SILVA FENNICA 1985, vol. 19 n:o 1: 73–80

A COMPARISON OF GRAVIMETRIC AND VOLUMETRIC SOIL PROPERTIES IN PEATLAND AND UPLAND SITES

CARL JOHAN WESTMAN, MICHAEL STARR AND JUKKA LAINE

Seloste

GRAVIMETRISESTI JA VOLUMETRISESTI ILMAISTUJEN MAAN OMINAISUUKSIEN VUOROSUHTEITA TURVE- JA KANGASMAILLA

Saapunut toimitukselle 26. 11. 1984

Transects from upland to peatland sites were laid out so as to encounter a wide range of nutritional and hydrological conditions and volumetric soil samples were taken at 20 m intervals. For organic material, in particular peats, the correlations of ignition loss with CEC and total N were clearly higher when the variables were expressed volumetrically. The volumetric expression of variables made comparison of soils with varying organic matter contents possible. In preliminary analyses of the relationships between soil variables and dominant height of the tree stand on mineral soil sites volumetric exchangeable bases, pH and C/N -ratio in the raw humus layer showed a significant correlation.

1. INTRODUCTION

Site classification in Finnish forestry is still based largely on the Cajanderian plant sociological system (Cajander 1909, 1913). Whilst site type plant sociological research has been extensive, minor interest has been focused on the direct relationships between fertility and corresponding site productivity.

For upland site types a positive relationship between productivity and soil nitrogen and calcium content has been generally found while phosphorus and potassium show negative or indifferent correlations (Valmari 1922, Viro 1951, Urvas and Erviö 1974). On virgin peatland the relationships between site type and nutritional factors have been studied in Finland by, for example, Vahtera (1955), Starr and Westman (1978) and Westman (1981). However, the relationships between stand productivity and nutritional factors tend to be overwhelmed by hydrological factors (e.g. Heikurainen 1971). After lowering the water table by drainage the amounts of macro-nutrients in the rooting zone are related to tree growth (e.g. Holmen 1964).

The concentrations of nutrients in the soil are usually expressed on a gravimetric basis. For plant-soil relationships this basis, however, may not be the most suitable expression to describe the nutrient conditions of the soil because of variation in bulk density among different soils and horizons within the same profile. Although requiring more exacting volumetric sampling the expression of soil properties on a soil volume basis is more logical in relation to root exploitation.

We are currently involved in a project which is broadly concerned with the relationships of soil chemical, physical and biological properties to vegetation and stand productivity along transects grading from upland to peatland site types. Some results concerning cellulose decomposition in the peatland sites have already been presented (Laine et al. 1984).

In this paper our aim is, firstly, to examine the differences between certain chemical soil properties when expressed either gravimetrically or volumetrically and, secondly, to study the relationships between the gravimetric and volumetric values. Particular emphasis is given to organic matter content since the supply of nutrients, especially nitrogen, is intimately associated with the decomposition of organic matter. Finally, a preliminary attempt is made to relate these soil properties to stand dominant height in the data for upland sites.

2. MATERIAL AND METHODS

21. Study material

The research was carreid out in the surroundings of the Helsinki University Forestry Station, Hyytiälä, in Central Finland (61° 48'N, 24° 19'E, c. 150 m a.s.l.). The mean effective temperature sum (+5°C threshold) of the area is 1150 d.d. °C. The annual precipitation averages c. 650 mm of which 240 mm falls as snow. The July mean temperature during 1958–1974 was 14.5°C.

In spring 1982 three transects from upland to peatland sites were laid out so as to encounter a wide range of nutritional and hydrological conditions (Figs. 1–3). Sampling points were located along the transects at 20 m intervals and volumetric samples were taken at each point. The upland soils, which were podzolic, were sampled by morphological horizons whereas for the peat soils 10 cm thick samples were taken from the surface down to 30 cm depth. Water table wells were installed at each sampling point and the depth to the water table recorded weekly during the growing season. The tree stand in a circular plot (0.01 ha) surrounding each sampling point was inventoried using standard methods.

22. Soil analyses

Bulk density was calculated from the dry mass of the volumetric samples. The organic matter content was determined as the loss on ignition by ashing to constant weight at 550°C. Particle size distribution of the parent material was determined by the pipette method according to Elonen (1971). Soil acidity was measured from both soil-water and soil-calcium chloride 1:2.5 (v/v) suspensions. The effective cation exchange capacity was calculated by summing the exchangeable acids (Al+H) and bases (Ca+Mg), which were determined from a 2 M potassium chloride extract. Total nitrogen was measured using a standard Kjeldahl method.

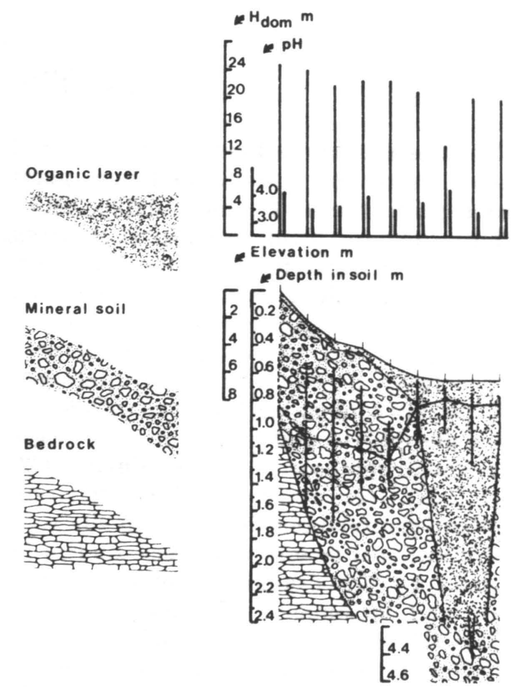

Figure 1. Stand dominant height, pH, elevation, soil depth, and median, max. and min. water table depths along transect 1.

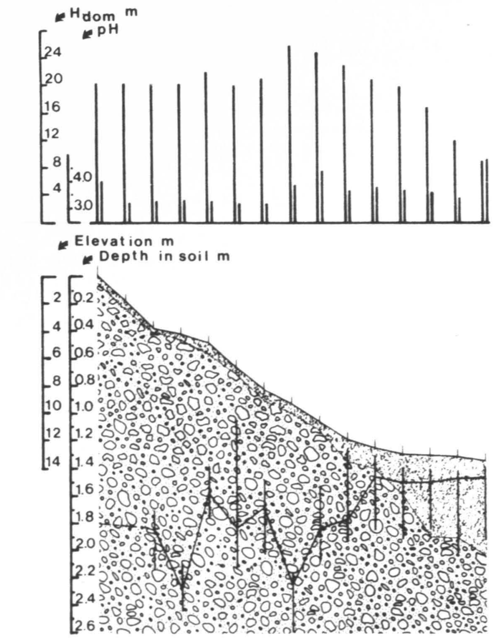

Figure 2. Transect 2 – see Fig. 1 for legend.

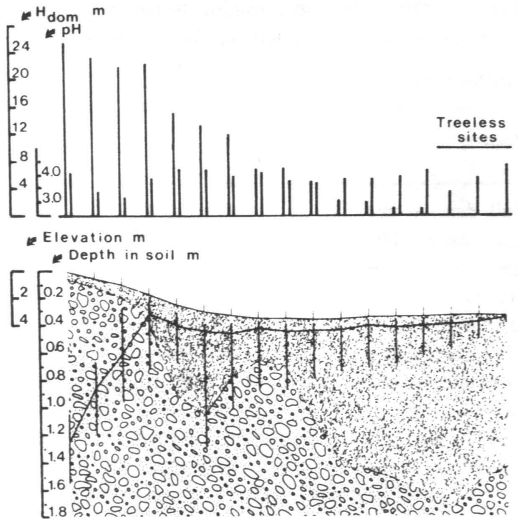

Figure 3. Transect 3 – see Fig. 1 for legend.

3. RESULTS AND DISCUSSION

31. Gravimetric versus volumetric values

Selected soil properties expressed gravimetrically and volumetrically are presented in Table 1. The values given are means and their standard deviations together with significance levels from Kruskal-Wallis one way analyses of variance (BMDP Statistical Software . . . 1983, 3S).

The distribution of organic matter in the upland soil profiles is, as expected, dominated by the raw humus layer. However, when the content is expressed on a volumetric basis this dominance is markedly reduced and the enrichment of organic matter in the B-horizon emphazised resulting in the statistically nonsignificant differences between the horizons. In peats, which have high organic matter contents, the situation is reversed: only the volumetric values differ statistically. The doubling of the amount of solids from the surface to the deepest layer is mainly the result of greater decomposition of the peat.

The cation exchange capacity in the podsolic soil profiles is, when expressed gravimetrically, dominated by the organic matter in the raw humus horizon. This dominance is again reduced when the values are given volumetrically. In the peat soils, because of lower decomposition and thus higher concentration of exchange sites per mass (e.g. Puustjärvi 1956, Greenland and Hayes 1978), the surface peat layer shows a significantly greater gravimetric cation exchange capacity. The high gravimetric CEC of organic matter can not, however, be realized in mineral soil layers because of the dominance of the mineral soil fraction. On a volumetric basis the cation exchange capacity of weakly as well as highly decomposed peat, raw humus and mineral soil horizons is observed to be of similar magnitude.

Soil nitrogen, being strongly related to the organic fraction, varies in the upland site profiles in accordance with the ignition loss. In peat soils the increasing total nitrogen content with increasing depth is largely explained by the collinear trend in bulk density.

Table 1. The mean and standard deviations for the soil properties common to both upland and peatland sites. Significance levels for Kruskal-Wallis one way analyses of variance are also given.

Upland sites

Property	Horizon A_0	E	B	C	Kruskal-Wallis[1]
Bulk den., $g \cdot cm^{-3}$	0.10±0.03	1.06±0.28	1.33±0.22	1.81±0.50	***
Ign. loss, $g \cdot 100\ g^{-1}$	65.2±15.2	3.9±1.9	4.6±2.2	2.0±0.9	***
Ign. loss, $mg \cdot cm^{-3}$	64±21	39±29	60±28	33±14	0
pH H_2O	3.5±0.2	3.9±0.2	4.6±0.1	4.9±0.2	***
pH $CaCl_2$	3.2±0.2	3.5±0.2	4.5±0.2	4.7±0.2	***
CEC, $meq \cdot 100\ g^{-1}$	20.30±3.68	2.81±0.93	1.67±0.59	1.14±0.87	***
CEC, $\mu eq \cdot cm^{-3}$	20±7	28±8	23±10	20±14	0
Base sat., %	40.5±11.2	14.2±5.2	19.9±7.2	30.3±10.7	***
Total N, $mg \cdot g^{-1}$	9.69±1.63	0.63±0.23	0.62±0.24	0.36±0.16	***
Total N, $mg \cdot cm^{-3}$	0.98±0.34	0.62±0.18	0.83±0.37	0.64±0.38	*

Peatland sites

	Layer 0–10 cm	10–20 cm	20–30 cm	
Bulk den., $g \cdot cm^{-3}$	0.06±0.02	0.11±0.33	0.11±0.03	***
Ign. loss, $g \cdot 100\ g^{-1}$	91.9±2.7	92.9±2.6	93.2±4.7	0
Ign. loss, $mg \cdot cm^{-3}$	56±19	97±29	105±27	***
pH H_2O	3.7±0.2	3.9±0.2	3.9±0.3	*
pH $CaCl_2$	3.5±0.2	3.6±0.2	3.7±0.2	**
CEC, $meq \cdot 100\ g^{-1}$	32.33±4.90	24.68±3.97	21.93±3.90	***
CEC, $\mu eq \cdot cm^{-3}$	19±6	25±5	24±6	*
Base sat., %	40.1	45.3	44.3	n.s.
Total N, $mg \cdot g^{-1}$	15.98±3.54	22.30±5.84	23.72±3.69	***
Total N, $mg \cdot cm^{-3}$	1.04±0.54	2.41±1.00	2.62±0.54	***

1) 0=<10 %, * =5 %, = <1 %, *** = <0.1 %, n.s. = non significant

32. Relationships between gravimetric and volumetric values

The main emphasis in this section is laid on the relationships between gravimetrically and volumetrically expressed organic matter contents and selected soil properties. The three groups of soil material (peats, upland raw humus and upland mineral soil horizons) are clearly distinct because of differences in organic matter content and consequently bulk density (Table 1). These differences make it difficult to compare gravimetrically expressed soil variables between the three groups. Using volumetrically expressed values, however, the influence of bulk density is eliminated and the material is made more uniform. This phenomenon is clearly illustrated in Figures 4 and 5.

Spearman rank correlation coefficients for selected variables are presented separately for each soil material group in Table 2. The rank correlation method was used to avoid the possible need to normalise and transform the data. Generally higher correlations are found between variables expressed on the same basis, i.e. gravimetric or volumetric. For raw humus and peats the correlations between the volumetrically expressed variables tend to be stronger than those between the gravimetrically expressed variables. In the mineral soil horizons, which have low organic matter contents, there is little difference between the volumetric and gravimetric correlations.

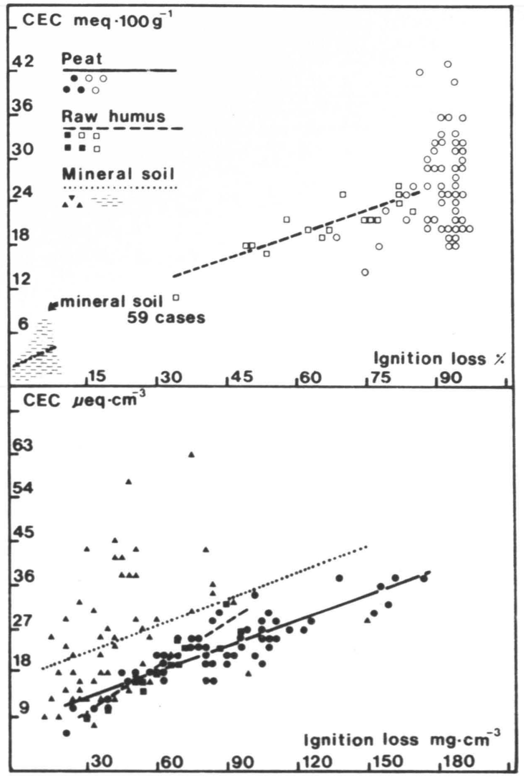

Figure 4. The relationship between ignition loss and effective cation exchange capacity of different soil materials; gravimetric (above) and volumetric (below).

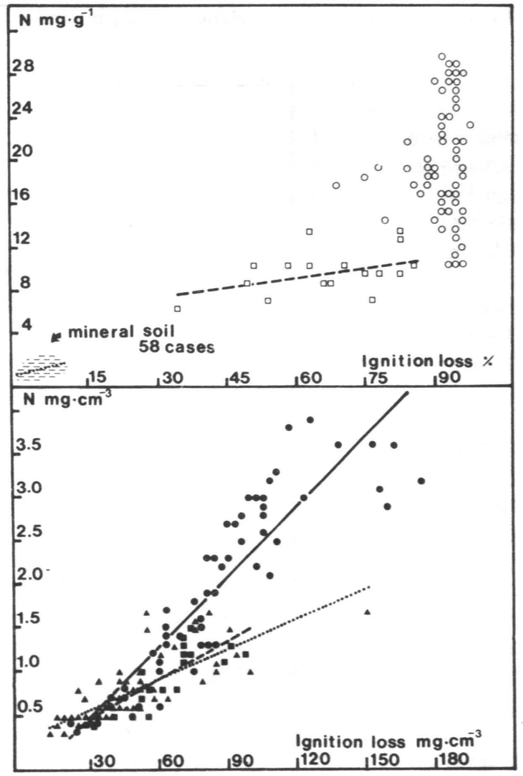

Figure 5. The relationship between ignition loss and total nitrogen in different soil materials. For symbol legend see Fig. 4.

It is of interest to note that for peats both CEC and total nitrogen significantly correlate with ignition loss only when expressed volumetrically.

33. Relationships between soil properties and dominant height

The present material includes sites with excessive soil water as well as sites with soil water deficiency. Those sites with excess soil water were rejected so as to leave a series of upland sites in which the effect of soil moisture (median depth to water table) on dominant height was linear. It was then possible to eliminate the effect of soil moisture on dominant height-soil properties relationships using partial correlation analysis. In this preliminary analysis, dominant height is used to indicate the productivity of the stable, mature stands in the present material.

All the measured and derived variables for each horizon and profile mean, expressed both gravimetrically and volumetrically, were included in the analysis. It was found that for the mineral soil horizons and profile mean none of the soil variables were significantly correlated with dominant height. For the raw humus layer only volumetric exchangeable bases (0.564), pH $_{H_2O}$ (0.701), and C/N-ratio (–0.672) were significantly correlated with dominant height.

Table 2. Spearman rank correlation coefficients between selected soil properties for each soil material group.

		1	2	3	4	5	6	7	8
		Raw humus (A_0)							
						n = 17			
						Critical value (5 %) = 0.490			
Bulk density	1	–							
Ign. loss (g)	2	–.532							
Ign. loss (v)	3	.444	.412						
pH H_2O	4	.431	–.509	–.090					
CEC (g)	5	–.333	.849	.574	–.477				
CEC (v)	6	.679	.028	.875	.096	.297			
Base sat.	7	.385	–.302	.069	.681	–.245	.184		
Total N (g)	8	.029	.410	.645	.061	.578	.532	.238	
Total N (v)	9	.757	–.211	.735	.343	.096	.863	.451	.615
		Mineral soil horizons (E+B+C)							
						n = 56			
						Critical value (5 %) = 0.265			
Bulk density	1	–							
Ign. loss (g)	2	–.525							
Ign. loss (v)	3	.073	.764						
pH H_2O	4	.467	–.343	–.714					
CEC (g)	5	–.439	.556	.287	–.774				
CEC (v)	6	.104	.326	.459	–.534	.799			
Base sat.	7	.340	–.480	–.294	.744	–.779	–.655		
Total N (g)	8	.469	.848	.681	–.332	.597	.425	–.355	
Total N (v)	9	.175	.544	.843	.050	.332	.594	.205	.727
		Peat soils (all layers)							
						n = 63			
						Critical value (5 %) = 0.251			
Bulk density	1	–							
Ign. loss (g)	2	–.120							
Ign. loss (v)	3	.994	–.046						
pH H_2O	4	.522	–.210	.513					
CEC (g)	5	–.748	.089	–.744	–.503				
CEC (v)	6	.832	–.176	.826	.309	–.303			
Base sat.	7	.086	.257	.092	.393	–.103	.062		
Total N (g)	8	.594	–.020	.604	.540	–.546	.366	.034	
Total N (v)	9	.940	–.124	.950	.613	–.744	.746	.058	.777

The relationship between pH of the humus layer and dominant height, which had the highest correlation, is illustrated in Figures 1–3. Acidity determined from soil-water suspensions was used in the analysis because this acidity variable, particularly in peats and raw humus, had higher correlations with the other soil variables than acidity determined from soil-calcium chloride suspensions.

Nitrogen is generally considered to be the most important nutrient factor determining stand growth. In the present study total nitrogen (gravimetric or volumetric) did not, however, correlate significantly with dominant height. On the other hand the C/N-ratio, which indicates the quality of organic matter and thus supply of available nitrogen, was fairly well correlated with dominant height.

4. CONCLUSIONS

It is concluded that there are certain advantages to be gained in using volumetrically expressed data when comparing different soil materials and studying relationships between soil properties and organic matter content. Thus, the pronounced differences in gravimetric cation exchange capacity and total nitrogen between the raw humus and mineral soil horizons are clearly lessened when expressed volumetrically and, in some cases, the trend reversed. In relating stand productivity to soil properties, only the quality of the raw humus, however, seems to be of relevance.

REFERENCES

BMDP Statistical Software, 1983 printing with additions. University of California Press. Berkley, Los Angeles, London. 1983. 734 p.

Cajander, A. K. 1909. Über Waldtypen. Acta For.Fenn. 1(1): 1–175.

— 1913. Studien uber die Moore Finnlands. Acta For. Fenn. 2(3): 1–208.

Elonen, P. 1971. Particle-size analysis of soil. Acta Agr. Fenn. 122. 122 p.

Greenland, D. J. & Hayes, M. B. 1978. The chemistry of soil constituents. John Wiley & Sons. 482 p.

Heikurainen, L. 1971. Virgin peatland forests in Finland. Acta Agr. Fenn. 123: 11–26.

Holmen, H. 1964. Forest ecological studies on drained peatland in the province of Upland, Sweden. Parts I–III. Studia For. Suecica 16. 236 p.

Laine, J., Mannerkoski, H., Starr, M. & Westman, C. J. 1984. Factors affecting microbiological activity in virgin Finnish mire sites. Proc 7th Intern. Peat Congr., Dublin. 1: 268–278.

Puustjärvi, V. 1956. On the cation exchange capacity of peat and on the factors of influence upon its formation. Acta Agr. Scand. 6: 410–449.

Starr, M. & Westman, C. J. 1978. Easily extractable nutrients in the surface peat layer of virgin sedge pine swamps. Silva Fenn. 12(2): 65–78.

Urvas, L. & Erviö, R. 1974. Influence of the soil type and chemical properties of soil on the determining of the forest type. J. Sci. Agr. Soc. Finl. 46: 307–319.

Vahtera, E. 1955. Über die Nährstoffgehalten der für Walderziehung entwässerten Moore. Commun. Inst. For. Fenn. 45(4): 1–108.

Valmari, J. 1921. Beiträge zur chemische Bodenanalyse. Acta For. Fenn. 20(4): 1–67.

Viro, P. J. 1951. Nutrient status and fertility of forest soil I. Pine stands. Commun. Inst. For. Fenn. 39(4): 1–44.

Westman, C. J. 1981. Fertility of surface peat in relation to the site type and potential stand growth. Acta For. Fenn. 172. 77 p.

Total of 15 references

SELOSTE

GRAVIMETRISESTI JA VOLUMETRISESTI ILMAISTUJEN MAAN OMINAISUUKSIEN VUOROSUHTEITA TURVE- JA KANGASMAILLA

Artikkelissa tarkastellaan tiheyden, orgaanisen aineksen, happamuuden, efektiivisen kationinvaihtokapasiteetin, emäskyllästysasteen sekä orgaanisen aineksen sisältämän kokonaistypen vaihtelua maaperässä aineistossa, joka käsittää vähitellen vaihettuvan sarjan kasvupaikkoja luonnontilaisista soista kuiviin kankaisiin.

Analyysituloksia tarkastellaan sekä gravimetrisesti että volumetrisesti. Kun maan orgaanisen aineksen määrä esitetään gravimetrisesti on luonnollista, että kivenäismaan päällä oleva raakahumuskerros dominoi jakaumaa profiilissa. Kun arvot esitetään volumetrisesti (g · cm^{-3}), erot eri morfologisten kerrosten välillä häviävät. Orgaanisten hajoamistuotteiden tendenssi saostua podsolimaannoksen rikastumiskerrokseen on selvä, joskaan ero muihin kerroksiin nähden ei ole merkitsevä.

Orgaanisen aineksen kationinvaihtokapasiteettia pidetään yleisesti suurena kivennäismaahan verrattuna. Maan orgaanisen aineksen merkitys kationinvaihtokapasiteettiin on kuitenkin vähäisempi kuin yleensä oletetaan maa-ainesten erilaisten massa- ja tilavuussuhteiden vuoksi. Tämä käy selvästi ilmi, kun tarkastellaan volumetrisesti esitettyjä vaihtokapasiteetin arvoja.

Maan typpivarojen ja orgaanisen aineksen määrän välillä on kiinteä riippuvuus. Tunnusten välisiä riippu-

vuuksia tarkasteltaessa aineisto jaettiin kolmeen ryhmään: turve, raakahumus ja kivennäismaa. Nämä ryhmät eroavat selvästi toisistaan orgaanisen aineksen määrän suhteen ja tästä syystä niiden gravimetrisesti ilmaistujen ominaisuuksien vertailu ei ole mielekästä. Sen sijaan tilavuusperustaisten tunnusten käyttö mahdollistaa ryhmien keskinäisen vertailun.

Korrelaatioanalyysien tulokset osoittavat, että volumetrisesti ilmaistujen orgaanisen aineksen määrän ja muiden maan ominaisuuksien väliset korrelaatiot ovat kiinteämpiä kuin vastaavat gravimetrisesti ilmaistujen tunnusten väliset, etenkin ryhmissä, joissa orgaanisen aineksen määrä on suuri. Erityisen merkillepantavaa on, että turpeissa kationinvaihtokapasiteetti ja typen määrä korreloivat orgaanisen aineksen kanssa vain jos tunnukset ilmaistaan volumetrisesti.

Maaperän ominaisuuksien ja puuston valtapituuden välistä riippuvuutta tutkittiin osittaiskorrelaatioanalyysillä, jossa pohjavedenpinnan mediaanisyvyyden vaikutus eliminoitiin maatunnusten ja valtapituuden välisestä korrelaatiosta. Koska aineisto on kaksijakoinen hydrologisen tekijän vaikutuksen suhteen rajattiin tarkastelu kivennäismaakohteisiin. Tilastollisesti merkitseviä korrelaatioita esiintyi vain valtapituuden ja eräiden raakahumuskerroksen ominaisuuksien (C/N -suhde, pH ja emäskationien volumetrinen määrä) välillä.