FOREST RESEARCH BRANCH

SEASONAL pH FLUCTUATIONS IN THE HUMUS LAYER OF SOME QUEBEC FOREST SOILS

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INTRODUCTION

A vast amount of work has been done on soil pH, and some authors (Small 1954, Wilde 1954) have written interesting reviews of literature on the subject, summarizing the various viewpoints and showing what is already proven and what is suspect, as well as what fruitful lines of research remain. It has been shown, for instance, that pH is a figure on a potentiometer, indicating something qualitative and not quantitative, and that its value depends on the extent to which it can be empirically correlated with certain observable phenomena.

Soil pH in itself is rarely responsible for poor forest growth. Within fairly wide limits the "effects" are indirect, varying tremendously from soil to soil, and in the presence of adequate nutrients, many plants will tolerate a range from pH 2.0 to 8.0 (Wilde 1954, Russell and Russell 1950, Lutz and Chandler 1949, and others). This means that pH is not an important factor in itself, but can usefully serve as a qualitative modifier and indicator of soil, humus, or mineral nutrition.

It is known, besides, that pH under field conditions fluctuates with time, and such fluctuations are fairly well documented (Small 1954, Bowser and Leat 1958, Lutrick 1961, Lötschert and Horst 1962). In the study by Bowser and Leat (op. cit.) the pH of the humus layer of a soil fluctuated between 5.8 and 7.8, depending on rainfall and temperature.

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Such fluctuations suggest that pH measurements are chiefly of relative significance, i.e. for making comparisons of the same soil over a period of time, or for making comparisons of different soils at the same time.

One problem is to find out a method of pH determination which would give a value not subject to seasonal fluctuations and which would lend itself to comparison of pH for different sites. Accordingly the objectives of this study were to assess the seasonal fluctuations of humus pH of some commonly occurring soils in northern regions, using different methods of pH determination.

Botanical nomenclature follows Fernald (1950).

I am indebted to many people for assistance during this study and for their criticisms of the manuscript. I would especially like to thank Dr. D.M. Brown and Mr. T.G. Honer of the Department of Forestry of Canada, for having processed the data and performed the statistical analyses.

STUDY AREA AND SOIL TYPES

The area lies at latitude 47°N., longitude 71°W. approximately, and about 40 miles north of Quebec City, in the Laurentide Park. Soils are stony, strongly acid tills of relatively coarse texture, mainly sandy loams. Linteau (1955) first described the forests of the area and more recently Hatcher (1960) collected additional information on those forests which are an important source of balsam fir (Abies balsamea (L.) Mill.) pulp.

Three different morphologically defined forest soil types most commonly found in the Boreal Forest Region (Rowe 1959) of Quebec were examined: an iron humus podzol, a humus podzol, and a hydromorphic bog soil. The podzols were uniform glacial till of sandy loam texture and the peaty soil was typical of the extensive swampy areas found in the region.

Iron humus podzol. This podzol supported a rich, well-drained climax association of balsam fir in mixture with white birch (Betula papyrifera Marsh.) and white spruce (Picea glauca (Moench) Voss). The stand was mature, even-aged with a uniform crown canopy of 80-percent density. The herb layer was well developed, with Dryopteris spinulosa (O.F. Muell.) Watt and Oxalis montana Raf. as dominant species. There were no shrub or bryophyte layers. The soil was characterized by a humus-rich, 2-3-inch thick blackish B_1 layer with a granular structure overlying a rust-coloured B_2 layer ten inches thick. The soil type was found on a middle slope, and the water table was below three feet.

Humus podzol. This soil supported a softwood stand of black spruce (Picea mariana (Mill.) BSP.) and balsam fir located on a lower slope. The herb layer included Oxalis montana Raf. as the dominant species. Bryophytes including Hylocomium splendens (Hedw.) BSG, Pleurozium schreberi (Brid.) Mitt.), formed a discontinuous mosaic on the forest floor. The soil was characterized by a peaty raw humus overlying a 4-inch thick humus-impregnated dark bleached earth. The B layer, 9 inches thick, was dark brown. The water table stayed at about 15 inches during the growing season.

Hydromorphic peaty soil. The bog soil was formed of a F layer overlying thick peat. The water table stayed at or close to the soil surface throughout the field season. The vegetation was entirely made up of Sphagnum mosses and sedges. No merchantable stand grew on this site. Samples were collected at two depths, 5 and 10 inches 3/, respectively.

Analyses of the soil layers of the podzols showed a C/N ratio of about 30 for the H layer and a continual decrease with progression in depth.

3/ For the sake of uniformity, these two depths are also called the F and H layers.

Total cation exchange capacities for the two podzols reflect a large degree of maturity in soil profile development. Total cation exchange capacities were higher in the H layer and progressively decreased down the sola. The pH was lower at the surface and progressively higher with soil depth.

METHODS

The following humus layers as described by Hoover and Lunt (1952) were recognized:

F layer - A layer of partly decomposed litter still recognizable as to origin;

H layer - A layer consisting of well-decomposed organic matter unrecognizable as to origin.

Two adjacent plots 50 by 50 feet in area were established on each of the three different morphologically defined soil types. Within each plot at 10 randomly chosen locations, soil samples were collected from the F and H layers and brought immediately to the laboratory for pH determination. Sampling was made at 8 irregular intervals, some following heavy rains, and others after prolonged dry periods, during the field season of 1962, and each time new locations had, of course, to be chosen.

The writer had conducted preliminary tests in the field with a Beckman pocket pH-meter (model 180) during the years 1960 and 1961, and considerable difficulties in the measurement of soil pH *in situ* were encountered. When the meter was moved from plot to plot it often became disadjusted, and had to be recalibrated using a buffer solution. Moreover, the glass electrode proved to be excessively fragile, and soil particles usually stuck to its sensitive base and thus affected the results.

Finally, fresh distilled water was inconvenient to carry, and the temperature of the soil paste had to be measured each time with a thermometer owing to the large temperature variations from site to site and between different layers of a given soil. As a consequence, the pocket pH-meter was abandoned, and subsequent determinations were made in the laboratory.

Therefore, all pH measurements were made electrometrically with a Beckman pH meter employing a glass electrode. Sticks, stones, and large roots were removed from the soil samples, and the following four methods of pH determination were tried. (I) In the first method, pH was determined using the fresh soil samples and distilled water. About 50 cc of soil was placed in a 100 ml. beaker, and the amount of distilled water necessary to form a soil-water ratio of 1:1 was added. The soil paste thus formed was mixed with a glass rod and left for an hour to reach an equilibrium before measuring the pH. To obtain more consistent results the beaker was shaken constantly while the meter was being read. (II) In this method a 0.1 N KCl solution was used instead of water. (III) Thirdly, soil samples were spread out at room temperature to air dry thoroughly, and pH was determined using distilled water. (IV) Finally, the ten separate thrusts made at random across each plot were composited. Each composite sample was thoroughly mixed and left for 24 hours in water to attain an equilibrium before measuring the pH. In each of the determinations the individual soil samples were equal in size in order not to affect the shape of pH distribution curves (Van Groenewoud 1961).

Analyses of variance for humus pH in relation to soil type, sampling date, and humus layer were run on an IBM 1620 electronic computer. Data represented 10 measurements for each of 8 sampling dates in two plots for each of two layers in three soil types. The analysis was calculated separately for each of the four methods of pH determination and the statistical significance for all items was calculated.

RESULTS AND DISCUSSION

For the three soil types a range of pH from 0.7 to 1.3 was found within each humus layer when sampled at the same time. This may be due to variations in measured pH or, as was shown by Van Groenewoud (1961), to heterogeneous buffering for pH in soil organic layers. Variations of 1.1 to 1.3 of a pH unit in humus reaction with the season were apparent on all three soil types.

The pH of the F layer of a given soil type in most instances was higher than that of the corresponding H layer, and the higher the site class the higher the humus pH (Table 1). It was further observed that method III (H_2O pH) and method IV (H_2O pH, composited samples) yielded very similar mean pH values. Method III, however, gave values more subject to seasonal fluctuations than method IV, as will be shown later.

The pH values obtained with method II (KCl pH) were lower, but more stable, than those obtained with any of the other methods of pH determination. The results obtained with method I (H_2O pH, fresh samples) may be closer to the "true" values, that is, those determined in situ, but they show the largest fluctuations between sampling dates. The seasonal variations in humus pH are shown in Figure 1.

The analyses of variance performed for each soil type within each method disclosed that there were significant variations of humus pH with time when separate thrusts are used. This conclusion is evident from inspection of Figure 1. When the separate thrusts are composited, however, the differences in pH values for different sampling dates failed in general to reach the level of significance. The interaction between sampling dates and soil types, for each method of pH determination, was significant. The seasonal fluctuations in humus pH of a given soil type contributed to very large mean squares for sampling dates.

The significant interaction between sampling dates and soil types can be interpreted as indicating that the three soil types did not behave similarly throughout the sampling period. Significant differences were also found between replicate plots for a given soil type which reflect the wide spatial variations in humus pH for a given soil type.

According to Van Groenewoud (1961) the pH determination of large composite samples is a method which would give a value not subject to seasonal fluctuations and which would lend itself to comparison of pH for different sites. This study supports Van Groenewoud's findings and it is therefore recommended that, when sampling humus for routine pH determinations, large composite samples be used rather than the average value of small separate thrusts.

It is of interest to note that Nichol and Turner (1957) discussed some of the difficulties encountered in interpreting the results of pH measurements of soils made in the laboratory in terms of field conditions. They pointed out that none of the methods gives results that can be related to field conditions, as far as pH is concerned. The following year, Turner and Nichol (1958) presented a means of calculating the pH of strongly acid soils under field conditions. Gorham (1960) reported the range of pH values obtained from different humus types by three methods, that is, direct insertion of glass electrodes into the soil, expressed solution, and aerated solution. Maximum differences among the three methods averaged 0.9 units in <u>mors</u>, 1.6 units in <u>mulls</u>, and 1.8 units in lake muds.

Considerable research has been done attempting to relate periodic climatic factors, especially rainfall and temperature, to pH in soils where seasonal fluctuations in humus pH have been observed. Recently Bowser and Leat (1958) determined seasonal fluctuations in pH values on soil samples from a modal Grey Wooded soil in Alberta. They found a maximum seasonal fluctuation of 2.0 pH units. These fluctuations appeared to be related to the soil moisture, and possibly to the soil temperature regime. In 1957, Manninger correlated periodic fluctuations of soil pH with periodic changes in the bacteria population, the soil moisture content, and the soil temperature.

Schütte and Elsworth (1954) showed that there are very marked pH fluctuations in soft-water vleis of South Africa. The cause of this variation in pH would be due to the removal of carbon dioxide from the water by photosynthesis. This would modify the buffering of the water. The large fluctuations in pH -- 1.5 units or more -- only occurred during hot sunny weather. According to Gorham (1960), in wet soils where escape of respired carbon dioxide to the atmosphere is greatly impeded, higher pH values are obtained after aeration, which reduces carbon dioxide tension to the level of atmospheric equilibration. Yaalon (1957) had noted, indeed, that atmospheric air has a fairly constant content of CO_2, about 0.03 per cent. In the soil atmosphere the CO_2 pressure is somewhat higher, and generally very variable. It may reach values of up to five per cent but varies mostly in the range of 0.2 to 1 per cent (op. cit.).

Small (1954) discussed the possible wide fluctuation in actual pH values for soils of low buffer capacity in relation to the effect of their variations in pH with their carbon dioxide content. He noted that the carbon dioxide content of soils is strongly affected by the microorganisms of the soil. Bacteria often respire at a much higher rate than flowering plants, but the respiration of the roots of the subaerial plants should be also considered in this relation.

The exact rôle that the quantity of rainfall played in this study is not clear. Moisture is undoubtedly important in causing soil pH variations. As the moisture is removed from a given sample of soil, the salt concentration in the solution surrounding the exchange complexes of the soil becomes greater. This will result in a replacement in the complex of H and Al ions, which are both effective in causing acidity in soils, by the mineral cations, causing a reduction in the pH of the solution (Nielsen 1958). The variation in rainfall distribution as shown in Figure 1 does not, however, correspond to the changes in humus reaction with season.

Evidently humus pH is influenced by season and is highest in mid-summer and decreases as winter approaches. A decrease in soil temperature evidently decreases the chemical and biological activity in the humus, which causes a decrease in the soil pH.

In order to make pH measurements meaningful they should be related to perceptible objects such as tree seedlings, surface litter types, soil morphology, etc. As stated by Small (1954) it is not the precise and real pH which is important but rather the degree of correlation between certain objective results and standardized pH measurements. However, the choice of objective factors to which the pH readings have been related in this study is questionable. Temperature and rainfall records from Stoneham may be inadequate insofar as they are not closely correlated with the microclimate of the forest floor where the study was made.

The question of reproducibility of pH measurements itself may be virtually unsolvable because of the influence of extrinsic factors of which combined effects are not themselves reproducible. For example, the combinations of temperature-moisture-microbial activity in humus layers can cause "random" fluctuations in pH, particularly in the range 5.5 to 7.0. At more acid pH's there may be more stability, although this partly depends on how well the system is buffered.

There is a need for a more detailed study of this problem as shown by the data presented. The factors and their interactions affecting humus pH are so numerous that it is often difficult to isolate the one, or the ones, having the greatest influence. Moisture supply, nutrient levels, microbial activity, aeration, and temperature, all of these factors affect pH variously, so that any interpretation of variations in pH must be regarded cautiously. Furthermore, the same factors will not always be related to pH on different sites because those factors most nearly limiting would be expected to have the most pronounced effect.

SUMMARY

The important facts that emerge from this study are that the differences in the reaction of humus layers of different morphologically defined soil types of the area for various sampling dates are highly significant, that when separate thrusts are composited differences in pH values for different sampling dates fail in general to reach the level of significance, and that the differences in pH between sampling dates do not appear to be related to rainfall intensity. A general, but undulating, decrease in humus pH was observed from late spring to fall. Of some interest is the decrease in mean humus pH observed on any sampling date with decreasing site productivity, as measured by site index. Such a

relationship has been noted by Linteau (1955) and by Thomson and McComb (1962). It is suggested that the measured pH of large composite samples should be used as the mean pH, instead of the calculated average of the pH of small samples.

LITERATURE CITED

Bowser, W.E., and J.N. Leat. 1958. Seasonal pH fluctuations in a Grey Wooded soil. Can. J. Soil Sci. 38: 128-33.

Fernald, M.L. 1950. Gray's manual of botany. 8th ed. American Book Co., New York, N.Y.

Gorham, E. 1960. The pH of fresh soils and soil solutions. Ecology 41:563.

Hatcher, R.J. 1960. Development of balsam fir following a clearcut in Quebec. Canada Dept. of Forestry, Forest Research Branch, Tech. Note No. 87. 21 pp.

Hoover, M.D., and H.A. Lunt. 1952. A key to the classification of forest humus types. Soil Sci. Soc. Amer. Proc. 16: 368-70.

Linteau, A. 1955. Forest site classification of the Northeastern Coniferous Section, Boreal Forest Region, Quebec. Canada Dept. of Northern Affairs and National Resources, Forestry Branch, Bull. 118. 85 pp.

Lötschert, W., and K. Horst. 1962. Zur Frage jahreszeilicher pH-Schwankungen. Flora 152: 689-701.

Lutrick, M.C. 1961. The effect of seasonal variation on soil reaction and nutrient status of some Western Florida soils. Soil and Crop Sci. Soc. Fla. Proc. 21: 179-85.

Lutz, H.J., and R.F. Chandler, Jr. 1949. Forest Soils. John Wiley and Sons, Inc., New York. 4th ed. 514 pp.

Manninger, E. 1957. Untersuchungen über die bodenbiologischbedingten periodischen Reaktionschwankungen der Waldböden. Acta Gron. Acad. Scient. Hungaricae 7: 216-29. In For. Abstr. 20: 503.

Nichol, W.E., and R.C. Turner. 1957. The pH of non-calcareous near-neutral soils. Can. J. Soil Sci. 37: 96-101.

Nielsen, K.F. 1958. Rate of change of pH in some acid soils due to liming. Can. J. Soil Sci. 38: 114-9.

Rowe, J.S. 1959. Forest regions of Canada. Canada, Dept. of Northern Affairs and National Resources, Forestry Branch Bulletin 123. 71 pp. and 1 map.

Russell, E. John, and E. Walter Russell. 1950. Soil conditions and plant growth. Longmans, Green and Co., New York, 8th ed.

Schütte, K.H., and J.F. Elsworth. 1954. The significance of large pH fluctuations observed in some South African vleis. J. Ecol. 42: 148-50.

Small, J. 1954. Modern aspects of pH. Bailliere, Tindall and Cox, London.

Thomson, G.W., and A.L. McComb. 1962. Growth of plantation balck walnut in relation to pH and certain chemical factors of the soil. For. Sci. 8:322-3.

Turner, R.C., and W.E. Nichol. 1958. The pH of strongly acid soils. Can. J. Soil Sci. 38:63-8.

Van Groenewoud, H. 1961. Variation in pH and buffering capacity of the organic layer of Grey Wooded soils. Soil Sci. 92: 100-5.

Wilde, S.A. 1954. Reaction of soils: facts and fallacies. Ecology 35: 89-92.

Yaalon, D.H. 1957. Problems of soil testing on calcareous soils. Plant and Soil 8: 275-88.

Table 1. Measured mean pH of each soil layer for all sampling dates combined, by methods.

Soil type	Iron-humus podzol		Humus podzol		Oligotrophic peat	
Site class	I		II		IV	
Layer	F	H	F	H	F	H
Method of pH determination						
I Fresh + H_2O	3.76 1/	3.61	3.76	3.59	3.52	3.49
II Fresh + KCl	3.05 1/	2.95	3.04	2.88	2.92	2.97
III Dry + H_2O	3.77 1/	3.54	3.78	3.55	3.61	3.51
IV Composited	3.82 2/	3.54	3.77	3.55	3.64	3.56

1/ Mean of 160 pH determinations for each layer by methods I, II, and III.

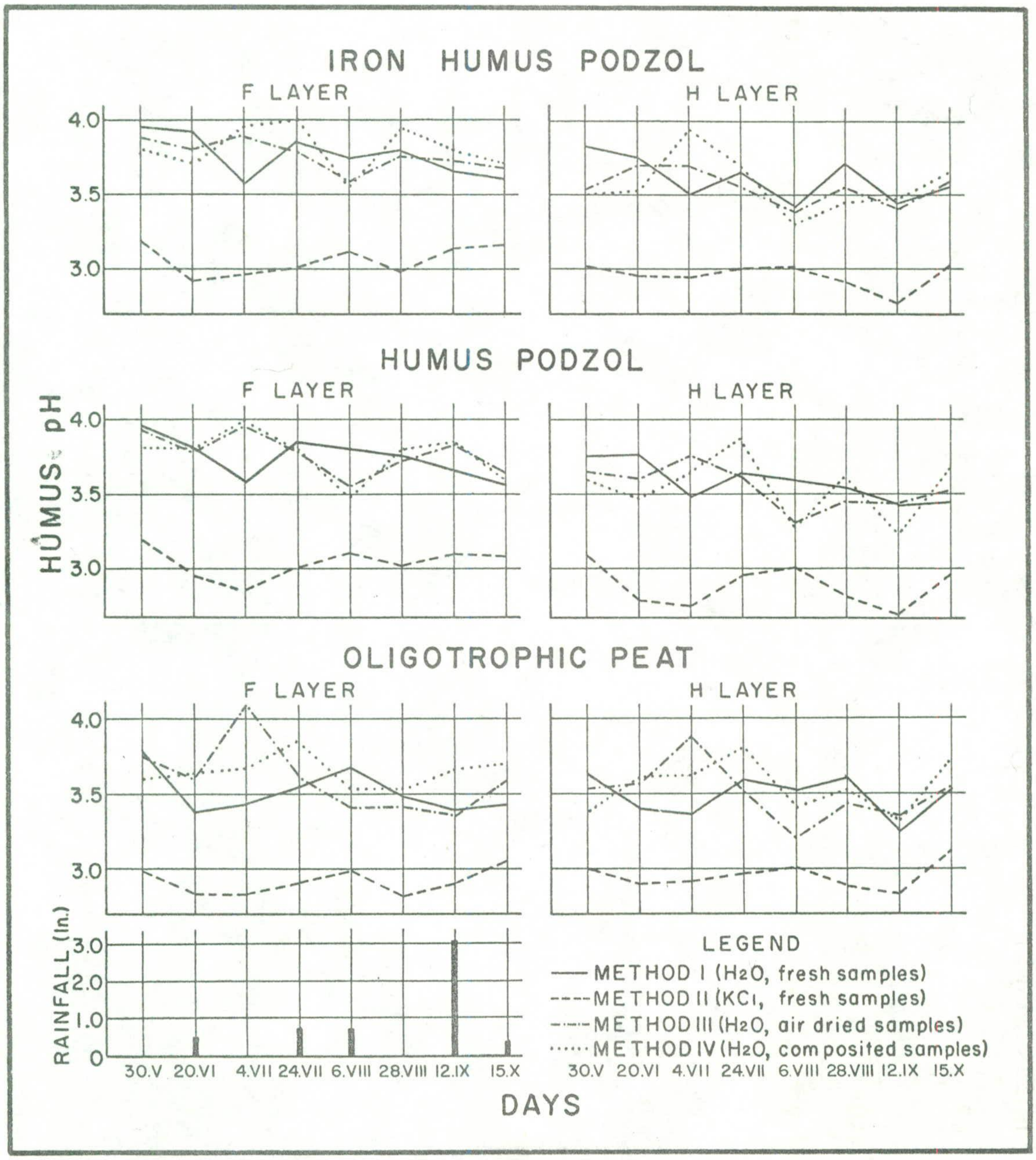
2/ Mean of 16 pH determinations for each layer with method IV.

Table 2. Analysis of variance for humus pH in relation to soil type, organic layer, and sampling date 1/.

Source of variation 2/	Degrees of freedom	Error term
S	2	P:S
L	1	LP:S
D	7	DP:S
SL	2	LP:S
SD	14	DP:S
LD	7	LDP:S
SLD	14	LDP:S
P:S	3	Error
LP:S	3	Error
DP:S	21	Error
LDP:S	21	Error
Error	864	
Total	959	

1/ Data represents 10 measurements for each of 2 layers of 3 soil types with 2 replicated plots per soil type. The analysis was calculated separately for each of 4 methods of pH determination.

2/ S = soil type, L = organic layer, and D = sampling date.



IRON HUMUS PODZOL
F LAYER
H LAYER
HUMUS pH
4.0
3.5
3.0
HUMUS PODZOL
F LAYER
H LAYER
OLIGOTROPHIC PEAT
F LAYER
H LAYER
RAINFALL (In.)
3.0
2.0
1.0
0
LEGEND
METHOD I (H_2O, fresh samples)
METHOD II (KCl, fresh samples)
METHOD III (H_2O, air dried samples)
METHOD IV (H_2O, composited samples)
30.V 20.VI 4.VII 24.VII 6.VIII 28.VIII 12.IX 15.X
30.V 20.VI 4.VII 24.VII 6.VIII 28.VIII 12.IX 15.X
DAYS

Fig. 1