# Impact of small-scale variability of soil pH on the vegetation composition in a mixed hardwood stand, East-Flanders Belgium

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## Summary

1 Soil pH of the forest stand varies widely for the different depths and is very important in determining the forest vegetation types. Main aim of the study was to examine the correspondence between forest vegetation composition and small-scale heterogeneity in pH by several statistical methods.

2 Ordination using DCA (Detrended Correspondence Analysis) found clear distinction in the vegetation structure and pointed pH differences as the main factor explaining the variability (*Eigenvalue= 0.76 for the first three axis).*

3 Clustering analysis by TWINSPAN resulted into four major vegetation groups. Most of these divisions were explained by differences in pH.

4 The spatial dependence of the pH at ectorganic and top mineral layers was examined by geostatistics analysis. All variograms showed a similar well-defined structure. The structure of variograms accounted for 95 - 100 % of the spatial dependence for the pH at all depths. All variograms represented the same range of 50 m for the pH at ectorganic horizons, but the distance of 65 and 72 m was calculated respectively for the pH at 0 - 5 and 5 -15 cm depth. All variograms increased to the maximum lag over which they were calculated.

5 The raster image of pH variability resulting from Kriging interpolation coincided significantly with the raster image of vegetation composition. It was concluded that it is possible to predict the pH value based on the vegetation composition or vice versa. Predicting the vegetation type from pH value is only possible for the range of the distance of the pH variogram.

**Keywords:** *soil pH, vegetation groups, TWINSPAN, DCA, Spatial analysis, Geostatistics*

## 1. Introduction

Investigations of heterogeneity in natural systems have indicated substantial variability, even at scales of less than one meter (Snaydon, 1962; Naesset, 1994). Environmental heterogeneity has hard an importance on the development of both experimental design and classical statistics. Conventional statistics generally are unable to treat adequately the spatial aspect of data in which neighboring samples may not be independent of each other. Moreover, they do not uniformily provide unbiased estimates for unsampled locations, or estimate optimal variances for the interpolated values (Journal & Huijbregts, 1978; Robertson, 1987; Rossi et al., 1992). Frequently, the spatial variation of ecological attributes varies continuously within a spatial unit in a way that cannot be described by classical statistics. This means that the sample points which are close together tend to be more similar than points further apart. Variables, whose variation can be explained by this definition, are called regionalized variables. Regionalized variables are spatially correlated to one another over short distances, but could be independent of one another over large distances. This approach has proven to be both flexible and powerful for answering research and management questions in the spatial domain.

Geostatistics can be used to quantify the spatial dependence between sampling locations and to provide optimal estimates for unsampled points (Matheron, 1963; Burgess & Webster, 1980 b; Yost et al., 1982 a). The heart of geostatistics is the semivariogram, which models the average degree of similarity between the values as a function of their separation distance, and Kriging, which estimates values at unsampled locations without bias and with a minimum variance.

Soil properties can vary considerably in woodland ecosystems and only scanty information is available on the size and density of samples. The heterogeneity of soils is often emphasized and several authors have determined relatively large differences in the chemical contents, particularly pH of soils, over distances of only a few centimeters (Purviz & Davidson, 1948; Ferrari & Vermeulen, 1955).

The acidity of forest soils varies widely and is very important in determining the type and quality of a forest which occurs on any particular stand. When the research of soil acidification effects on forest started in the 1970s, the main hypotheses indicated that input of acid to the soil would increase the leaching of "base" cations like $Ca^+$, $Mg^+$ and possibly $K^+$. The forest soil would gradually become deficient in these important nutrients in the long term. The most likely effect would be a gradual decline in forest. Later, Ulrich et al. (1980) claimed that the main effect of soil acidification would be an increased mobilization of $Al^+$, injury to plant roots, reduced growth and finally forest damage.

During the 1980s a number of alternative and supplementary hypotheses were proposed by several authors both in Europe and North America to explain the "***new forest decline***". Most hypotheses concentrated on man-made factors and, in particular, factors that were connected to air pollution (Binkley et al., 1989; Abrahamsen et al., 1994).

The acidity of most forest soils varies only slightly with seasonal changes (Hallbacken & Tamm, 1986; Skyllberg, 1991). The degree of variation is influenced by magnitude of seasonal changes, but changes are seldom more than 1.0 pH unit. Hallbacken & Tamm (1986) Considerable differences in acidity are often found among horizons of the same soil. The H layer of forest floor and A1 horizon of Spodosols are often very acid with some increase in pH value with soil depth. Soils derived from basic materials are often more acid in the surface layers, because these layers are subjected to more leaching than those at greater depth (Pritchett & Fisher, 1987; Miller & Danahue, 1990; Abrahamsen et al., 1994). Piper and Prescott (1949) among others have suggested that such variations in pH from point to point are of greater significance than the seasonal variation. Great variation in pH values of the humus layers can also be found in the same forest stand (Raunpach, 1951; Frankland et al., 1963; Ball & Williams, 1968).

The objective of the present study, is to examine the spatial variation of soil pH at different depths in relation to vegetation composition. This objective is achieved by means of the variogram analysis and Kriging interpolation.

## 2. Materials and methods

The investigated zone covers an area of 1.8 ha, which has been fenced for protection to possible disturbances. The elevation of the study area ranges from 18.5 m up to 21 m above sea level. This area is located on the north-east part of the Aelmoeseneie forest in East-Flanders (Belgium).

The soil and vegetation conditions of the highest and lowest part of the study area differ considerably. At a glance, two main forest types can be observed as oak-beech and ash stands, both being some 75 years old. The oak-beech (Quercus robur – Fagus sylvatica) forest type on the slope side of the study area (1.1 ha) is a typical thin Quaternary deposit of the sandy loam texture on a shallow impermeable clay and sand complex of the Tertiary formation.

The ash (*Fraxinus excelsior*) forest type on flat side of the investigated area (0.8 ha) is an alluvial deposit with thick Quaternary of the loamy texture, where the impermeable layer ceases and the Tertiary origin cannot be found at least at 4 m depth.

## 3. Sampling strategy, Analytical procedure and Statistical methods

In vegetation community sampling, it is realistic that the species are as fully represented as possible. Considering Ellenberg's points of view about the minimal area (1974), 169 permanent rectangular square plots (10×10 m) have been chosen systematically for vegetation and soil analysis in the study area. In addition to the grid plots, 10 strip transects were established randomly for the analysis of the soil properties. The length of each transect is 20 m, which is divided into 4 m distances between each other, so that each transect consists of six points. From the center of each grid plot, a circle with 1.1 m radius was marked as a micro-plot for studying moss species. The phytosociological study was performed on the grid and transect points. The analytical procedure of soil properties has been carried out on half of the grid plots and on all the transect points (totally, 125 samples), since 20 points coincided with each other. In every grid, a phytosociological study was performed based on mosses, herbal vegetation (*vernal and summer*) using the Braun-Blanquet combined scale (*cover and abundance*). After sampling of the plots, all plant species (herbs and mosses) present, were listed with a numerical estimation of their cover and abundance. The recording of herbal vegetation was mostly done in two periods, in April-May (*vernal vegetation*) and in the July-August (*summer vegetation*).

One of the basic ideas in phytosociological studies in the present research was to obtain a group of differential species, which can be characterized by stand characteristics or vice versa. The idea of differential species is essentially quantitative : the species abundance or pseudospecies.

The vegetation data from the field recording had to be processed into one set of data in a uniform style. Vegetation data (grid points) were brought together into one table, which was composed of a two-dimensional array of sample plots and species names (samples listed in columns and species in rows). After these procedures, one table in Cornel condensed format was prepared (Compose program by Mohler, 1987). This is a table representing species and samples by integer numbers coding. This format is compatible with most ordination and clustering programs (DECORANA & TWINSPAN) which were used in the present study.

At first glance, the spatial variation within vegetation features and soil properties are obvious between the two forest types (oak-beech & ash) in the study area. In order to examine this variability, it was necessary to sample the study area sufficiently.

From the total number of grid points, 78 discontinuous samples and from transects points 60 continuous samples of each layer (L, F and H) were collected separately. The soil mineral layers were sampled by auguring at the depth of 0-5 cm, 5-15 cm from the center of each grid and transect points. Samples of the ectorganic horizons were air-dried, gravel, mineral contaminants and roots were removed. The subsamples were ground by a mill and passed through a 2 mm sieve. Samples of the mineral horizons (0-5, 5-15) were treated as described above. The pH was determined using distilled water. We took a 1 g subsample from the organic horizons, mixed by 20 ml distilled water and 5 g subsample from mineral horizons and added 100 ml distilled water.

In this research, the basic method of the vegetation analysis is based on the two-way indicator species analysis (TWINSPAN), designed by Hill (1979 a). One of the basic ideas in the TWINSPAN method comes from the original idea in phytosociology, that each group of sites can be characterized by a group of differential species, the species that appears to prevail in one side of dichotomy (Jongman et al., 1996). The convenience of vegetation as an indicator of soil quality has been recognized by several botanists (Cragg,1962; Rogister,1978; Pritchett & Fisher,1987, Rieley & page, 1990; Ellenberg, 1992; Jongman et al., 1996).

In order to reveal the major vegetation gradients, an eigenvector method for preliminarily ordination (DCA) was carried out using the computer program DECORANA (Hill, 1979a). The main objective of this investigation was to study the spatial distribution of the soil pH within the different vegetation types. The spatial variability of the soil pH was studied by geostatistical analysis (Kriging interpolation), and we used the GEO-EAS program (Enlund and Sparks, 1991). For the monitoring of the spatial interpolation, we applied the GIS computer software, IDRISIWIN by Eastman (1995).

### 4. Results and discussion

### Preliminary vegetation analysis

The complete vegetation data set was ordinated using Detrended Correspondence Analysis (DCA) of the program DECORANA (Hill, 1973), in order to determine the major vegetation gradients. The result of ordination in two dimensions (two axes) is a diagram in which sites are represented by points. Points that are close together correspond to sites that are similar in species composition, and points that are far apart correspond to sites that are dissimilar in species composition.

The species of the first three-ordination axes is presented in Figure 1. The first axis is the most significant, because it has the highest eigenvalue and it explains 57% of total variability (the first axis has eigenvalue 0.76, the second axis 0.24 and the third axis 0.19). The first axis indicates the soil acidity gradient. Associated species at the positive side are *Polytrichum formosum*, *Dicraneralla heteromella* (moss species) and *Pteridium aquilinum*, which are acidophile species according to Ellenberg (1992). The species at the negative side of the first axis (*Geranium robertianum, Lamium album, Adoxa moschatellina*) are nitrophylic species (Ellenberg, 1992).

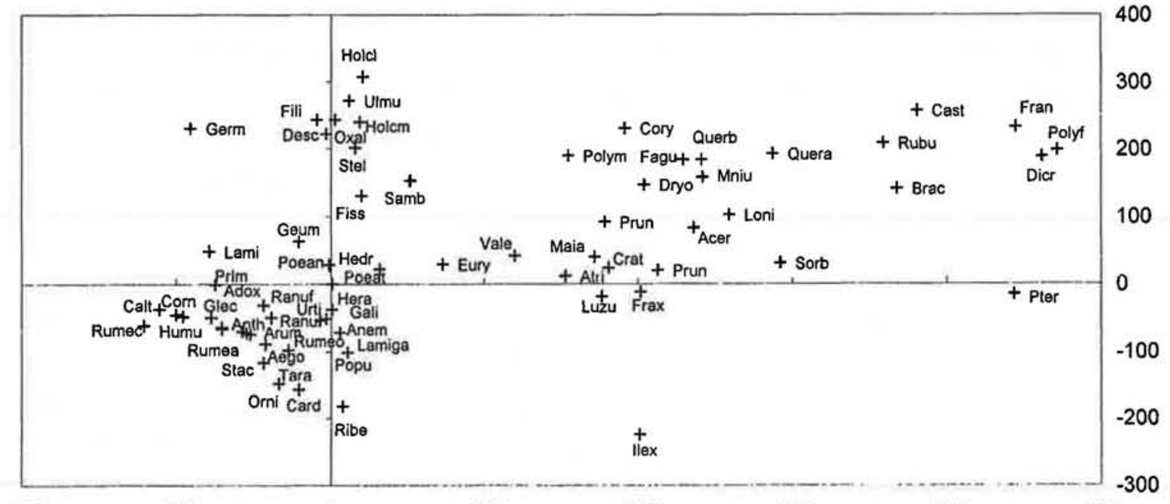


Figure 1. *DCA species ordination diagram.*

Figure 2 shows the ordination diagram for the sampling points. The first axis is the most significant since it has the highest eigenvalue (0.76) in comparison with other axes. Most of the points towards the positive side of this axis are situated in the oak-beech stand. The points towards the negative side of the first axis are sampling positions situated in the ash stand.
Figure 2 seems to show a gradient from the moderate site with low pH (*oak-beech stand*) to a richer nutrient site with a higher pH (ash stand).

The second DCA axis could be related to a light demanding gradient. Based on the vegetative elements like *Oxalis acetosella* and *Holcus mollis*, at the positive side (shade tendency) and some light tendency at the negative side, it must be considered as an axis of light gradient.

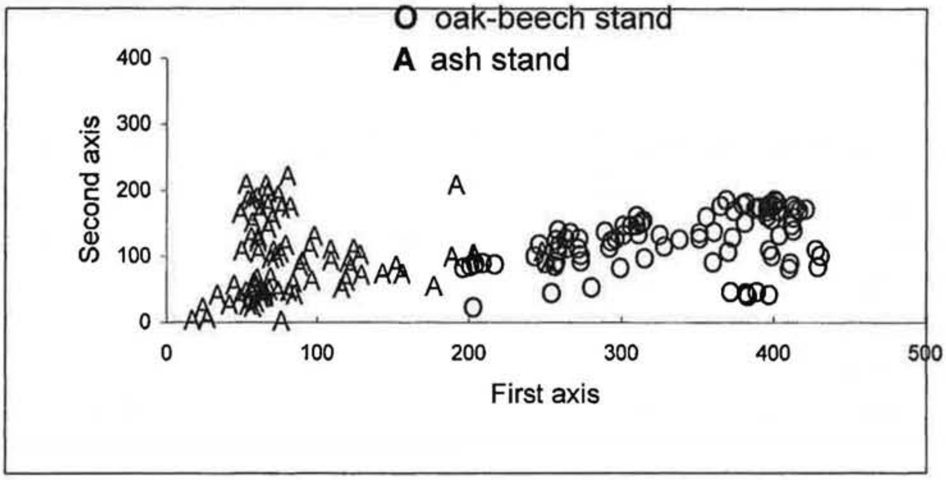


Figure 2. *DCA sample ordination diagram.*

### 5. Clustering vegetation analysis

In order to reveal the major outlines of divergence in the vegetation pattern and its environmental control, the complete vegetation data set, consisting of 169 sample plots, was analyzed by the TWINSPAN classification method. As explained above, TWINSPAN not only classifies the site, but also constructs an ordered two-way table and is based on the idea that each group of sites can be characterized by a group of differential species, species that appear to prevail in one side of a dichotomy.

The first two levels of the dichotomous hierarchical classification of the complete data set, are presented in a dendrogram (Fig 3). The indicator species of each division are presented in decreasing order of the importance. The numbers in brackets indicate the occurrence of each species in the left and right subset produced by each division.

In general, the hierarchical classification approach presented in this study allows for a more precise definition of environmental conditions than does simple classification by plant communities. TWINSPAN usually considers more than one species (or pseudospecies) as indicators, hence reducing the probability for misclassification.

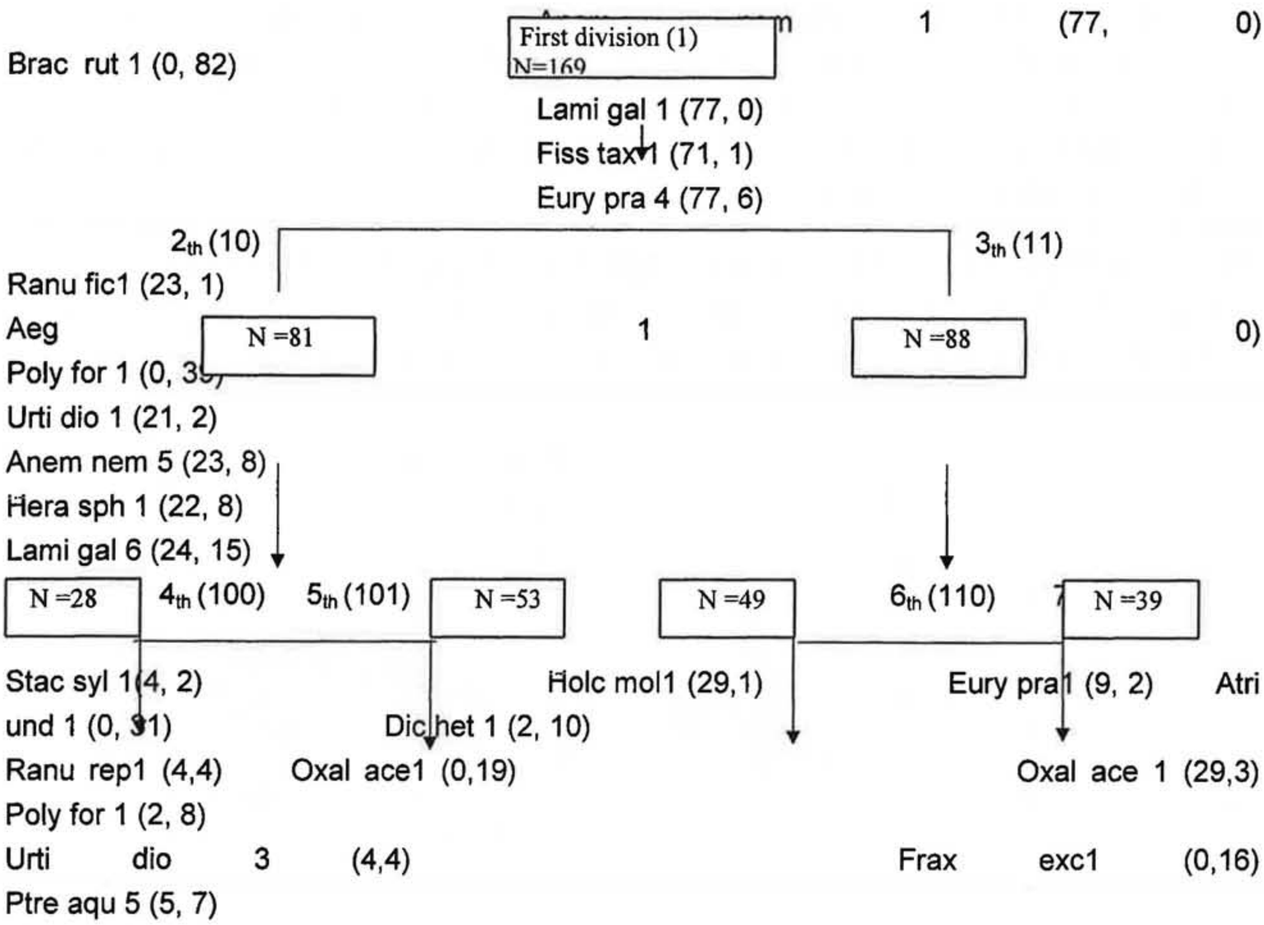


Figure 3. *The dendrogram shows the classification by TWINSPAN analysis for the vegetation data set. The number after the species names gives the abundance value of each species in every division. Numbers between brackets give the occurrence of each pseudospecies in the left and right (negative and positive subset) cluster respectively.*

Results from the application of the clustering analysis are given in Table 1. Considering the variability from first division with an eigenvalue 0.54 affirms this division serves rather well in revealing the main direction of vegetation variation. Thus, the major division of the vegetation data seems to reflect a distinct environmental discontinuity. There are only a few species, which are common to both high and low pH-sampling points. The major axis of the vegetation variation seems to be associated with the soil fertility gradient. Both extremes of this axis represented by subset (10), with typical nitrophile species (richest site) and a rather moderate site indicated by subset (11), which consists of a acidophile species (*Polytrichum formosum*) can most clearly be distinguished.

Subsets (100) and (101) consist of acid mull vegetative elements (*Oxalis acetosella and Holcus mollis)*, which are good indicators respectively from more rich stand with a higher pH value to the relative rich stand with moderate pH value. Table 3.4 shows the variability between subsets (100) and (101) respectively with eigenvalues 0.160 and 0.185, that are rather close to each other.

Subsets (110) and (111) include the species, which prefer to the positive side of the major cluster. The indicator species tend to be a lower pH and rather poor site in comparison with the subsets of the negative side of main cluster. The eigenvalues of these subsets show that there is more variability between two subsets in comparison with subsets of negative side of the major cluster. The species, which are situated within the subset (110), are *Atrichium undulatum and Eurynchium praelongum.* The subset (111) has a perspective herb and moss indicators (*Pteridium aquilinum, Polytrichum formosum and Dicranella heteromella*), shows the mor-moder stand according to Ellenberg (1992).

Comparing the vegetative elements, which are located between the two subsets, indicates that the subset 111 is more acid tolerant species than the subset 110. Nevertheless, this division is ecologically less easy to interpret, mainly due to the general drawback of the divisive classification programs: misclassification tend to accumulate, and their appearance becomes more effective as the division process proceeds (Gauch, 1982). Thus, the four major groups, subsets (100), (101), (110) and (111) will be used for studying the relationship between vegetation and environmental variables.

Table 1. *Indicator species of the complete data set valuable for the separated subsets by* TWINSPAN. *The Eigenvalues from the first to the seventh divisions are respectively 0.54, 0.185, 0.274, 0.16, 0.185, 0.22, 0.10*

| Division | Negative group | Cover | Frequency | Positive group | Cover | Frequency |
|---|---|---|---|---|---|---|
| First | Anem nem | 0.5 % | -77, 0 | Brac rut | 0.5 % | 0, +82 |
| N= 169 | Lami gal | 0.5 % | -77, 0 | - | - | - |
| | Fiss tax | 0.5 % | -71, +1 | - | - | - |
| | Eury pra | 8.75 % | -77, +6 | - | - | - |
| Second | Ranu fic | 0.5 % | -23, +1 | - | - | - |
| N= 81 | Aego pod | 0.5 % | -15, 0 | - | - | - |
| | Urti dio | 0.5 % | -21, +2 | - | - | - |
| | Anem nom | 18.75% | -23, +8 | - | - | - |
| | Hera sph | 0.5 % | -22, +8 | - | - | - |
| Third | - | - | - | Poly for | 0.5 % | 0, +39 |
| N= 88 | | | | | | |
| Fourth | Stac syl | 0.5 % | -4, +2 | Oxal ace | 0.5 % | 0, +19 |
| N= 28 | Ranu rep | 0.5 % | -4, +4 | Frax exc | 0.5 % | 0, +16 |
| | Urti dio | 3.75 % | -4, +4 | - | - | - |
| Fifth | Holc mol | 0.5 % | -29, +1 | - | - | - |
| N= 53 | Oxal ace | 0.5 % | -29, +3 | - | - | - |
| Sixth | Eury pra | 0.5 % | -9, +2 | Atri und | 0.5 % | 0, +31 |
| N= 49 | | | | | | |
| Seventh | - | - | - | Dic het | 0.5 % | -2, +10 |
| N= 39 | - | - | - | Poly for | 0.5 % | -2, +8 |
| | - | - | - | Pter aqu | 18.75% | -5, +7 |

### Statistical analysis of soil pH at different depths

Results of clustering analysis (TWINSPAN) indicated that four vegetation groups have different characteristics from on edaphical point of view. Herbal and moss species within vegetation groups have different tendency to soil properties in two forest stands of study area (*oak-beech* and *ash).*

Marked differences are frequently observed in the pH of different layers in a soil sample. The H layer and 0-5 cm soil depth are commonly more acid than other layers. Maximum pH values were encountered in the sub-mineral layer. The comparison of the summary statistics of the pH at ectorganic horizons indicates that the mean value decreases with increasing depth. The coefficient of variation however increases slightly with increasing ectorganic depth. This confirms that nevertheless a decrease of the mean value with soil depth, the relative variability increases slightly with depth. This variability at the ectorganic horizons may be related to the discontinuity of the ground vegetation, the variable depth of the litter and differences in the supply of free calcium. Several studies have documented the mean and coefficient variation in soil pH at the levels similar to those we have found. Lowe (1972) measured pH-H2O at the ectorganic layers within a mixed hardwood stand. He found that the pH was the highest in the L layer, slightly lower in the F layer and the lowest in the H layer. The mean value of pH at mineral layers increases as the soil depth increases.

Summary statistics of the pH-$H_2O$ at different soil depths (L, F, H, 0-5 cm & 5-15 cm) is given in Table 2. Soil pH at layers H, 0-5 cm and 5-15 cm have distributions which depart from normality. This is indicated by the highly significant skewness (g1> 0) and kurtosis (g2> 3) values using a t-test (Van Meirvenne, 1991). The soil pH at the F layer shows a smaller deviation from a normal frequency distribution, although the kurtosis coefficient is still significant. All data sets of pH at the L layer are not significantly different from normal distribution (Table 2 and Fig 4).
Nevertheless, some soil variables could be normalized by a log-transformation. But, soil pH is already a negative logarithm of the active hydrogen ion concentration in solution. A geostatistics analysis has no strict requirement for data to be normally distributed (Van Meirvenne, 1991).

Table 2. *Descriptive statistics of soil pH at different depths*

| Statistical parameter | L | F | H | 0-5 cm | 5-15 cm |
|---|---|---|---|---|---|
| Number of samples | 117 | 103 | 80 | 117 | 117 |
| Mean | 5.18 | 4.52 | 4.09 | 4.23 | 4.27 |
| Variance | 0.21 | 0.22 | 0.23 | 0.26 | 0.24 |
| Std. Deviation | 0.45 | 0.47 | 0.48 | 0.51 | 0.49 |
| Coef. Variation % | 8.7 | 10.4 | 11.7 | 12 | 11.5 |
| Skewness (g1) | 0.20 | 0.53* | 1.9*** | 1.65*** | 1.59*** |
| Kurtosis (g2) | 2.21 | 2.2 | 7.17*** | 5.57*** | 5.99*** |
| Minimum | 4.23 | 3.59 | 3.43 | 3.60 | 3.49 |
| Median | 5.16 | 4.38 | 3.98 | 4.10 | 4.20 |
| Maximum | 6.23 | 5.59 | 5.88 | 6.10 | 6.03 |

*, **, ***: Significant at P = 0.05, 0.01and 0.001respectively

Moreover, some problems exist in back-transforming logarithmically transformed data. Thus, the data were not transformed to allow for unbiased comparisons among variables and sites (Isaaks & Srivastava, 1989).

Plant species exerts a strong influence on soil acidity through the litter which it supplies. The species whose foliage contains a high content of bases tend to prevent the development of excessive acidity in the surface soil layers. In fact, instances are known where the surface soil layers are less acid than deeper layers because of this concentration of bases in the litter (Lutz & Chandler, 1949; 1963; Pritchett & Fisher, 1987). Vegetation group 1 with typical nitrophile species and group 4 with acidophile species indicated, respectively a higher and a lower pH value than other groups at ectorganic and mineral layers.

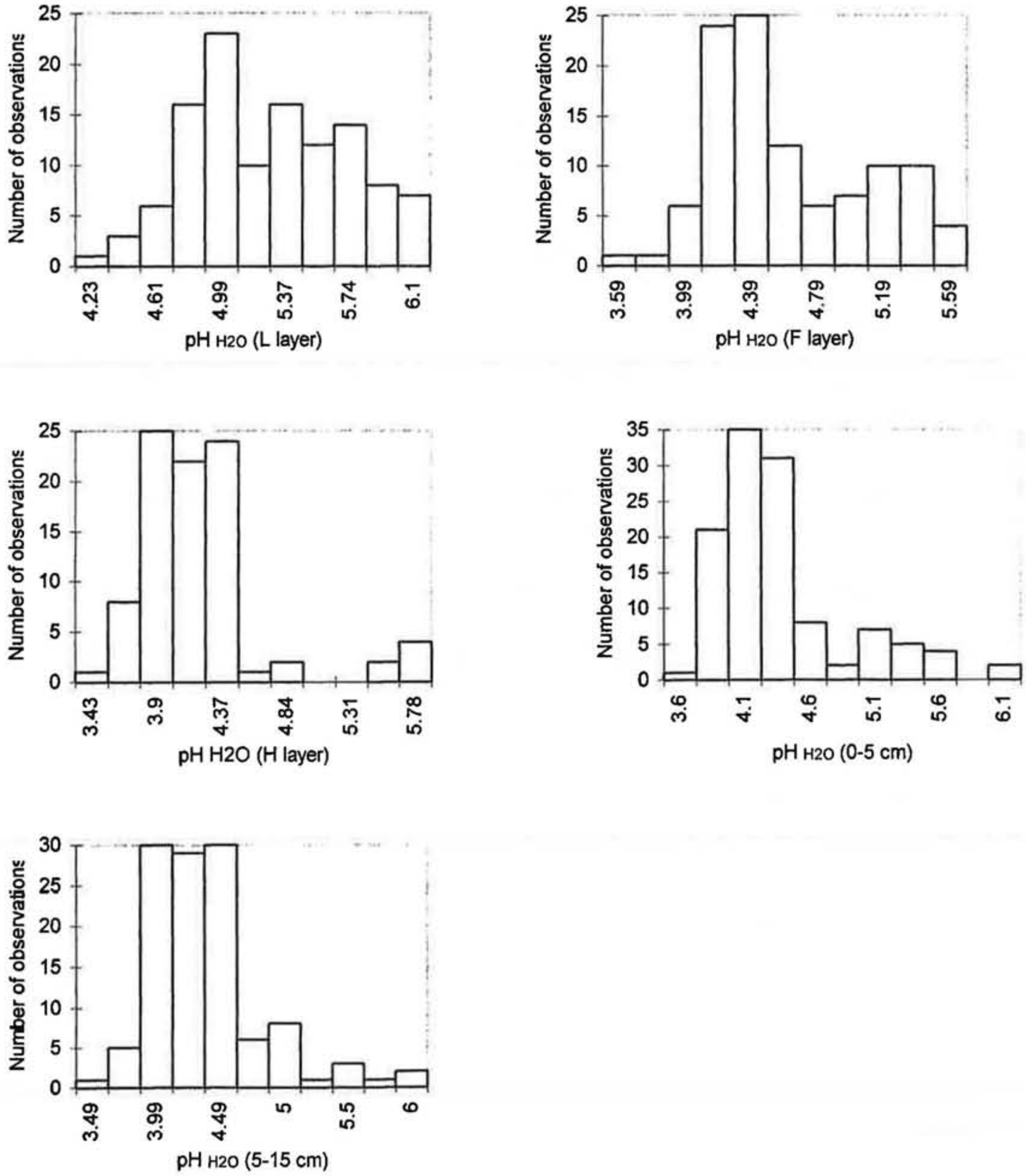


Figure 4. *Frequency distribution of* pH-$H_2O$ at *different soil depths.*

Multiple comparisons of soil pH were tested at different depths among vegetation groups. The results of the Tukey tests indicated that the pH between these groups varies strongly significantly. No significant differences were found between group 3 and group 4 for the L and F layers (Table 3a), since the vegetative elements are relatively similar to each other. The reason for these differences between other groups may be related to the clustering analysis or other factors like litter quality and humus type. No significant differences in soil pH at top-mineral layers (0-5 and 5-15 cm) were present between vegetation groups 3 and 4 and between groups 2 and 3 (Table 3b).

Result of mean comparison (t-test) analysis of pH at different soil depths was found to be significantly differences between these two stands (Table 3c).

Table 3a. *Multiple comparisons of pH of the ectorganic horizons between vegetation groups using the Tukey tests*

| | Group 2 | | | Group 3 | | | Group 4 | | |
|---|---|---|---|---|---|---|---|---|---|
| | (L ) | (F) | (H) | (L ) | (F) | (H) | (L ) | (F) | (H) |
| | Mean difference | | | Mean difference | | | Mean difference | | |
| Group 1 | .27$^{*}$ | - | - | .71$^{***}$ | - | - | .87$^{***}$ | - | - |
| Group 2 | | | | .48$^{***}$ | .52$^{***}$ | .21$^{ns}$ | .64$^{***}$ | .68$^{***}$ | .33$^{***}$ |
| Group 3 | | | | | | | .16$^{ns}$ | .15$^{ns}$ | .24$^{***}$ |

Table 3b. *Multiple comparisons of pH of the mineral layers between vegetation groups using the Tukey tests*

| | Group 2 | | Group 3 | | Group 4 | |
|---|---|---|---|---|---|---|
| | 0-5 cm | 5-15 cm | 0-5 cm | 5-15 cm | 0-5 cm | 5-15 cm |
| | Mean differences | | Mean differences | | Mean differences | |
| Group 1 | 0.70$^{***}$ | 0.45$^{***}$ | 0.88$^{***}$ | 0.69$^{***}$ | 1.1$^{***}$ | 0.88$^{***}$ |
| Group 2 | | | 0.18$^{ns}$ | 0.24$^{*}$ | 0.32$^{**}$ | 0.43$^{***}$ |
| Group 3 | | | | | 0.13$^{ns}$ | 0.19$^{ns}$ |

Table 3c. *Mean comparison (t-test) of pH at different depths between oak-beech & ash sites*

| | (L) | (F) | (H) | 0-5 cm | 5-15 cm |
|---|---|---|---|---|---|
| Mean difference | .66$^{***}$ | .69$^{***}$ | .61$^{***}$ | .56$^{***}$ | .53$^{***}$ |

The mean difference is significant at the 0.05 level: $P \leq 0.001$=***, $P \leq 0.01$=**, $P \leq 0.05$=* and ns: not significant

**Spatial analysis**

Semivariograms were calculated using data points of the pH at different depths. The spatial dependence of soil pH was examined by variograms computed in different directions. The structure of the variograms was found to be the same at all directions so isotropy or a similar spatial continuity was assumed.

The parameters of the models fitted to the experimental variograms are given in Table 4. All variograms of the soil pH (ectorganic and mineral layers) could be well fitted by spherical model for their first part (Fig 5).

All relative nugget effects show a minimum value from zero or 5 % of the sill indicating that there was very little small-scale random variability or unpredictability associated with the soil pH values at small lag distances (Table 4).

The structural variance or degree of spatial dependence for each of the six variables was calculated from nugget effect and sill values of each semivariogram. The index of structural variance (C/Sill × 100) in soil pH ranged from 95-100 %, which indicated a high degree of spatial dependence of soil pH at different depths.

The distance over which there was spatial dependence in soil pH differed among ectorganic and mineral layers. In the ectorganic horizons, the range was the same: 50 m. The range of variograms for the pH at 0 - 5 cm and 5 – 15 cm soil depths were 65 and 72 m, being the maximum lag over which the semivariance could be calculated.

Therefore, considering these spatial patterns, the study area could be divided into two different acidity zones on the basis of two different forest and vegetation types.

In general, all variograms increased to the maximum lag over which they were calculated. The variograms were generally similar, reflecting relatively small differences in spatial dependence implying a small-scale spatial pattern of soil pH.

Table 4. *Parameters of the models fitted to experimental variograms of the soil pH*

| Depth | Model | Nugget variance | | C | Sill | Structured part = C/sill ×100 | Range of continuity (m) |
|---|---|---|---|---|---|---|---|
| | | Real | Relative | | | | |
| L | Spherical | 0.005 | 4 | 0.126 | 0.131 | 96 | 50 |
| F | Spherical | 0.000 | 0.0 | 0.135 | 0.135 | 100 | 50 |
| H | Spherical | 0.002 | 5 | 0.042 | 0.044 | 95 | 50 |
| 0-5 cm | Spherical | 0.000 | 0.0 | 0.210 | 0.210 | 100 | 65 |
| 5-15 | Spherical | 0.008 | 4 | 0.175 | 0.183 | 96 | 72 |

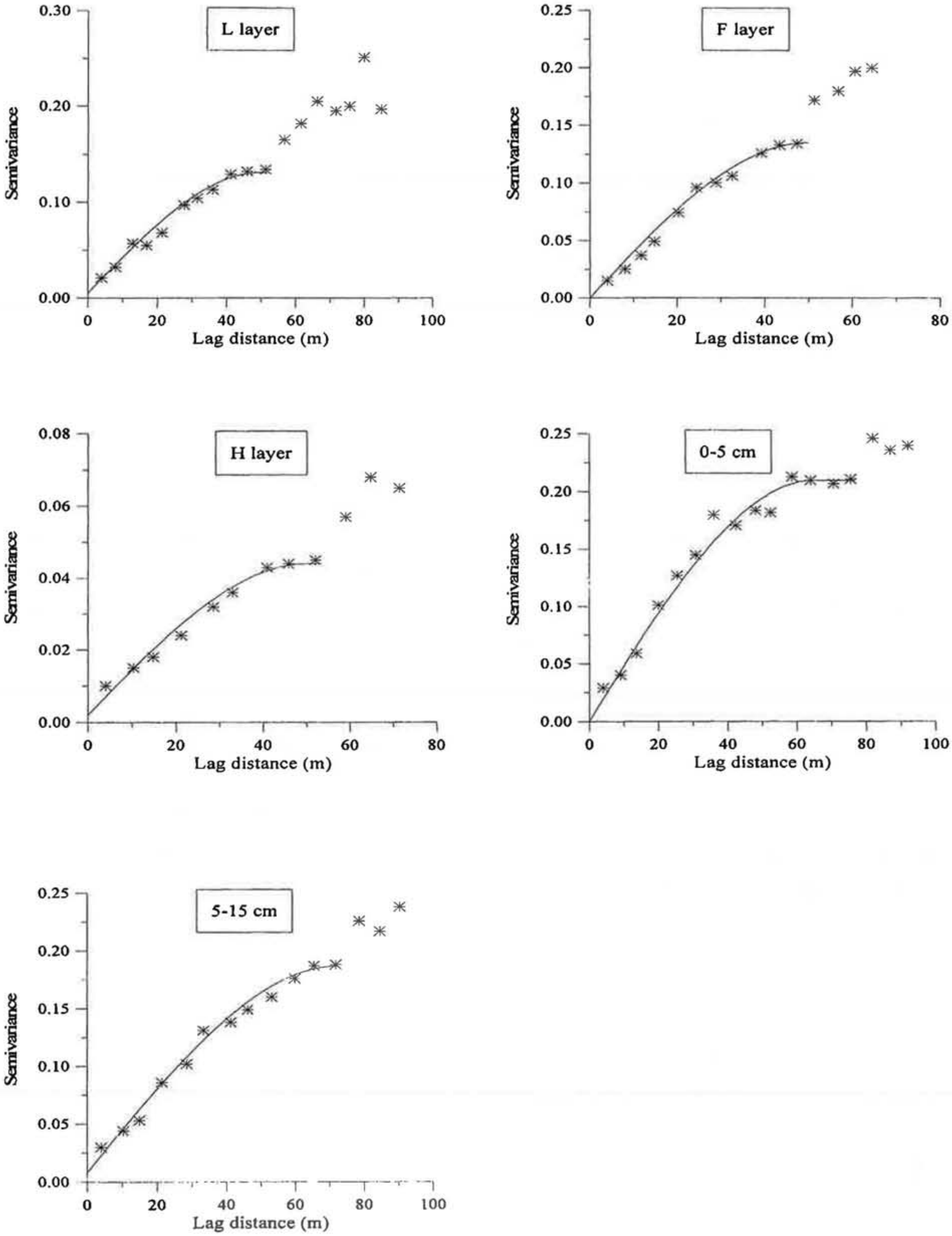


Figure 5. *Experimental variograms (points) and spherical fitted models (lines) of the pH* H2o *at ectorganic and top-mineral layers.*

## Kriging interpolation of soil pH at different depths

Ordinary Kriging was used to predict the soil pH at different depths over the study area. A grid with blocks of 2 × 2 m was used for Kriging interpolation.

As discussed earlier, soil pH in ectorganic layers showed a lower spatial variability than in the mineral horizons. Evidently, the pH within F and H layers was only interpolated for the areas where ectorganic layers were presented.

The Kriged map at L layer (Fig 6) indicated that about 59 % of the interpolated site shows a pH between 4.6 - 5 at the oak-beech stand, while only 5 % of the estimated areas indicate a pH within this range in the ash stand.

The estimated maps at F layers illustrated that about 47 % of interpolated site shows a pH ranging between 4.2 - 4.6, while in the ash stand only 16 % of estimated area indicates a pH within this class (Table 5).

The Kriged map indicated that about 57 and 38 % of the interpolated areas show respectively a pH between 3.8 - 4.2 at H layer for the oak-beech and ash stands (Table 5).

Comparing the interpolated maps for different ectorganic horizons indicate that the pH value decreases with increasing depth in the humus layers. The acidity deposition problem at the H layer is much more server in oak-beech stand than ash stand, which may be affected by several factors like plant species, litter quality and humus characteristics in the study area.

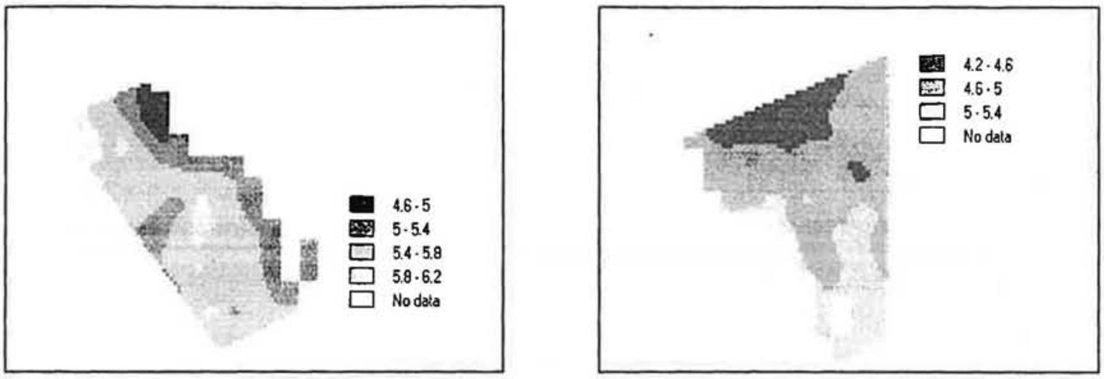
Table 5. *Percentage of the interpolated area for the pH at different depths within two stands*

[Oak-Beech stand}

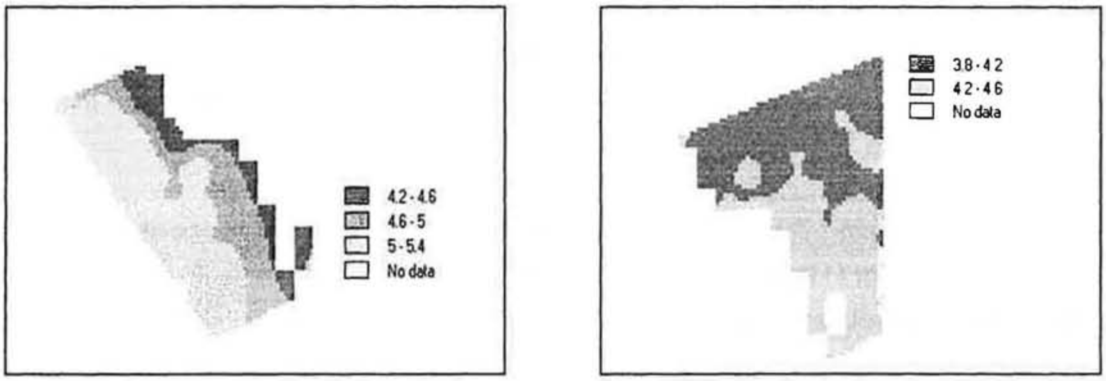
| Range of pH | L (%) | F (%) | H (%) | 0 - 5 cm (%) | 5 - 15 cm (%) |
|---|---|---|---|---|---|
| 3.4 - 3.8 | - | - | 39 | 22 | 14 |
| 3.8 - 4.2 | - | 53 | 57 | 74 | 73 |
| 4.2 - 4.6 | 18 | 47 | 4 | 4 | 13 |
| 4.6 - 5 | 59 | - | - | - | - |
| 5 - 5.4 | 23 | - | - | - | - |

[Ash stand]

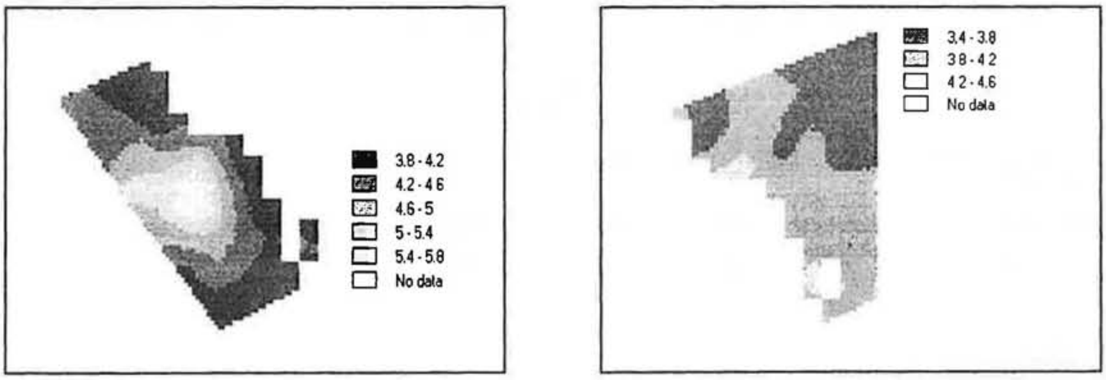
| Range of pH | L (%) | F (%) | H (%) | 0 - 5 cm (%) | 5 - 15 cm (%) |
|---|---|---|---|---|---|
| 3.8 - 4.2 | - | - | 38 | 39 | 20 |
| 4.2 - 4.6 | - | 16 | 29 | 32 | 56 |
| 4.6 - 5 | 5 | 29 | 17 | 18 | 16 |
| 5. - 5.4 | 28 | 55 | 11 | 8 | 4 |
| 5.4 - 5.8 | 59 | - | 5 | 2 | 3 |
| 5.8 - 6.2 | 8 | - | - | 1 | 1 |



Ash stand (L layer) Oak-Beech stand (L layer)



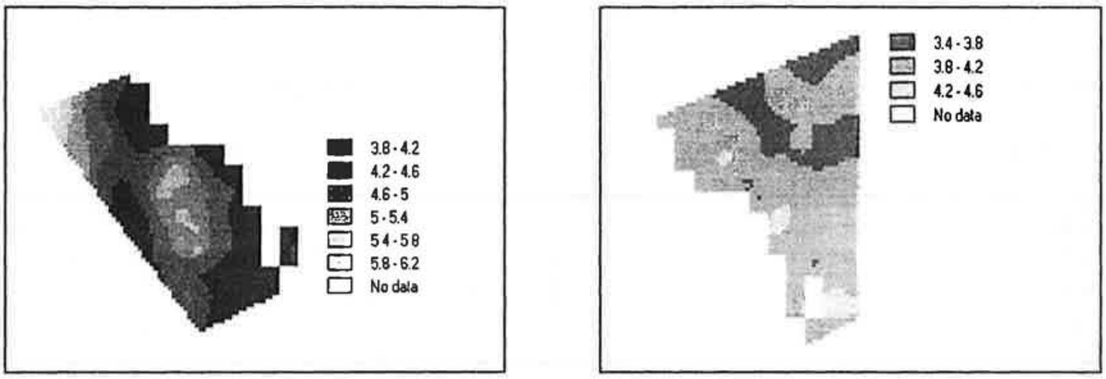
Ash stand (F layer) Oak-Beech stand (F layer)



Ash stand (H layer) Oak-Beech stand (H layer)

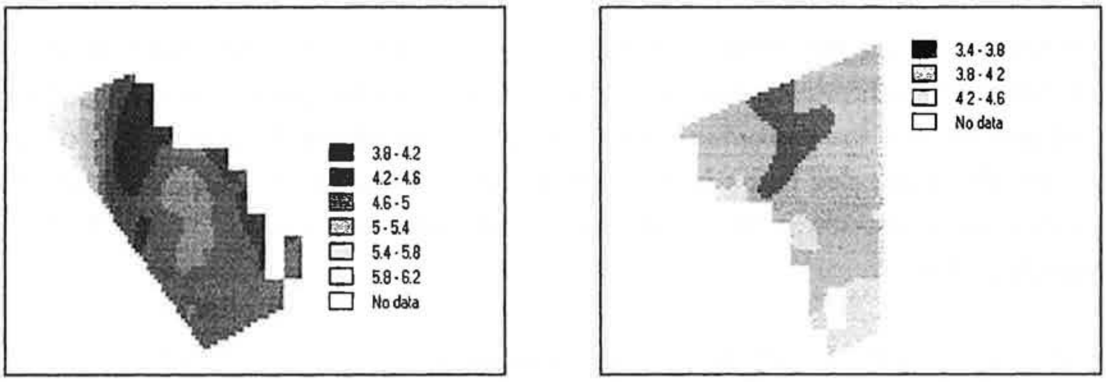
Figure 6. *pH Kriged maps of two different forest types at ectorganic horizons.*

The Kriged maps of the top-mineral (0-5 cm) layer showed that about 74 and 39% of the interpolated areas indicate respectively a pH within the range 3.8 - 4.2 in the oak-beech and ash stand. Whereas, the estimated maps at 5-15 cm soil depth indicated that about 73 and 20 % of the interpolated areas show a pH between 3.8 - 4.2 within oak-beech and ash stands respectively. It implies that the increasing of pH value within oak-beech stand is very slightly with increasing soil depth at top-mineral layers (Table 5 and Fig 7).



Ash stand (0-5 cm)

Oak-Beech stand (0-5 cm)



Ash stand (5-15 cm)

Oak-Beech stand (5-15 cm)

Figure 7. *pH Kriged maps of two different forest types at the top-mineral layers.*

Comparing the Kriged maps between the two stands indicated that the increase of pH within the top-mineral layers with the soil depth was larger in the ash stand than oak-beech stand.

The estimated pH maps on the basis of vegetation groups clearly illustrate a spatial variation. The Kriged maps of ectorganic layers among four vegetation groups showed that the highest and the lowest of pH value within interpolated areas were found respectively for group 1 and group 4. The lowest class of pH value within group 1 (5 - 5.4) is equal to the highest class for group 4 and about 11 % of the estimated area shows a pH in this class for both groups.

Comparing the estimated maps for different depths of the ectorganic horizons indicate that the pH is known to be highly heterogeneous between vegetation groups and is often associated with a variation in plant species (Nykvist and Skyllberg, 1989; Emmer, 1995). However, within areas with a similar vegetative elements and soil characteristic, significant differences in the pH of the humus layers can occur (Nykvist and Skyllberg, 1989).

Spatial heterogeneity in soil pH can vary at the scale of individual vegetation group. The lowest pH value at ectorganic layers can be found at the H horizon with 63 % of the interpolated area ranging between 3.4 - 3.8 within vegetation group 4 (Table 6).

Table 6. *Percentage of the interpolated areas for the pH-$H_2O$ at ectorganic layers within the four vegetation groups*

| Vegetation groups | Group 1 | | | Group 2 | | | Group 3 | | | Group 4 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Range of pH | L(%) | H(%) | F(%) | L(%) | H(%) | F(%) | L(%) | H(%) | F(%) | L(%) | H(%) | F(%) |
| 3.4 - 3.8 | - | - | - | - | - | - | - | - | 18 | - | - | 63 |
| 3.8 - 4.2 | - | - | - | - | 2 | 56 | - | 37 | 75 | - | 70 | 37 |
| 4.2 - 4.6 | - | - | - | - | 23 | 27 | 12 | 60 | 7 | 25 | 30 | - |
| 4.6 – 5 | - | - | - | 8 | 37 | 13 | 55 | 3 | - | 64 | - | - |
| 5 - 5.4 | 11 | - | - | 37 | 38 | 4 | 33 | - | - | 11 | - | - |
| 5.4 - 5.8 | 68 | - | - | 55 | - | - | - | - | - | - | - | - |
| 5.8 - 6.2 | 21 | - | - | - | - | - | - | - | - | - | - | - |

The pH Kriged maps within the top-mineral layer (0-5 cm) indicated that about 12 and 54 % of the estimated areas show pH values in the range of 3.8 - 4.2 for group 1 and group 2. Whereas, about 82 and 64 % of the interpolated areas fall within this interval for group 3 and group 4 (see Table 4.9). The estimated maps at 5-15 cm showed that about 13, 24, 62 and 86 % of the interpolated areas include a pH within the critical range 8 - 4.2 for groups 1, 2, 3 and 4 respectively (Table 7).

Comparing the results of pH Kriging interpolation at two mineral layers showed that the vegetation group 4 is more acid favored than other groups.

Table 7. *Percentage of the interpolated areas for the pH-$H_2O$ at top-mineral layers(0 - 5 and 5 - 15 cm) within four vegetation groups*

| | Group 1 | | Group 2 | | Group 3 | | Group 4 | |
|---|---|---|---|---|---|---|---|---|
| Vegetation groups Range of pH | 0-5 cm (%) | 5-15 cm (%) | 0-5 cm (%) | 5-15 cm (%) | 0-5 cm (%) | 5-15 cm (%) | 0-5 cm (%) | 5-15 cm (%) |
| 3.4 - 3.8 | - | - | - | - | 10 | 14 | 36 | 14 |
| 3.8 - 4.2 | 12 | 13 | 54 | 24 | 82 | 62 | 64 | 86 |
| 4.2 - 4.6 | 26 | 36 | 35 | 66 | 8 | 24 | - | - |
| 4.6 - 5 | 32 | 26 | 11 | 10 | - | - | - | - |
| 5 - 5.4 | 21 | 13 | - | - | - | - | - | - |
| 5.4 - 5.8 | 6 | 12 | - | - | - | - | - | - |
| 5.8 - 6.2 | 3 | - | - | - | - | - | - | - |

**Similarity assessment of two independent maps**

In order to compare the agreement between two independent maps, a cross-tabulation analysis was used for similarity assessment. Since the percentage agreement of agreement in this analysis may be misleading, the Kappa index agreement (KIA) (Cohen, 1960) was also considered for similarity assessment.

The pH Kriged map (pHKG) and vegetation maps were classified based on the results from the TWINSPAN analysis. An ordered cross-tabulation was obtained between the pHKG and the vegetation maps. The similarity between two maps at different depths was studied for the vegetation groups separately.

More detailed statement of accuracy are often derived from the error matrix in the form of an individual class accuracy (Story, 1986). The reason for additional assessment is clear. If a classified map is stated to have a certain value of overall agreement, the value represents the accuracy of the entire way. Therefore, the overall agreement can not show how the accuracy is distributed across the individual classes. Two alternatives might be possible for determining individual classes. One of them can be estimated by the number of correctly classified cells of each pH and the corresponding vegetation group divided by the column total and what is really being measured using this method are errors of omission. Another possibility can be calculated by summing up of the cells of every pH and coinciding vegetation group divided by the row total. In this case, what is being measured are errors of commission. In fact, a better name for the second method may be reliability (Congalton & Rekas, 1985; Story, 1986). Therefore, individual class accuracies are needed to completely assess the value of the classified map for a specific application, like comparing two categories (pHKG and vegetation) within groups.

Comparing the results of cross-tabulation between pH classified maps at different soil depths and vegetation group maps indicated that the overall accuracy of the pHKG at 5-15 soil depth (77 %) with a 64 % KIA improvement in group 4 is the highest agreement in comparison with other layers. Overall accuracy and KIA was found respectively an agreement of 86% and 75% for pHKG at the 5-15 cm soil depth within vegetative elements in two stands (*Oak-Beech and Ash stands*). This study demonstrates that the agreement between pH classes and vegetation groups depends on the species within individual group. The results of the KIA suggest that the classes of pH at the top-mineral layers and vegetation groups illustrate more accuracy in comparison with other layers. Comparing the pH classes with corresponding vegetation categories show that the range, which was defined by Ellenberg et al., (1992) for describing the ecological response of the species to soil reaction, is relatively smaller than for pH kriging interpolation. Nevertheless, the vegetative elements as an indicator value for the soil acidification could be relatively reliable for predicting of soil acidity by cover and composition of the vegetation species.

## Conclusions

Comparing the results of a statistical analysis of the pH at different soil depths showed a trend of variability of individual vegetation group with soil depth.

No significant differences were found between pH at L, F, 0-5 and 5-15 cm depth within vegetation groups 3 and 4 using multiple comparisons analysis (Tukey tests). Soil pH at 15 - 50 cm depths and other layers was found to be significantly different among all groups.

Results of mean comparison (t-test) of soil pH at different depths within two forest types (*oak-beech and ash stands*) showed a high significant differences between the two stands. The low mean value of pH at H and 0-5 cm depths indicates that the oak-beech stand encounters a serious problem for regeneration and survival of forest seedlings. This difficulty could be recognizable in some areas of the ash stand.

The spatial dependence of the pH at ectorganic and top mineral was examined by a semivariogram analysis. All variogerams represented the same range of 50 m for the pH at ectorganic horizons, but the distance of 65 and 72 m were calculated respectively for the pH at 0 - 5 and 5 -15 cm depth. All variograms increased to the maximum lag over which were calculated. We concluded that there exist a small-scale spatial pattern of soil pH in the study area and the distance of spatial dependence was estimated to be half the longest dimension of the investigated zone.

Ordinary block Kriging was used to produce maps of pH estimation at different depths. The result of ordinary kriging estimation indicated that the lowest pH value was found mainly within the oak-beech stand, which contains acidophile species with moder humus characteristics. Whereas, the highest pH values were predicted within ash stand including the nitrophytic species showing typical mull characteristics. It was concluded that the most of area within the oak-beech stand encounter with a critical problem for soil acidification.

Kriged map at ectorganic horizons within four vegetation groups showed that the highest and the lowest pH values were found respectively for groups 1 and 4. It was found that the pH interpolation maps for ectorganic and mineral layers indicated a sever soil acidification problem for the H and top-mineral layers within the two forest types and all vegetation groups.

The result of the similarity assessment between two independent classified maps (pH and vegetation group maps) indicated a large agreement with 64 % of the KIA of pH at 5-15 cm depth. The KIA (75%) showed that the similarity between classes of pH at the 5-15 cm within vegetative elements in two stands was larger than in comparison with other layers.

Comparing pH classes with coincided vegetation groups confirms the range defined by Ellenberg (1992) for describing the ecological response of species to soil acidity, could be relatively reliable for predicting the soil pH by the help of the cover and composition of herbal and moss species in the study area.

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