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FIELD APPLICATION IN SPECIFIC ENVIRONMENTS

Temperate

Discrimination between the effects on soils of 4 tree species in pure and mixed stands using cotton strip assay

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1 *Summary*
Soil differences which are thought to have developed more than 20 years after planting under experimental stands of 4 different tree species, at Gisburn Forest, Lancashire, could not readily be detected by chemical analysis.

Cotton strip assay, however, indicated that there were clear between-species effects on soil biological activity. This method was also able to discriminate between the soils of a given tree species, according to whether or not it was grown in association with other tree species. The height growth of most of the tree species in mixture was improved, apparently through modification of soil nutrient availability, paralleled by the rate of decomposition of the cotton strips.

2 *Background*
It is generally agreed that soils are influenced by afforestation, and that different tree species are likely to have differing effects. Further, species in mixture may interact in their effects, both on each other and on the properties of the site. To obtain information on these points, a long-term afforestation experiment was established at Gisburn (in the Lancashire/Yorkshire border area of the west Pennines) in 1955. This experiment has enabled the effects on vegetation and soils of 4 tree species, both pure and mixed, to be monitored (Holmes & Lines 1956; Brown & Harrison 1983). The tree species planted consist of 2 conifers, Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*), and 2 deciduous hardwoods, oak (*Quercus petraea*) and alder (*Alnus glutinosa*). The mixed stands comprise all possible 2-species combinations. Each of the resulting 10 treatments was planted as a 0.2 ha plot in a randomized experiment with 3 replicate blocks.

The elevation of the experimental site ranged from 260 m to 290 m, with a mean annual rainfall of 1370 mm. Soils were surface water gleys, tending towards peaty gleys; the original vegetation consisted of a grazed fescue/bent-grass/mat-grass (*Festuca/Agrostis/Nardus*) sward similar to the poorest (Class 6) of Ball *et al.*'s (1981) rough pastures.

In attempting to measure changes in the soil and the effects of the different species, the question arose of which attributes should be assessed. Initially, emphasis was placed on chemistry, using standard soil analytical methods. Twenty years after planting the different stands, chemical analyses of the soils gave no consistent differences, even between the different monocultures, for most major nutrients (total nitrogen (N), extractable phosphorus (P), potassium (K) and magnesium (Mg)). Analytical methods developed for agricultural soils are not appropriate for distinguishing differences in the predominantly poor soils used for forestry. In such soils, the rate of nutrient cycling may be more important than the size of the nutrient pool (Harrison 1985), and Jacks' (1963) conclusion that the 'natural fertility of a soil is a biophysical rather that a physicochemical phenomenon' accords with this view. At Gisburn, there was evidence that, in soil biological terms, differences between the stands were developing at a relatively early stage in their life; for example, very different populations of higher fungi were evident in the different stands (Brown 1978). It was, therefore, concluded that a biological assessment of soil differences might be informative. Organic matter decomposition processes are regarded as important both in nutrient cycling and as precursors of soil chemical and pedological changes (Harrison 1985); therefore, some measure of decomposer activity was considered most relevant. Measurement of the decomposition of the different species of tree litter would be of very little value, as species differences in litter quality are confounded with the differences in site properties, developed in the different stands. A method which was integrative over a period, rather than instantaneous like most measurements of respiration, was desirable. A method that could assay the changes in properties which might have developed down the mineral soil profile, in addition to the forest floor, was also to be preferred. The cotton strip assay, providing an index of decomposer potential with a standard substrate, appeared very suitable.

3 *Monoculture comparisons*
Following a pilot study in the pure plots of one replicate block, a large-scale seasonal study of the 4 mono-

cultures of all 3 replicate blocks at Gisburn was undertaken. This work is described more fully elsewhere (Brown & Howson 1988), but can be summarized here. A discrete 12-week assay was repeated at 6-weekly intervals for a whole year. The pattern of tensile strength loss of cotton (CTSL) (averaged for whole strips) showed seasonal differences in decomposer activity, and between each of the 4 stands (Figure 1 in Brown & Howson 1988). Clear and significant differences between treatments were evident on 8 of the 9 occasions, and these were consistent between the 3 blocks. Although the interpretation of these differences may be open to argument (Howard 1988), good discrimination was achieved between the effects of species on soil. It demonstrated that the soils under the different trees were now different, in some way related to an important soil attribute – *viz* the potential for decomposition of organic matter. The relevance of these differences to other site parameters or processes is partly explored in the next paper (Brown & Howson 1988). Emphasis in the present paper is, however, placed on the effects of the mixed-species plots at Gisburn, perhaps the most important aspect of this long-term forestry experiment.

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Figure 1. Layout of a 2-species mixture at Gisburn

4 *Mixture comparisons*

The mixed-species stands consist of a checkerboard planting of groups of 3 x 6 trees of one species, alternating each way with similar groups of the admixed species (Figure 1). Compared with soil differences between monoculture species, those developing between subplots under the various mixture treatments (ie under a given single species within the 18-tree groups) could be expected to be small and possibly undetectable, using traditional chemical methods. Nevertheless, that soil differences might exist was suggested by the presence of differences in tree performance observed in the mixed plots (Lines 1982). Spruce, oak and alder heights have been significantly influenced by the presence of the admixed species (Figure 2). The sequence of effects brought about by the admixed species is pine >alder >oak = spruce (with pine and alder always having a positive influence, spruce invariably a negative one, and oak a negative or neutral effect). In contrast, height growth of pine has remained identical, whether pure or mixed. One possible explanation of such differential height growth is through changes in soil 'fertility'. As a starting point for differentiating the changes in these soils, the cotton strip assay was again applied. Because of manpower limitations, oak and oak mixtures were not included.

All the strips were buried in June 1980 in each treatment of both pure and mixed trees (except for the different oak combinations) and in the 3 replicate blocks. In the mixed stands, sampling points were located as near as possible to the centre of 8 sample 18-tree 'subplots', distributed on a systematic basis through each plot and in equivalent positions in pure stands. Four strips were inserted, about 20 cm apart, at each sampling point. One strip per sampling position was subsequently removed on each of 4 retrieval occasions, 3, 6, 9 and 12 weeks after insertion. Following standard preparation and testing for tensile strength (Latter & Howson 1977), decay curves were derived (Figure 3), again averaged over the whole strip, and combining data from all 3 blocks.

Differences between tree treatments were significant, and it is evident that the sequence of mixture effects on CTSL for spruce and alder, at least, was the same as that for the height data, ie pine >alder >spruce. That these 2 variables appear to be related is indicated in Figure 4, in which tree heights are plotted against CTSL after 9 weeks, ie the position on the decay curve closest to a 50% CTSL. This degree of CTSL is regarded as providing optimum information (Hill *et al.* 1988). In both spruce and alder, highly significant relationships exist. In the case of pine, in which there was no effect of mixtures on heights, there is a corresponding lack of a mixture effect on CTSL (Figure 3).

How can this close relationship between tree heights and the decomposition of buried cotton cloth be interpreted? One possible hypothesis is that the trees – in mixture – are growing better through some nutritional advantage, as already suggested, and that the increased CTSL in the mixed plots reflects an increase in the availability of the appropriate nutrient(s). The standard approach for checking on the nutritional status of trees – at least in conifers – is to carry out foliar analysis. Where the availability of an element is limiting tree growth, a relationship between foliar concentration of the element in question and tree height growth can sometimes be expected. At Gisburn, foliar sampling of the spruce trees (both pure and mixed) was carried out in the autumn of 1982, taking a lateral shoot from the first whorl on the south side of 10 trees per plot. All 3 replicate blocks were sampled, and the needles were analysed for N, P and K – the 3 nutrients which most commonly limit tree growth on this type of site. No significant relationship between tree heights and K content was obtained, but

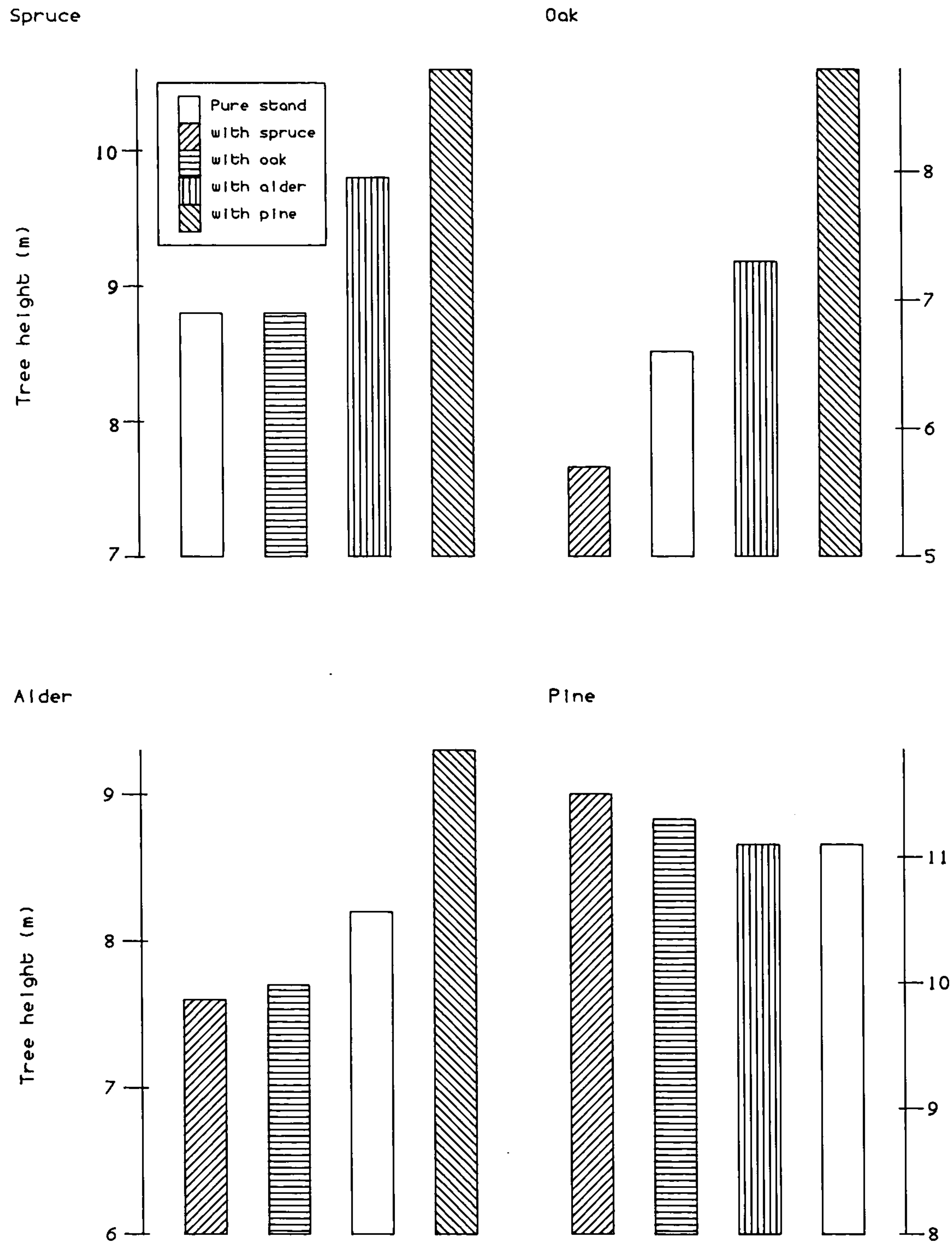

Figure 2. Heights at 26 years of 4 tree species in pure and mixed stands at Gisburn, 1981 (mean of 3 blocks)

the correlations with both N and P concentrations were statistically significant (Figure 5). These graphs make it clear that spruce growing in the presence of pine and alder were not only tallest but had highest foliar N and P, whereas the poorer growth of the monoculture replicates and those mixed with oak was associated with lowest mean foliar concentrations.

The most likely source of these higher levels of N and P in the plots with better growth – which, as has already been noted, were those with the highest CTSL – is the organic matter within and/or beneath the forest floor (Brown & Harrison 1983). The release of N and P, known to be the most tightly held nutrients within organic materials, is likely to vary directly with organic turnover. In fact, a direct relationship between CTSL and foliar N or P can be demonstrated for spruce stands at Gisburn (Figure 6), supporting the view that the improvement in N and P nutrition has been derived largely from soil organic, rather than any other, sources. It should not be inferred from the present results that foliar analysis could replace soil assessment. In the present case, foliar analysis alone would have given no direct clue to the source of any nutrient found

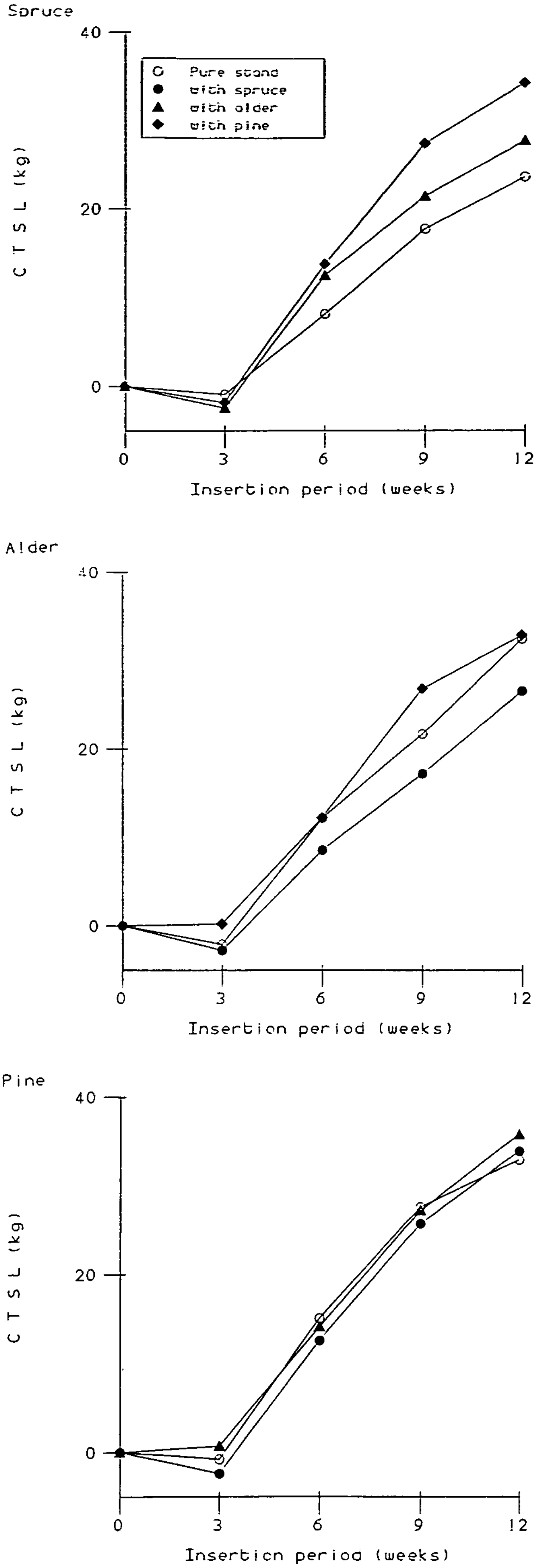

Figure 3. Inverse decay curves for cotton strip tensile strength loss (CTSL) under 3 tree species in pure and mixed stands at Gisburn, 1980 (mean of 3 blocks)

to be limiting growth. Further, in other situations, foliar analysis may be impossible, inappropriate or yield negative results, even where differences in soil properties occur – differences which may well be amenable to assay by the cotton strip method.

5 *Conclusion*

The evidence from the Gisburn experiment supports the view that the different mixture treatments are influencing N and P availability, presumably from organic matter turnover, and that, in turn, these differences in N and P levels influence tree growth. All these site attributes, which can be loosely related to site 'fertility', are well reflected by the results from the cotton strip assay. The use of this assay, therefore, enabled discrimination to be made, not only between the monocultures despite the lack of detectable soil chemical differences, but also between the different soils developed under a given single tree species, when influenced by the presence of other admixed species.

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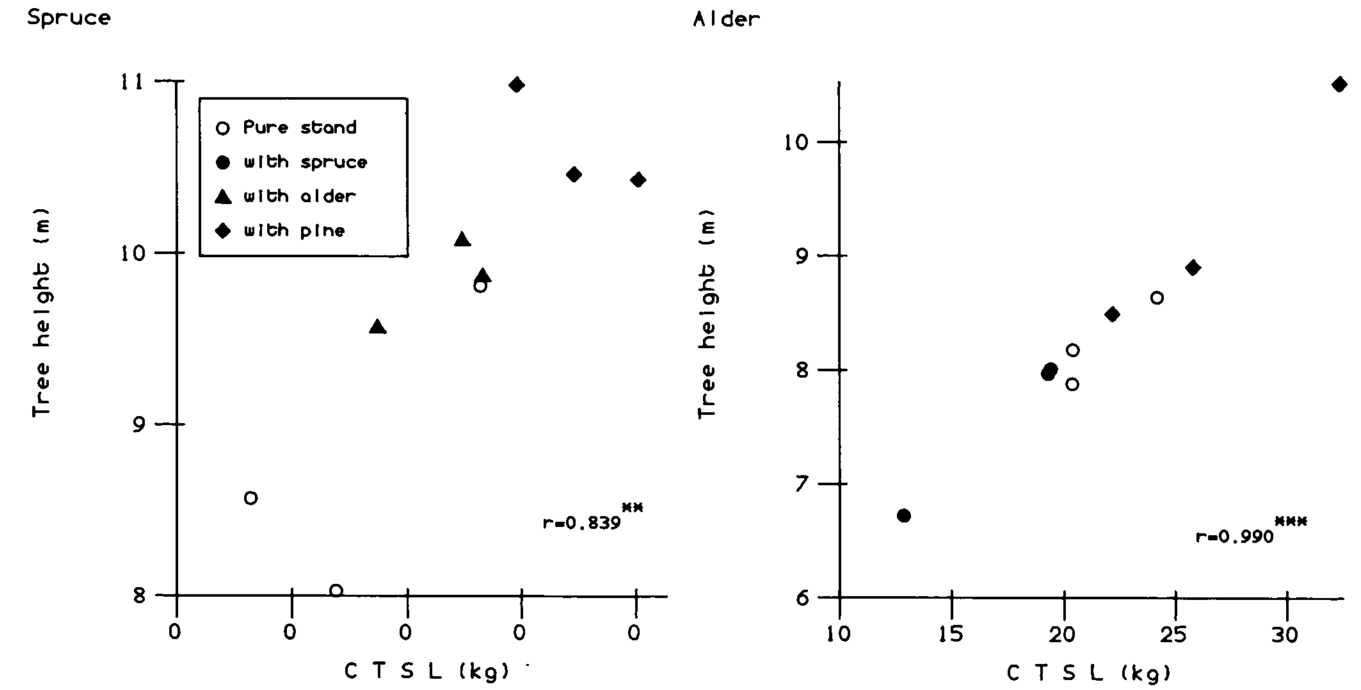

Figure 4. Relationship between tree heights at 26 years (1981) and tensile strength loss of cotton strips after 9 weeks (1980) in pure and mixed stands at Gisburn (means per plot)
*(** Significant at $P<0.01$; *** $P<0.001$)*

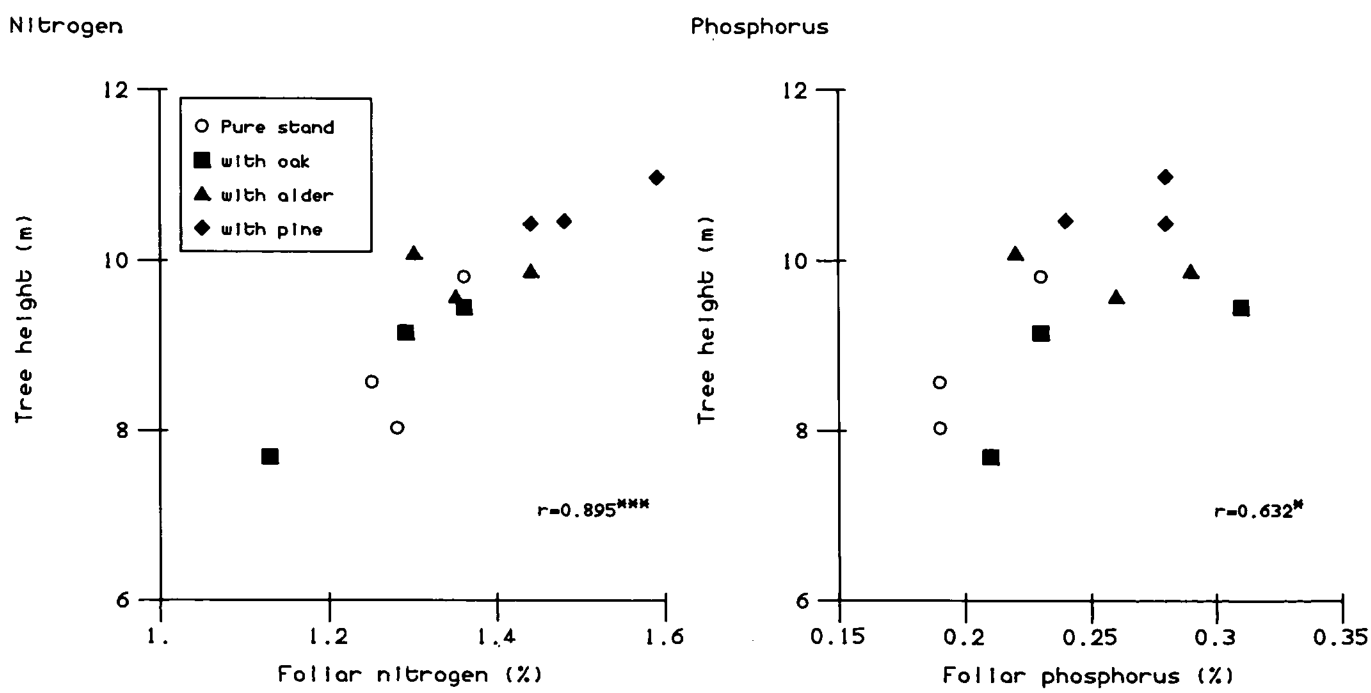

Figure 5. Relationship between tree heights and concentrations of nitrogen and phosphorus in pure and mixed spruce stands at Gisburn, 1981 (means per plot)
($P<0.05$; *** $P<0.001$)*

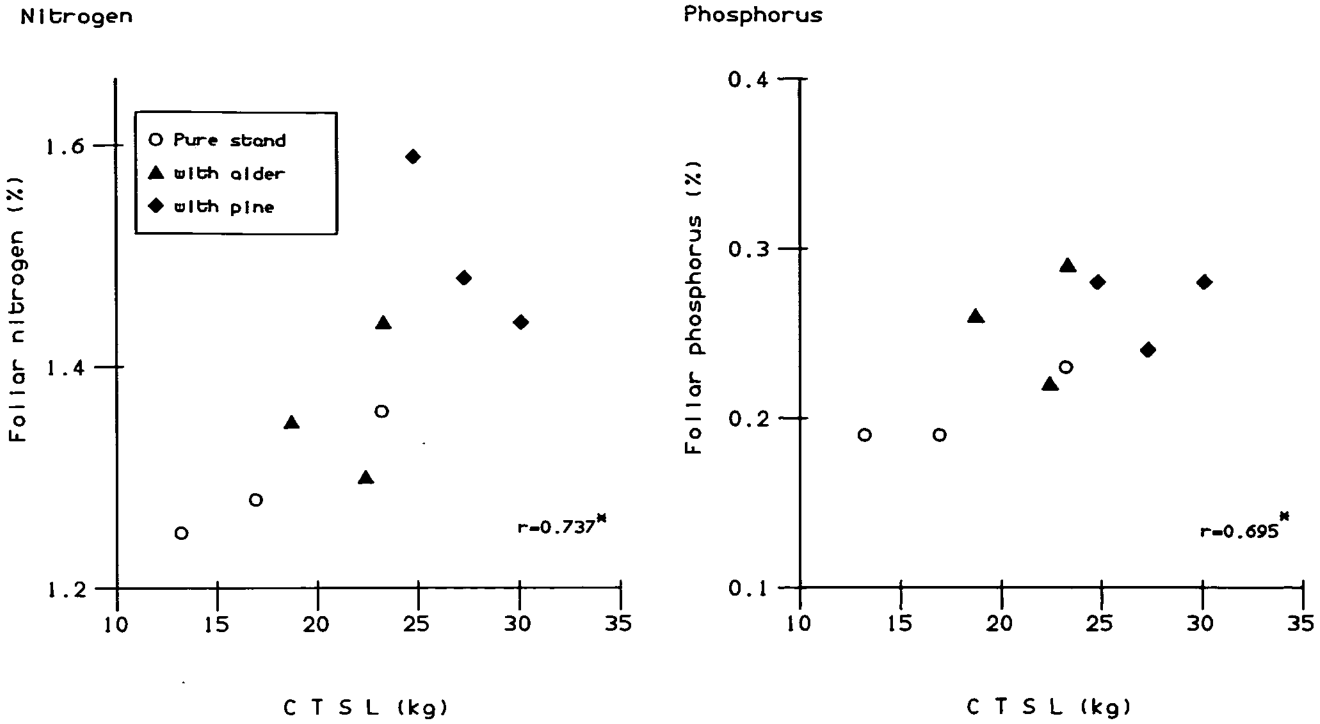

Figure 6. Relationship between foliar concentrations of nitrogen and phosphorus (1981) and tensile strength loss of cotton strips for pure and mixed spruce stands (1980) at Gisburn (means per plot) (P<0.05)