THE INFLUENCE OF 12 TREE SPECIES ON THE ACIDIFICATION OF THE UPPER SOIL HORIZONS

12 TRÆARTERS INDFLYDELSE PÅ DE ØVRE JORDLAGS FORSURING

BY

H. HOLSTENER-JØRGENSEN, M. KRAG AND H. C. OLSEN

(Særtryk af Det forstlige Forsøgsvæsen i Danmark beretning nr. 353, bd. XLII, h. 1, 1988).

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INTRODUCTION

Forestry literature abounds in opinions on the influence exerted by various tree species on the soil. Some species are considered to be generators of raw humus, others to be mull sustainers. In our latitudes the raw-humus-generating tree species are presumed to be acidifying and thereby to cause podzolization of the soil. No critical review of the comprehensive literature on this subject will be offered on this occasion. Specially interested readers may be referred to articles such as *Hallbäcken & Tamm,* 1986, in which some key publications are discussed. The Danish investigation reported below may presumably contribute to a revision of much hereditary knowledge.

The last few decenniums have enriched the debate with opinions on the acidifying effect of air pollution on our forest soils. It would therefore seem of essential importance that the extent to which forestry as such acts acidifying on our soils should be elucidated as exactly as possible. Well planned experiments with even-aged tree species must be considered particularly well suited to such investigations. The Danish Forest Experiment Station has at its disposal 13 experimental areas in which within the same planting year 12 different tree species of the same provenance were transplanted, and the acidity of the soil has been examined in these areas.

RESEARCH MATERIAL AND METHODS

During the planting season autumn 1964 to spring 1965 the 12 different tree species were transplanted into randomized plots in the 13 experimental areas. The localization of these areas appears from Figure 1 (*Holmsgaard & Bang,* 1977). It shows that the experimental areas are geographically well distributed and represent soils of various geological origin, and also that the climatic zones in this country are well represented.

Holmsgaard & Bang (1977), moreover, provide all details concerning the utilization of the experimental areas (forest, field, pasture) before the planting, the provenances of the plants (which for each species is the same in all areas), the establishment of the plantation, etc. It should be mentioned that in some areas a few plots miscarried totally, and other tree species were planted. These plots are *not* included in the present investigation.

The 12 tree species are:

Abies alba	*Pinus contorta*
Abies grandis	*Pinus mugo rostrata*
Abies procera	*Pseudotsuga Menziesii*
Larix leptolepis	*Chamaecyparis Lawsoniana*
Picea abies	*Quercus robur*
Picea sitchensis	*Fagus sylvatica*

In most of the plots, permanent production sample plots have in the course of time been laid out. These are measured by the Production Department of the Experimental Station, which has supplied this investigation with production data, from 6–8 plots per area.

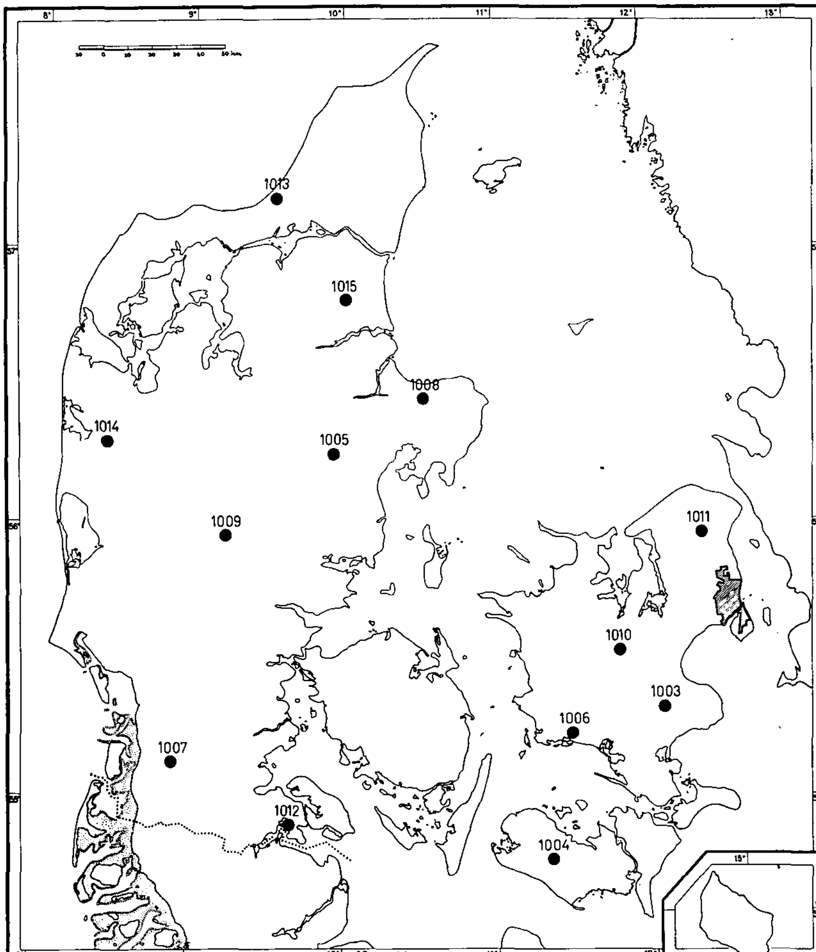


Figure 1. The tree-species experiment 1964/65. The 13 experimental areas.
Figur 1. Træartsforsøget 1964/65.

De 13 forsøgsarealer er

1003	Bregentved	1010	Skjoldenæsholm
1004	Christianssæde	1011	Stenholt
1005	Frijsenborg	1012	Sønderborg
1006	Holsteinborg	1013	Tranum
1007	Lindet	1014	Ulborg
1008	Løvenholm	1015	Willestrup
1009	Randbøl		

In each plot, soil samples have been taken till the depth of 5 cm, loose litter (needles, leaves, twigs) having beforehand been carefully removed. 10 pits were dug in each plot, and the material was mixed into a common sample. The samples were dried at 60°C and homogenized. Plot by plot the pH was then measured (glass electrode and calomel reference electrode) in:

a. Aqueous suspension in the weight ratio soil:liquid = 1:2.5
b. 0.01 molar $Ca\ Cl_2$ suspension in the weight ratio 1:2.5
c. 1.0 molar KCl suspension in the weight ratio 1:2.5

The measurements were performed as determinations in duplicate after the suspensions had been left for at least 4 hours. Mean values of the determinations in duplicate are included in the subsequent statistical computations.

The *production data* employed in the computations below are first and foremost the average annual basal-area increment during the period from the establishment of the experiment till the latest measuring, which was performed some time between autumn 1984 and autumn 1986. The difference in length of the period occurs in the statistical analyses as a difference in level between the experimental areas.

In some plots the growth has been so fast that more than one measuring has been performed, so that it has been possible to include also the current basal-area increment in the latest measured period in the analyses.

pH is an expression of the content of H^+-ions in the soil. When pH is low, the content of H^+-ions is high, which means that the content of other cations (Ca^{++}, Mg^{++}, K^+, etc) is relatively low. Such other cations have disappeared, either because the plants have assimilated them, or because they have been leached out.

The basal-area increment is a measure of the increment of the trees and thereby of the accumulation of biomass in the area. In the biomass, assimilated plant nutrients, including cations, have been immobilized. If assimilated cations are not substituted in the soil through supplies by, for instance, weathering processes or through supplies from outside (by precipitation, as dust, or by fertilization), the soil is acidified.

In stands of forest trees, an acidification of the soil must therefore be expected to occur as a function of the increment of the trees. This is the underlying working hypothesis in the present investigation.

That the basal-area increment has been used as an expression of the volume increment in the individual plots has not in this connexion been disregarded, nor that the volume units have different densities or content of dry matter. In these respects the tree species differ from one another, just as it must be presumed that the tree species differ in respect of nutrient assimilation and thereby of cation immobilization. Attempts could be made to adjust for these differences, but it is our view that with the existing knowledge such adjustments would be extremely speculative. This does not mean, however, that is would not be justifiable to invest some man-years in procuring more knowledge in these fields, if a reasonable basis is desired for prognoses concerning the long-term productivity of our soils.

Fig. 2.1.

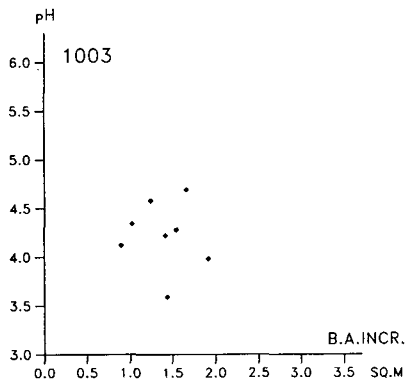


Fig. 2.2.

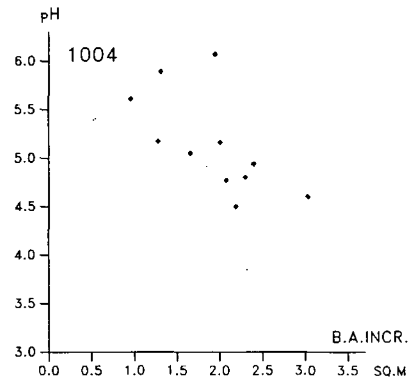


Fig. 2.3.

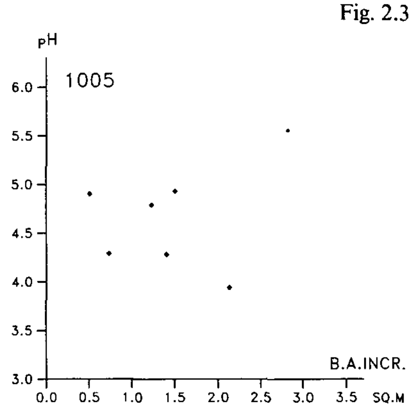


Fig. 2.4.

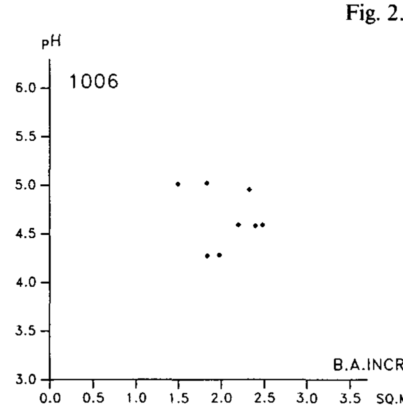


Fig. 2.5.

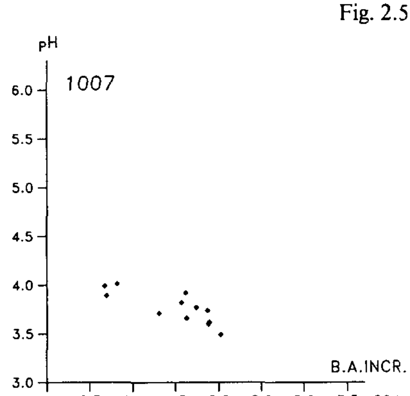
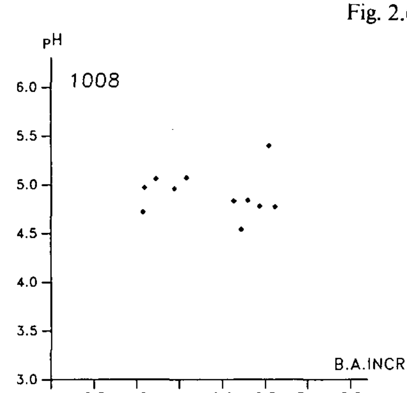


Fig. 2.6.



Figures 2.1–2.13. pH, H_2O in each experimental area superimposed on the individual plots' average annual basal-area increments in m^2 per ha and year from planting to the latest timber-measuring year. 1003, 1004, etc. are the registration numbers of the experimental areas, cf. Figure 1.

Figur 2.1–2.13. pH, H_2O på de enkelte forsøgsarealer lagt op over de enkelte parcellers gennemsnitlige årlige grundfladetilvækst i m^2 pr. ha og år fra plantning til seneste træmålingsår. 1003, 1004 og så videre er forsøgsarealets registreringsnummer jævnfør figur 1.

Fig. 2.7.

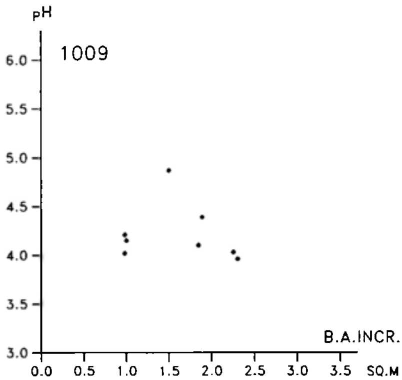


Fig. 2.8.

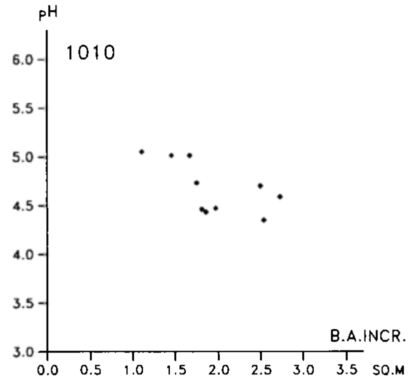


Fig. 2.9.

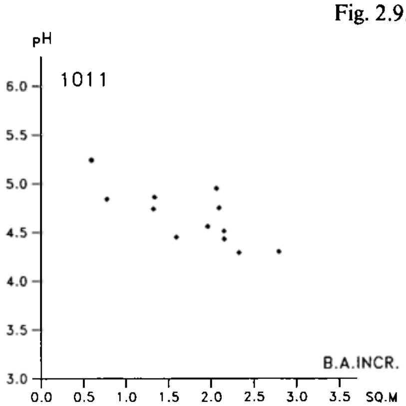


Fig. 2.10.

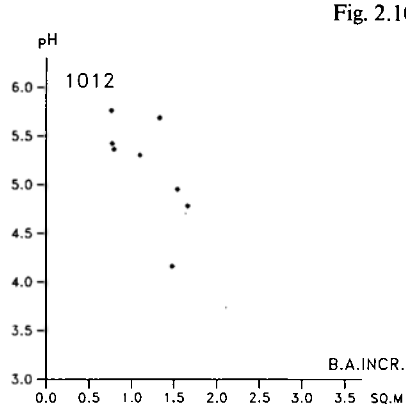


Fig. 2.11.

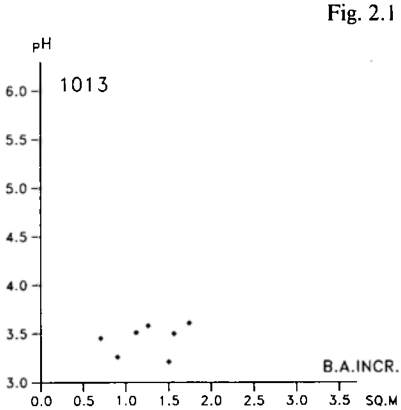


Fig. 2.12.

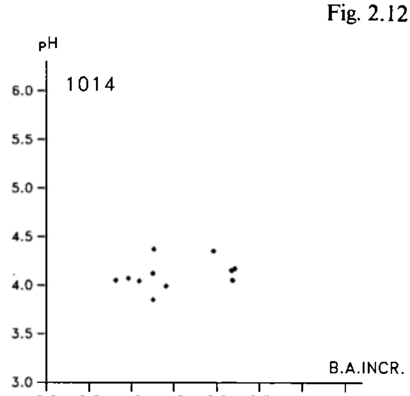
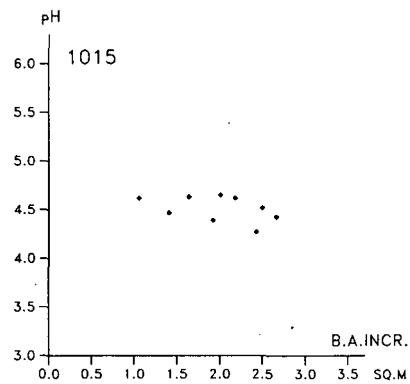


Fig. 2.13.



RESULTS

Figures 2.1 to 2.13 show for each experimental area the relationship between pH, H_2O (ordinates) and average annual basal-area increment (abscissas) from planting to the latest measuring. In most cases there is a clear negative correlation: *The higher increment, the lower pH.*

However, the figures also show that there are different pH-levels in the areas, whose location in this country appear from Figure 1. This is not surprising, since the soils are of different geological origin, and the areas have previously been utilized for different purposes (*Holmsgaard & Bang,* 1977). At the statistical treatment it has therefore been felt natural to insert "experimental area" as a level parameter, by which also the variation in the latest timber-measuring years is introduced. A comparison of the separate slopes of the plots showed a slight significance for pH, $CaCl_2$ ($p = 0.0174$) and pH KCl ($p = 0.0050$), but not for pH H_2O ($p = 0.0603$). Due to the limited number of observations in the individual plots we chose in the subsequent analyses to imply a mutual slope. The following regression-analytic model has been used:

$$pH = b\ i_g + a_j + \varepsilon$$

where b is the regression coefficient, i_g is basal-area increment, and a_j is the level in plot j.

The analyses show high significance for levels and for the regression ($p < 0.00001$).

Table 1 presents a survey of the R^2-values and the regression coefficients for the 3 different pH-values that have been measured. It appears that an increase of the basal-area increment of 1 m^2 per ha and year involves a pH-drop (acidification) of 0.24 units in the top 5 cm of the soil. With the model used this is an average for all areas irrespective of their pH-level.

Table 2 characterises the experimental areas by the estimated level for each area. At present this table affords no grounds for comments.

That much about the final analysis, which explain a surprisingly great part of the variation in the material. As already mentioned, the material does not call for residual analyses. Nevertheless, such analyses have been carried out in some respects, and below some (expected) results of these analyses will be briefly surveyed:

Table 1. Survey of correlation coefficients and regression coefficients.
Tabel 1. Oversigt over korrelationskoefficienter og regressionskoefficienter.

Variables *Variable*	R^2 R^2	Regression-coefficients *Regressions-koefficienter* b	Standard error *Standard error* s_b
i_g – pH, H_2O	0.996	−0.238	0.053
i_g – pH, $CaCl_2$	0.996	−0.243	0.050
i_g – pH, KCl	0.995	−0.246	0.049

Table 2. Estimated pH-levels for the 13 experimental areas.
Tabel 2. Estimerede pH-niveauer for de 13 forsøgsarealer.

Experimental area *Forsøgsareal*	pH, H_2O *pH*, H_2O	pH, $CaCl_2$ *pH*, $CaCl_2$	pH, KCl *pH, KCl*
1003	4.56	4.22	3.72
1004	5.60	4.94	4.60
1005	4.82	4.35	3.94
1006	5.15	4.23	4.11
1007	4.12	3.50	3.25
1008	5.35	4.64	4.23
1009	4.60	3.96	3.74
1010	5.14	4.62	4.16
1011	5.08	4.53	4.17
1012	5.46	4.91	4.52
1013	3.74	3.32	3.01
1014	4.47	3.82	3.71
1015	4.98	4.29	4.10

(1) The tree species are distributed quite evenly around the common regression line. None of them show a demonstrable significantly biased position. This is interpreted in the way that they have the same effect on the pH-changes (the acidification). Nothing but the increment achieved (volume accumulation, cation immobilization) decides the pH-changes.

(2) It has been attempted to use the latest current basal-area increment as explanatory parameter. However, pH is not significantly related to the latter. This is not surprising. The culmination of the current increment occurs at different times in the various tree species, and it occurs at different times in the individual areas. Moreover, at good growth and thereby with more frequent measurings, more thinning operations will have been performed, which influences the soil processes. In short: the average increment from establishment till the date of computation is best suited to describe the volume accumulation and the cation immobilization.

(3) Finally, it shall not be left unmentioned that also analyses by polynomials of degree 2 have been carried out. They gave lower levels of significance, so for the present the rectilinear relationship must be considered the most precise. The pH-changes (the acidificative processes) are proportional to the average increment or volume accumulation and thereby to the cation immobilization.

DISCUSSION AND CONCLUSION

A discussion of the results submitted and a final conclusion (thesis) can be rendered briefly.

On the basis of a rather extensive experimental material it has been demonstrated that forestry acts acidifying on the soil. The precision in the investigation is surprisingly high, even though no adjustments have been made for dry-matter production, differences between the various tree species in their nutrient assimilation, and other more or less speculative factors. The acidification is clearly dependent on the average basal-area increment of the trees, which reflects the biomass accumulated so far by the stands and thereby their cation assimilation and immobilization.

As a matter of course the results apply only to the early, closed phase, in which the cation immobilization is intensive (*Nilsson et al.,* 1982). Thinning operations etc. may on the long view reveal a changed picture. Thus, *Holstener-Jørgensen* (1956) has shown that in young, dark beech stands there is a tendency towards formation of raw humus, which is replaced by a better condition when the stands grow older and the ground receives more light allowing a ground flora to thrive.

Attention should be drawn to *Bloomfield's* (1954) studies of podzolization processes, which showed that aqueous extracts of ash leaves are very active in furthering the podzolization processes in the soil. Usually ash is considered a mull tree species, but ash stands are normally light with a rich ground flora. The soil formation of the ash stand is the resultant of an interplay of several species.

It should be emphasized that in the present investigation it has not been possible to sort out specific effects of tree species on the pH of the forest floor.

It is noteworthy that the acidification measured as pH-changes is the same at the given pH-levels (0.24 pH-units per m^2 average basal-area increment). Where the pH-level is low, a given pH-change means considerably larger H^+-quantities than where the level is high. Some of the explanation may be that where the pH-level is high, the cation loss can be made good by liberation of greater amounts of cations (weathering); but also differences in the buffer-systems of the soil may play a part.

The mentioned precision and the geographical distribution of the experimental areas may on consideration easily lead to the conclusion that under Danish conditions any effect of an atmospheric contribution to the soil-acidific processes is of marginal and almost improvable importance. This conclusion agrees very well with *Binkley's* (1986) views.

In short, forest is soil acidifying, and the acidification of a given stand depends on its increment, which means its cation immobilization.

Rosenquist (1978 *inter alia*) has rightly referred to acidification of lakes in former times which has been traceable to increasing forest percentages in terms of area and increased stand density.

SUMMARY

In 13 experimental areas (Figure 1), each containing 12 plots with 10 conifer species and beech and oak planted in the same year, and where within each tree species the same provenance was used, pH was measured in the topmost 5 cm of the soil.

pH was correlated with the average basal-area increment in m^2 per ha and year from planting to the latest year in which timber measuring was performed so far on 6-8 plots per locality. The correlation in the individual experimental areas is illustrated in Figures 2.1–2.13. It appears that there are differences in level between the areas, which are ascribed to differences between the areas in the geological origin of the soil and the former use of the area (see Table 2).

After diverse statistical analyses it was found reasonable to make a joint linear regression analysis. The results of the latter appear from Table 1, which shows a surprisingly high explanatory level. 99.5-99.6 % of the variation in the material is explained by the model shown on page 23.

The main result of the investigation is that an increase of the basal-area increment by 1 m^2 per ha and year causes a fall in pH of 0.24 units during a period of well over 20 years. The fall in pH is the same in all localities irrespective of the differences in level. Further, there are no differences between the tree species. The fall in pH is ascribed to an increment-conditioned immobilization of cations in the accumulated wood volume.

RESUMÉ

På 13 forsøgsarealer (fig. 1) med hver 12 parceller med 10 nåletræarter og bøg og eg plantet i samme år, og hvor der af den enkelte træart er anvendt samme proveniens, er pH i jordens øvre 5 cm målt.

pH er korreleret med den gennemsnitlige grundfladetilvækst i m^2 pr. ha og år fra plantningen til det seneste år, hvor der er gennemført træmåling. Korrelationen på de enkelte forsøgsarealer er illustreret i figur 2.1–2.13. Det fremgår, at der er niveauforskelle mellem arealerne, som tilskrives forskelle mellem arealerne i jordens geologiske oprindelse og arealets tidligere benyttelse (se tabel 2).

Efter diverse statistiske analyser er det fundet rimeligt at gennemføre en samlet lineær regressionsanalyse. Resultaterne af denne fremgår af tabel 1, som viser et forbavsende højt forklaringsniveau. 99.5–99.6 % af variationen i materialet er forklaret med modellen, som er vist side 23.

Hovedresultatet af undersøgelsen er, at 1 m^2 større grundfladetilvækst pr. ha og år medfører et pH-fald på 0.24 enheder over en godt 20-årig periode. pH-faldet er det samme på alle lokaliteter uanset niveauforskelle. Der er endvidere ingen træartsforskelle. pH-faldet tilskrives en tilvækstbetinget immobilisering af kationer i den ophobede vedmasse.

REFERENCES

Binkley, D., 1986: Forest nutrition management. John Wiley and Sons, New York: 1–290.

Bloomfield, C., 1954: A study of podzolization. V. The mobilization of iron and aluminium by Aspen and Ashleaves. J. Soil Sci. 5.

Hallbäcken, L. & C. O. Tamm, 1988: Changes in soil acidity from 1927 to 1982–1984 in a forest area of south-west Sweden. Scand. J. For. Res. 1: 219–232.

Holmsgaard, E. & C. Bang, 1977: Et træartsforsøg med nåletræer, bøg og eg. De første 10 år. (A species trial with conifers, beech and oak. The first ten years). Forstl. Forsøgsv. Danm. 35: 159–196.

Holstener-Jørgensen, H.: 1956: Floraundersøgelser i Mølleskoven. 3. beretning. (The flora in Mølleskoven forest. Third report). Forstl. Forsøgsv. Danm. 22: 247–273.

Nilsson, S. I., H. G. Miller & J. D. Miller, 1982: Forest growth as a possible cause of soil and water acidification: An examination of the concepts. Oikos 39: 40–49.

Rosenquist, I. Th., 1978: Alternative sources of acidification of riverwater in Norway. The Science of the Total Environment 10: 39–49.