ISSN 0308 3675

MERLEWOOD RESEARCH AND DEVELOPMENT PAPER

No 102

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

by

P J A HOWARD & D M HOWARD

Institute of Terrestrial Ecology
Merlewood Research Station
Grange-over-Sands
Cumbria
England
LA11 6JU

November 1984

Suggested citation:

HOWARD, P J A & HOWARD, D M 1984

Effects of trees on soil properties, a resampling of J D Ovington's plots at West Tofts. (Merlewood research and development paper no. 102). Grange-over-Sands: Institute of Terrestrial Ecology.

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 and Abbotswood were given in Howard and Howard (1983 a, b and c). This paper presents the results for species planted at West Tofts (Norfolk).

2 SITES AND SAMPLING PLOTS

The West Tofts area, altitude 30-46 m, is flat, and the soil, except for the underlying chalky boulder clay, is sandy throughout. The lowermost light yellow chalky clay, at an average depth of 70 cm, is compact and few roots penetrate it. Ovington (1953) stated that, except for the lowermost reddish layer, the sandy soil had no clearly-defined horizons, but showed a gradual change from greyish-brown above to a yellowish-brown and finally a yellow colour below. Chalk particles and flints were present throughout the profile. The pH varied with depth from 5 to 8.5. This area was formerly part of the Breckland heath; it was ploughed and planted in 1930. Ovington noted that oak regeneration occurred in all the plots except that planted with *Pseudotsuga menziesii*.

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. Scheffé'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 illustrates more clearly than the first type the magnitudes of the differences between years, the relative values of the species in either year, and the signficant differences, or lack of differences, 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: *Pinus nigra* litter had the greatest loss-on-ignition (lowest ash content) in both 1951 and 1974 (Figure 4). *Alnus incana* litter showed a significant decrease in loss-on-ignition from 1951 to 1974, and had the lowest value (greatest ash content) in 1974. Original manuscript tables at Merlewood gave a different loss-on-ignition of the F/H layer under *A. incana* from that published (Ovington 1954). The original value (92.64%) is used here. The *A. incana* F/H layer had the greatest loss-on-ignition in 1951, but it decreased significantly to become the second lowest in 1974. The F/H layer under *Larix leptolepis* had the greatest loss-on-ignition in 1974, although in that year there was no significant difference between species. In 1974, the lowest F/H layer loss-on-ignition was under *Betula alba*, which showed a significant decrease from 1951.

Nitrogen (total): In 1951 and 1974, in both L and F/H layers, *Pinus nigra* had the smallest total nitrogen content and *Alnus incana* the largest (Figure 6). The ranges were similar in both years but the maximum and minimum values were greater in 1974. In 1974, the mean total nitrogen content of the hardwood litters was significantly ($p < 0.001$) greater than that of the coniferous litters. However, taking the species individually there were significant differences in L layer total nitrogen between all species except *Pseudotsuga menziesii* and *Betula alba* , while in the F/H layer it was significantly greater under *Alnus incana* than under all the other species except *Larix leptolepis*. Between 1951 and 1974 there were significant increases under all species in the L layer, and under all species except *Betula alba* in the F/H layer.

Sodium (total): In 1951, the L layers under *Pinus nigra* and *Larix leptolepis* had the lowest total sodium content. Under *Pseudotsuga menziesii*, both the L and F/H layers had the greatest total sodium content in both 1951 and 1974 (Figure 8). In 1974, the *P. menziesii* L layer had a significantly greater total sodium content than that under any species except *L. leptolepis*. *Alnus incana* had the smallest total sodium content in the L layer in 1974, and in the F/H layer in both years. In 1974, the mean extractable sodium content of the F/H layers under the hardwood species was significantly ($p < 0.01$) lower than that under the coniferous species. However, taking the species individually, there was no significant difference between the 3 coniferous species, or between *Betula alba*, *Larix leptolepis* and, *P. nigra*, or between *L. leptolepis*, *B. alba*, and *A. incana*. There was no significant difference between years in the L layers. In the F/H layers, there were significant decreases under *P. nigra* and *B. alba*.

Potassium (total): *Betula alba* L and F/H layers had the greatest total potassium content in 1951 and 1974 (Figure 10). In 1974, the total potassium content of the L layer under *B. alba* was significantly greater than that under all the other species except *Pseudotsuga menziesii*, and in the F/H layer under *B. alba* it was significantly greater than that under all the other species. There were significant decreases between 1951 and 1974 in the L layers under *B. alba* and *Alnus incana*, but no significant changes were found in the F/H layers. In the L layers the range of total potassium values was smaller in 1974 than in 1951.

Calcium (total): In the L layer, *Betula alba* and *Alnus incana* had significantly greater total calcium contents than the coniferous species in both years (Figure 12) but there were significant differences between coniferous litters. In the F/H layer, *B. alba* had the greatest total calcium content in both years, and in 1974 it was significantly greater than that of any other species except *A. incana*. There were no significant differences between the individual hardwood or coniferous species, and *A. incana* F/H layer was not significantly different from those of *Pseudotsuga menziesii* and *Larix leptolepis*. Between 1951 and 1974 there were significant decreases in total calcium in the L layers under *B. alba, A. incana,* and *Pinus nigra*. In the F/H layers there were significant decreases under all species except *Larix leptolepis*.

Magnesium (total): L and F/H layers under *Betula alba* had the greatest total magnesium contents in both years, the content in the F/H layer in 1974 being significantly greater than those under all other species (Figure 14). *Larix leptolepis* and *Pinus nigra* had the smallest total magnesium contents in the L layers in both years, and in the F/H layer in 1974. *L. leptolepis* also had the lowest content in the F/H layer in 1951. In 1974 the mean total magnesium contents of the L and F/H layers under the hardwood species was significantly ($p < 0.01$) greater than that under the coniferous species. However, taking the species individually, *B. alba* litter was not significantly different from that of *Pseudotsuga menziesii*, and there were no significant differences between *Alnus incana* and the 3 coniferous species. *B. alba* F/H layer was significantly greater than that of any other species, and there were no significant differences among the remaining species. There were significant decreases between years in the L layers under *B. alba, A. incana,* and *P. nigra*, but there were no significant differences in the F/H layers. The L layers showed a narrowing in the range of total magnesium values from 1951 to 1974.

Phosphorus (total): L and F/H layers under *Betula alba* had the greatest total phosphorus contents in both years, and those under *Pinus nigra* had the lowest (Figure 16). In 1974, the mean total phosphorus content of the hardwood litters was significantly ($p < 0.01$) greater than that of the coniferous litters. However, taking the species individually, there were no significant differences between the L layers of the hardwood species and *Pseudotsuga menziesii*, or between *Alnus incana* and *L. leptolepis*, or between *L. leptolepis* and *P. nigra*. In the F/H layers the coniferous species were not significantly different from each other or from *A. incana*, and there was no significant difference between the 2 hardwood species and *P. menziesii*. and *L. leptolepis*. Only *B. alba* and *P. nigra* differed significantly. The only significant difference between years was a decrease in total phosphorus in litter of *B. alba*.

4.2 Soils, analysis of variance

pH; The means are shown plotted against depth in Figure 1. In Figure 2, for each soil layer, the mean values of the plots (species) are ordered on a single axis for each year. In 1974, soil under *Alnus incana* was the most acid at all depths except 65-70 cm, whereas soil under *Pinus nigra* was the least acid at all depths except 0-5 cm. Between 1951 and 1974 there was a significant decrease in pH in soil above 20 cm depth under *A. incana*, and an increase at all depths below 25 cm under *P. nigra*. There was a significant increase at 65-70 cm depth under all species, and at 45-50 cm under all species except *A. incana*.

Loss-on-ignition: The means are shown plotted against depth in Figure 3. In Figure 4, for each soil layer, 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 *Alnus incana* had the greatest loss-on-ignition in both years. In 1974, soil under *Pinus nigra* had the lowest loss-on-ignition at all depths down to 30 cm. At 0-5 cm the mean loss-on-ignition under the hardwood species was significantly ($p < 0.001$) greater than that under the coniferous species. However, taking the species individually there was no significant difference between species if *A. incana* was removed (Figure 4). Between 1951 and 1974 there were significant decreases in loss-on-ignition at 5-10 cm, 15-20 cm, and 25-30 cm depth under *P. nigra* and *Larix leptolepis*.

Nitrogen (total): The means are shown plotted against depth in Figure 5. In Figure 6, for each soil layer, the mean values of the plots (species) are ordered on a single axis for each year. In both 1951 and 1974, soil under *Alnus incana* had the greatest total nitrogen content at 0-5 cm and 5-10 cm, and in 1974 at 0-5 cm it was significantly greater than under any other species. At 0-5 cm and 5-10 cm the mean total nitrogen content was significantly ($p < 0.001$) greater under the hardwood species than under the coniferous species. However, taking the species individually there was no significant difference at 0-5 cm if *A. incana* was removed, and at 5-10 cm *Betula alba* was not significantly different from *Pseudotsuga menziesii* (Figure 6). By contrast with Bedgebury and Abbotswood (Howard & Howard 1984b, c) there were few statistically significant changes from 1951 to 1974, and they were small and occurred only at one or two depths for each species. The only significant change at 0-5 cm was a small increase under *A. incana*.

Sodium (extractable): The means are shown plotted against depth in Figure 7. In Figure 8, for each soil layer, the mean values for the plots (species) are ordered on a single axis for each year. In 1974, there was one replicate with a very high level of extractable sodium at 45-50 cm and 65-70 cm under both *Alnus incana* and *Larix leptolepis*. However, the mean values for those soils were not significantly different from the mean values at the same depths under the other species. The only significant differences between species in 1974 occurred at 5-10 cm, 15-20 cm, and 25-30 cm. There was a significant decrease in extractable sodium at 5-10 cm, 15-20 cm, and 25-30 cm under *Pinus nigra*, at 5-10 cm and 25-30 cm under *Larix leptolepis*, and at 0-5 cm and 5-10 cm under *A. incana*.

Potassium (extractable): The means are shown plotted against depth in Figure 9. In Figure 10, for each soil layer, the mean values for the plots (species) are ordered on a single axis for each year. There were no significant differences between species at any depth in 1974, but soil under *Betula alba* had the greatest, and under *Pinus nigra* the smallest, content of extractable potassium down to 20 cm depth. There were only 2 statistically significant changes, an increase under *B. alba* at 25-30 cm and an increase under *Alnus incana* at 45-50 cm.

Calcium (extractable): The means are shown plotted against depth in Figure 11. In Figure 12, for each soil layer, the mean values of the plots (species) are ordered on a single axis for each year. In 1974, there was one replicate with a very high level of extractable calcium at 45-50 cm and one at 65-70 cm under both *Alnus incana* and *Larix leptolepis*, but the only significant difference between species in 1974 was between *Pinus nigra* and *A. incana* at 5-10 cm depth. There were significant decrease at 0-5 cm under *L. leptolepis* and *A. incana*, and at 5-10 cm, 15-20 cm, and 25-30 cm under *P. nigra*, and a significant increase at 45-50 cm under *A. incana*.

Magnesium (extractable): The means are shown plotted against depth in Figure 13. In Figure 14, for each soil layer, the mean values for the plots (species) are ordered on a single axis for each year. In 1974 there was one replicate with a very high level of extractable magnesium at 45-50 cm and one at 65-70 cm under both *Alnus incana* and *Larix leptolepis*. In 1974, the mean extractable magnesium content of soil at 0-5 cm depth was significantly ($p < 0.01$) greater under the hardwood species than under the coniferous species. However, taking the species individually, there was no significant difference if *Betula alba* was removed (Figure 14). There were significant decreases at 0-5 cm, 5-10 cm, and 15-20 cm, under all 5 species, and at 25-30 cm under all species except *B. alba*.

Phosphorus (extractable): The means are shown plotted against depth in Figure 15. In Figure 16, for each soil layer, the mean values of the plots (species) are ordered on a single axis for each year. There were no differences between species below 15 cm. At 0-5 cm there was no difference between species if *Pinus nigra* was removed, and at 5-10 cm there was no difference if *Alnus incana* was removed (Figure 16). From 1951 to 1974 there was a significant increase at 0-5 cm under *Pseudotsuga menziesii*, and there were significant decreases at 15-20 cm under *P. nigra* and *Larix leptolepis*.

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

As at Bedgebury and Abbotswood (Howard & Howard 1984b, c), loss-on-ignition has the lowest coefficient of variation, here 17%. Potassium showed most variation (CV 84%). As at Abbotswood, total potassium, calcium, magnesium, and phosphorus are all positively intercorrelated ($p < 0.01$), but unlike the Abbotswood data, there were no other significant correlations.

The first 3 eigenvalues of the correlation matrix are likely to be of practical importance, together they account for 86% of the total variance. The first component, accounting for 50% of the total variance is, like that of the Abbotswood samples, dominated by total potassium, magnesium, calcium, and phosphorus. The second component, accounting for 19% of the total variance, is dominated by total sodium, which accounts for almost 60% of the variance in that component (cf Abbotswood). The third component, accounting for 16% of the total variance, is dominated by total nitrogen, which accounts for about 63% of the variance in that component. The first and second components are plotted in Figure 17.

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

As in the Bedgebury and Abbotswood L layers, loss-on-ignition had a very low coefficient of variation (5%). The coefficients of variation of the other variables range from 28% for total phosphorus to 53% for total calcium. Unlike Bedgebury and Abbotswood, there are no significant correlations.

Only the first 3 components are of practical importance, together they account for 96% of the total variance. The 3 zero eigenvalues are due to the fact that there are only 5 sets (species) but 7 variables. The first component, accounting for 57% of the total variance, is dominated by total magnesium, calcium, phosphorus, and nitrogen. The second component, which accounts for almost 23% of the total variance, is chiefly due to a combination of total sodium and loss-on-ignition. The third component, accounting for 17% of the total variance, is mainly due to a contrast between total sodium and total potassium. The first and second component values are plotted in Figure 18, with the minimum spanning tree in 3 dimensions superimposed.

In the F/H layers,as in the L layers, loss-on-ignition has the smallest coefficient of variation, but here it is larger (16%). Total calcium has the greatest coefficient of variation (50%).

Total phosphorus is significantly correlated with total magnesium ($r = 0.948$) and total potassium ($r = 0.885$), and total magnesium is significantly correlated with total potassium ($r = 0.934$) (cf Abbotswood, Howard & Howard 1984c).

Only the first 2 eigenvalues are of practical importance, together they account for 91% of the total variance. As with the L layer data, there are 3 zero eigenvalues due to there being 7 variables but only 5 data sets. The first component, accounting for 66% of the total variance, is chiefly a contrast between total magnesium, calcium, phosphorus, and potassium on the one hand, and loss-on-ignition on the other. The second component, which accounts for 25% of the total variance, is due chiefly to total nitrogen, which accounts for 53% of the variance in that component. The first and second component values are plotted in Figure 19.

4.5 Soils, principal component analysis

The means, standard deviations, and coefficients of variation of the variables for the soils are given in Table 2. As at Bedgebury and Abbotswood, pH showed least variability (CV 14%). However, unlike those 2 sites, extractable phosphorus does not show greatest variation (here CV 33%), that is shown by extractable calcium (CV 205%). Total nitrogen is also very variable (CV 104%).

The correlation half-matrix is given in Table 3. The pattern of significant correlations is not similar to those at Bedgebury and Abbotswood.

The first 2, possibly 3, eigenvalues of the correlation matrix may be considered to be of practical importance, the first 2 account for 74% of the total variance, the first 3 account for 83% (Table 4). The first component, accounting for 44% of the total variance, is essentially a contrast between pH on the one hand, and total nitrogen, loss-on-ignition and extractable potassium on the other (Table 5). The second component, accounting for 30% of the total variance, gives large positive weightings to extractable calcium, sodium, and magnesium. The third component, accounting for 9% of the total variance, is dominated by extractable phosphorus, which accounts for about 77% of the variance in that component.

The first and second components are plotted in Figure 20. The positions of the points on the first axis are due chiefly to horizon and species, and there are no large changes with time. The lowest first component values are for *Alnus incana* 0-5 cm (1951 and 1974), and for all soil depths this species has low component values relative to those of other species at the same depth. There is a decrease in second component value for all species in the upper soil layers, but *A. incana* and *Larix leptolepis* show large increases for 45-50 cm and 65-70 depths. *L. leptolepis* showed a decrease in third component value for all depths, the largest decrease being for 65-70 cm depth. Most other species showed increases in third component values with time.

For the 1974 data only, the order 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 axes vary with depth, no variable is consistently important at all depths. At one depth 2 variables may be associated, but at another they may form a contrast, eg loss-on-ignition and extractable calcium at 5-10 cm and 15-20 cm. The important variables are different from those at Bedgebury and Abbotswood. Notably, at Bedgebury total nitrogen and extractable potassium were important at all depths, at Abbotswood loss-on-ignition and pH were contantly important at all depths.

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 50% of the total variation, and the order of the species plots on it summarizes their relative positions in a general way, although the second axis, which accounts for a further 40% of the variation, reveals differences between *Alnus incana* and *Betula alba* and the remaining species associated with high loss-on-ignition, total nitrogen, and extractable potassium in the former.

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 pH range at 0-5 cm was 5.05 (*Pseudotsuga menziesii*) to 6.58 (*Larix leptolepis*). By 1974, the pH under *L. leptolepis* had decreased (significantly) to 4.89, while that under *P. menziesii* had not changed significantly. There were significant decreases in pH under *Alnus incana* at 0-5 cm, 5-10 cm, 10-15 cm, and 15-20 cm, and the range at 0-5 cm in 1974 was 4.23 (*A. incana*) to 6.08 (*Betula alba*). Franklin *et al.* (1968) found that soil calcium and magnesium were lower under *Alnus rubra* than under *P. mensiesii*, and attributed this to greater leaching losses under *Alnus* associated with fixation of nitrogen and production of nitrate. Crocker and Major (1955) commented on the remarkable acidifying effect of *Alnus crispa* on morainic debris. The pH of the uppermost (0-5 cm) soil horizons fell from 8.0 or more to 5.0 within 35 to 50 years, and leaching of calcium carbonate was rapid. Bormann and De Bell (1981) found the pH of mineral soil to be lower under red alder (*A. rubra*) than under *P. menziesii*.

In 1974, all plots showed increased acidity of the 0-15 cm mineral soil compared with that below 30 cm, and this effect was more pronounced than in 1951 (Ovington 1953). *Betula alba* showed the smallest pH difference (1.23 units) and *A. incana* the largest (2.69 units) between the upper and lower soils. The central zone of maximum pH found in 1951 was not present in 1974, due to increases in pH below 30 cm.

Loss-on-ignition was greatest under *A. incana* in both years at 0-5 cm and 5-10 cm. It appears that organic matter tends to accumulate under *Alnus* species. In a study of mixed hardwood sites in Poland, Karkanis (1975) found that the organic matter content was greatest under *A. glutinosa*. Bormann and De Bell (1981) found that under *A. rubra* the organic matter content of the mineral soil was 20% greater, and the pH and bulk density much lower, than beneath adjacent *P. menziesii* stands. Franklin *et al.* (1968) found that A_{11} horizons of 40-year-old Red alder (*A. rubra*) stands averaged one third greater organic matter content than those under *P. menziesii*, presumably because of greater acidity under *A. rubra* as a result of nitrogen fixation and nitrification.

In both 1951 and 1974, *A. incana* had the largest total nitrogen content in both L and F/H layers. Bollen and Lu (1968) found that nitrification was especially rapid in the F layer beneath *A. rubra* despite a very low pH. In 1951, at 0-5 cm, the range of total nitrogen contents was 0.03 (*Pseudotsuga menziesii*) to 0.12 (*A. incana*), the latter showing a significant increase to 0.16 in 1974. In 1951, at 5-10 cm, the range was 0.02 (*Betula alba*) to 0.05 (*A. incana*). Because of the ability of *Alnus* species to fix atmospheric nitrogen, soils under them usually have high nitrogen contents. For example, Franklin *et al.* (1968) found that total nitrogen content was one-third greater in the A_{11} horizon under 40-year-old *A. rubra* stands than under a coniferous stand of mainly *P. menziesii* (see also Cole & Johnson 1981). From 1951 to 1974 at 5-10 cm there were significant increases under *P. menziesii* and *B. alba*. There was a significant decrease under *Pinus nigra* at 15-20 cm, and under *A. incana* at 25-30 cm. In general, the changes in total nitrogen were not as large as those at Bedgebury and Abbotswood.

Karkanis (1975) found that soil potassium content increased under *Alnus glutinosa*. Here, under *A. incana*, there was a significant increase from 1951 to 1974 only at 45-50 cm. By contrast with Bedgebury and Abbotswood, there were very few increases in extractable potassium between 15 cm and 50 cm only under *B. alba* at 25-30 cm and *A. incana* at 45-50 cm.

In 1951 at 0-5 cm, the range of extractable calcium contents was 26.1 (*Pseudotsuga menziesii*) to 81.8 (*Alnus incana*), and soil under *P. menziesii* had the lowest extractable calcium content down to 30 cm depth. The high value for soil under *A. incana* at 0-5 cm in 1951 does not agree with the propensity of that species, noted above, to encourage acidification and leaching. However, it may be related to within-plot variation and the presence of the underlying chalky boulder clay. From 1951 to 1974, the only significant changes at 0-5 cm were losses under *A. incana* and *L. leptolepis*.

In 1951, at 5-10 cm, the range of extractable calcium values was 40.4 (*Pseudotsuga menziesii*) to 286.8 (*Pinus nigra*). Soil under *Larix leptolepis* also had a large extractable calcium content (159.6). The only significant change by 1974 was a decrease under *P. nigra*. At 15-20 cm, the 1951 range was larger, 117 (*P. menziesii*) to 588.7 (*P. nigra*), with soil under most species having quite large values (*Betula alba* 166.5, *Alnus incana* 173.8, *L. leptolepis* 478.4). Again, the only significant change by 1974 was a decrease under *P. nigra*. At 25-30 cm in 1951, the range was smaller, 78.5 (*P. menziesii*) to 377.7 (*P. nigra*), and again there was a significant decrease under *P. nigra*.

The large extractable calcium values in 1974 under *Larix leptolepis* and *A. incana* at 45-50 cm and 65-70 cm suggest that in those plots the chalky boulder clay came closer to the surface than in the other plots, and probably also than in the same plots in the 1951 samples, so sensible comparisons cannot be made at those depths.

Soil under all species showed significant losses of extractable magnesium at 0-5 cm, 5-10 cm, and 15-20 cm, and under all except *Betula alba* at 25-30 cm. In 1951, the range of extractable magnesium contents at 0-5 cm was 4.0 (*Pinus nigra*) to 9.6 (*Larix leptolepis*). In 1974, the range was 0.58 (*P. nigra*) to 2.56 (*B. alba*). The smallest decrease occurred under *P. nigra* and the largest under *L. leptolepis*. In 1951, at 5-10 cm, the range was 2.8 (*P. nigra*) to 4.5 (*L. leptolepis*), in 1974 the range was 0.86 (*A. incana*) to 1.68 (*Pseudotsuga menziesii*). The smallest loss, again, was under *P. nigra* and the largest under *L. leptolepis*. At 15-20 cm, in 1951, the range was 2.4 (*B. alba*) to 4.0 (*L. leptolepis*). In 1974, the range was 1.22 (*B. alba* and *P. nigra*) to 1.98 (*L. leptolepis*). The smallest loss occurred under *B. alba* and the largest under *P. menziesii* and *L. leptolepis*.

In 1951, at 0-5 cm, the range of extractable phosphorus contents was 1.15 (*Pseudotsuga menziesii*) to 2.94 (*Larix leptolepis*). The only significant change was a gain under *P. menziesii*. At 5-10 cm, the range was 1.32 (*Alnus incana*) to 3.37 (*Pinus nigra*). There were no significant changes at this depth. At 15-20 cm, the 1951 range was 2.35 (*P. menziesii*) to 4.09 (*P. nigra*), and there were significant decreases under *P. nigra* and *L. leptolepis*.

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. Comparisons of the orders of the species plots at the various depths are not helpful as they have different important variables, and they are not comparable with those at Bedgebury and Abbotswood.

Taking the results of the principal component analyses and the analysis of variance together, the main changes at West Tofts from 1951 to 1974 are summarized in Table 8. It is difficult to put the species in order of the intensity of leaching of the soils under them. Soil under *Pinus nigra* showed no significant change in pH down to 20 cm, although there was a significant decrease in extractable calcium at 5-10 cm, 15-20 cm, and 25-30 cm. No other species had significant losses at those depths. At 0-5 cm and 5-10 cm, *P. nigra* had the smallest decrease in extractable magnesium. Bonneau *et al.* (1979) found that on a sandy site *P. nigra* 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. Results obtained from Bedgebury and Abbotswood (Howard & Howard 1984a, b, c) were not consistent with the reputation of *P. nigra* for accelerating soil acidification and leaching of bases.

Soil under *Alnus incana* and *Larix leptolepis* showed a significant decrease in pH (1.7 units) at 0-5 cm, and a significant decrease in extractable calcium. Franklin *et al.* (1968) found that soil under *A. rubra* had lower calcium and magnesium contents than under *Pseudotsuga menziesii*, and attributed this to leaching of bases under alder associated with nitrogen fixation and nitrate production. Duchaufour and Bonneau (1961) found losses of calcium, potassium, and magnesium and a decrease in pH of 0.5 unit, at 0-10 cm under *P. menziesii* compared with soil under oak-hornbeam. 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-Svendsen & 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.

Alnus incana, *Pinus nigra*, and *Betula alba* all showed significant decreases in total calcium in the L and F/H layers which, if it is not simply due to spatial variation between the 2 years' samplings, means a reduction in the return of nutrients to the soil surface and suggests a trend towards a decrease in extractable calcium in the upper horizons, unless it can be replaced by weathering. If this is so, it is unusual that it should happen under *B. alba* as birch species are usually considered to be good at returning bases, especially calcium, in their litter.

Anderson (1950) considered all the species studied at West Tofts, except *Pinus nigra* , to be valuable as soil improvers.

The only tree species in common at Abbotswood and West Tofts is *Pinus nigra* (Howard & Howard 1984a). The data for 0-5 cm under *P. nigra* and *Pseudotsuga menziesii* which both occur at West Tofts and Bedgebury are given in Table 7. The pH at West Tofts was about 1 unit higher than at Bedgebury under both species in both years. Loss-on-ignition, total nitrogen and extractable sodium were 3 to 7 times lower at West Tofts than at Bedgebury. Under *P. menziesii* extractable potassium was 5 times lower at West Tofts than at Bedgebury but under *P. nigra* it was 9 to 11 times lower and there was a significant decrease between years at Bedgebury. At West Tofts extractable calcium was lower under both species in 1951 but higher in 1974 following increases at West Tofts but significant decreases at Bedgebury. Extractable magnesium was up to 5 times lower at West Tofts than at Bedgebury and there were significant decreases at both sites under both species between years. Extractable phosphorus was 3 to 5 times greater at West Tofts than at Bedgebury and the only significant change between years was an increase under *P. menziesii* at West Tofts.

It seems clear that different tree species have different effects on soils and that for a given species the effects may depend upon 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) *Alnus incana* L and F/H layers had the greatest total nitrogen contents in both years, although in the F/H layer it was not significantly different from that of *Larix leptolepis*. Between 1951 and 1974 there were significant increases in total nitrogen content in the L layers under all species, and in the F/H layers under all species except *Betula alba*. The ranges were similar in both years, but the maximum and minimum values were greater in 1974.

ii) *Betula alba* L and F/H layers had the greatest total potassium, calcium, magnesium, and phosphorus contents in both years, although in 1974 they were not always significantly greater than under any other species.

iii) The range of total potassium and magnesium contents in the L layers narrowed from 1951 to 1974, due chiefly to significant decreases under *Betula alba* and *Alnus incana*. There was also a narrowing in the range of L layer total phosphorus contents, due to a significant decrease under *B. alba* and a non-significant increase under *Pinus nigra*.

iv) From 1951 to 1974 there were significant decreases in L and F/H layer total calcium content under *Betula alba*, *Alnus incana*, and *Pinus nigra*, and in the F/H layer under *Pseudotsuga menziesii*.

v) Between 1951 and 1974 there was a significant decrease in pH in soil down to 20 cm depth under *Alnus incana*, and at 0-5 cm under *Larix leptolepis*. In 1974 soil under *A. incana* had the lowest pH at all depths except 65-70 cm, although only at 5-10 cm was it significantly different from soil under any other species. In 1974 soil under *P. nigra* was the least acid at all depths except 0-5 cm, although its pH was not significantly greater than that of soil under some other species.

vi) Soil at 0-5 cm and 5-10 cm depth under *Alnus incana* had the greatest loss-on-ignition in both years, and this is no doubt connected with its low pH as in (v). Nitrification under *Alnus* species, consequent upon nitrogen fixation, may be responsible for soil acidification and hence organic matter accumulation. In 1974, soil under *Pinus nigra* had the lowest loss-on-ignition at all depths down to 30 cm.

vii) In both 1951 and 1974, soil under *Alnus incana* had the greatest total nitrogen content at 0-5 cm and 5-10 cm. By contrast with Bedgebury and Abbotswood, there were few statistically significant decreases from 1951 to 1974.

viii) In 1974 at 0-5 cm depth, soil under *Betula alba* had the greatest (but not significantly) extractable potassium, calcium, and magnesium contents.

ix) The soils here, unlike those at Bedgebury and Abbotswood, showed few significant increases in extractable potassium or decreases in calcium.

x) Soils under all species showed significant decreases in extractable magnesium content down to 20 cm depth, and under all except *Betula alba* at 25-30 cm.

xi) As the first component is the axis of maximum variation, and any effect of species is likely to be most pronounced at the surface, the order of the species on the first component at 0-5 cm may be taken to indicate, in a general way, the relative effects of the species. Comparisons of the orders of the species at the various depths are not helpful as they have different important variables.

REFERENCES

ANDERSON, M.L. 1950. *The selection of tree species.* Edinburgh: Oliver & Boyd.

BOLLEN, W.B. & LU, K.C. 1968. Nitrogen transformations in soils beneath red alders and conifers. In: *Biology of alder*, edited by J.M. Trappe, J.F. Franklin, R.F. Tarrant & G.M. Hansen, 141-148. Portland, Oregon: USDA For. Serv. Pacific NW For. Range Exp. Station.

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.

BORMANN, B.T. & DeBELL, D.S. 1981. Nitrogen content and other soil properties related to age of red alder stands. J. Soil Sci. Soc. Am., 45, 428-432.

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

COLE, D.W. & JOHNSON, D. 1981. The cycling of elements within forests. In: Forest soils of the Douglas fir region, edited by P.E. Heilman, H.W. Anderson & D.M. Baumgartner, 185-198. Pullman: Washington State University.

CROCKER, R.L. & MAJOR, J. 1955. Soil development in relation to vegetation and surface age at Glacier Bay, Alaska. J. Ecol., 43, 427-448.

DUCHAUFOUR, P. & BONNEAU, M. 1961. Changes in a deciduous forest soil (terra fusca) after some thirty years under a *Pseudotsuga menziesii* plantation. Revue for. fr., 12, 793-799.

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

FRANKLIN, J.F., DYRNESS, C.T., MOORE, D.G. & TARRANT, R.F. 1968. Chemical soil properties under coastal Oregon stands of alder and conifers. In: *Biology of alder*, edited by J.M. Trappe, J.F. Franklin, R.F. Tarrant & G.M. Hansen, 157-172. Portland, Oregon: Pacific Northwest Forest and Range Exp. Stn.

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.

HOWARD, P.J.A. & HOWARD, D.M. 1984c. Effects of trees on soil properties, a resampling of J.D. Ovington's plots at Abbotswood. (Merlewood research and development paper no. 101). 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.

SCHEFFÉ, 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.

ACKNOWLEDGEMENTS

We thank the Forestry Commission, and especially Mark Anderson, for their co-operation in this work. We are also grateful to Allan Nelson and Sarah Beattie of NERC Computing Service for producing the figures, to Merlewood Chemistry Section for performing the analyses, and to Malcolm Mountford for computing Fisher's randomization test.

Table 1. Ovington's sites resampled in 1974 at West Tofts, Norfolk (Thetford Chase)

Species	Planted
Pseudotsuga menziesii (Mirb.) Franco	1930
Pinus nigra var *maritima* (Ait.) Melv.	1930
Larix leptolepis (Sieb & Zucc.) Gord.	1930
Alnus incana (L.) Moench.	1930
Betula alba (nomen ambiguum)	1930

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

		Min.	Max.	Mean	S.D.	C.V.%
pH		4.23	8.47	7.39	1.06	14
LOI % OD		0.40	4.91	1.24	0.84	68
Total N % OD		0.01	0.16	0.03	0.03	104
Extractable	Na	0.10	3.50	1.04	0.65	62
"	K	0.50	3.30	1.33	0.58	44
"	Ca	26.10	2486.00	226.74	465.52	205
"	Mg	0.20	9.60	2.32	2.23	96
"	P	1.00	4.90	2.39	0.79	33

Extractables are given as mg/100 g OD soil

Table 3. Correlation half-matrix for West Tofts soil data (1951 plus 1974)

		pH	LOI	N	Na	K	Ca	Mg
pH		1						
LOI % OD		-.687***	1					
Total N % OD		-.711***	.943***	1				
Extractable	Na	.396**	-.152	-.196	1			
"	K	-.436***	.636***	.660***	-.076	1		
"	Ca	.267*	-.168	-.158	.856***	.115	1	
"	Mg	-.216	.455***	.287*	.441***	.426***	.458***	1
"	P	.432***	-.279*	-.287*	.393**	-.137	.364**	.108

Table 4. Eigenvalues of the correlation matrix of the West Tofts soil data (1951 plus 1974)

Component	Eigenvalue	Percentage of variability	
		Component	Cumulative
1	3.50	43.8	43.8
2	2.41	30.2	74.0
3	0.72	9.0	82.9
4	0.49	6.2	89.1
5	0.42	5.3	94.4
6	0.34	4.3	98.7
7	0.08	1.0	99.7
8	0.03	0.3	100.0

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

Variable		Eigenvector for component		
		1	2	3
pH		0.45*	0.04	0.12
LOI % OD		-0.49*	0.15	0.12
Total N % OD		-0.49*	0.11	0.16
Extractable	Na	0.23	0.53*	-0.24
"	K	-0.37*	0.25	0.20
"	Ca	0.18	0.55*	-0.24
"	Mg	-0.16	0.50*	-0.12
"	P	0.26	0.26	0.88*

*Absolute value greater than 0.75 times the largest absolute value

Table 6. The order of the West Tofts 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
High Ca, pH, P, Na	**High pH, Ca, Na, Mg, P Low LOI, N**	**High N, LOI, Ca, Mg**	**High Na, LOI, Mg Low P**	**High Mg, Ca, Na, P, K Low pH**
Betula alba	*Pinus nigra*	*Larix leptolepis*	*Pseudotsuga menziesii*	*Alnus incana*
Pseudotsuga menziesii	*Pseudotsuga menziessi*	*Pseudotsuga menziessi*	*Larix leptolepis*	*Larix leptolepis*
Larix leptolepis	*Larix leptolepis*	*Betula alba*	*Alnus incana*	*Pseudotsuga menziesii*
Pinus nigra	*Betula alba*	*Alnus incana*	*Betula alba*	*Pinus nigra*
Alnus incana	*Alnus incana*	*Pinus nigra*	*Pinus nigra*	*Betula alba*
Low Ca, pH, P, Na	**Low pH, Ca, Na, Mg, P High LOI, N**	**Low N, LOI, Ca, Mg**	**Low Na, LOI, Mg High P**	**Low Mg, Ca, Na, P, K High pH**

Table 7. Data for 0-5 cm soil under *Pseudotsuga menziesii* and *Pinus nigra* at Bedgebury and West Tofts, 1951 and 1974

	pH	LOI	N	Na	K	Ca	Mg	P
P. menziesii, 1951								
West Tofts	5.05	1.65	0.03	0.6	1.8	26.1	7.3	1.15
Bedgebury	4.16	9.72	0.22	2.9	9.2	32.2	7.9	0.35
P. menziesii, 1974								
West Tofts	5.28	1.98	0.06	0.8	1.81	58.4	1.1	2.44
Bedgebury	4.13	9.20	0.21	2.6	8.9	18.4	3.3	0.50
P. menziesii, change								
West Tofts	+0.23	+0.33	+0.03	+0.2	+0.01	+32.3	-6.2***	+1.29*
Bedgebury	-0.03	-0.52	-0.01	-0.3	-0.3	-13.8*	-4.6***	+0.15
P. nigra, 1951								
West Tofts	5.98	2.05	0.04	0.6	1.2	32.8	4.0	1.31
Bedgebury	4.43	9.54	0.25	2.6	12.7	53.4	9.7	0.24
P. nigra, 1974								
West Tofts	5.17	1.42	0.04	0.6	1.1	35.4	0.6	0.98
Bedgebury	4.24	9.60	0.20	2.0	9.7	15.9	3.0	0.40
P. nigra, change								
West Tofts	-0.81	-0.63	0	0	-0.1	+2.6	-3.4***	-0.33
Bedgebury	-0.19	+0.06	-0.05	-0.6	-3.0*	-37.5***	-6.7***	+0.16

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

	Alnus incana	*Larix leptolepis*	*Pinus nigra*	*Pseudotsuga menziesii*	*Betula alba*
L	↑N ↓K Ca Mg	↑N	↑N P ↓Ca Mg	↑N	↑N ↓K Ca Mg P
F/H	↑N ↓Ca	↑N	↑N ↓Na Ca	↑N ↓Ca	↓Na Ca
0-5 cm	↑N ↓pH Na Ca Mg	↓pH Ca Mg	↓Mg	↑P ↓Mg	↓Mg
5-10 cm	↓pH Mg Na	↓Na Mg	↓Na Ca Mg	↑N ↓Mg	↑N ↓Mg
15-20 cm	↓pH Mg	↓Mg P	↓N Na Ca Mg P	↓Mg	↓Mg
25-30 cm	↓N Mg	↓Na Mg	↑pH ↓Na Ca Mg	↓Mg	↑K ↓Na

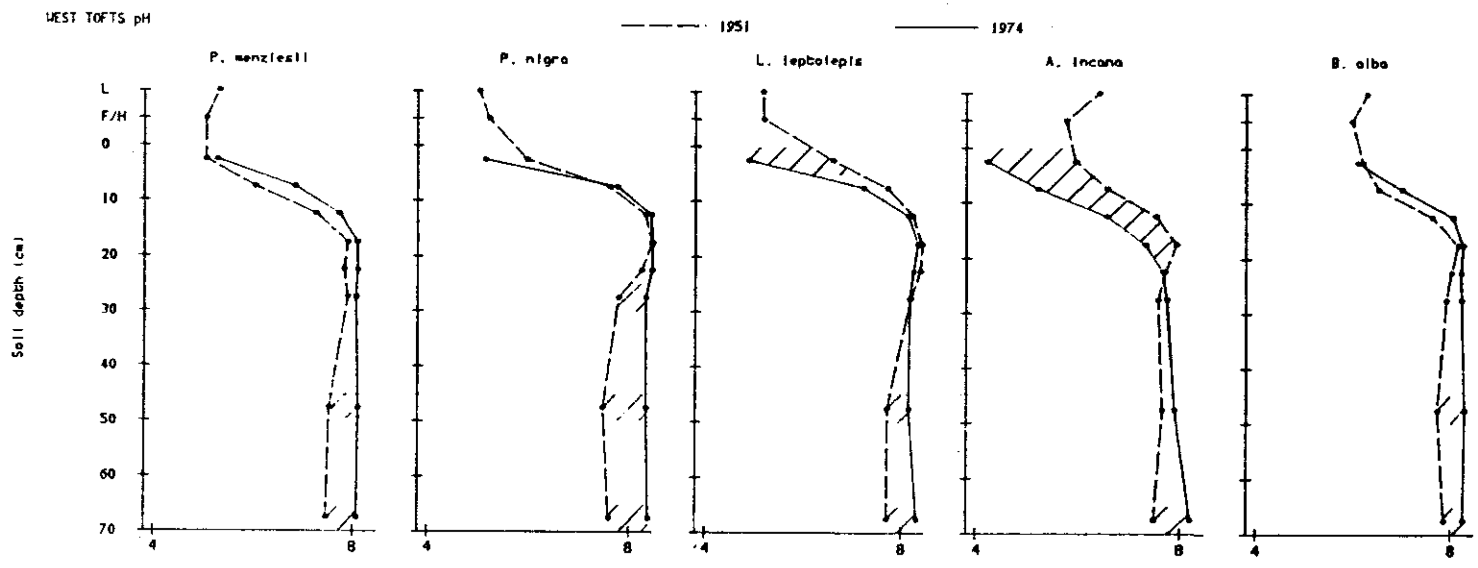

Figure 1. pH at different depths under different species in 1951 and 1974. Differences significant at $p < 0.05$ are hatched.

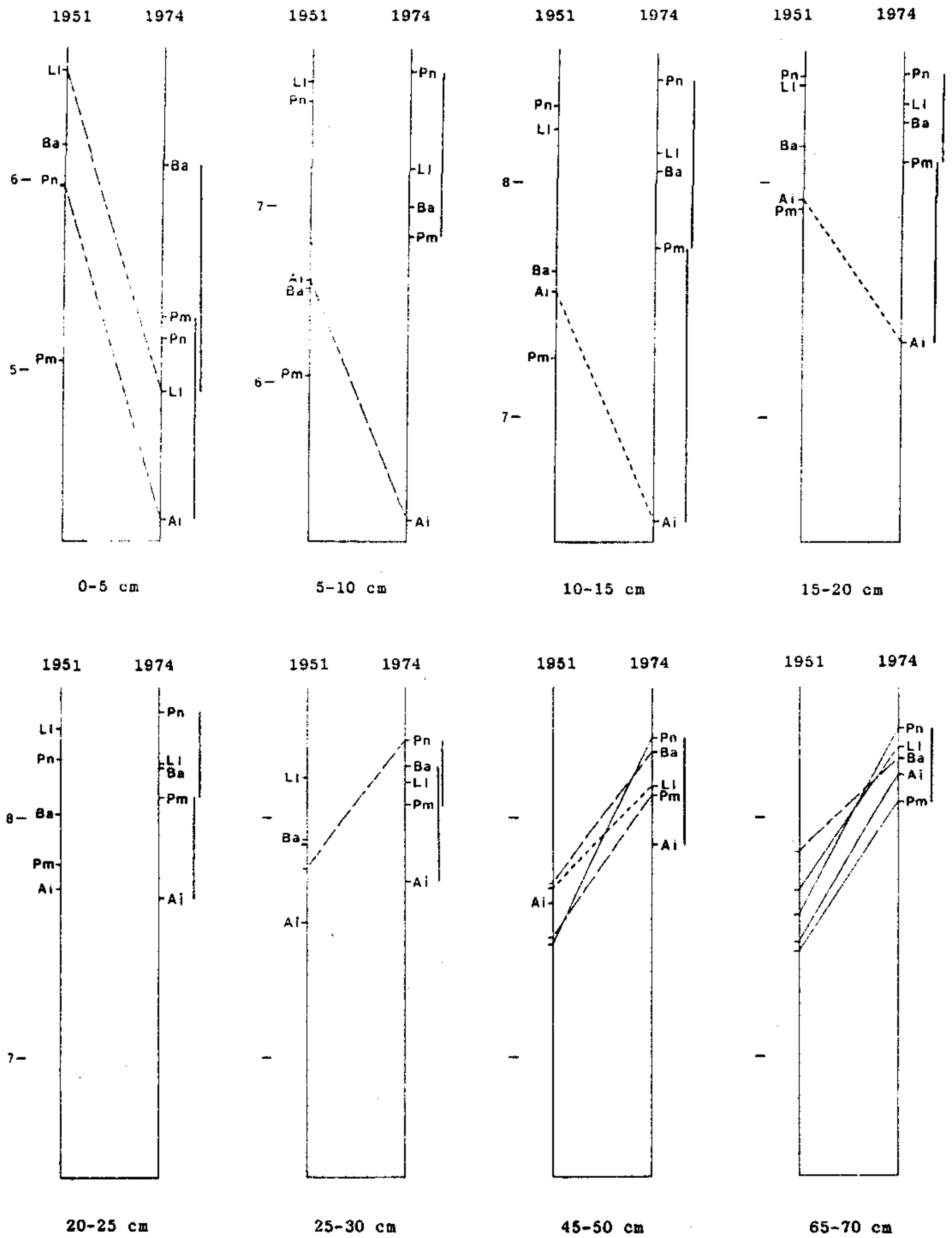

Figure 2. Changes in pH between 1951 and 1974 under different species (names abbreviated) at different depths, significant at $p < 0.05$ - - - -, $p < 0.01$ —— ——, $p < 0.001$ ———. The vertical lines link species not significantly different in 1974 (Tukey's HSD $p < 0.05$).

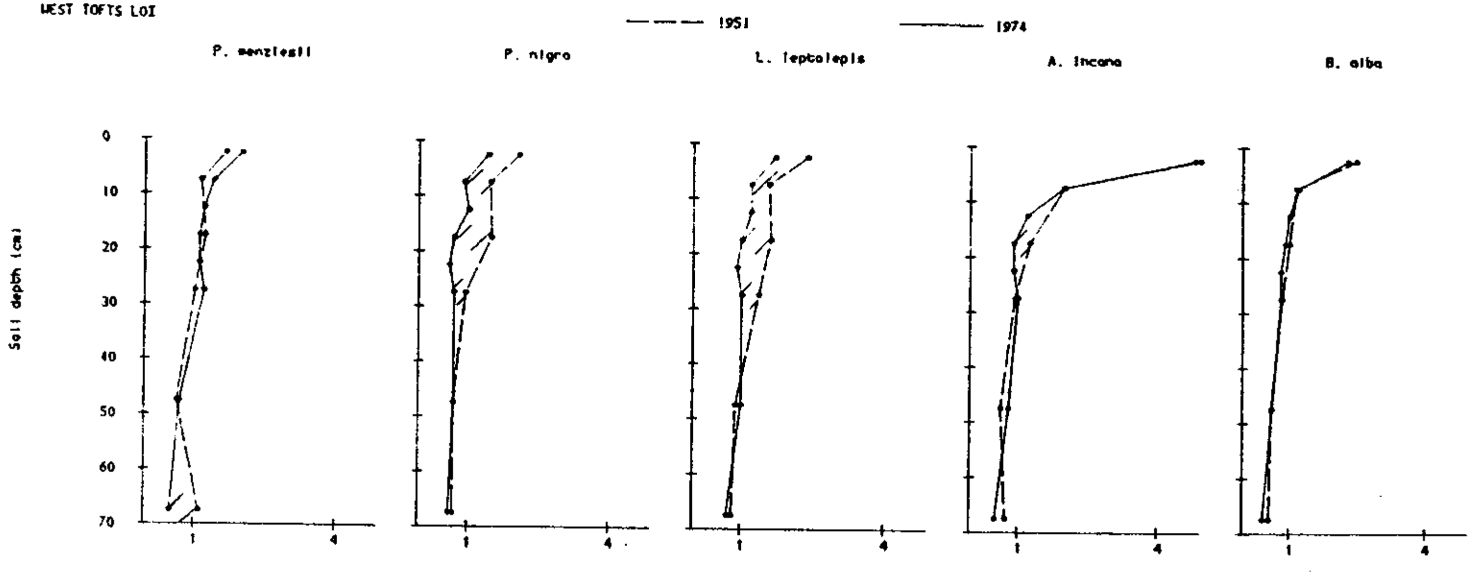

Figure 3. Loss-on-ignition at different depths under different species in 1951 and 1974. Differences significant at $p < 0.05$ are hatched.

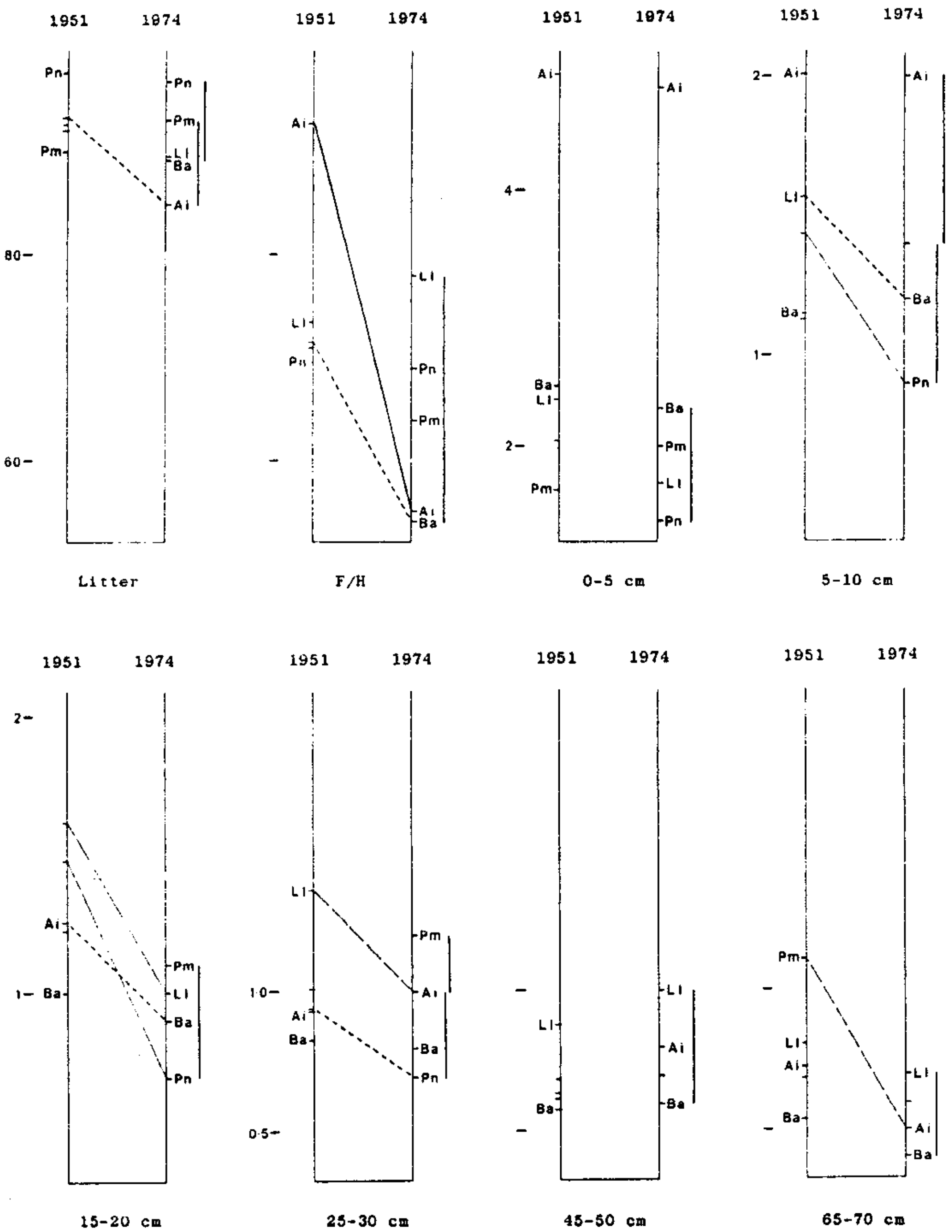

Figure 4. Changes in loss-on-ignition between 1951 and 1974 under different species (names abbreviated) at different depths, significant at $p < 0.05$ - - - -, $p < 0.01$ — —, $p < 0.001$ ——. The vertical lines link species not significantly different in 1974 (Tukey's HSD $p < 0.05$).

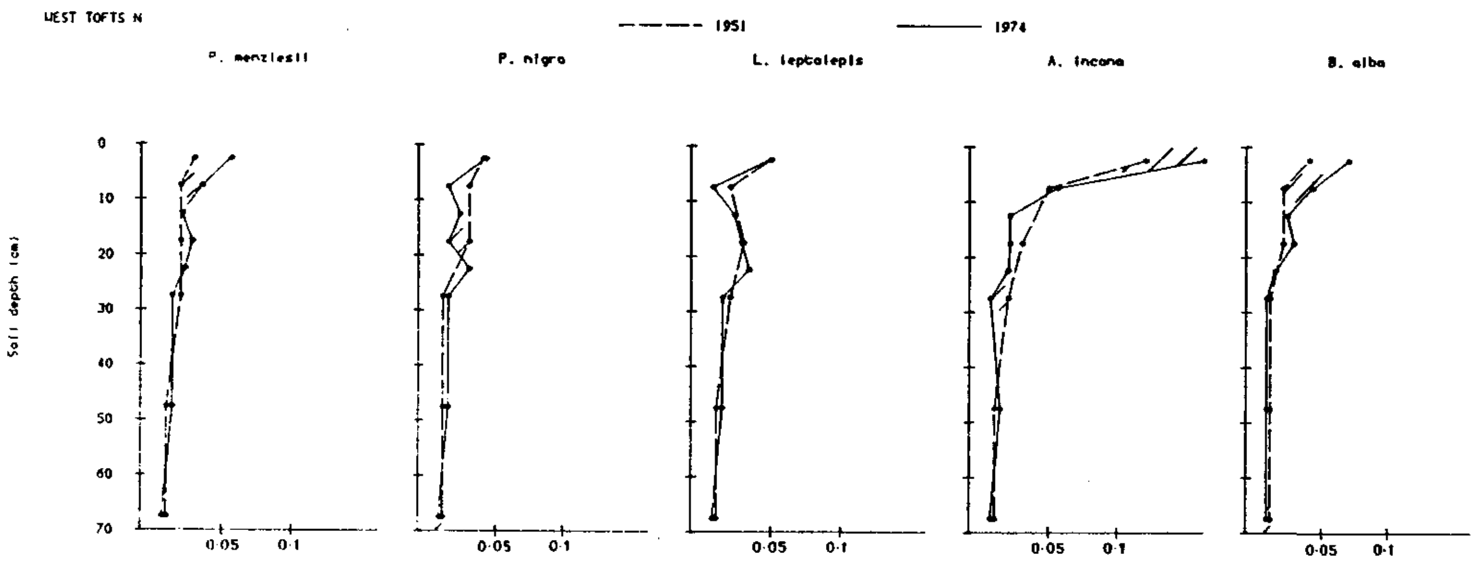

Figure 5. Total nitrogen at different depths under different species in 1951 and 1974. Differences significant at $p < 0.05$ are hatched.

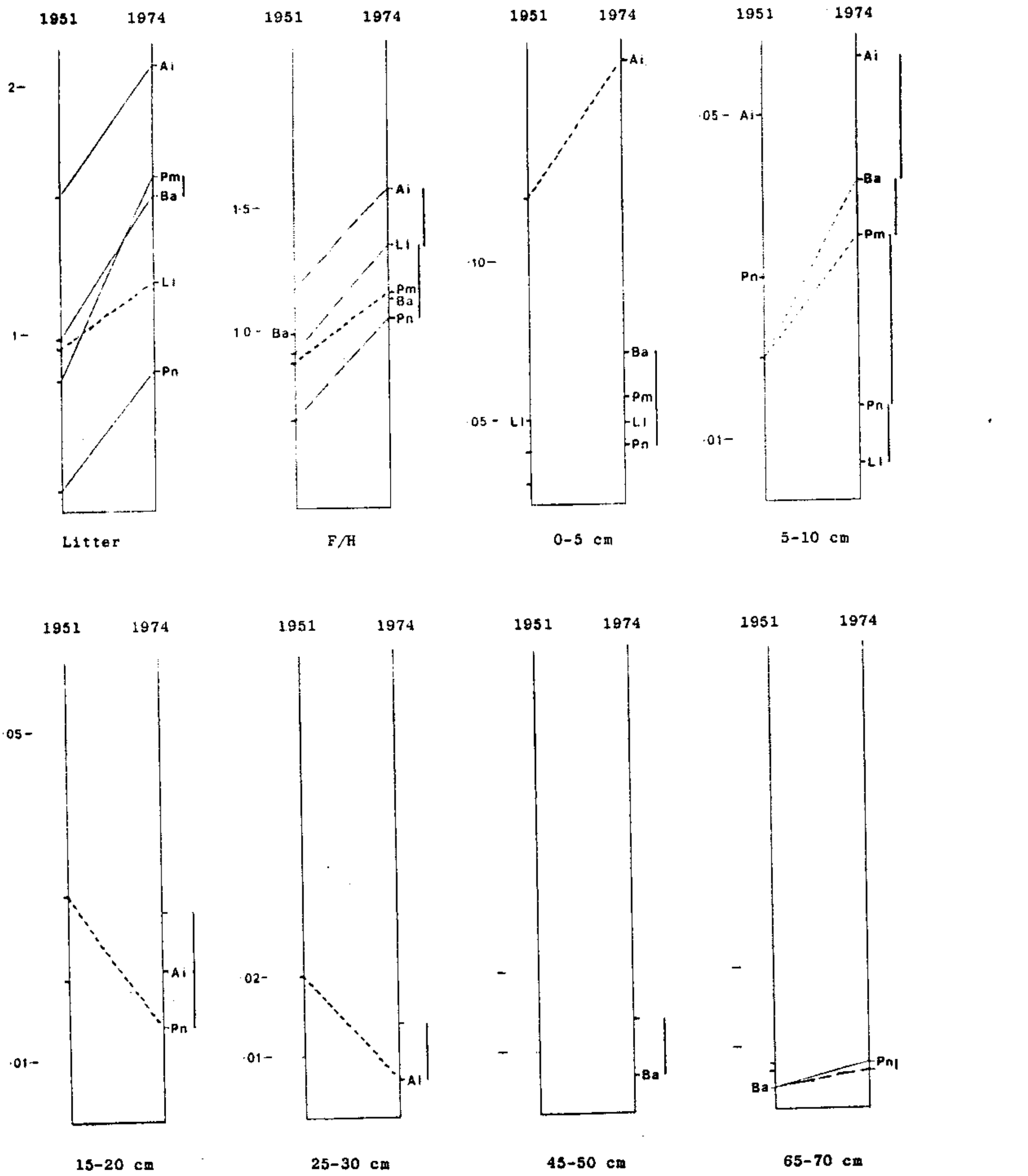

Figure 6. Changes in total nitrogen between 1951 and 1974 under different species (names abbreviated) at different depths, significant at $p < 0.05$ - - - -, $p < 0.01$ —— ——, $p < 0.001$ ————. The vertical lines link species not significantly different in 1974 (Tukey's HSD $p < 0.05$).

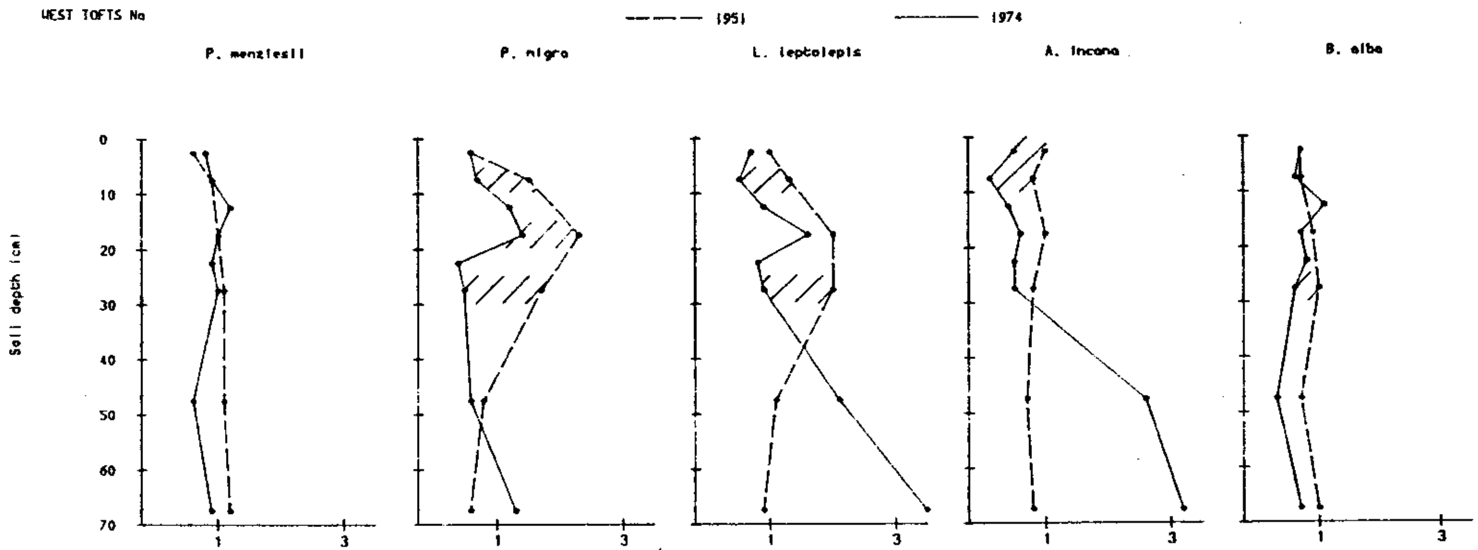

Figure 7. Extractable sodium at different depths under different species in 1951 and 1974. Differences significant at $p < 0.05$ are hatched.

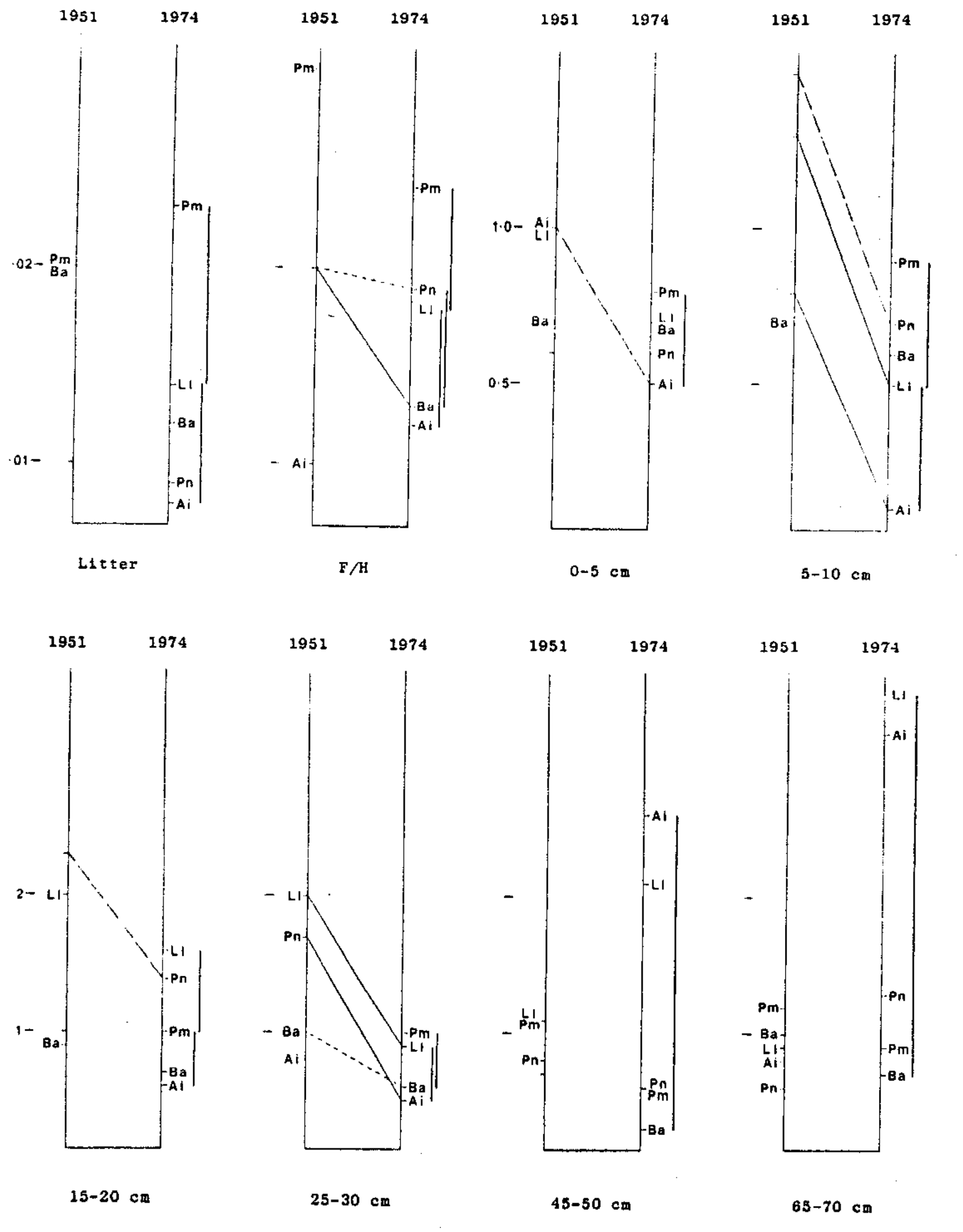

Figure 8. Changes in sodium between 1951 and 1974 under different species (names abbreviated) at different depths, significant at $p < 0.05$ - - - -, $p < 0.01$ — —, $p < 0.001$ ——. The vertical lines link species not significantly different in 1974 (Tukey's HSD $p < 0.05$).

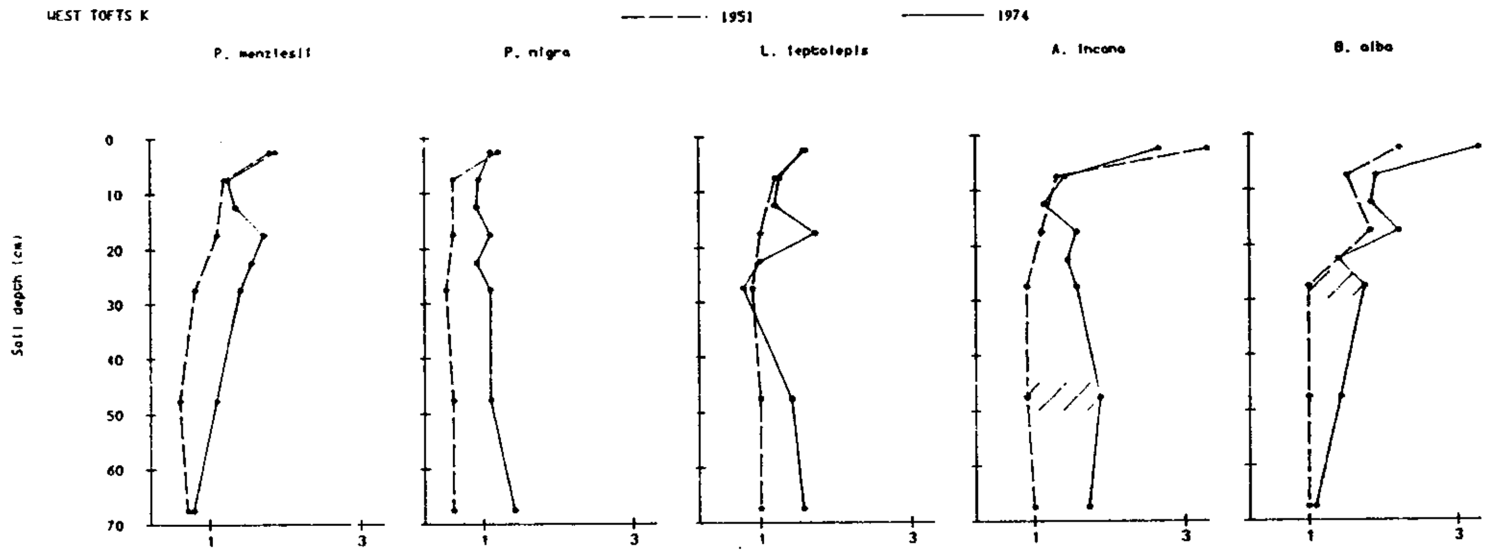

Figure 9. Extractable potassium at different depths under different species in 1951 and 1974. Differences significant at $p < 0.05$ are hatched.

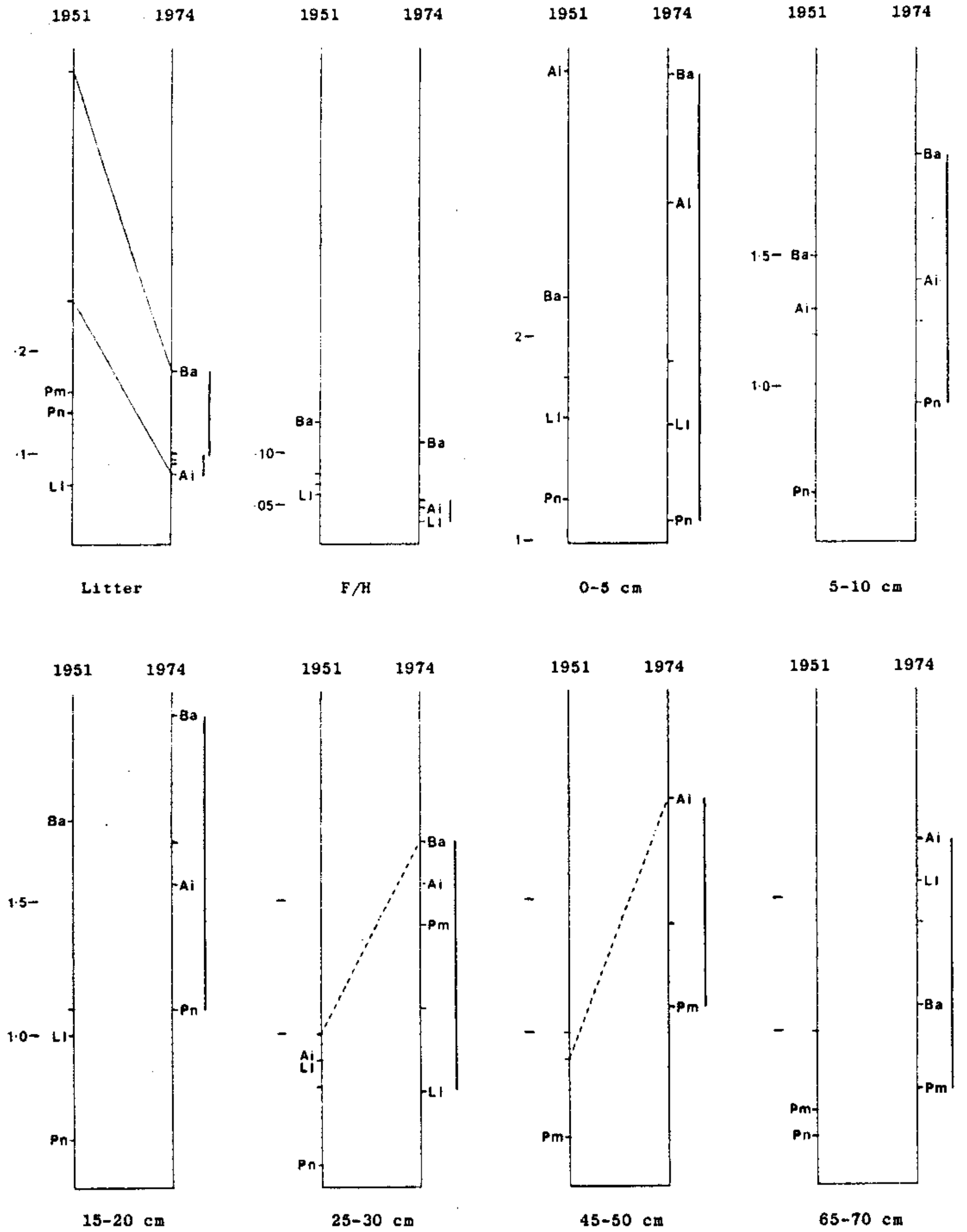

Figure 10. Changes in potassium between 1951 and 1974 under different species (names abbreviated) at different depths, significant at $p < 0.05$ - - - -, $p < 0.01$ — —, $p < 0.001$ ——. The vertical lines link species not significantly different in 1974 (Tukey's HSD $p < 0.05$).

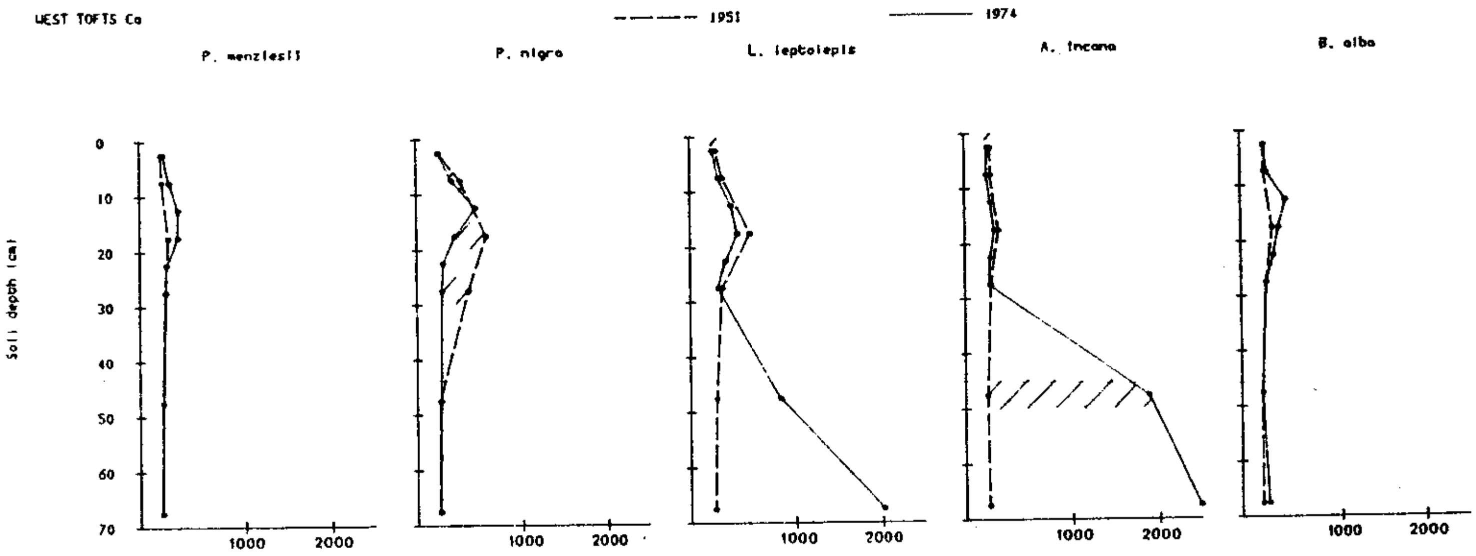

Figure 11. Extractable calcium at different depths under different species in 1951 and 1974. Differences significant at $p < 0.05$ are hatched.

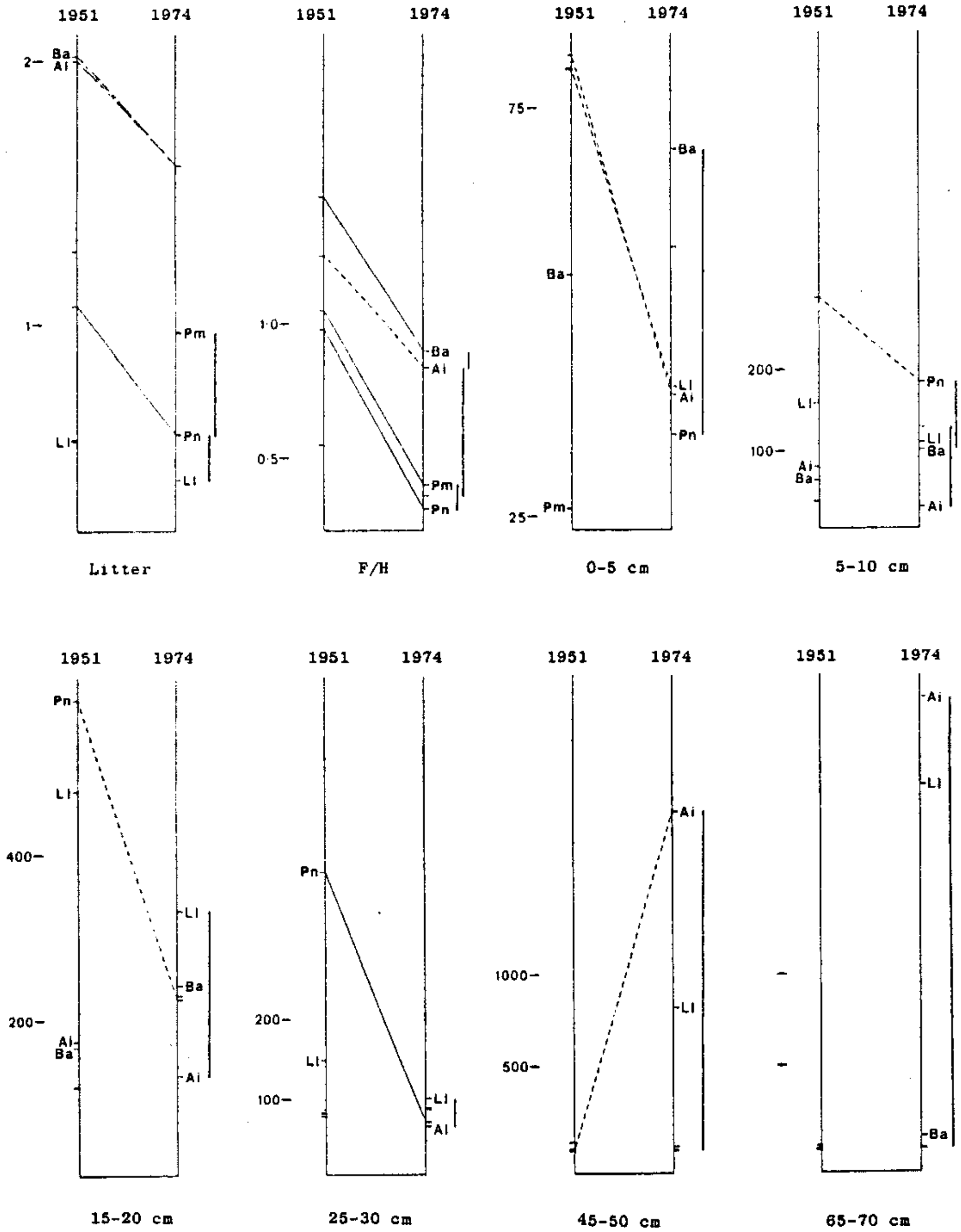

Figure 12. Changes in calcium between 1951 and 1974 under different species (names abbreviated) at different depths, significant at $p < 0.05$ - - - -, $p < 0.01$ — —, $p < 0.001$ ——. The vertical lines link species not significantly different in 1974 (Tukey's HSD $p < 0.05$).

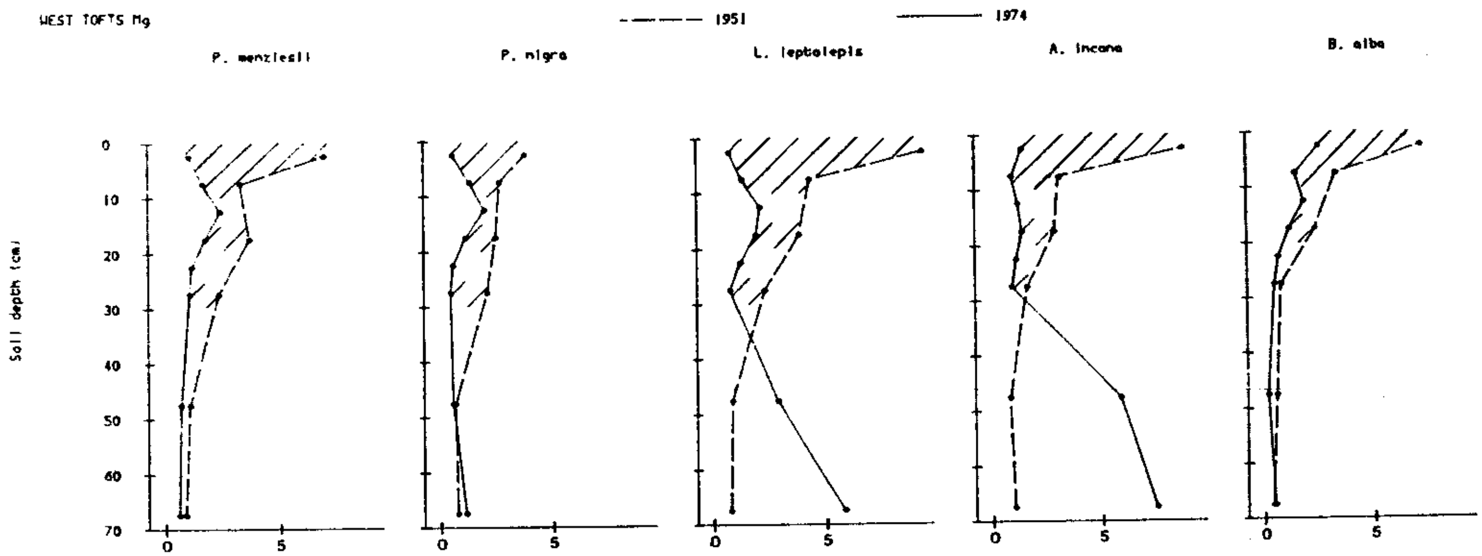

Figure 13. Extractable magnesium at different depths under different species in 1951 and 1974. Differences significant at $p < 0.05$ are hatched.

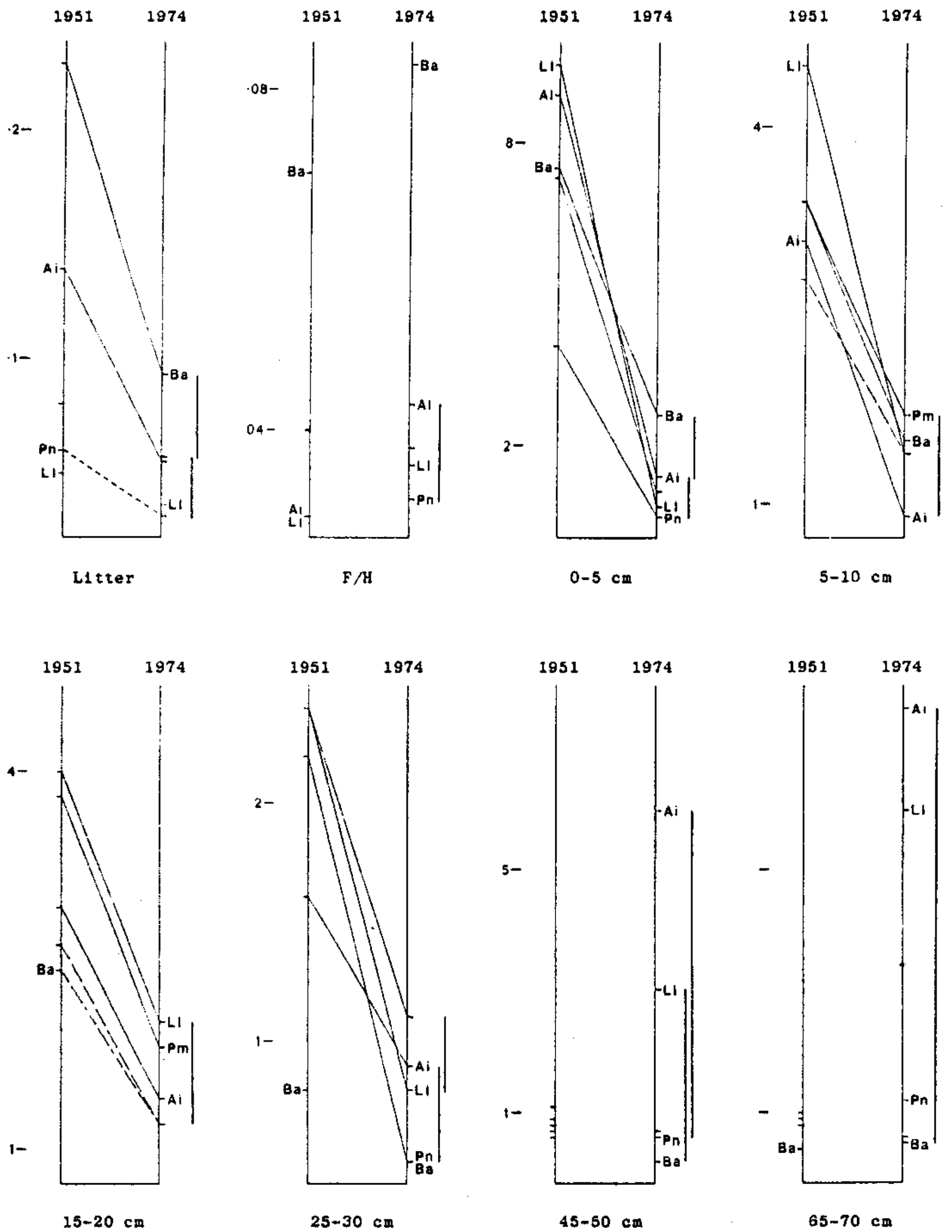

Figure 14. Changes in magnesium between 1951 and 1974 under different species (names abbreviated) at different depths, significant at $p < 0.05$ - - - -, $p < 0.01$ — —, $p < 0.001$ ——. The vertical lines link species not significantly different in 1974 (Tukey's HSD $p < 0.05$).

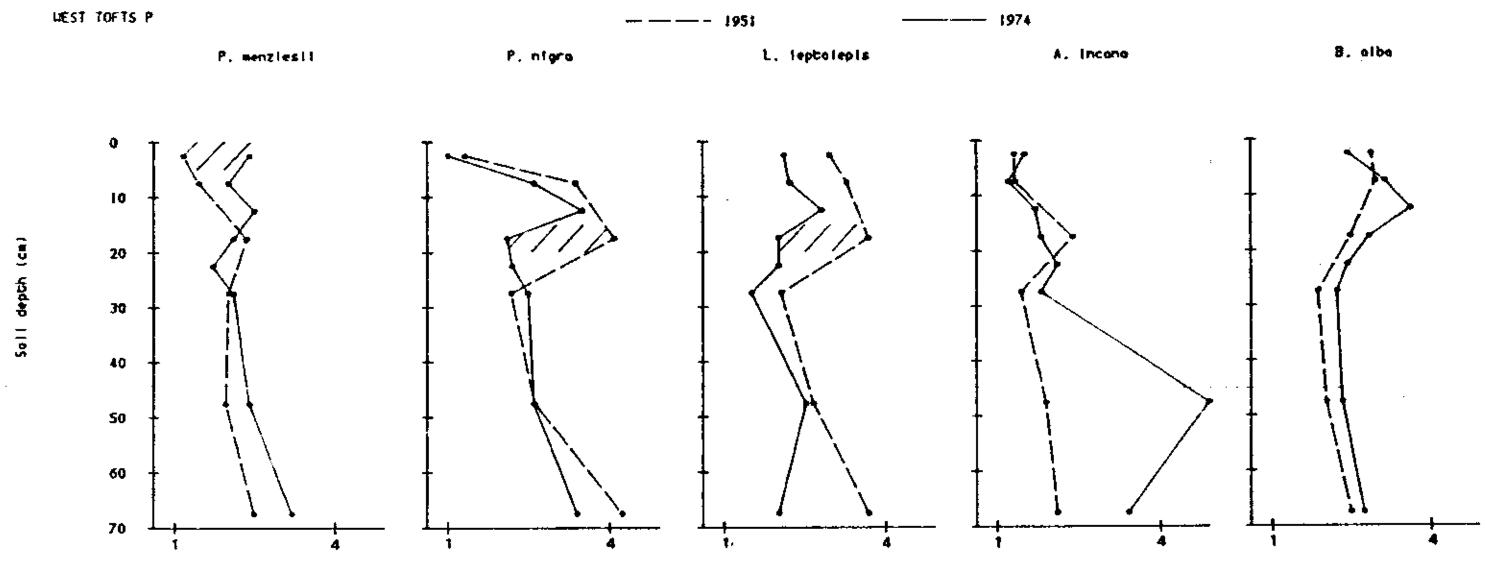

Figure 15. Extractable phosphorus at different depths under different species in 1951 and 1974. Differences significant at $p < 0.05$ are hatched.

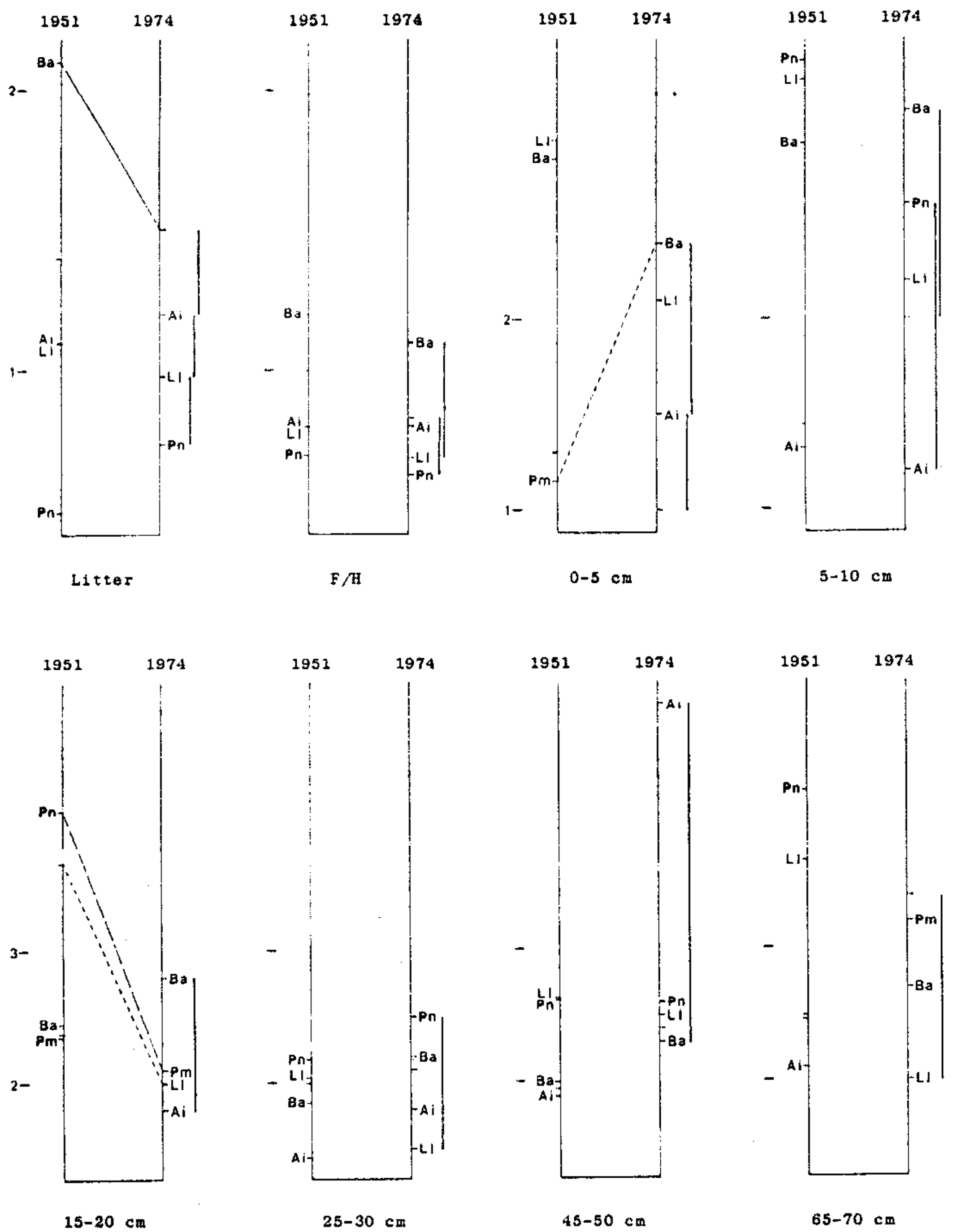

Figure 16. Changes in phosphorus between 1951 and 1974 under different species (names abbreviated) at different depths, significant at $p < 0.05$ - - - -, $p < 0.01$ — —, $p < 0.001$ ——. The vertical lines link species not significantly different in 1974 (Tukey's HSD $p < 0.05$).

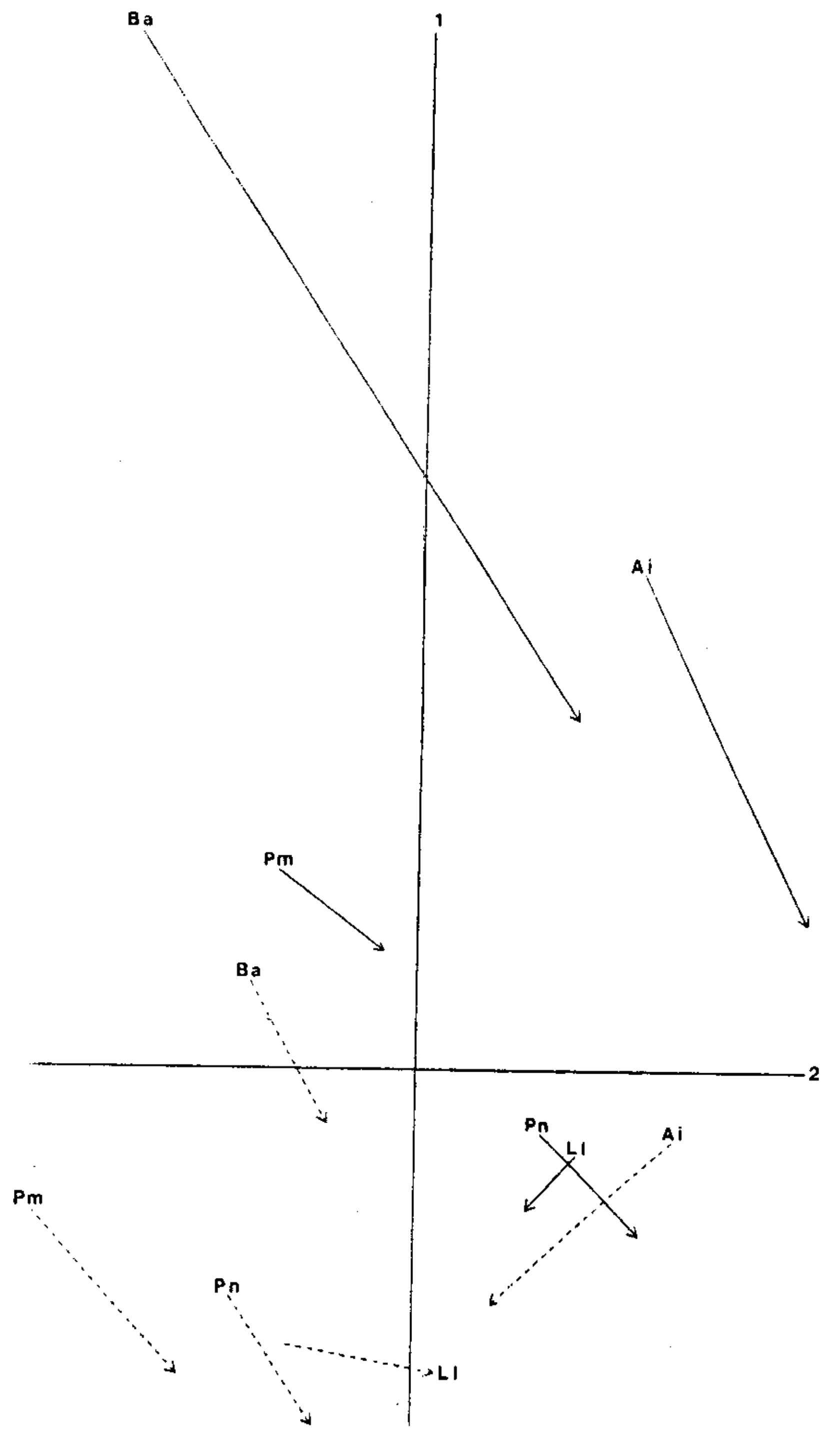

Figure 17. First and second components of the correlation matrix for the L (——) and F/H (- - - -) layers under different species (names abbreviated), showing changes from 1951 to 1974.

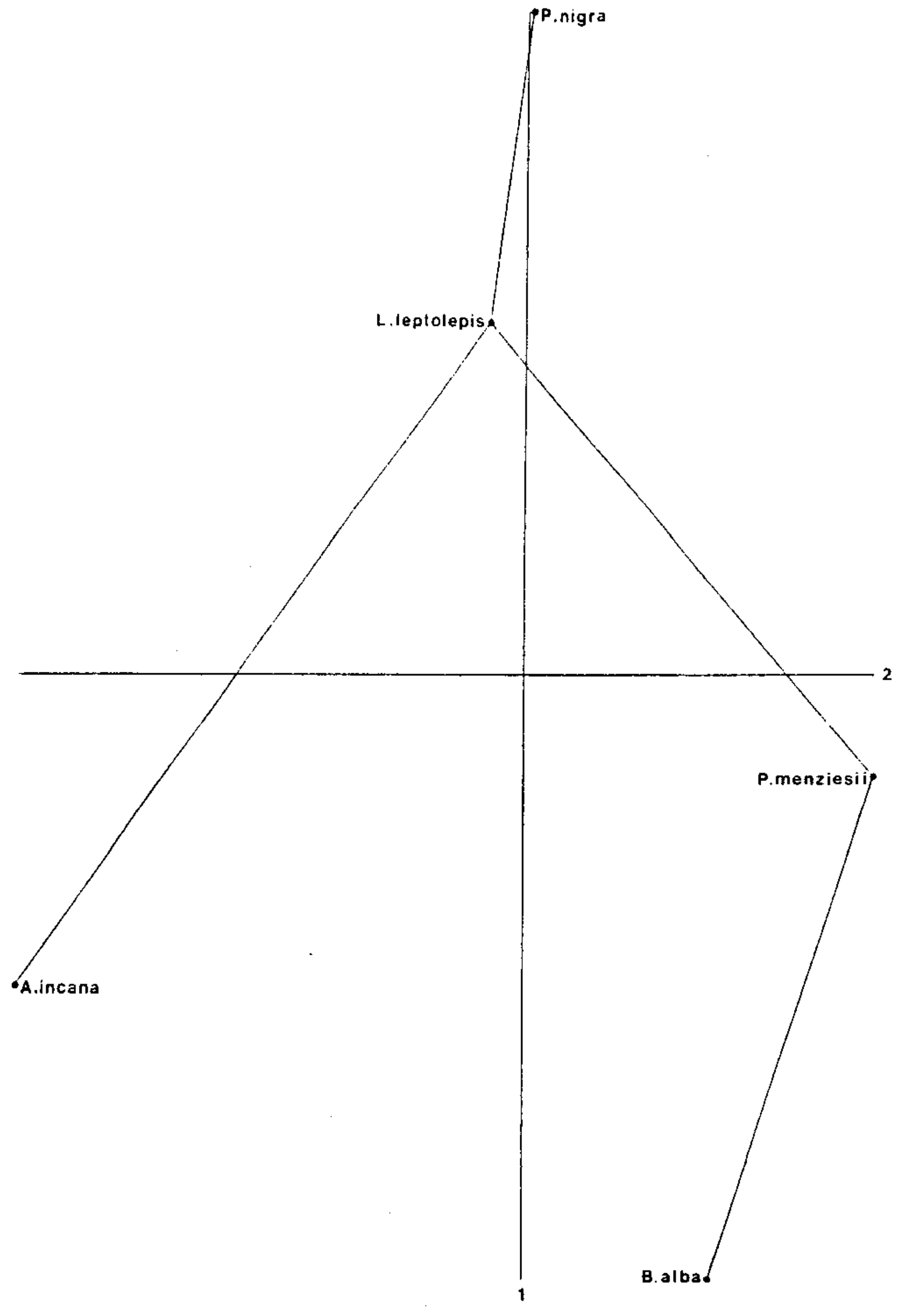

Figure 18. First and second components of the correlation matrix for the 1974 L layers under different species with the minimum spanning tree in 3 dimensions superimposed.

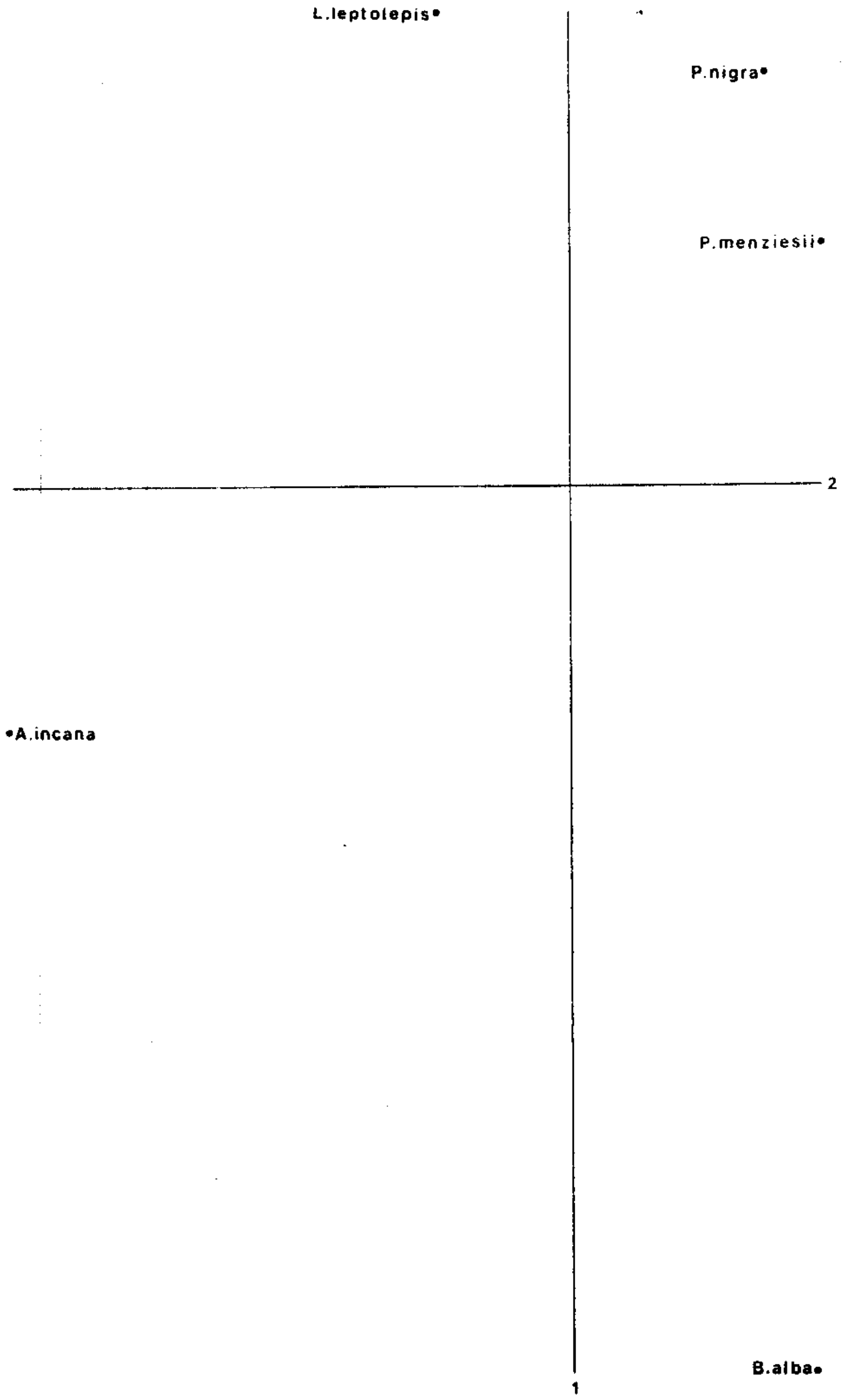

Figure 19. First and second components of the correlation matrix for the 1974 F/H layers under different species.

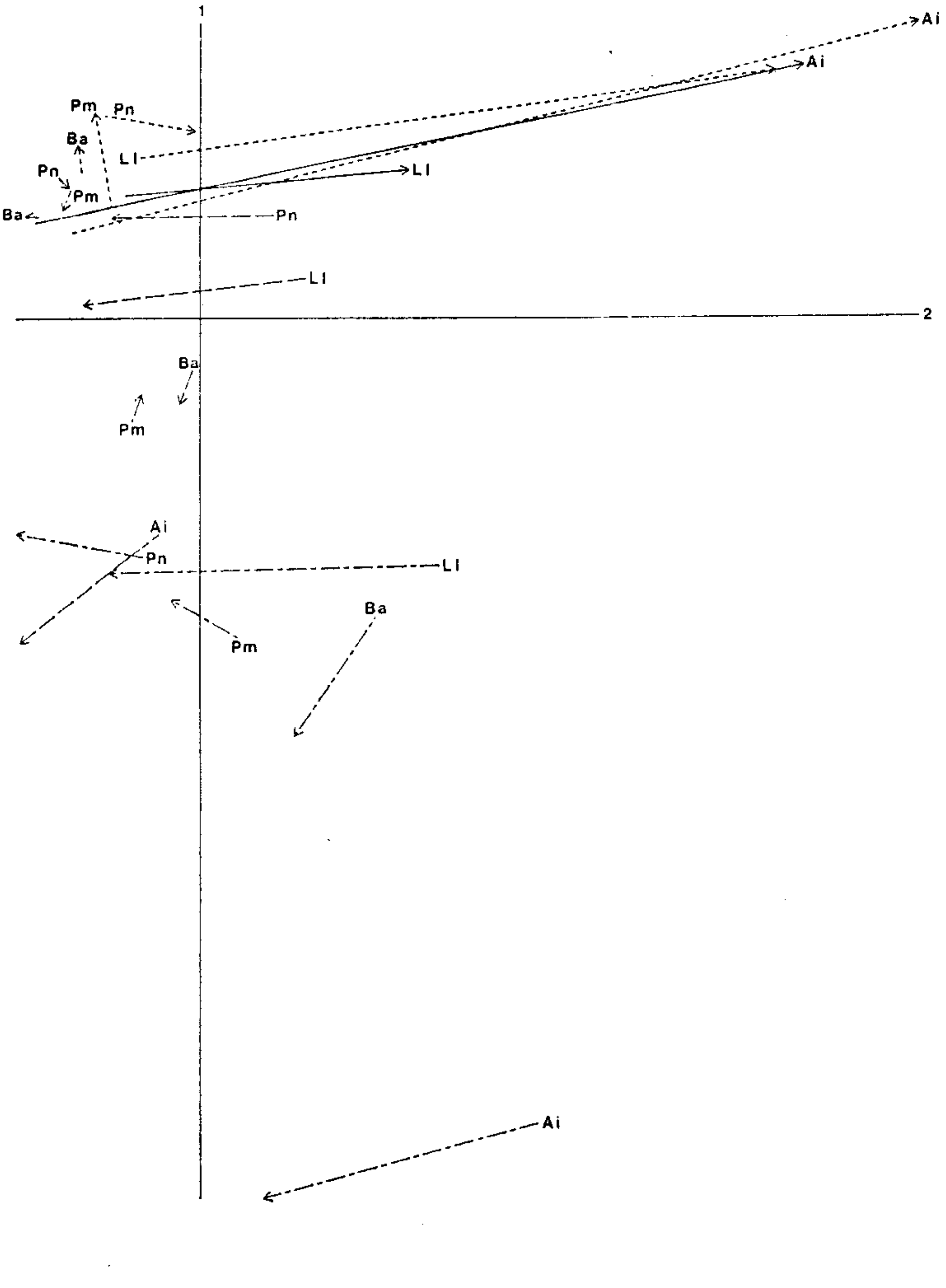

Figure 20. First and second components of the correlation matrix for the soils under different species (names abbreviated), showing changes from 1951 to 1974. — - — 0-5 cm, — — 5-10 cm, —— 45-50 cm, - - - - 65-70 cm (15-20 cm and 25-30 cm omitted for clarity).

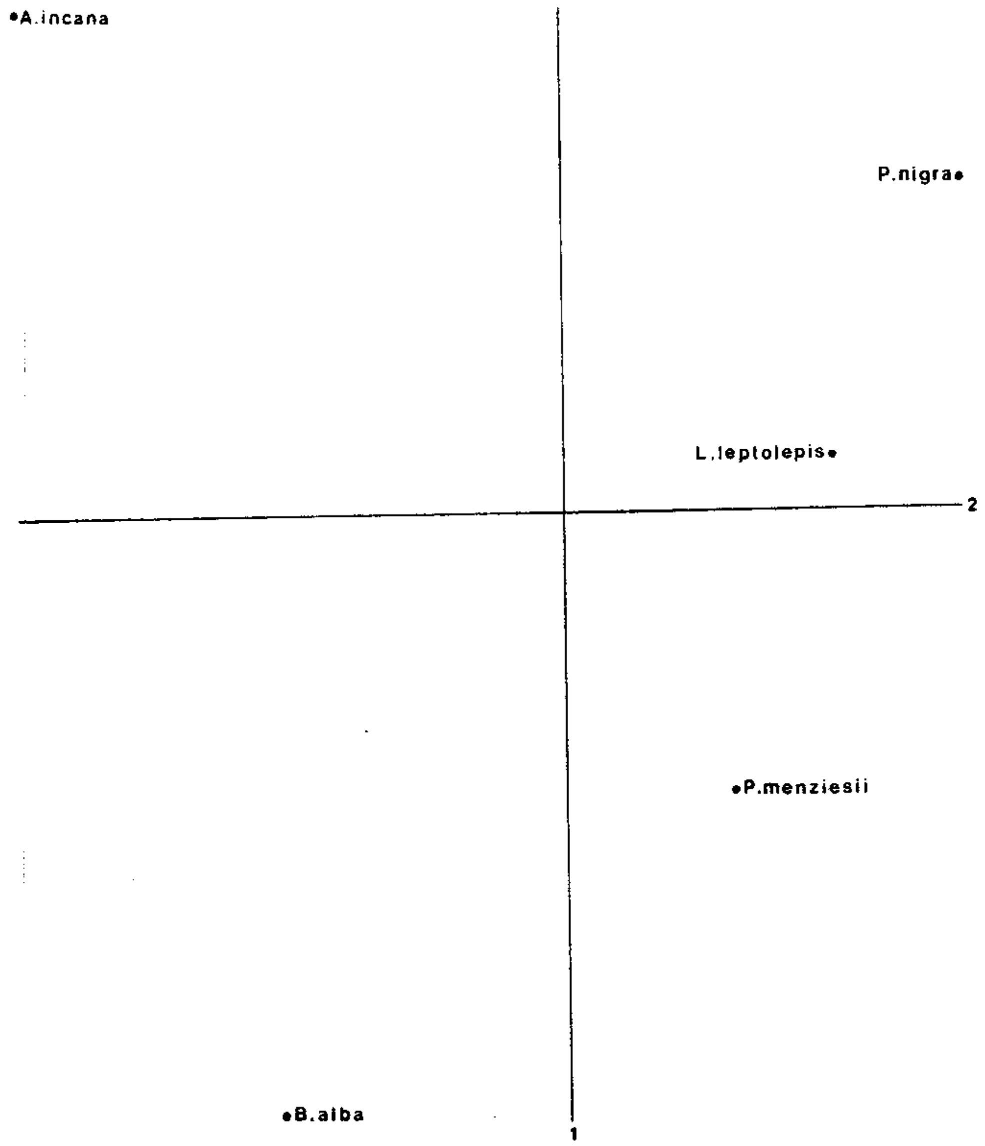

Figure 21. First and second components of the correlation matrix for the 0-5 cm soil under different species in 1974.

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		*P. menziesii*	*P. nigra*	*L. leptolepis*	*A. incana*	*B. alba*
LOI	L	92.9	96.6	89.4	84.9	89.0
	F/H	64.0	69.0	78.0	55.0	54.0
Total N	L	1.86	0.96	1.37	2.36	1.77
	F/H	1.31	1.19	1.53	1.79	1.28
Total Na	L	0.023	0.009	0.014	0.008	0.012
	F/H	0.024	0.019	0.018	0.012	0.013
Total K	L	0.100	0.090	0.094	0.080	0.180
	F/H	0.055	0.054	0.034	0.047	0.110
Total Ca	L	0.97	0.59	0.42	1.60	1.60
	F/H	0.40	0.31	0.36	0.84	0.90
Total Mg	L	0.057	0.031	0.036	0.055	0.093
	F/H	0.038	0.032	0.036	0.043	0.083
Total P	L	0.150	0.074	0.098	0.120	0.150
	F/H	0.083	0.063	0.069	0.080	0.110

Variable	Sampling depth (cm)					
pH	0- 5	4.97	4.86	4.58	3.92	5.77
	5-10	6.52	7.46	6.91	4.93	6.69
	10-15	7.41	8.13	7.82	6.26	7.74
	15-20	7.78	8.16	8.03	7.01	7.95
	20-25	7.78	8.15	7.93	7.36	7.91
	25-30	7.75	8.03	7.85	7.43	7.92
	45-50	7.79	8.04	7.83	7.58	7.98
	65-70	7.76	8.08	8.00	7.88	7.95
LOI	0- 5	2.0	1.4	1.7	4.8	2.3
% OD	5-10	1.4	0.9	1.2	2.0	1.2
	10-15	1.2	1.0	1.2	1.2	1.0
	15-20	1.1	0.7	1.0	0.9	0.9
	20-25	1.1	0.6	0.9	0.9	0.8
	25-30	1.2	0.7	1.0	1.0	0.8
	45-50	0.7	0.7	1.0	0.8	0.6
	65-70	0.5	0.6	0.7	0.5	0.4
Total N	0- 5	0.08	0.06	0.07	0.23	0.10
% OD	5-10	0.05	0.02	0.01	0.08	0.06
	10-15	0.03	0.03	0.03	0.03	0.03
	15-20	0.04	0.02	0.04	0.03	0.04
	20-25	0.03	0.04	0.05	0.03	0.02
	25-30	0.02	0.02	0.02	0.01	0.01
	45-50	0.02	0.02	0.02	0.02	0.01
	65-70	0.01	0.01	0.01	0.01	0.01

1974 data

Variable	Sampling depth (cm)	*P. menziesii*	*P. nigra*	*L. leptolepis*	*A. incana*	*B. alba*
Extract-able Na	0- 5	0.8	0.6	0.7	0.5	0.7
	5-10	0.9	0.7	0.5	0.1	0.6
	10-15	1.2	1.2	0.9	0.4	1.1
	15-20	1.0	1.4	1.6	0.6	0.7
	20-25	0.9	0.4	0.8	0.5	0.8
	25-30	1.0	0.5	0.9	0.5	0.6
	45-50	0.6	0.6	2.1	2.6	0.3
	65-70	0.9	1.3	3.5	3.2	0.7
Extract-able K	0- 5	1.2	0.7	1.0	1.7	2.1
	5-10	0.8	0.6	0.8	0.9	1.2
	10-15	0.9	0.6	0.8	0.7	1.2
	15-20	1.1	0.7	1.1	1.0	1.4
	20-25	1.0	0.6	0.6	0.9	0.9
	25-30	0.9	0.7	0.5	1.0	1.1
	45-50	0.7	0.7	0.9	1.2	0.9
	65-70	0.5	0.9	1.0	1.1	0.7
Extract-able Ca	0- 5	58	35	41	40	70
	5-10	129	185	111	33	102
	10-15	235	468	256	81	328
	15-20	230	225	331	130	242
	20-25	95	85	191	76	177
	25-30	89	71	101	66	87
	45-50	57	58	825	1875	39
	65-70	40	44	2016	2486	111
Extract-able Mg	0- 5	1.1	0.6	0.8	1.4	2.6
	5-10	1.7	1.4	1.4	0.9	1.5
	10-15	2.5	2.1	2.2	1.2	1.9
	15-20	1.8	1.2	2.0	1.4	1.2
	20-25	1.2	0.6	1.3	1.1	0.7
	25-30	1.1	0.5	0.8	0.9	0.5
	45-50	0.7	0.6	3.0	6.0	0.2
	65-70	0.6	1.2	6.0	7.7	0.5
Extract-able P	0- 5	2.4	1.0	2.1	1.5	2.4
	5-10	2.0	2.6	2.2	1.2	3.1
	10-15	2.5	3.5	2.8	1.7	3.6
	15-20	2.1	2.1	2.0	1.8	2.8
	20-25	1.7	2.2	2.0	2.1	2.4
	25-30	2.1	2.5	1.5	1.8	2.2
	45-50	2.4	2.6	2.5	4.9	2.3
	65-70	3.2	3.4	2.0	3.4	2.7