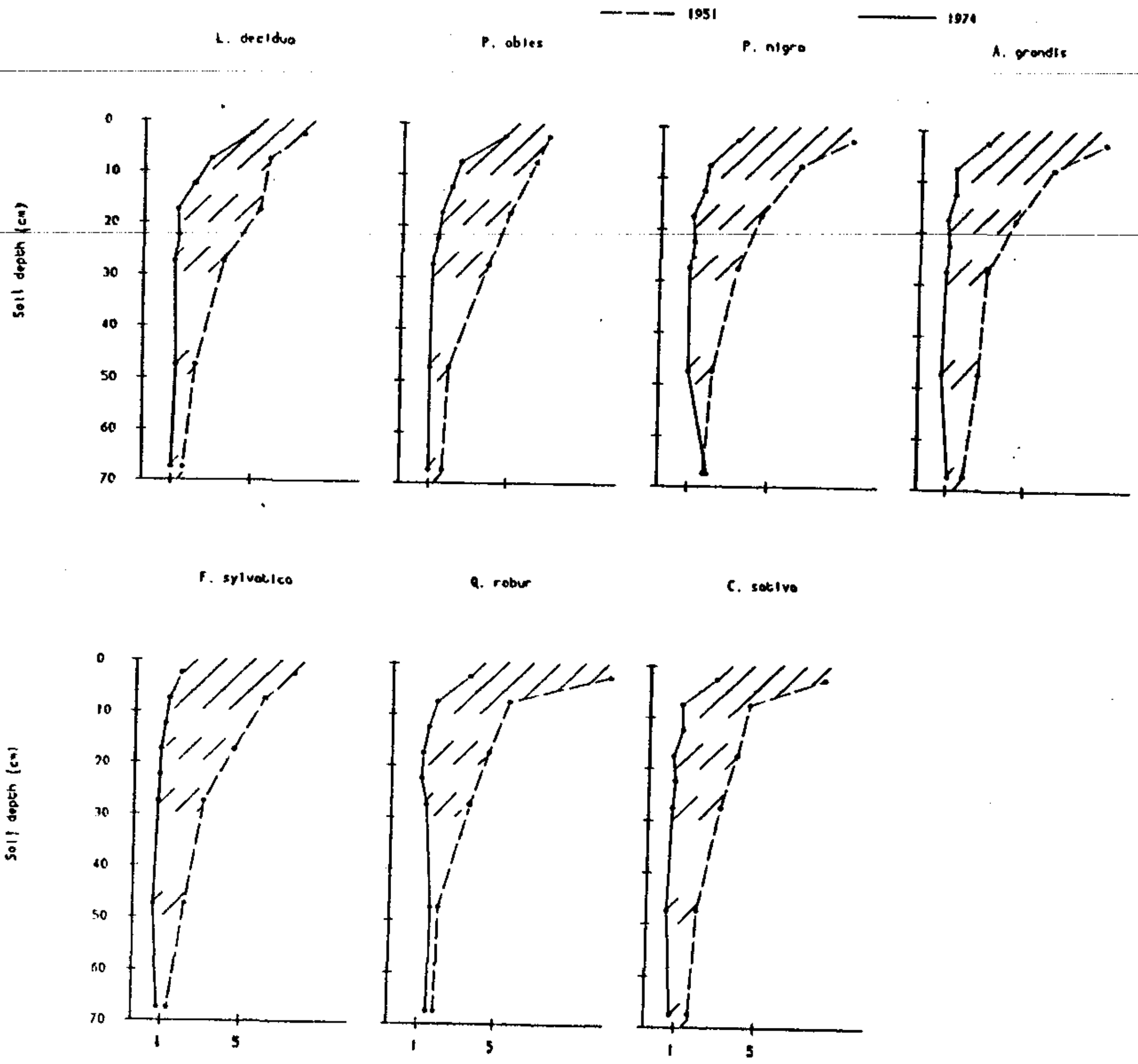


Figure 13. Extractable magnesium at different depths under different species in 1951 and 1974. Differences significant at $p < 0.05$ are hatched.

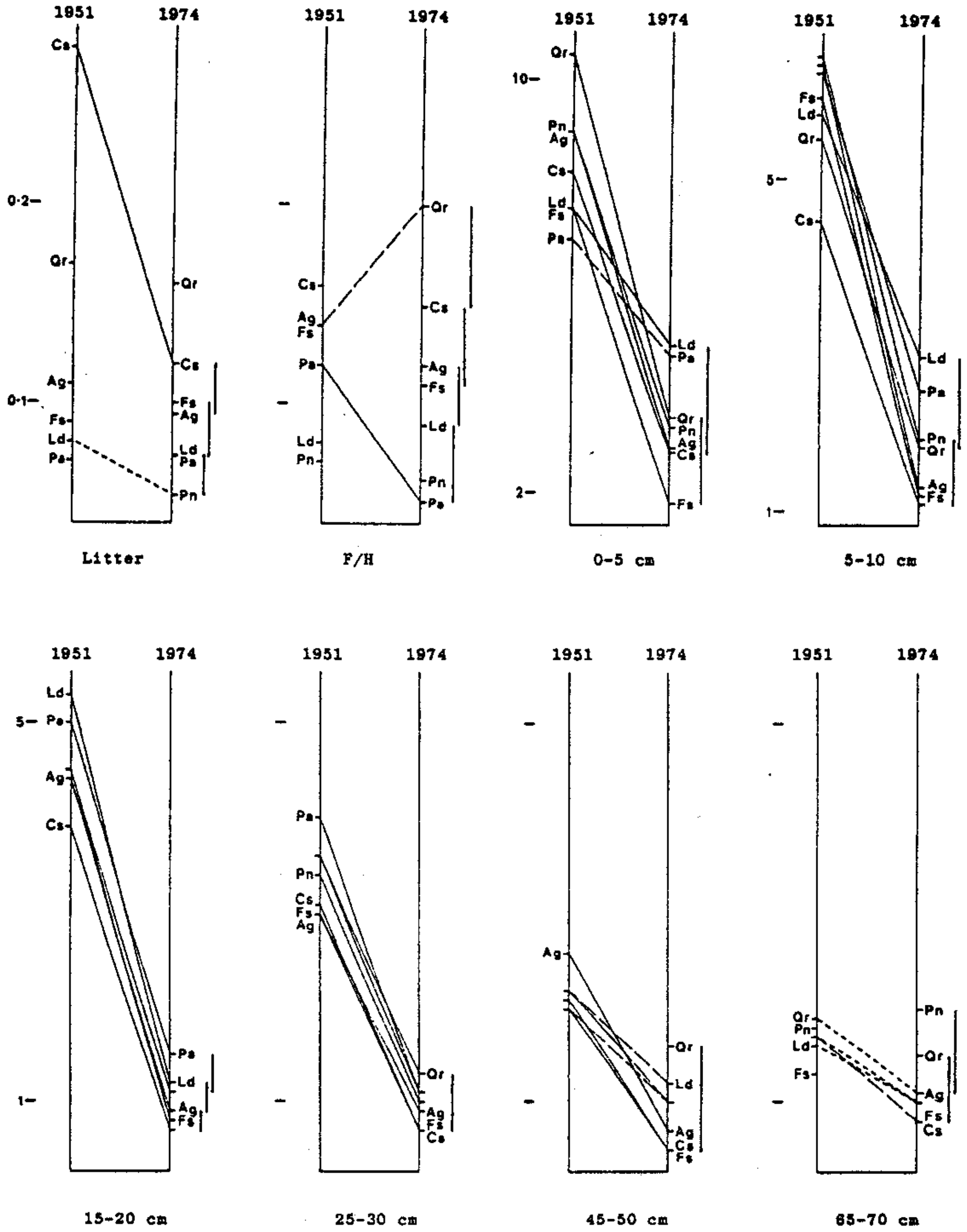


Figure 14. Changes in magnesium between 1951 and 1974 under different species (names abbreviated) at different depths, significant at $p < 0.05$ ----, $p < 0.01$ — —, $p < 0.001$———. The vertical lines link species not significantly different in 1974 (Tukey's HSD $p < 0.05$).

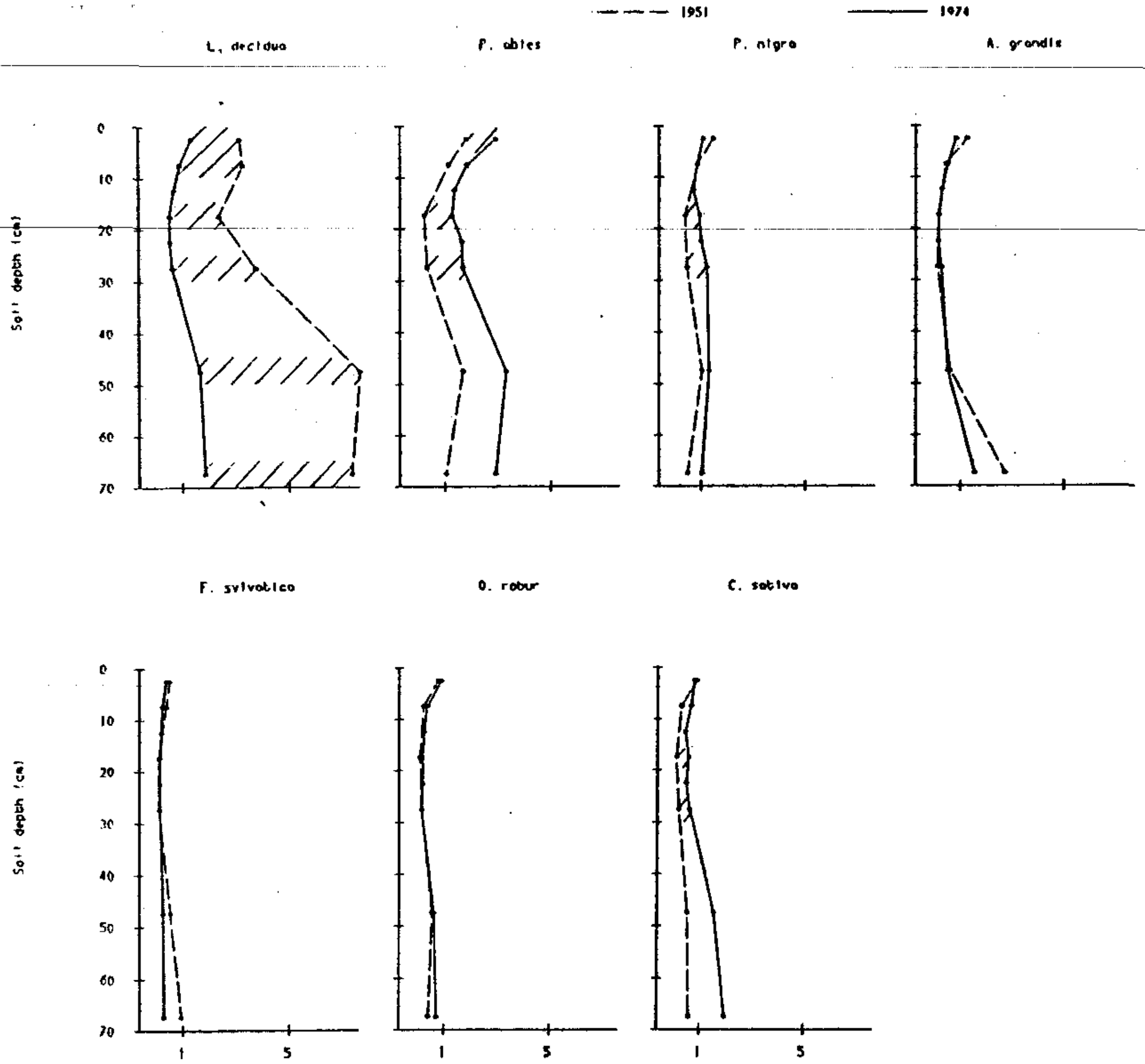


Figure 15. Extractable phosphorus at different depths under different species in 1951 and 1974. Differences significant at $p < 0.05$ are hatched.

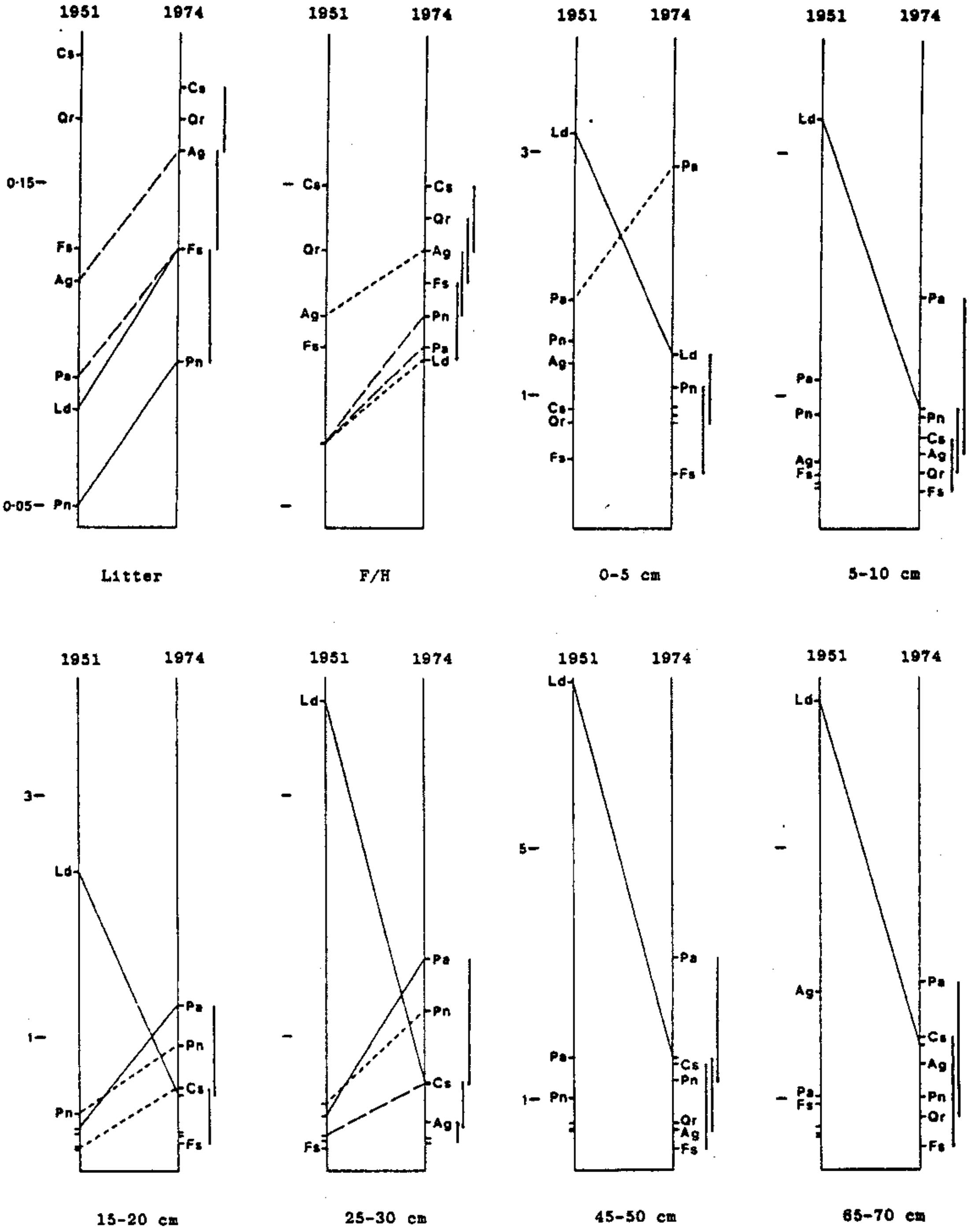


Figure 16. Changes in phosphorus between 1951 and 1974 under different species (names abbreviated) at different depths, significant at p <0.05 ----, p <0.01 — —, p <0.001 ———. The vertical lines link species not significantly different in 1974 (Tukey's HSD p <0.05).

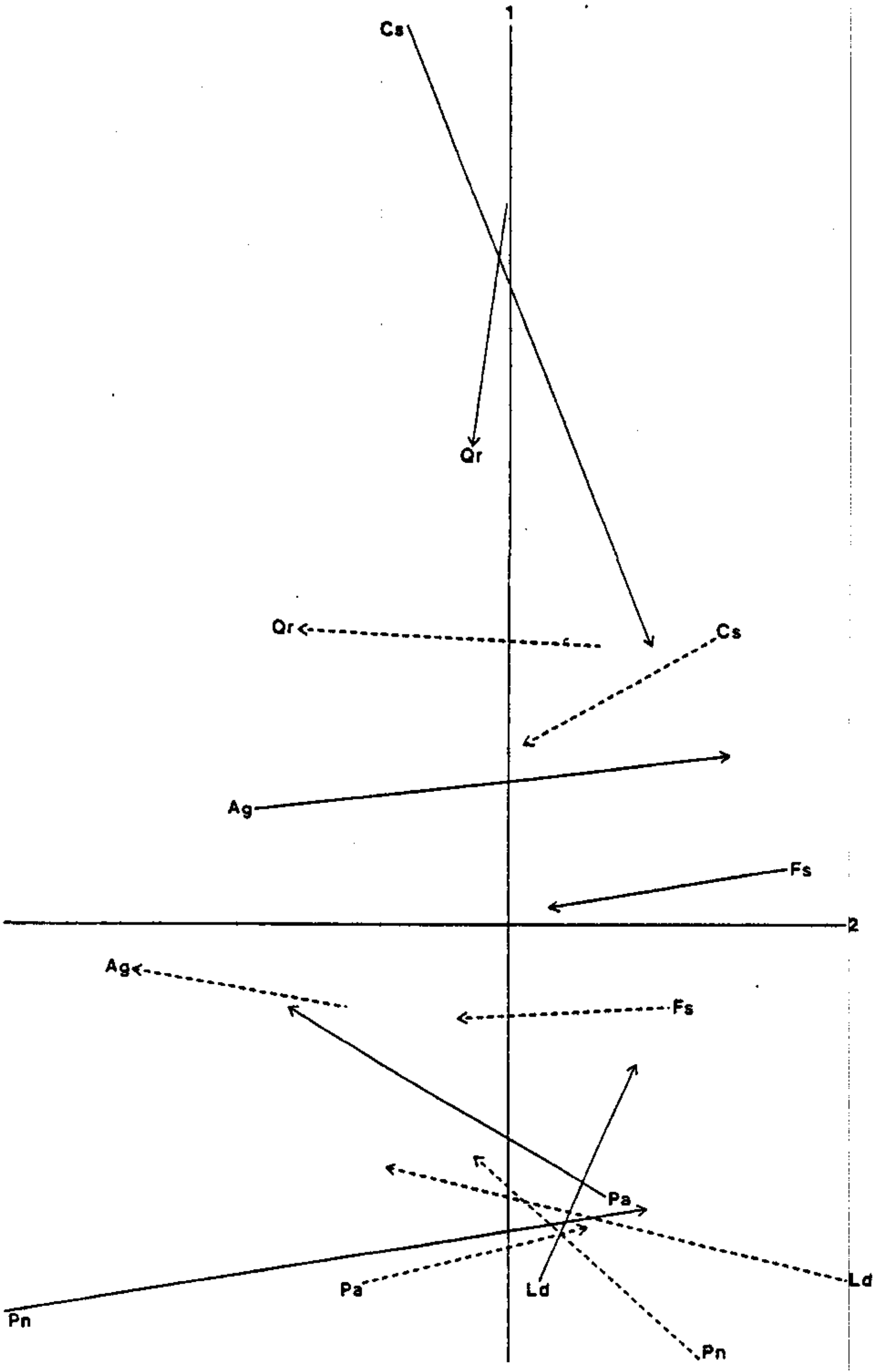


Figure 17. First and second components of the correlation matrix for the L (———) and F/H (----) layers under different species (names abbreviated), showing changes from 1951 to 1974.

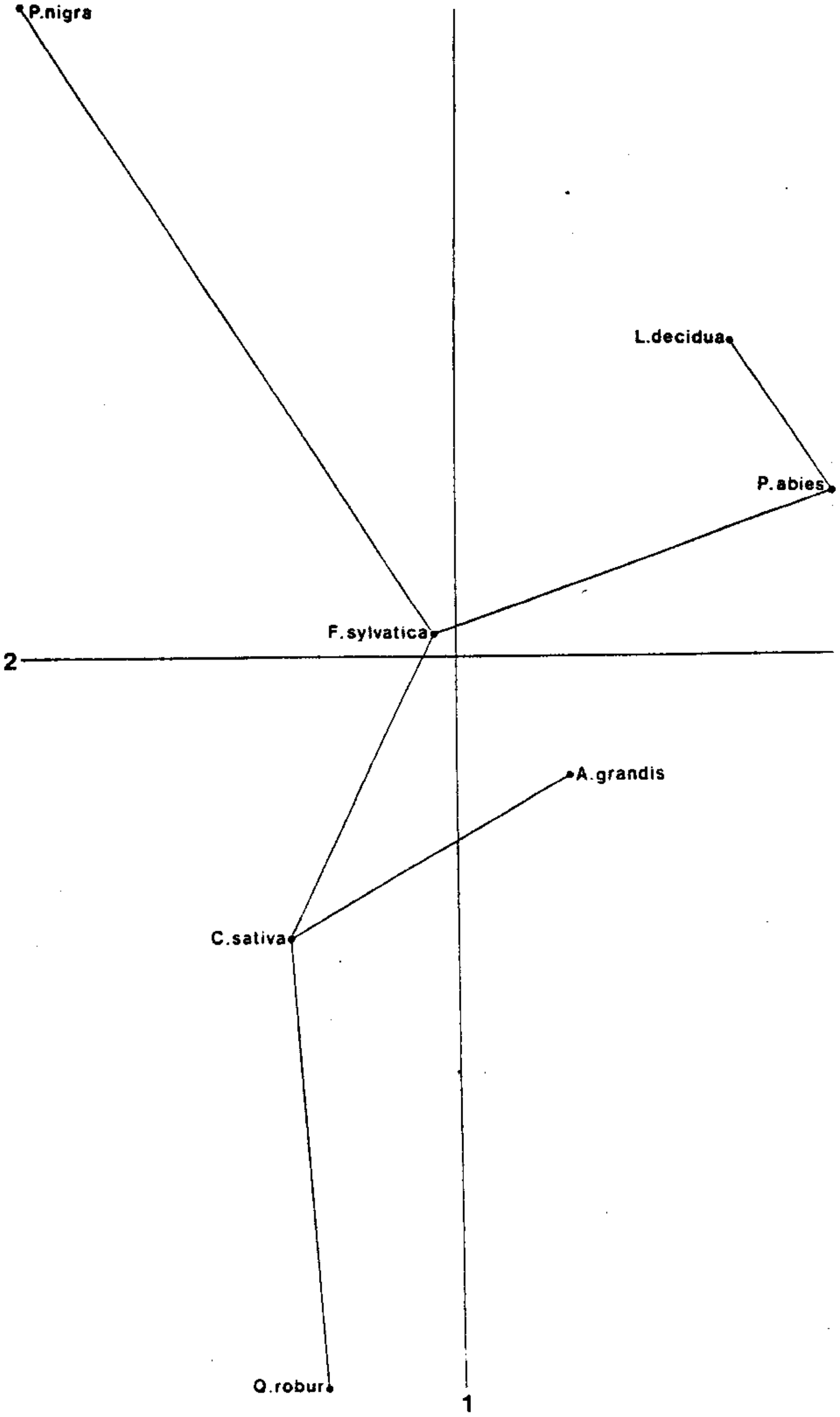


Figure 18. First and second components of the correlation matrix for the 1974 L layers under different species with the minimum spanning tree in 3 dimensions superimposed.

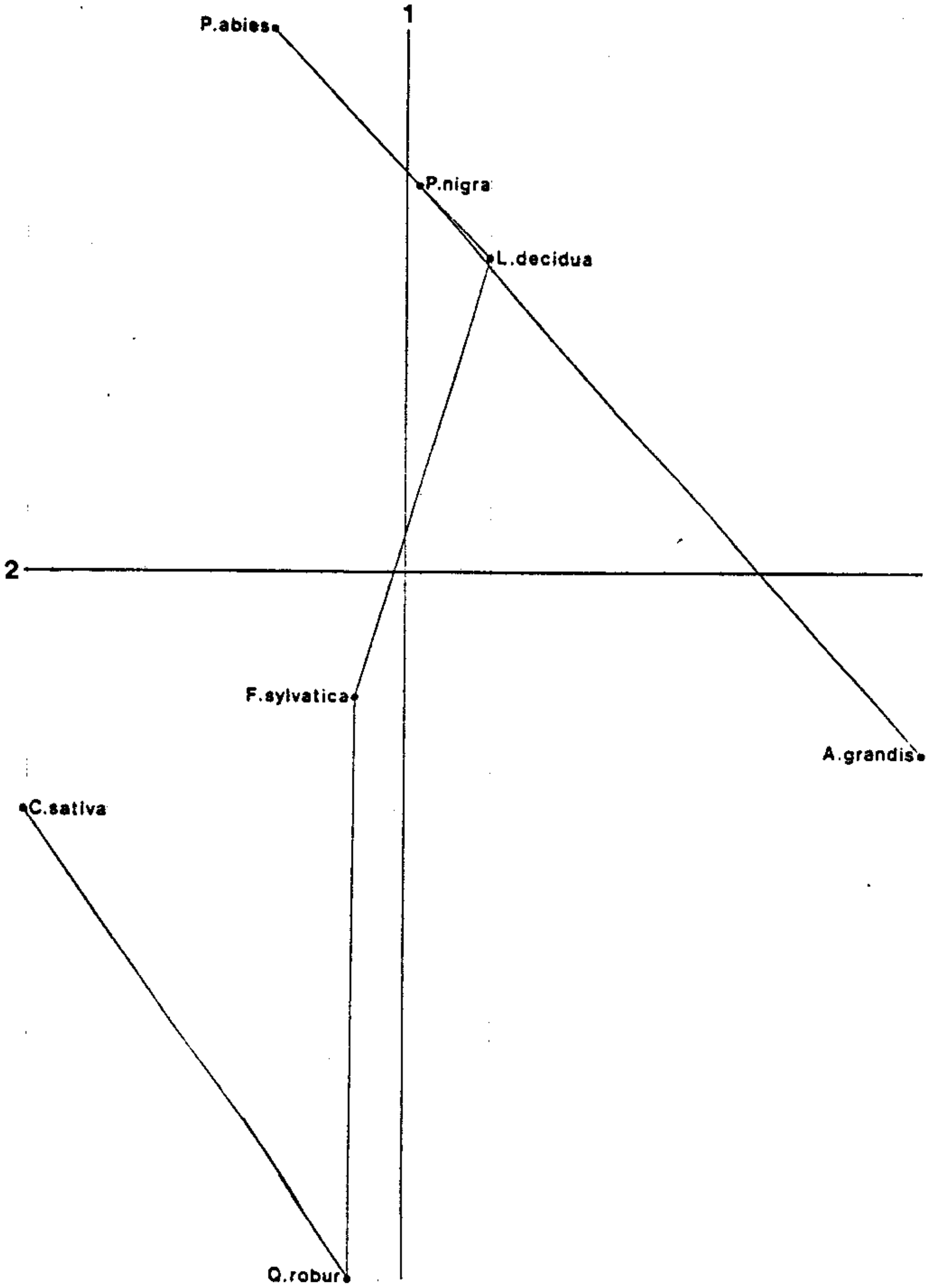


Figure 19. First and second components of the correlation matrix for the 1974 F/H layers under different species with the minimum spanning tree in 3 dimensions superimposed.

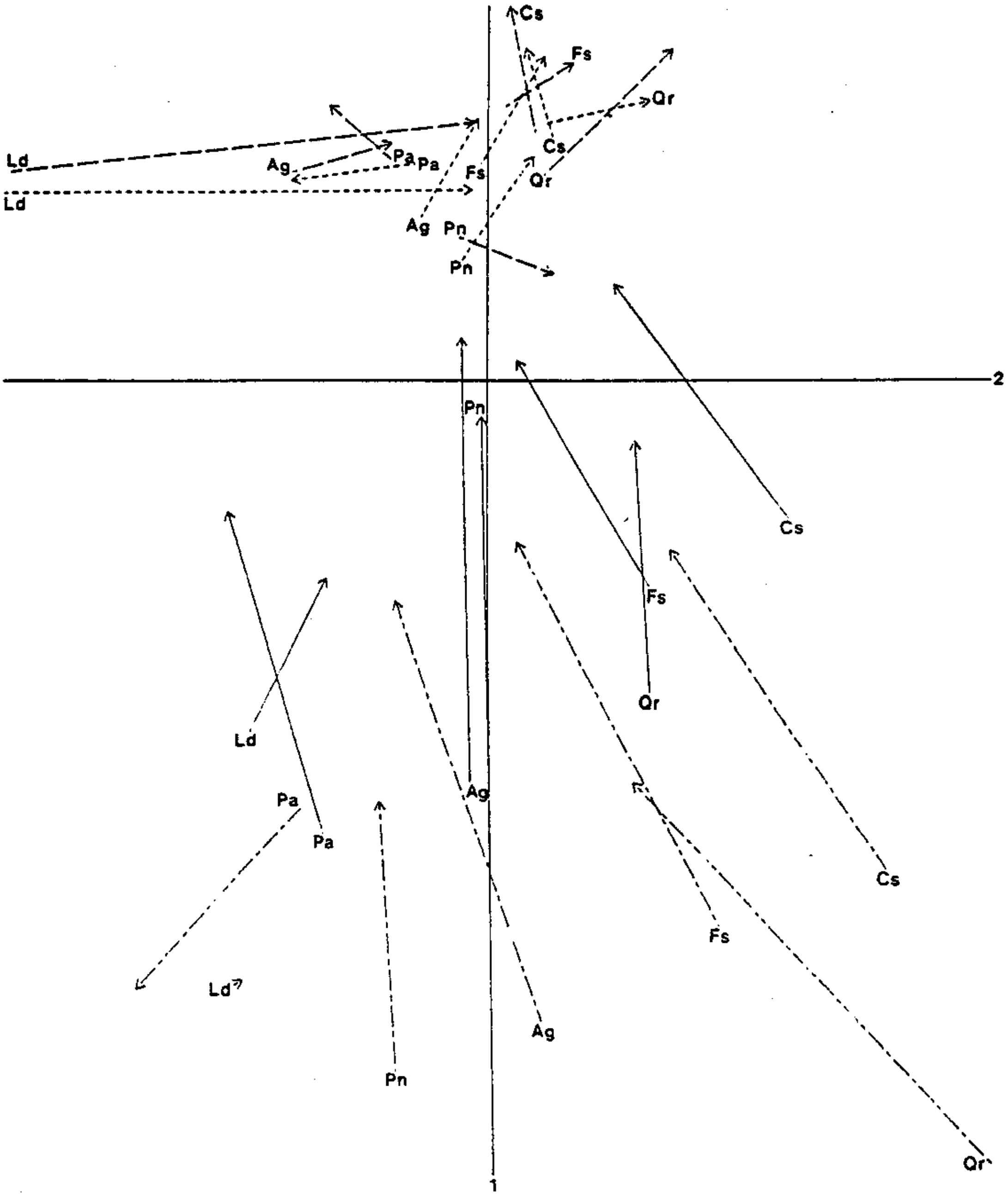


Figure 20. First and second components of the correlation matrix for the soils under different species (names abbreviated), showing changes from 1951 to 1974 —— - —— 0-5 cm, ——— 5-10 cm, ---- 45-50 cm, — — 65-70 cm (15-20 cm and 25-30 cm omitted for clarity).

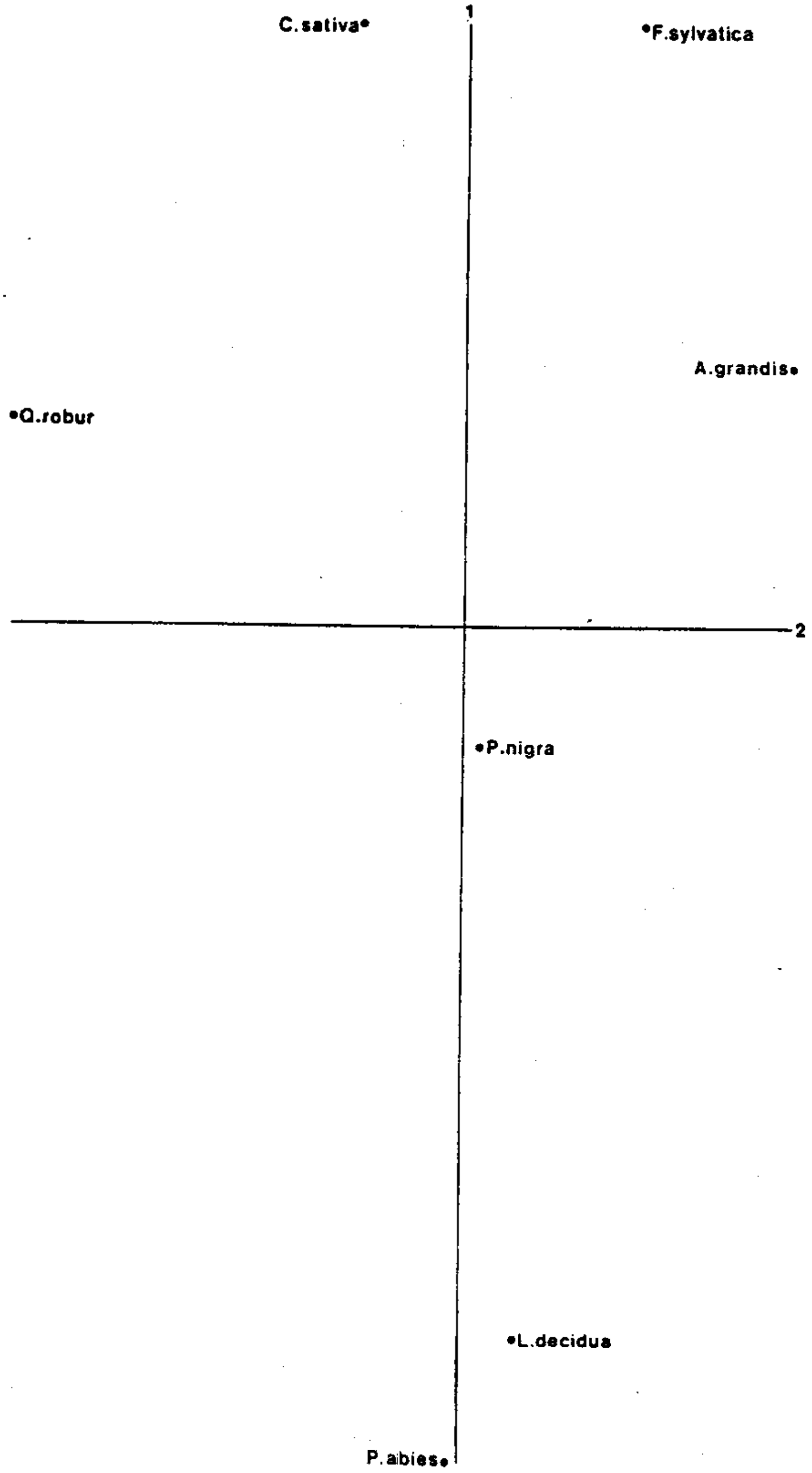


Figure 21. First and second components of the correlation matrix for the 0-5 cm soil under different species in 1974.

Appendix 1

Chemical methods

		1951	1974
LOI % OD*	(all samples)	2 hrs at 800°C	2 hrs at 550°C
Total N % OD	(L and F/H)	Kjeldahl with $CuSO_4$ catalyst, followed by distillation.	Peroxide/Sulphuric acid digestion method, colorimetric determination with indophenol blue.
Total N	soil 1951 mg/100 g OD 1974 % OD	Ditto	Kjeldahl with HgO catalyst, colorimetric determination with indophenol blue.
Total minerals	(L and F/H) 1951 mg/100 g OD 1974 % OD	Nitric/Perchloric/Sulphuric acid digestion followed by:	Peroxide/sulphuric acid digest followed by:
		Na} EEL flame K } photometer	} EEL flame photometer
		Ca-EDTA with murexide Mg-Titan yellow	} Atomic absorption with lanthanum to suppress interference
		P-Molybdenum blue	Mo blue
Extractables	(soil) 1951 and 1974 mg/100 g OD	Extracted for 2 hours with 2.5% acetic acid, 25 parts to 1 part AD soil (2 mm sieve).	As 1951 but for 1 hour.
		Na} flame K } photometer	Flame photometer
		Ca-EDTA with murexide Mg-Titan yellow	} Atomic absorption with lanthanum to suppress interference.
		P-Molybdenum blue	Mo blue

* 1951 oven dry = 80°C
1974 oven dry = 105°C

Correction factors

L and F/H Total N 1951 equivalent = 1974 N x 0.882

soil N 1951 equivalent = 1974 N x 0.707
K 1951 equivalent = 1974 K x 1.564

pH* 1951 equivalent for Bedgebury add 0.3 pH units
for Abbotswood add 0.49 pH units
for West Tofts add 0.31 pH units

* pH corrections M. Anderson, pers. comm.

1974 chemical analyses were performed by the Chemical Service at Merlewood.
1974 pH measurements were supplied by M. Anderson.

Appendix 2

1974 data for L and F/H layers and soils.

The data are means of 5 profiles per plot, but there were not always 5 L or F/H layers per plot.

1974 data

Variable % OD		*L. decidua*	*P. abies*	*P. nigra*	*A. grandis*	*F. sylvatica*	*Q. robur*	*C. sativa*
LOI	L	89.3	90.4	96.5	92.4	89.9	91.5	94.0
	F/H	80.0	82.0	80.0	67.0	73.0	70.0	81.0
Total N	L	1.87	1.73	1.35	2.37	1.65	2.07	2.03
	F/H	1.65	1.83	1.83	1.74	1.58	1.66	1.81
Total Na	L	0.018	0.032	0.012	0.020	0.017	0.024	0.019
	F/H	0.023	0.018	0.022	0.031	0.016	0.020	0.017
Total K	L	0.13	0.14	0.13	0.17	0.20	0.27	0.18
	F/H	0.15	0.14	0.17	0.24	0.21	0.29	0.22
Total Ca	L	0.41	0.58	0.60	0.59	0.69	1.03	0.80
	F/H	0.37	0.29	0.30	0.34	0.50	0.82	0.69
Total Mg	L	0.073	0.072	0.052	0.094	0.100	0.160	0.120
	F/H	0.089	0.049	0.060	0.120	0.110	0.200	0.150
Total P	L	0.130	0.130	0.095	0.160	0.130	0.170	0.180
	F/H	0.096	0.100	0.110	0.130	0.120	0.140	0.150

Variable	Sampling depth (cm)							
pH	0- 5	3.41	3.33	3.56	3.69	3.78	4.02	4.15
	5-10	3.52	3.45	3.76	3.86	3.85	4.06	4.10
	10-15	3.66	3.54	3.87	3.88	3.91	4.11	4.17
	15-20	3.83	3.67	3.92	3.89	3.93	4.09	4.18
	20-25	3.88	3.74	3.96	3.90	3.96	4.12	4.15
	25-30	3.91	3.75	4.00	3.90	3.98	4.15	4.26
	45-50	3.99	3.89	4.00	3.96	4.04	4.19	4.21
	65-70	4.03	3.95	3.97	3.91	4.09	4.26	4.17
LOI % OD	0- 5	9.5	10.0	7.5	5.4	5.8	6.6	5.4
	5-10	5.6	5.3	4.5	3.5	3.9	4.1	4.0
	10-15	4.4	4.5	4.1	3.2	4.0	3.3	3.4
	15-20	4.0	4.0	4.0	2.9	3.7	3.2	3.0
	20-25	3.4	3.7	3.7	3.1	3.7	2.7	2.9
	25-30	2.5	2.9	2.6	2.5	1.9	1.0	2.1
	45-50	2.9	2.5	2.1	2.1	2.2	1.7	1.7
	65-70	2.1	1.5	2.1	1.9	1.9	1.4	1.3
Total N % OD	0- 5	0.30	0.30	0.24	0.18	0.19	0.25	0.20
	5-10	0.20	0.18	0.14	0.12	0.16	0.15	0.15
	10-15	0.14	0.14	0.13	0.10	0.13	0.12	0.11
	15-20	0.12	0.12	0.12	0.09	0.13	0.11	0.10
	20-25	0.11	0.10	0.09	0.07	0.12	0.09	0.08
	25-30	0.09	0.11	0.10	0.10	0.13	0.08	0.09
	45-50	0.06	0.06	0.04	0.05	0.05	0.04	0.04
	65-70	0.05	0.04	0.04	0.04	0.04	0.02	0.03

1974 data

Variable	Sampling depth (cm)	*L. decidua*	*P. abies*	*P. nigra*	*A. grandis*	*F. sylvatica*	*Q. robur*	*C. sativa*
Extractable Na	0- 5	1.6	1.5	1.2	1.2	0.9	1.2	0.8
	5-10	1.1	1.1	0.8	1.0	0.8	0.9	0.6
	10-15	0.7	1.3	0.9	0.9	0.7	0.7	0.6
	15-20	0.7	1.0	0.7	0.8	0.6	0.6	0.5
	20-25	0.7	0.8	0.8	0.8	0.6	0.6	0.5
	25-30	0.6	0.9	0.8	0.9	0.7	0.6	0.6
	45-50	0.6	0.8	0.5	0.7	0.4	0.3	0.5
	65-70	0.5	0.7	0.8	0.8	0.4	0.2	0.3
Extractable K	0- 5	3.5	4.0	5.0	3.8	5.3	7.7	5.9
	5-10	3.5	3.5	5.5	3.4	3.9	6.0	4.6
	10-15	3.6	3.1	5.5	3.1	3.4	4.1	3.4
	15-20	3.8	2.8	4.8	2.8	2.7	3.3	3.0
	20-25	4.0	3.1	5.1	2.8	2.6	3.2	3.1
	25-30	3.7	2.8	4.8	2.3	2.4	3.4	2.9
	45-50	3.6	2.8	4.6	2.0	1.5	3.5	1.9
	65-70	3.2	2.0	6.1	2.2	1.8	3.3	2.1
Extractable Ca	0-5	15.2	14.9	14.8	10.5	8.1	12.1	9.1
	5-10	8.3	5.1	4.4	4.4	5.0	6.1	1.7
	10-15	4.9	4.4	5.7	3.8	4.0	2.9	3.8
	15-20	3.0	3.1	4.0	2.3	2.8	1.5	2.3
	20-25	3.4	2.9	4.6	3.3	3.0	3.1	3.3
	25-30	4.4	2.3	4.5	3.9	4.1	3.6	2.5
	45-50	2.5	1.5	2.5	1.5	1.5	3.0	1.3
	65-70	1.8	1.5	3.6	1.9	2.4	2.6	1.3
Extractable Mg	0- 5	4.9	4.7	3.3	2.9	1.8	3.5	2.8
	5-10	2.9	2.5	1.9	1.3	1.2	1.8	1.1
	10-15	2.1	2.0	1.7	1.3	1.0	1.4	1.2
	15-20	1.2	1.5	1.1	0.9	0.6	1.1	0.7
	20-25	1.3	1.3	1.2	1.0	0.6	1.0	0.8
	25-30	1.1	1.1	1.0	0.9	0.7	1.3	0.7
	45-50	1.2	1.0	1.0	0.7	0.5	1.6	0.5
	65-70	1.0	1.0	2.0	1.1	0.8	1.5	0.8
Extractable P	0- 5	1.35	2.89	1.07	0.64	0.36	0.91	0.78
	5-10	0.90	1.83	0.83	0.53	0.21	0.37	0.66
	10-15	0.69	1.35	0.68	0.32	0.17	0.27	0.43
	15-20	0.51	1.27	0.93	0.18	0.12	0.21	0.57
	20-25	0.53	1.64	0.99	0.17	0.11	0.22	0.47
	25-30	0.62	1.66	1.22	0.29	0.12	0.16	0.60
	45-50	1.68	3.29	1.31	0.53	0.24	0.63	1.57
	65-70	1.87	2.90	1.03	1.56	0.27	0.72	2.00