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Small-scale spatial variation in forest soil properties and its implications for sampling procedures

Variabiliteten i några av skogsmarkens egenskaper inom små ytor och dess betydelse för markprovtagningsmetodiken

by

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ABSTRACT

Soil samples from the various horizons have been collected from points in a square lattice in two areas representing typical Swedish forest types, at Garpenberg (60°27′ lat.N, Dalarna) and Vindeln (64°17′ lat. N, Västerbotten). The samples were analysed for N, P, K and loss on ignition, and the values obtained were expressed both as percentages and per unit area. The conclusion to be drawn from the results is that to obtain good precision in analytical values, it is necessary to take a greater number of samples when the results are expressed in weight per unit area than when they are expressed in percentages by weight. As a rule, it is necessary to use samples from at least 10—15 points (often more)—aggregated to a composite sample—to depress the coefficient of variation below 10 per cent for the values per unit area of the studied elements. The paper also contains tables showing the distribution of these elements in the profiles examined.

Introduction

Since statistical methods have become more widely used in biological research, the need for information on the precision of analytical data has increased constantly. In particular, analyses of cultivated soils have revealed great variation in the analytical data even within quite small plots (Ferrari & Vermeulen 1956 p. 115). This problem has been studied in its wider implications within OEEC (Project No. 156, Paris 1956). Hardly any work of a similar nature has been published from the Scandinavian countries, where most profiles are podzols developed in glacial till or glacifluvial sediments. Very little was known about the variability of forest soils in other countries, when the present investigation was planned in 1957. The situation has since improved (Cline & Lathwell, 1963, Ike & Clutter, 1968, Mader & Lull, 1968).

Another phase of the Scandinavian forest soils work has been the formulation of general rules concerning the procedure for collecting soil samples in the field (Gjems *et al.*, 1960). The present work is closely connected with these studies. All sample collection in the field from various soil horizons was done in accordance with these rules, and the details of the method are therefore not repeated here.

Description of sample plots

The sample plot at *Garpenberg* /about 225 m S of Getmossen (a small farmhouse)/ is situated 196 m above sea level immediately above the highest postglacial shore line.

The soil consists of a sandy-silty till (Table 1) which is fairly typical of Sweden in its grain-size distribution. This type of till has been described in detail by Troedsson & Lyford (not yet published).

The topsoil is a podzol (Typic Fragiorthod) of a type indicating a favourable site. The underlying rock of the leptite formation usually produces soils relatively poor mineralogically. The till contains an admixture of diabases, hyperites and other greenstones which together with historical circumstances (grazing, etc.), may explain a tendency to formation of brown podzolic soil in patches. A_0 = 7.0 cm; A_1 = 4.4 cm; B = 16.5 cm; (A_2 very irregular, often lacking).

Vegetation: The stand (see Fig. 1) consist of Norway spruce (*Picea abies*),

Fig. 1. Sampling at Garpenberg. — Photo C. O. Tamm.

site quality class 6 m³ per hectare, age class V, stocking density 0.6. The lesser vegetation is described below (October 1957):

Shrub layer:	Sorbus aucuparia (small shrubs)	1
Dwarf shrubs:	—	
Herbs:	Majanthemum bifolium	1
	Melampyrum silvaticum	2
	Solidago virgaurea	1
	Veronica officinalis	2
	Viola sp.	2
Grasses:	Agrostis tenuis	1
	Deschampsia flexuosa	3—4
Grasses:	Festuca rubra	1
	Luzula pilosa	3
Mosses:	Dicranum rugosum (undulatum)	2
	Dicranum scoparium	2
	Hylocomium splendens	5
	Pleurozium Schreberi	4
	Ptilium crista castrensis	2
	Rhodobryum roseum	2
Lichens:	—	

(Coverage scale 1 = single, 2 = sparse, 3 = scattered, 4 = frequent, 5 = abundant, according to the Hult-Sernander-Du Rietz scale)

The sample plot at *Vindeln* is situated 162 m above sea level, near river Vindelälven. *The soil* consists of deep outwash sand of glacifluvial origin, in places coarse sand (see Table 2). The material has been carried a long way by glacial streams and is rich in quartz. As a quaternary glacifluvial deposit it is typical of Swedish conditions. Similar deposits are very common along the river valleys of northern Sweden.

The topsoil is a lichen podzol (Typic Haplorthod, A_2 very weak). The underlying rock consists of an acid gneiss, but owing to the movement of ice and the general direction of transport, most of the sand material originates from so-called Revsund granites. $A_{00} = 2.7$ cm; $A_0 = 1.7$ cm; $A_2 = 3.2$ cm; $B = 24.5$ cm.

Vegetation: The stand consists of Scots pine (Pinus silvestris), site quality class 1 m³ per hectare, age class V, and the vegetation consists of:

Dwarf shrubs:	Calluna vulgaris	4
	Vaccinium vitis-idaea	4
Mosses:	Pleurozium Schreberi	5
	Dicranum (rugosum and scoparium)	4
Lichens:	Cladonia (rangiferina and silvatica)	4

The two sample plots at Garpenberg and Vindeln thus represent two typical Scandinavian forest types. As already noted the Garpenberg plot lies considerably farther south, and this forest soil type is very common in Sweden. It may be added that the site quality of the Garpenberg plot is higher than the average of the region.

The Vindeln plot is in its way typical of the "lichen-pine" forests on coarse-textured sediments of northern Sweden, and the low yield is also typical of such sites. By and large, it might be said that the larger part of Sweden's forests is ecologically similar to these sites, or intermediate between them. Common exceptions are slopes with flushing, areas with lime-rich Cambro-Silurian material in the soil or sites with a high water table. Their variability in the respects dealt with in this paper remains to be studied.

Sampling procedure

The sample plots in each type of forest were selected as uniformly as possible. The soil was examined outside the sample plots before sampling from the plots commenced. The two sample plots, measuring 9×11 and 10×10 metres respectively, were then divided up by strings pegged out in

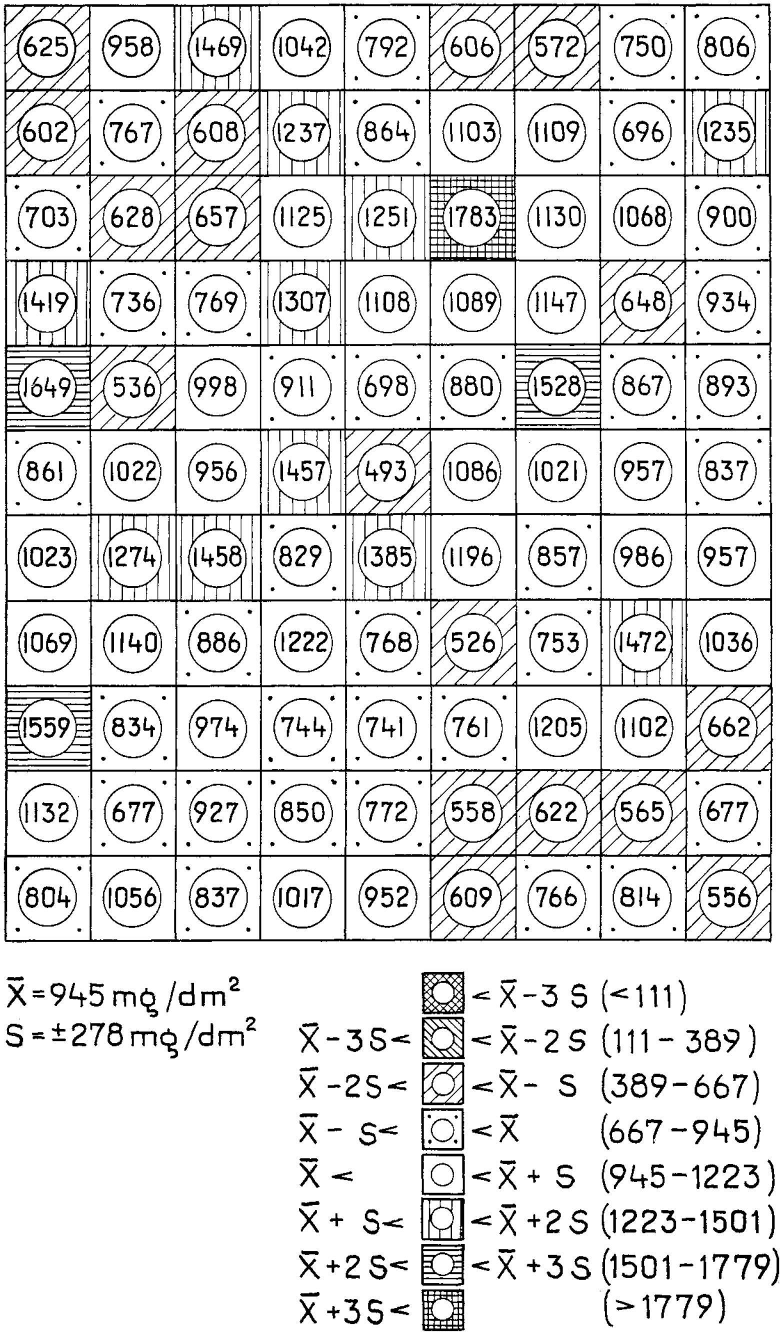

Fig. 2. Garpenberg: Variation in total nitrogen (mg/dm²) within a small area (9 m × 11 m).

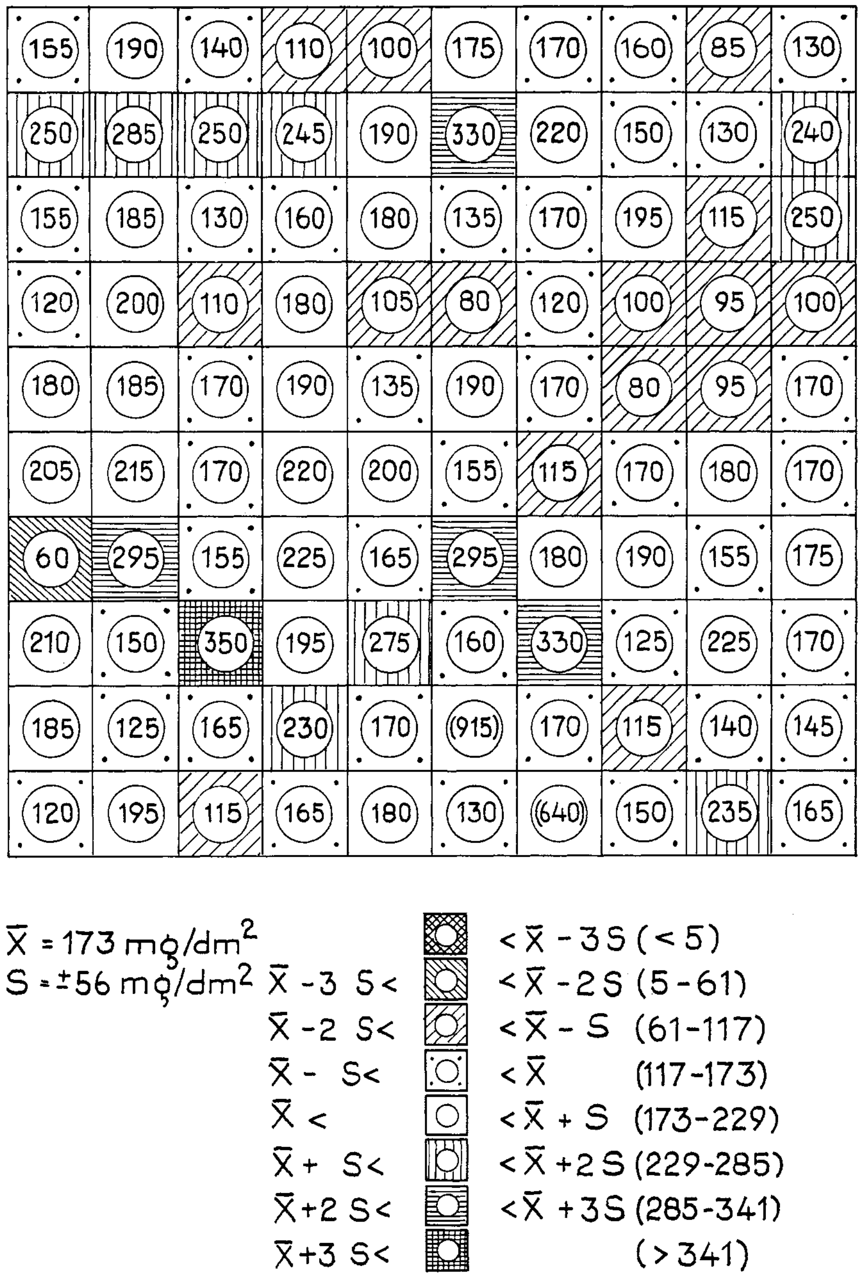

Fig. 3. Vindeln: Variation in total nitrogen (mg/dm²) within a small area (10 m × 10 m).

one-metre spacing (see Fig. 1). Samples of the A horizon were taken at the points of intersection between strings (A_0 and A_1 at Garpenberg, A_0 and A_2 at Vindeln) with a cylindrical core sampler which extracted samples from an area of about 1 dm^2. About 100 samples were thus obtained from each plot. Some results are shown in Figs. 2 and 3.

Twenty sample holes—likewise in a square lattice—were dug for analysis of mineral soil samples. All horizons in these holes were sampled by cutting out areas of 4 dm^2, the A horizons being sampled *in toto*. The B and C horizons were likewise sampled so that the figures obtained could be expressed both as percentages by weight and in terms of area. The analyses of these profiles are given in Figs. 6—7 and Tables 3—4.

As mentioned earlier, the sampling procedure agreed with the general recommendations jointly established for Denmark, Norway and Sweden (Gjems *et al.*, 1960).

Chemical analyses

The preparation of the samples for analysis and the determination of loss on ignition took place at the Department of Plant Ecology and Soil Science of the Royal College of Forestry. Other analyses were performed at the National Laboratory for Agricultural Chemistry, according to their methods developed for agricultural soil testing. (Kungl. Lantbruksstyrelsen/Swedish National Board of Agriculture/, 1950, 1959 and 1961).

Preparation of samples for analysis: Humus samples were sieved (for removal of living roots, etc.) and were then ground and mixed thoroughly. Mineral soil samples were sieved through a screen with 2-mm round mesh. Weights of material greater and less than 2 mm in diameter were determined. Only the fractions < 2 mm were analysed. The analyses are given in Tables 3 and 4.

pH was determined in both water extract and KCl solution. The measurements were made with a glass electrode.

Loss on ignition: The soil sample was dried to 105°C, weighed after cooling and then ignited to about 550°C. The loss is expressed as a percentage by weight.

Nitrogen: Total N was determined by the macro-Kjeldahl process, Cu and Hg being used as catalysts (Kungl. Lantbruksstyrelsen 1950).

Phosphorus was determined both by the acid lactate extraction process

(P-AL) and by extraction with hydrochloric acid (P-HCl), according to EGNÉR *et al.* (1960).

Potassium was determined both by the acid lactate extraction (K-AL) and by extraction with hydrochloric acid (K-HCl), according to EGNÉR *et al.* 1960 and Kungl. Lantbruksstyrelsen 1961.

Statistical analysis

The main object of the present investigation has been to study the sampling density required for obtaining acceptable precision in the analytical values from some common types of forest soil analysis. Estimated mean values $(\overline{x})$ and standard deviations (S) of the chemical analysis results are shown in Table 5. The problem may be formulated briefly as follows: how many sampling points per unit area must be used to ensure that a predetermined level of precision will be reached in the chemical analysis values? It is assumed here that the soil samples from the required number of sampling points are aggregated to form a composite sample which is well mixed prior to the extraction of a small aliquot for chemical analysis. The calculations are strictly valid only if the sampling points are in a square lattice of the density used here, but a completely random sampling would probably give very similar results. Note that a square lattice sampling must be avoided where silvicultural treatments (e.g. planting or soil working) have been made in rows.

As was mentioned earlier, the two types of forest were selected as being typical of firstly, an "average" till and secondly, a poorer soil (but "average" of its kind) on deep outwash sand.

The calculations were made according to the following formulae:

$$\overline{x} = \frac{1}{n}\Sigma x_i$$

$$S^2 = \frac{1}{n-1}\Sigma(x_i - \overline{x})^2$$

x_i	individual observations
$\overline{x}$	average of all x_i
n	total number of sampling points
S	standard deviation
S^2	variance

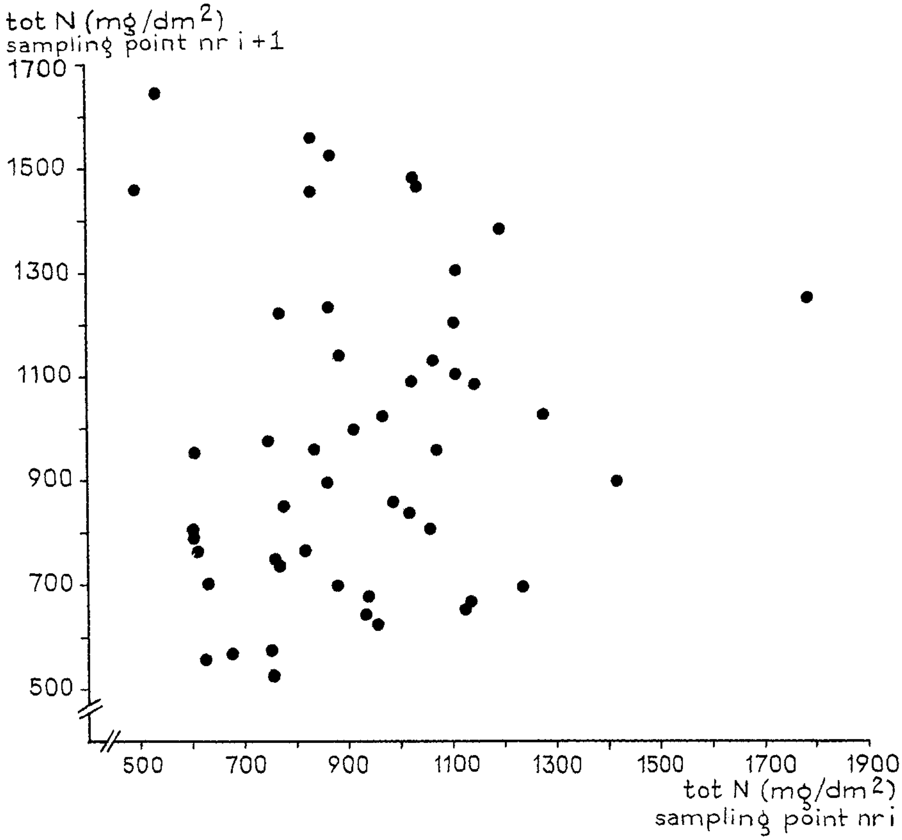

Fig. 4. Diagram showing that there is probably no correlation between values from sampling points one meter a part at Garpenberg.

The formula for the standard error presupposes that there is no correlation between values from sampling points near each other. As may be concluded from Fig. 4 and 5 this assumption seems to be fulfilled for points one meter a part.

If we need a standard error of $p\%$ of the mean we can use the approximate formula

$$\frac{S}{\sqrt{n}} = \frac{p}{100} \cdot \bar{x}$$

From this we obtain

$$n = \left(\frac{S}{\bar{x}} \cdot \frac{100}{p}\right)^2$$

Only the data for the loss on ignition and the N determinations have been based on the larger material of some 100 auger samples from each plot. In the

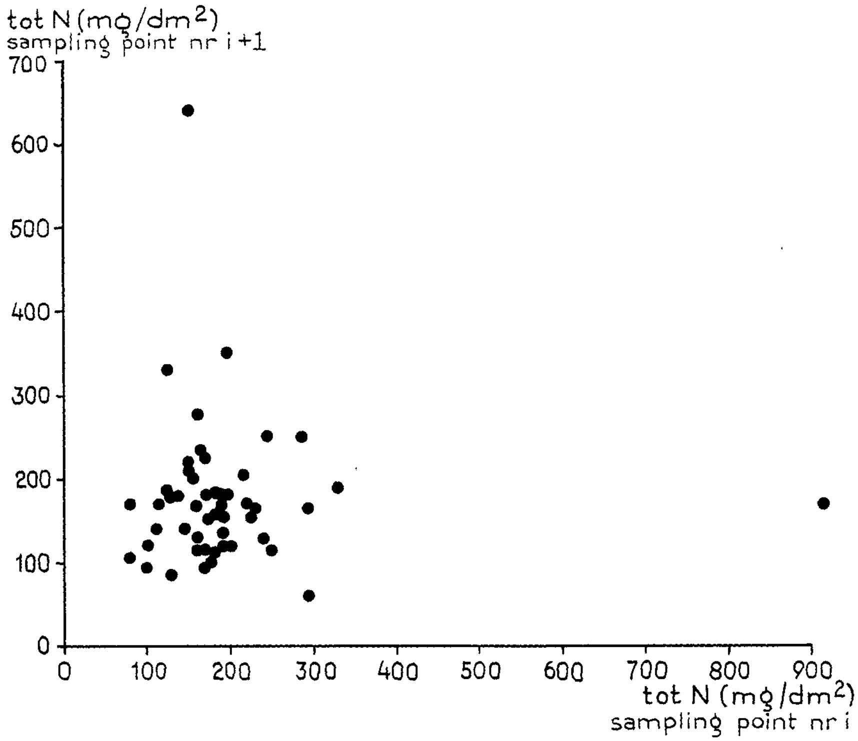

Fig. 5. Diagram showing that there is probably no correlation between values from sampling points one meter a part at Vindeln.

other tables, the number of samples taken was only 20, spaced in a square lattice. The sampling method was fairly simple and the volume determinations not very accurate. Some of the estimates in Table 5 are inaccurate because the number of samples was insufficient, but nevertheless they have been included for the sake of completeness.

Discussion of some analytical data from the two plots

As mentioned above the two sample areas—Garpenberg and Vindeln—represent two different but common forest site types in Sweden. General conclusions from results from these two sites will therefore have a fairly

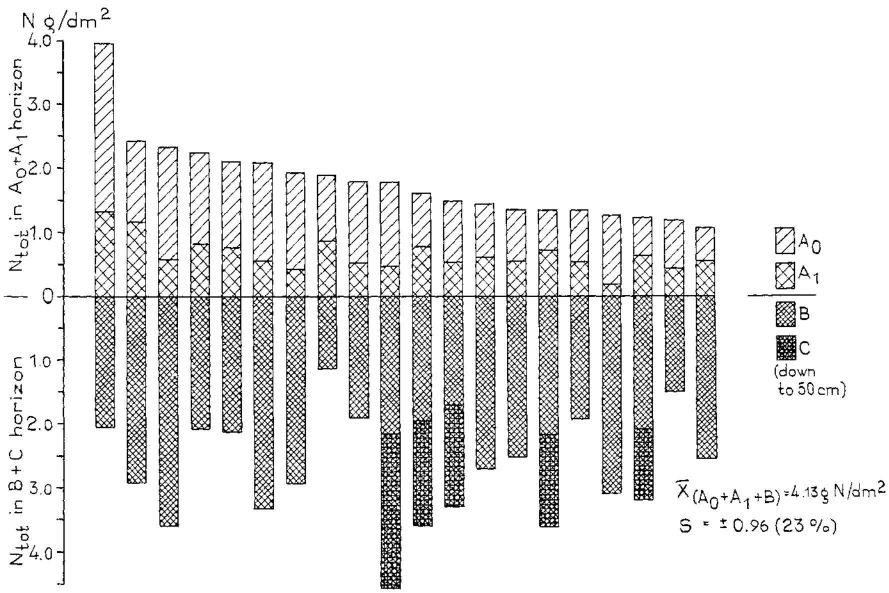

Fig. 6. Total content of nitrogen in 20 profiles from Garpenberg

wide applicability. Forest growth is often limited by scarcity in nitrogen on similar sites, while no evidence has been found for an immediate growth-stimulating effect of fertilization with phosphorus or potassium. Therefore the following discussion will concentrate on the nitrogen distribution in the soil profiles.

The total nitrogen content in the profile down a depth of 50 cm is shown in Figs. 6 and 7. The analyses are derived from the 20 samples collected from the pits. The columns representing the nitrogen content in the various horizons are arranged in descending order of height of A horizon N. The diagrams make it clear—as indeed a number of authors have pointed out—that the amount of nitrogen bound in the B horizon is often much greater than that present in the A horizon.

The "lichen-pine" plot at Vindeln, in particular, which is poor as regards forest yield, shows a nitrogen content in the humus layer which may be as little as one-tenth of the total content to a depth of 50 cm. At Garpenberg the ratio here is about 1:3. If it were possible to release the bound nitrogen from the lower levels, this would by far exceed the amounts supplied today by fertilization in Swedish forests. Other investigations show that a small fraction of the Garpenberg B horizon nitrogen is released as ammonium and nitrogen ions in long-term incubation experiments (Tamm & Pettersson, 1969). The release from a B horizon sample from a poor pine stand on

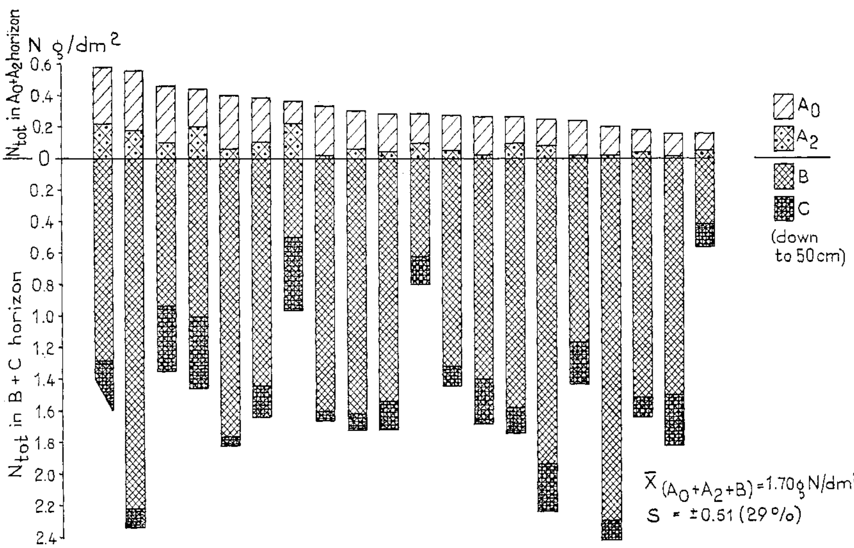

Fig. 7. Total content of nitrogen in 20 profiles from Vindeln.

outwash sand in South Sweden was smaller, but the low "radiocarbon age" of the B horizon organic matter from these and other sites suggest a continuous turn-over, including break-down of humus at the same time as of new material is deposited (TAMM & HOLMEN 1967).

An interesting observation can be made in Fig. 6 and 7, viz. that there is apparently no correlation between A horizon nitrogen and B horizon nitrogen within the same site. On the other hand there is tendency towards positive correlation between the amounts of nitrogen in the A_0 horizon and in the underlying A_1 or A_2. However, the difficulty in exact separation of the various parts of the A horizon may be responsible for this.

Table 1 gives the mechanical analyses of the C horizon at Garpenberg. Only five of the twenty sample pits have been analysed down to the deepest level but against the background of the analytical data the till appears to be relatively uniform.

The particle-size distribution of the glacifluvial sediment shows even greater uniformity. The larger number of analyses performed here was in fact superfluous.

Tables 3 and 4 contain the complete analytical results for the 20 sampled profiles on each site. As the present project is concerned with methods, it was considered important that the primary results should be presented in their entirety.

Discussion of the soil variability within the two plots

It should be noted that the two sample plots were judged by visual inspection to be as homogeneous as possible before they were laid out. Each sample plot had an area of 100 m^2, and it is not particularly difficult to find apparently uniform plots of such limited area in Swedish coniferous forests. Nevertheless, the analytical results show great variation.

We shall start the discussion of the results by an account of the variation in amount of nitrogen per unit area in Garpenberg (Fig. 2) and Vindeln (Fig. 3). An attempt has been made to illustrate the variation in diagrammatic maps by using various symbols. Six of the sampling points on the Vindeln plot lie outside $\pm$ 2 S (one of these was in part of a charcoal pit that had been completely concealed by vegetation), while the corresponding number on the Garpenberg plot was only four. Generally speaking the variations in the amount of nitrogen per unit area are considerably greater in the Vindeln plot, where the effect of the processes of soil formation has been weaker, partly on account of the climate, than in the Garpenberg plot. This is true despite the fact that the geological foundation is considerably more homogeneous at Vindeln. In this area, a prime cause of the variation is probably an irregular history with special frost-heave conditions, windfallen trees etc. There is for instance no correlation between the depth and the weight of the samples collected in the A_0 horizon in Vindeln.

In practice, then, Table 5 shows that if a coefficient of variation of 10 per cent be accepted for the N_{tot} analyses it will be necessary to take 11 samples at Vindeln and 9 at Garpenberg (to be mixed for preparation of a composite sample), if it is desired to express the results of the analysis in kilogram per hectare. A much lower number of samples gives the same accuracy for the percentages of nitrogen. In general there is more variation in the depth and weight of organic soil horizons than in their chemical composition.

The rest of the calculations in the table are based on the 20 profiles in a square lattice (each sample is taken with a knife from small areas of about 4 dm^2). This is often a more realistic way of sampling stony soils. The Garpenberg analyses of total nitrogen content calculated per unit area show, however, that not even 20 sampling points are sufficient to give acceptable precision.

Incidentally, P-HCl and K-HCl require fewer samples per unit area than P-AL or K-AL in the A_0 horizon, while the reverse is true of the A_2 horizon.

In the B horizon, 20 samples do not suffice to give an idea of the P-AL content, while in the C horizon, the nutrients investigated are so uniformly distributed in both plots that only a few samples per unit area are needed to obtain the acceptable coefficient of variation of 10 per cent.

Conclusion

Sampling forest soils for chemical analyses of nitrogen, phosphorus and potassium, it is necessary to accept a not too low standard error, if the field work is not to become unduly laborious. If samples are taken from a square lattice and are then mixed to provide a composite sample, 15—20 sampling points will give (in the typical and common types of forest investigated here) a coefficient of variation of the nitrogen content and loss on ignition less than 10 per cent in the A_0 horizon irrespective of whether the results are expressed as percentages or per unit area.

Generally speaking, ten samples (collected in the described way) are sufficient for concentrations of the phosphorus and potassium in the A_0—C horizons. However, occasional deviations occur, also in the material presented here, and a larger number of samples is then required to attain a satisfactory degree of precision.

On the other hand, this work also shows that differences of 10 to 20 per cent in the analytical results should be regarded with great caution unless the number of soil samples collected is sufficiently great.

Acknowledgement

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Sammanfattning

Variabiliteten i några av skogsmarkens egenskaper inom små ytor och dess betydelse för markprovtagningsmetodiken

I modern biologisk forskning försöker man så långt det är möjligt att beskriva olika företeelser kvantitativt. Detta gäller även beskrivningen av skogsmarken och dess kemiska egenskaper. Det är då nödvändigt att studera precisionen i de siffror som kan framräknas för exempelvis näringsmängderna i skogsmarken. Vissa uppgifter föreligger sedan rätt länge om heterogeniteten hos odlade jordar med avseende på vissa växtnäringsämnen. För skogsjordar förelåg 1957, då denna undersökning planerades, över huvud taget inga sådana uppgifter publicerade. Sedermera har flera amerikanska undersökningar publicerats, där markens variabilitet bl. a. med avseende på halterna och mängderna av olika växtnäringsämnen undersökts.

Föreliggande undersökning är ett led i de undersökningar som sedan länge bedrivits vid Skogshögskolan rörande skogsmarkens roll för skogens växtnäringsförsörjning, ett problem som även intresserar forskningsinstitutionerna i våra grannländer och som bl. a. resulterat i gemensamma rekommendationer för provtagning av skogsmark (Gjems m. fl. 1960).

Undersökningen tillgick så att markprov från olika markhorisonter insamlades från förut bestämda punkter i ett rutnät inom två provytor representerande två vanliga svenska skogstyper: 1. en gammal granskog av god bonitet på morän i Garpenberg, sparsam markvegetation med ett visst inslag av lågörter (se artförteckning på sid. 6) samt 2. en tallskogsyta av låg bonitet med lavrik markvegetation på glacifluvial sand nära Vindeln. Ett hundratal humusprov från vardera lokalen analyserades med avseende på kväve och glödgningsförlust varjämte 20 prov från varje horisont på vardera lokalen analyserades med avseende på fosfor (P-AL och P-HCl), kalium (K-AL och K-HCl) samt glödgningsförlust. I figurerna 2 och 3 återges kvävemängderna i mg/dm^2 (= kg/ha) för det större antalet provpunkter på bägge ytorna medan tabell 3 och 4 återger de bestämningar som gjordes på de 20 profilproven.

För varje lokal och analystyp räknades sedan den statistiska spridningen ut. Tabell 5 återger utom medelvärdena och deras standardavvikelser även de antal prov som behöver insamlas för att variationskoefficienten för ett generalprov, blandat ur dessa enskilda delprov, skall understiga vissa värden, 5, 10, 15, 20 och 30 %.

Slutsatsen av undersökningen är att det i regel är nödvändigt att använda generalprov på åtminstone 10 à 15 delprov för att erhålla variationskoefficienter under 10 %, om man vill uttrycka resultaten som mängder per ha för de vanligaste växtnäringsämnena. Om man nöjer sig med att uttrycka värdena i viktsprocent räcker det i regel med ett lägre antal provpunkter.

Tables

Tab. 1. Garpenberg: Mechanical analyses (%) of C-horizon.

Soil sample No.	C-horizon	Fractions in mm									Base mineral-index
		0.002	0.002—0.006	0.006—0.02	0.02—0.06	0.06—0.2	0.2—0.6	0.6—2.0	2.0—6.0	6.0—20.0	
100	40—50 cm	5.5	7.0	14.0	12.5	13.3	9.7	8.7	20.0	9.3	7.6
104	47—62 cm	7.0	9.0	17.5	14.0	12.7	9.0	9.5	14.6	6.7	9.0
108	40—50 cm	8.0	8.5	15.5	11.5	11.7	8.3	8.7	20.3	7.5	7.6
112	44—54 cm	6.5	7.5	14.0	14.0	14.0	10.7	9.6	18.2	5.5	8.2
116	40—53 cm	9.3	8.0	13.7	12.5	13.2	9.0	8.6	19.7	6.0	8.5
On average		7.2	8.0	14.9	13.0	13.0	9.3	9.0	18.6	7.0	8.2

Tab. 2. Vindeln: Mechanical analyses (%) of C-horizon.

Soil sample No.	C-horizon	Fractions in mm							Base mineral-index
		0.002	0.002—0.006	0.006—0.02	0.02—0.06	0.06—0.2	0.2—0.6	0.6—2.0	
105	30—40 cm	2.5	0.1	0.9	1.0	19.7	75.6	0.2	14.1
110	23—33 cm	2.6	0.3	2.8	4.2	24.2	65.6	0.3	16.0
115	21—31 cm	2.2	0.0	0.1	0.3	14.1	83.0	0.3	13.1
120	29—39 cm	2.4	0.0	0.6	0.5	20.2	76.0	0.3	14.5
125	26—36 cm	2.3	0.1	0.9	1.2	14.4	80.9	0.2	15.5
135	26—36 cm	2.3	0.0	0.3	0.0	8.5	88.6	0.3	13.3
140	34—44 cm	2.3	0.0	0.2	0.1	19.7	77.4	0.3	13.6
145	34—44 cm	2.3	0.0	0.2	0.1	16.9	80.3	0.2	13.2
160	46—56 cm	2.4	0.0	0.3	0.2	23.9	73.1	0.1	13.5
165	34—44 cm	2.4	0.0	0.3	0.1	11.3	84.4	1.5	11.4
170	27—37 cm	2.2	0.0	0.2	0.0	7.9	89.6	0.1	12.8
175	30—40 cm	2.5	0.2	0.6	1.0	27.5	68.0	0.2	14.3
180	29—39 cm	2.2	0.1	0.2	0.1	9.2	88.1	0.1	15.2
On average		2.4	0.1	0.6	0.7	16.7	79.2	0.3	13.9

Tab. 3. Analyses from Garpenberg.

Horizon	Sample No	Depth	Tot. weight/dm² (air-dry samples)	pH-H_2O	pH-KCl	Loss on ignition	N_{tot} (% of loss on ign.)	P-AL	P-HCl	K-AL	K-HCl	P-AL	P-HCl	K-AL	K-HCl
		cm	g	—	—	%	%	mg/100 g air-dry weight				kg/ha			
A_0	101	4.5	159	4.1	3.3	62.9	1.38	11.3	34	92.6	98	18	54	147	156
A_1	102	3.5	641	3.7	3.0	12.8	1.95	2.4	15	10.6	30	15	96	68	192
B	103	17.0	2 550	4.7	4.1	4.2	1.91	0.8	20	4.1	32	20	510	105	816
C	100	10.0	4 000	5.2	4.4	1.5	1.92	3.5	20	3.0	44	140	800	120	1 760
A_0	105	4.0	260	4.4	3.6	28.2	1.88	2.8	23	41.3	56	7	60	107	146
A_1	106	5.0	768	4.2	3.4	10.4	2.02	1.8	13	8.1	30	14	100	62	230
B	107	16.0	2 400	4.8	4.1	4.1	2.19	0.8	17	4.1	32	19	408	98	768
C	104	15.0	4 000	5.1	4.4	1.8	2.06	3.3	25	3.2	45	132	1 000	128	1 800
A_0	109	4.5	156	4.2	3.5	64.3	1.60	12.1	34	78.4	100	19	53	122	156
A_1	110	5.5	881	4.0	3.3	9.3	1.94	2.7	14	7.2	28	24	123	63	247
B	111	18.0	2 700	4.7	4.1	3.3	2.20	1.0	16	3.6	32	27	432	97	864
C	108	10.0	3 520	5.2	4.4	2.6	1.84	2.8	26	3.4	53	99	915	119	1 865
A_0	113	6.0	432	4.4	3.6	32.6	1.84	5.5	25	45.5	63	24	108	197	272
A_1	114	3.0	549	4.1	3.4	8.3	2.17	2.3	13	5.9	25	13	71	32	137
B	115	16.0	2 400	4.6	4.1	4.5	2.07	1.0	25	3.9	39	24	600	94	936
C	112	10.0	4 000	5.0	4.4	2.9	2.08	2.0	25	3.8	44	80	1 000	152	1 760
A_0	117	6.0	262	4.4	3.7	33.2	2.20	6.4	25	50.4	69	17	66	132	181
A_1	118	4.0	567	4.2	3.3	8.4	2.26	2.2	12	7.2	33	12	68	41	187
B	119	12.0	1 800	4.6	3.9	3.8	2.13	0.8	17	3.9	39	14	306	70	702
C	116	13.0	4 480	5.1	4.4	2.2	1.92	1.7	25	3.0	60	76	1 120	134	2 688
A_0	120	6.0	309	3.9	3.0	60.9	1.49	6.6	25	58.6	71	20	77	181	219
A_1	121	5.5	1 034	3.8	3.0	9.3	1.72	1.6	14	8.8	35	17	145	91	362
B	122	16.5	2 475	4.5	3.9	4.1	2.06	0.7	20	3.4	37	17	495	84	916
A_0	123	4.5	126	4.0	3.2	65.3	1.78	11.0	29	85.8	97	14	37	108	122
A_1	124	3.5	382	3.7	2.8	10.7	1.68	2.0	10	8.0	34	8	38	31	130
B	125	21.0	3 150	4.4	3.8	4.1	1.97	1.0	14	4.4	28	32	441	139	882
A_0	126	4.5	177	4.1	3.3	53.7	1.71	9.3	28	78.2	83	16	50	138	269
A_1	127	3.0	598	4.0	3.2	9.4	1.91	2.8	12	6.8	32	17	72	41	191
B	128	12.5	1 875	4.6	4.0	5.0	2.05	1.2	18	3.4	34	22	338	64	638
A_0	129	7.5	184	4.0	3.2	66.7	1.66	8.4	32	82.4	89	32	59	152	164
A_1	130	6.5	865	3.8	3.2	8.3	2.41	2.4	11	6.1	26	21	95	53	225
B	131	16.0	2 400	4.4	3.9	3.4	1.99	0.7	17	3.8	25	17	408	91	600
A_0	132	8.0	312	4.0	3.2	63.8	1.57	6.6	24	43.0	53	21	75	134	165
A_1	133	6.0	416	4.0	3.3	16.1	1.61	2.2	16	7.2	41	9	67	30	171
B	134	21.0	3 150	4.4	4.0	4.6	2.34	3.4	26	4.1	61	107	819	129	824

Tab. 3. (cont.)

Horizon	Sample No	Depth	Tot. weight/dm² (air-dry samples)	pH-H_2O	pH-KCl	Loss on ignition	N_{tot} (% of loss on ign).	P-AL	P-HCl	K-AL	K-HCl	P-AL	P-HCl	K-AL	K-HCl
		cm	g	—	—	%	%	mg/100 g air-dry weight				kg/ha			
A_0	135	13.0	434	3.4	2.6	79.9	1.54	5.8	25	48.6	56	25	108	211	243
A_1	136	7.0	1 274	3.9	3.1	10.8	1.94	1.6	10	6.6	27	20	127	84	344
B	137	14.0	2 850	4.8	4.0	3.0	2.36	0.7	20	3.7	32	20	570	105	912
A_0	138	13.0	342	3.9	3.0	64.0	1.59	7.7	26	51.3	54	26	89	175	185
A_1	139	7.0	493	3.8	2.9	12.7	1.89	2.1	13	7.2	26	10	64	36	128
B	140	20.0	3 000	4.5	3.8	4.9	2.45	0.9	20	4.8	30	27	600	144	900
A_0	141	12.0	330	3.9	3.0	47.9	1.88	7.1	26	54.5	58	23	86	180	191
A_1	142	3.0	272	3.7	2.9	12.2	2.62	1.7	11	11.1	25	5	30	30	68
B	143	22.0	3 300	4.5	3.9	3.5	2.54	0.7	20	4.9	32	23	660	162	1 056
A_0	144	5.5	408	4.3	3.5	40.4	1.56	5.7	25	45.5	60	23	102	186	245
A_1	145	4.5	880	4.1	3.3	6.9	1.74	1.4	12	6.7	25	12	106	59	220
B	146	12.0	1 800	4.7	4.0	4.7	2.23	0.9	17	4.1	25	16	306	74	450
A_0	147	6.0	352	3.9	3.0	43.5	1.38	6.5	35	48.0	59	23	123	169	208
A_1	148	1.5	234	3.9	3.0	8.9	2.02	2.9	12	8.8	27	7	28	21	63
B	149	15.5	2 325	4.6	3.9	6.6	2.02	2.3	20	5.0	32	53	465	116	744
A_0	150	9.0	360	4.2	3.3	35.2	2.13	4.5	23	46.0	58	16	83	166	209
A_1	151	3.0	953	3.9	3.2	8.5	1.88	2.0	11	7.1	24	19	105	68	229
B	152	16.0	2 400	4.6	4.0	3.8	2.32	0.5	17	4.4	28	12	408	106	672
A_0	153	7.0	347	4.5	3.8	38.1	1.92	5.8	30	54.8	65	20	104	190	226
A_1	154	6.0	1 165	4.2	3.4	13.1	1.53	1.4	16	8.8	28	16	186	103	326
B	155	17.0	2 550	4.7	4.1	4.5	2.53	0.9	34	5.4	36	23	867	138	918
A_0	156	5.0	276	4.6	3.8	25.9	2.24	3.6	21	30.3	53	10	58	84	146
A_1	157	4.5	636	4.4	3.6	9.6	2.08	1.7	15	9.0	34	11	95	57	216
B	158	15.5	2 325	4.5	4.0	5.4	2.14	1.5	16	4.7	39	35	372	109	907
A_0	159	7.5	288	4.4	3.7	26.6	1.95	4.9	21	50.7	65	14	60	146	187
A_1	160	4.5	698	4.3	3.8	7.7	1.69	1.4	12	7.5	30	10	84	52	209
B	161	13.0	1 950	4.8	4.2	3.8	2.02	0.8	20	4.1	34	16	390	80	663
A_0	162	7.0	179	4.3	3.7	58.3	1.56	8.6	34	95.1	98	15	61	170	175
A_1	163	2.0	634	3.9	3.3	7.9	2.15	1.8	12	6.8	24	11	76	43	152
B	164	18.5	2 775	4.6	4.1	3.5	2.63	0.8	17	3.8	30	22	472	105	832

Tab. 4. Analyses from Vindeln.

Horizon	Sample No	Depth	Tot weight/dm² (air-dry samples)	pH-H_2O	pH-KCl	Loss on ignition	N_{tot} (% of loss on ign.)	P-AL	P-HCl	K-AL	K-HCl	P-AL	P-HCl	K-AL	K-HCl
		cm	g	—	—	%	%	mg/100 g air-dry weight				kg/ha			
A_0	102	2.5	34	4.0	3.2	48.2	1.04	6.1	36	39.5	75	2	12	13	25
A_2	103	2.0	280	4.1	3.3	6.5	1.38	4.0	15	5.3	34	11	42	15	95
B	104	23.0	3 220	4.7	3.9	3.9	1.41	1.8	59	3.4	25	58	1 900	109	805
C	105	20.0	3 000	4.9	4.3	0.6	1.67	2.0	47	1.0	37	60	1 410	30	1 110
A_0	107	1.0	52	3.9	3.1	52.1	1.32	7.4	35	50.0	85	4	18	26	44
A_2	108	2.0	280	4.0	3.1	9.4	1.06	4.6	30	10.5	45	13	84	29	126
B	109	17.5	2 450	4.7	3.8	2.8	1.25	1.1	54	2.5	23	28	1 361	63	580
C	110	27.0	4 050	5.1	4.5	0.7	1.43	1.8	43	2.5	37	73	1 742	101	1 498
A_0	112	1.0	34	3.9	2.9	27.9	1.43	5.2	25	30.0	57	2	8	10	19
A_2	113	5.0	700	4.1	3.4	4.6	1.09	2.9	17	3.4	23	20	119	24	161
B	114	12.0	1 680	4.7	3.8	2.0	1.50	2.3	66	2.5	34	39	1 109	42	571
C	115	29.0	4 350	5.1	4.7	0.5	2.00	1.5	37	1.0	50	65	1 610	44	2 175
A_0	117	1.0	35	3.9	3.0	36.1	1.23	5.2	34	27.0	65	2	12	10	23
A_2	118	2.0	280	4.2	3.1	6.4	1.09	3.0	28	5.0	34	8	78	14	95
B	119	25.0	3 500	4.7	4.4	3.3	1.36	1.1	47	2.5	25	38	1 645	88	875
C	120	21.0	3 150	4.6	3.9	0.6	0.83	1.8	39	1.0	45	57	1 228	32	1 418
A_0	122	1.5	50	3.8	3.1	46.1	1.23	8.0	36	41.0	65	4	18	20	32
A_2	123	1.5	210	4.0	3.3	8.9	1.18	4.0	21	6.5	34	8	44	14	71
B	124	19.0	2 660	4.6	3.9	4.6	1.20	3.4	36	3.7	30	90	958	98	798
C	125	24.0	3 600	4.8	4.3	0.5	1.00	2.3	42	1.0	40	83	1 512	36	1 440
A_0	127	2.0	65	3.8	2.9	42.9	1.27	8.0	30	58.0	60	5	20	38	39
A_2	128	4.5	630	4.0	2.8	2.9	1.55	2.5	7	2.5	15	16	44	16	94
B	129	23.0	3 220	5.1	4.6	3.6	1.11	1.1	100	2.0	30	35	3 220	64	966
C	130	16.0	—	—	—	—	—	—	—	—	—	—	—	—	—
A_0	132	2.0	74	3.9	3.0	41.9	1.21	7.0	23	42.5	60	5	17	31	44
A_2	133	2.0	280	4.0	3.3	6.0	1.00	3.0	10	3.7	20	8	28	10	56
B	134	29.0	4 060	4.7	4.1	3.9	1.28	2.1	52	2.3	20	85	2 111	93	812
C	135	14.0	2 100	4.9	4.3	0.5	1.00	1.3	27	1.0	50	27	567	21	1 050
A_0	137	2.0	31	4.0	3.3	43.9	1.05	9.0	35	41.0	65	3	11	13	20
A_2	138	2.0	280	4.2	3.4	6.9	1.01	4.4	21	6.5	30	12	59	18	84
B	139	27.0	3 780	4.7	3.8	3.1	1.29	2.0	68	2.3	30	76	2 570	87	1 134
C	140	16.0	2 400	4.8	4.8	0.5	1.00	2.3	42	1.5	37	55	1 008	36	888
A_0	142	2.0	34	3.9	3.2	57.7	1.14	8.8	34	54.0	75	3	11	18	25
A_2	143	3.0	420	3.9	2.9	8.6	0.91	4.0	11	5.3	25	17	46	22	105
B	144	25.0	3 500	4.6	3.8	3.2	1.25	2.3	85	2.3	30	80	2 975	80	1 050
C	145	16.0	2 400	4.7	4.5	0.6	1.67	1.6	34	1.5	53	38	816	36	1 272
A_0	147	0.5	41	3.9	3.0	35.1	1.23	10.0	35	49.0	75	4	14	20	31
A_2	148	2.0	280	4.1	2.9	6.8	1.10	4.3	16	6.0	20	12	45	17	56
B	149	16.0	2 240	5.1	4.7	3.4	1.32	0.9	97	2.5	25	20	2 173	56	560
C	150	29.0	4 350	4.8	4.5	0.6	1.67	1.3	34	1.5	40	57	1 479	65	1 740

Tab. 4. (cont.)

Horizon	Sample No	Depth	Tot weight/dm² (air-dry samples)	pH-H_2O	ph-KCl	Loss on ignition	N_{tot} (% of loss on ign.)	P-AL	P-HCl	K-AL	K-HCl	P-AL	P-HCl	K-AL	K-HCl
		cm	g	—	—	%	%	mg/100 g air- dry weight				kg/ha			
A_0	152	3.0	54	3.9	3.1	49.9	0.92	9.4	31	49.0	65	5	17	26	35
A_2	153	3.0	420	4.0	3.2	4.7	1.38	2.6	6	3.7	15	11	25	16	63
B	154	29.0	4 060	4.8	4.3	2.9	1.38	1.0	80	2.3	25	41	3 248	93	1 015
C	155	12.0	1 800	5.1	4.6	0.5	1.00	1.5	31	1.5	57	27	558	27	1 026
A_0	157	2.0	68	4.0	3.1	44.6	1.12	6.1	27	41.0	57	4	18	28	39
A_2	158	4.0	560	4.1	3.2	4.1	1.34	1.9	4	3.4	15	11	22	19	84
B	159	36.0	5 040	4.7	4.3	2.5	1.40	0.6	66	2.3	25	30	3 326	116	1 260
C	160	4.0	600	5.3	4.7	0.5	2.00	1.5	30	1.5	45	9	180	9	270
A_0	162	1.0	36	3.8	2.9	50.5	1.19	9.4	30	58.0	75	3	11	21	27
A_2	163	2.5	350	4.0	3.1	4.4	1.36	2.3	6	5.3	20	8	21	18	70
B	164	28.5	3 990	5.1	4.8	2.6	1.15	0.5	70	2.3	34	20	2 842	93	1 380
C	165	16.0	2 400	4.4	4.0	0.6	1.67	1.0	26	1.0	40	24	624	24	960
A_0	167	1.0	69	3.9	3.2	24.1	1.37	4.2	29	26.0	50	3	20	18	35
A_2	168	2.0	280	4.1	3.3	1.8	1.39	1.7	2	3.0	15	5	6	8	42
B	169	22.0	3 080	4.7	4.3	3.8	1.32	1.6	90	2.0	23	49	2 772	62	708
C	170	23.0	3 450	4.3	3.7	0.4	1.25	1.9	29	1.0	45	66	1 000	34	1 552
A_0	172	1.0	37	3.9	3.2	31.4	1.24	12.3	40	49.0	80	4	15	18	29
A_2	173	3.0	420	4.1	3.3	6.2	1.05	3.7	13	4.5	23	16	55	19	97
B	174	24.0	3 360	4.7	4.0	4.2	1.07	1.0	72	2.3	25	34	1 728	77	840
C	175	20.0	3 000	4.7	4.4	0.6	1.67	1.5	39	1.0	45	45	1 170	30	1 350
A_0	177	3.0	36	3.9	3.0	33.7	1.48	5.4	28	35.0	53	2	10	13	19
A_2	178	7.0	980	4.1	3.3	4.7	1.28	3.6	10	3.7	20	35	98	36	196
B	179	18.0	2 520	4.8	4.0	2.2	1.14	0.6	52	2.3	30	15	1 310	58	756
C	180	21.0	3 150	4.8	3.8	0.4	1.25	1.6	29	1.5	45	50	914	47	1 418
A_0	182	1.5	44	4.0	3.3	40.3	1.22	12.3	34	60.0	70	5	15	26	31
A_2	183	1.0	140	4.1	3.3	6.1	1.07	2.9	9	5.0	20	4	13	7	28
B	184	31.5	4 410	4.7	4.3	1.9	1.58	1.0	25	1.5	15	45	1 120	67	672
C	185	14.0	2 100	5.1	4.6	0.5	1.00	1.8	37	1.0	37	38	777	21	777
A_0	187	1.0	30	3.8	2.9	43.6	1.38	8.8	37	53.0	85	3	11	16	26
A_2	188	2.5	350	4.0	3.2	3.3	1.36	2.9	3	3.0	15	10	10	10	52
B	189	30.0	4 200	4.5	3.8	4.1	1.34	1.3	111	2.3	25	55	4 662	97	1 050
C	190	15.0	2 250	4.7	4.5	0.4	1.25	1.9	39	1.0	45	43	878	22	1 012
A_0	192	3.0	52	3.9	3.1	51.5	1.11	8.3	36	52.0	75	4	19	27	39
A_2	193	4.5	630	4.1	3.2	2.6	1.73	1.3	1	3.4	20	8	6	21	126
B	194	33.0	4 620	4.8	4.3	2.8	1.20	1.1	72	2.5	30	51	3 326	116	1 386
C	195	6.0	900	5.1	4.8	0.6	0.83	1.9	19	1.5	30	17	171	14	270
A_0	197	1.0	20	4.0	2.9	47.2	1.23	6.2	29	42.0	70	1	6	8	14
A_2	198	9.0	1 260	4.1	3.1	6.5	1.31	4.2	12	5.0	25	53	151	63	315
B	199	21.0	2 940	4.5	4.2	1.2	1.25	1.5	47	2.0	30	44	1 382	59	882
C	200	17.0	2 550	5.1	4.6	0.4	1.25	3.4	36	1.5	40	87	918	38	1 020

Tab. 5. Number of sampling points required for different degress of precision in estimates of various chemical soil characteristics.

Nutrients and sampled horizon	*Vindeln:* Lichen-pine forest (weak iron podzol)				*Garpenberg:* Spruce forest with Hylocomium (iron podzol)			
	$\bar{x}$	S	Required number of samples	Permitted coefficient of variation	$\bar{x}$	S	Required number of samples	Permitted coefficient of variation
N mg/dm² A_0 (98 auger samples)	173	56	42 11 5 3 2	± 5% 10% 15% 20% 30%	945	278	35 9 4 3 1	± 5% 10% 15% 20% 30%
Loss on ignition g/dm² A_0 (98 auger samples)	14.8	6	66 17 8 5 2	± 5% 10% 15% 20% 30%	56.7	17.6	39 10 5 3 2	± 5% 10% 15% 20% 30%
N in % of loss on ignition A_0 (98 auger samples)	1.18	0.16	8 2 1 1 1	± 5% 10% 15% 20% 30%	1.68	0.25	9 3 1 1 1	± 5% 10% 15% 20% 30%
N mg/dm² A_0 (20 auger samples cut out with a knife from small areas, about 4 dm²)	231	82	51 13 6 4 2	± 5% 10% 15% 20% 30%	1.149	506	78 20 9 5 3	± 5% 10% 15% 20% 30%
Loss on ignition (%) A_0 (20 auger samples, as described above)	19.1	7.2	57 15 7 4 2	± 5% 10% 15% 20% 30%	66.9	31.2	87 22 10 6 3	± 5% 10% 15% 20% 30%
N in % of loss on ignition A_0 (20 auger samples, as described above)	1.22	0.14	6 2 1 1 1	± 5% 10% 15% 20% 30%	1.75	0.25	9 3 1 1 1	± 5% 10% 15% 20% 30%
N mg/dm² A_2 in Vindeln A_1 in Garpenberg (20 auger samples, as described above)	84	68	263 66 30 17 8	± 5% 10% 15% 20% 30%	646	262	66 17 8 5 2	± 5% 10% 15% 20% 30%
Loss on ignition g/dm² B (20 auger samples, as described above)	1379	458	45 12 5 3 2	± 5% 10% 15% 20% 30%	2332	606	28 7 3 2 1	± 5% 10% 15% 20% 30%
P-HCl mg/100g A_0 (20 auger samples, as described above)	32.2	4.32	8 2 1 1 1	± 5% 10% 15% 20% 30%	27.25	4.38	11 3 2 1 1	± 5% 10% 15% 20% 30%

Tab. 5. (cont.)

Nutrients and sampled horizon	*Vindeln:* Lichen-pine forest (weak iron podzol)				*Garpenberg:* Spruce forest with Hylocomium (iron podzol)			
	$\bar{x}$	S	Required number of samples	Permitted coeffi- cient of variation	$\bar{x}$	S	Required number of samples	Permitted coeffi- cient of variation
P-AL mg/100g A_0 (20 auger samples, as described above)	7.86	2.19	31	± 5%	7.0	2.46	50	± 5%
			8	10%			13	10%
			4	15%			6	15%
			2	20%			4	20%
			1	30%			2	30%
K-AL mg/100g A_0 (20 auger samples, as described above)	44.85	9.83	20	± 5%	59.0	18.65	40	± 5%
			5	10%			10	10%
			3	15%			5	15%
			2	20%			3	20%
			1	30%			2	30%
K-HCl mg/100g A_0 (20 auger samples, as described above)	68.10	9.82	9	± 5%	70.2	16.89	24	± 5%
			3	10%			6	10%
			1	15%			3	15%
			1	20%			2	20%
			1	30%			1	30%
P-AL mg/100g A_2 (20 auger samples, as described above)	3.19	0.93	35	± 5%	2.0	0.534	29	± 5%
			9	10%			8	10%
			4	15%			4	15%
			3	20%			2	20%
			1	30%			1	30%
P-HCl mg/100g A_2 (20 auger samples, as described above)	12.10	7.98	174	± 5%	12.7	1.76	8	± 5%
			44	10%			2	10%
			20	15%			1	15%
			11	20%			1	20%
			5	30%			1	30%
K-AL mg/100g A_2 (20 auger samples, as described above)	4.74	1.75	55	± 5%	7.8	1.20	10	± 5%
			14	10%			3	10%
			7	15%			2	15%
			4	20%			1	20%
			2	30%			1	30%
K-HCl mg/100g A_2 (20 auger samples, as described above)	23.4	7.98	47	± 5%	29.2	4.38	9	± 5%
			12	10%			3	10%
			6	15%			1	15%
			3	20%			1	20%
			2	30%			1	30%
P-AL mg/100g B (20 auger samples, as described above)	1.42	0.692	96	± 5%	1.07	0.651	149	± 5%
			24	10%			38	10%
			11	15%			17	15%
			6	20%			10	20%
			3	30%			5	30%
P-HCl mg/100g B (20 auger samples, as described above)	67.45	21.46	41	± 5%	19.55	4.35	20	± 5%
			11	10%			5	10%
			5	15%			3	15%
			3	20%			2	20%
			2	30%			1	30%

Tab. 5. (cont.)

Nutrients and sampled horizon	*Vindeln:* Lichen-pine forest (weak iron podzol)				*Garpenberg:* Spruce forest with Hylocomium (iron podzol)			
K-AL mg/100g B (20 auger samples, as described above)	2.39	0.454	15 4 2 1 1	± 5% 10% 15% 20% 30%	4.18	0.534	7 2 1 1 1	± 5% 10% 15% 20% 30%
K-HCl mg/100g B (20 auger samples, as described above)	26.74	4.54	12 3 2 1 1	± 5% 10% 15% 20% 30%	33.85	7.44	20 5 3 2 1	± 5% 10% 15% 20% 30%
P-AL C Vindeln (19 auger samples), and Garpenberg (5 auger samples)	1.78	0.513	34 9 4 3 1	± 5% 10% 15% 20% 30%	2.66	0.706	29 8 4 2 1	± 5% 10% 15% 20% 30%
P-HCl C Vindeln (19 auger samples), and Garpenberg (5 auger samples)	34.74	6.78	16 4 2 1 1	± 5% 10% 15% 20% 30%	24.2	2.14	4 1 1 1 1	± 5% 10% 15% 20% 30%
K-AL C Vindeln (19 auger samples), and Garpenberg (5 auger samples)	1.29	0.372	34 9 4 3 1	± 5% 10% 15% 20% 30%	3.28	0.299	4 1 1 1 1	± 5% 10% 15% 20% 30%
K-HCl C Vindeln (19 auger samples), and Garpenberg (5 auger samples)	43.05	6.37	9 3 1 1 1	± 5% 10% 15% 20% 30%	49.2	6.37	7 2 1 1 1	± 5% 10% 15% 20% 30%