PHOSPHORUS IN VIRGIN PEAT SOILS

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Our present information of phosphorus in peat soils is scarce. Finnish peat lands are considered to be poor in phosphorus, a view corroborated by the fact that when cultivated they generally respond to phosphate fertilizers. This perhaps is the reason why only very little attention has been paid to the native peat phosphorus.

In connection with some Finnish investigations the total phosphorus content of virgin peat soils has been determined (12), but almost nothing is known of the forms in which this peat phosphorus occurs. Also in other countries the composition of phosphorus in peat soils has only in a low degree interested soil scientists. This probably can be partly attributed to the difficulties connected with the analyses of peat samples.

In the present paper results are reported of an attempt to elucidate the phosphorus composition of some virgin peat soils in Finland. The main object was to study the organic phosphorus content of these soils and the factors on which it depends. Also some data upon the solubility of inorganic phosphorus are examined.

Material and methods

The material of this investigation consisted of 217 samples of various kinds of peat collected mostly from Northern Finland, although also other parts of the country were represented. Samples were taken both from the surface and the deeper layers.

The peat type and the degree of humification were determined by direct examination of the fresh samples in the field. All the other analyses were performed using samples which were air-dried and ground in a Wiley mill.

The soil pH was estimated in water suspension (1 : 4, vol.) using a Beckman pH-meter with glass electrode. The volume weight was determined with an apparatus developed by Mr. Jaakko Kivekäs M.S. in this laboratory (8).

The Kjeldahl procedure was modified to allow the common determination of nitrogen and the colorimetric estimation of total phosphorus from the aliquotes of the same digest. For that purpose sodium selenite and sodium sulphate were substituted for copper sulphate and potassium sulphate, respectively.

All the phosphorus analyses were performed by the molybdenum blue method modified by the author (7). When the solutions obtained from the Kjeldahl digestion were analysed, it was sometimes found that about half an hour after the reduction the blue solution began to turn turbid. Therefore, care was taken to measure the colour intensity of these solutions within 25 minutes after the reduction. The cause of this phenomenon was not examined in more detail. Perhaps it may be attributed to the effect of selenite although this was present only in a very low concentration. A similar phenomenon was found to occur also when digests of plant material were analysed.

Organic phosphorus content was determined by the acid-alkali extraction method developed for the analyses of peat soils and also an ignition method was used (11). The data reported are average values of the results of both these methods.

In addition to the information of the solubility of inorganic phosphorus obtained in connection with the analyses of organic phosphorus, also phosphorus soluble in 0.5 N acetic acid was estimated. These extractions were performed in a ratio of 1 to 20, and the time of extraction was one hour.

The peat samples and some of their characteristics are listed in Table 1 as groups of various kinds of peat and in the order of the increasing degree of humification. The title »Bog type» means peat land vegetation type. The letter R = räme or pine bog, N = neva or wet treeless oligotrophic bog, K = korpi or spruce-broad-leaved tree swamp, and L = letto or rich treeless fen. The column titled »Bo» represents the degree of land quality, estimated on the basis of the surface vegetation. The grading from 1 to 10, common in Finnish soil survey, is used, the classes from 5 to 10 being tillable.

The 32 samples of *Sphagnum* peat (Sp) represent treeless oligotrophic bogs or pine bogs with a low degree of land quality. The origin of the 34 samples of *Carex-Sphagnum* peat (CSp) is not markedly better, but the average sampling depth of a large part of the CSp group was greater. Among the 62 samples of *Sphagnum-Carex* peat (SCp) a large number was collected from tillable peat lands, but also the poor land quality is represented. All the 12 samples of eutrophic *Sphagnum-Carex* peat (EuSCp) are from rich treeless fens, and also the peat lands from which the 36 samples of *Bryales-Carex* peat (BCp) originates are of a high quality, mostly fens. The 41 samples of *Carex* peat (Cp) were taken from various kinds of peat lands: peat lands with a poor surface vegetation were represented by samples from the deeper layers.

In connection with this work no attention was paid to the content of ligneous residues in some of these samples. It may be mentioned that samples A1-A3 and 105 can be determined as LS-peat, samples 35, 69—71 as LCS-peat, samples K23 as LSC-peat, and samples 23, 30 — 32, 38, 111, 137, K27 and K30 as LC-peat.

Table 1. Peat samples.

Sample		Bog type	Bo	Depth dm	H	pH	Volume weight	Ash %	N %
1		2	3	4	5	6	7	8	9
				Sphagnum peat					
	65	N	1—2	0—2	1	3.7	0.05	1.4	0.82
	144	R	1	0—2	1	5.1	0.07	1.5	0.89
K	31	N	1	0—2	1	4.2	0.08	5.9	2.44
K	32	N	1	4—6	1	4.4	0.08	3.9	1.47
K	21	N	2	0—2	1	4.3	0.09	8.0	0.86
K	34	N	2	0—2	1	4.2	0.09	5.0	1.03
A	4	R	1	3—5	1	4.7	0.10	1.0	0.64
K	37	N	1	0—2	1	4.5	0.11	4.9	1.45
K	6	R	2	1—2	1	4.5	0.11	4.2	1.19
A	27	N	2	0—2	1	4.5	0.12	5.2	0.73
	36	R	2	0—2	1	4.0	0.12	11.2	1.24
A	58	N	1	1—3	1	3.8	0.13	4.2	0.47
A	37	N	2	0—2	1	4.4	0.28	10.8	1.09
A	31	N	2	0—2	1	3.9	0.29	5.7	1.89
K	22	R	1	2—4	2	5.0	0.14	2.8	1.15
K	7	R	2	2—3	2	4.6	0.17	4.5	1.49
V	6a	N	1	1—3	2	4.9	0.22	10.6	1.82
	66	N	1—2	2—5	2	3.6	0.09	1.5	0.95
A	5	R	1	5—7	3	4.9	0.23	2.1	1.17
V	6b	N	1	5—7	3	5.1	0.26	7.4	2.24
A	1	R	1	2—3	3	3.7	0.29	4.4	1.72
A	32	N	1	3—5	3	4.0	0.34	4.0	2.16
A	6	R	1	12—14	4	4.7	0.21	2.9	1.19
V	1a	N	3	1—3	4	4.3	0.31	7.6	1.92
V	15a	N	1	1—3	4	4.5	0.33	8.1	3.34
	67	N	1—2	5—9	4	3.8	0.21	2.9	2.07
	105	R	2	2—4	4	4.4	0.20	2.2	1.42
V	1b	N	3	5—7	5	4.3	0.33	8.5	2.15
A	2	R	1	3—4	5	3.8	0.49	4.3	1.75
	68	N	1—2	9—11	6	4.2	0.32	2.4	1.49
V	15b	N	1	5—7	6	4.4	0.41	4.9	1.96
A	3	R	1	7—10	7	4.4	0.38	6.3	1.85
				Carex-Sphagnum peat					
V	24a	N	2	1—3	1	4.5	0.10	7.9	1.03
	100	N	2	0—2	1	5.1	0.11	7.7	1.71
V	23a	N	2	1—3	1	4.5	0.11	9.5	1.26
V	16a	N	3	1—3	2	4.4	0.12	6.9	0.96
	69	R	2	0—3	2	4.2	0.09	3.4	1.22
V	2a	N	3	1—3	2	4.3	0.15	5.5	1.06
K	38	N	1	2—4	2	4.6	0.23	5.0	2.23
	101	N	2	3—5	3	5.2	0.14	6.5	2.30
	107	N	3	1—3	3	4.4	0.16	5.0	3.26

1		2	3	4	5	6	7	8	9
V	24b	N	2	5—7	3	4.8	0.17	7.5	3.14
V	23b	N	2	5—7	3	4.9	0.19	7.8	2.97
	28	N	3	4—6	3	4.2	0.23	2.7	2.98
	37	N	2	0—3	3	4.7	0.33	9.9	2.99
A	52	N	2	1—3	3	3.8	0.33	7.8	2.01
K	39	N	1	4—6	4	4.6	0.25	4.3	2.12
V	21a	N	3	1—3	4	5.0	0.30	4.9	2.02
V	21b	N	3	5—7	4	5.2	0.28	9.8	2.86
A	28	N	2	5—7	4	4.3	0.30	3.5	1.11
	70	R	2	3—5	4	4.4	0.25	9.7	2.11
V	16b	N	3	5—7	4	4.5	0.29	6.0	2.27
V	22b	N	3	5—7	4	5.1	0.28	4.3	1.87
V	2b	N	3	5—7	4	4.2	0.31	4.6	2.03
	34	N	3	0—3	4	4.5	0.34	12.4	2.74
V	22a	N	3	1—3	4	4.7	0.37	13.4	2.45
	35	R	3	0—3	4	4.5	0.38	9.4	2.47
K	8	R	2	3—4	5	4.6	0.39	5.5	2.41
K	33	R	1	6—8	5	4.5	0.25	5.8	2.61
	102	N	2	7—10	5	5.3	0.31	4.9	2.60
	29	N	3	15—20	5	5.1	0.33	4.4	2.74
A	29	N	2	8—10	5	4.1	0.35	4.0	1.70
	106	N	7	2—4	6	4.7	0.26	22.4	2.32
	71	R	2	7—10	6	4.3	0.36	6.2	2.71
K	42	R	2	2—4	7	3.9	0.39	12.4	2.37
A	46	R	2	4—6	7	4.1	0.49	6.6	2.13
				Sphagnum-Carex peat					
K	28	N	1	0—2	1	4.5	0.20	6.5	1.74
V	3a	N	3	1—3	1	4.4	0.14	6.7	1.07
A	19	N	2	1—3	2	5.0	0.25	12.3	1.86
A	13	N	3	8—10	2	4.8	0.20	6.5	1.71
A	12	N	3	3—5	2	4.8	0.25	4.0	1.75
A	23	N	2	1—3	2	4.7	0.38	8.0	2.68
V	19a	N	5	1—3	2	4.7	0.21	8.1	1.74
V	5a	N	4	1—3	2	4.6	0.24	16.3	2.03
K	12	N	4	0—1	3	4.4	0.27	9.8	3.40
A	53	N	2	1—3	3	4.2	0.42	11.0	1.96
	59	N	5	0—2	3	3.6	0.23	24.4	1.65
A	47	R	2	2—4	3	4.6	0.23	9.6	1.90
V	3b	N	3	5—7	3	4.3	0.25	5.1	1.19
A	11	N	3	0—2	3	4.9	0.26	16.7	2.28
A	16	N	2	6—8	3	4.5	0.30	3.7	2.08
V	5b	N	4	5—7	3	4.9	0.30	8.5	2.42
A	35	N	6	0—4	3	5.5	0.31	9.3	2.43
V	10a	N	3	1—3	3	4.7	0.27	18.4	2.61
V	10b	N	3	5—7	3	4.9	0.24	8.1	2.37
V	9a	N	3	1—3	3	4.9	0.27	18.9	2.75
V	13a	N	4	1—3	3	4.4	0.25	9.7	2.88
K	18	N	4	0—2	3	5.5	0.27	15.4	4.51

1	2	3	4	5	6	7	8	9
V	9b	N	3	5—7	3	4.9	0.24	11.5	2.54
V	14a	N	4	1—3	4	4.5	0.29	9.2	3.21
V	20a	N	5	1—3	4	4.6	0.33	7.8	1.61
K	24	R	1	6—8	4	5.1	0.35	2.2	2.51
A	49	N	5	1—3	4	4.3	0.34	6.2	2.49
	86	N	6	0—2	4	4.4	0.21	4.7	2.40
	89	N	6	0—2	4	4.5	0.22	9.4	2.35
V	11a	N	3	1—3	4	4.7	0.28	22.0	2.19
V	11b	N	3	5—7	4	4.8	0.24	14.4	2.78
V	8a	N	4	1—3	4	4.7	0.25	15.8	2.40
	57	N	6	0—3	4	4.8	0.25	15.5	2.57
	33	N	6	0—3	4	4.7	0.30	5.1	3.24
A	20	N	2	4—6	4	4.2	0.30	5.8	2.07
V	12a	N	4	1—3	4	4.4	0.30	10.8	3.27
V	17a	N	4	1—3	4	4.8	0.30	10.1	2.32
V	17b	N	4	5—7	4	4.9	0.30	5.8	2.24
V	18a	N	4	1—3	4	4.8	0.32	7.4	2.27
V	18b	N	4	5—7	4	4.9	0.31	5.7	2.22
A	15	N	2	2—4	4	4.3	0.34	6.5	2.02
	55	N	6	0—3	4	5.2	0.44	25.5	2.50
V	8b	N	4	5—7	4	4.9	0.24	6.1	2.39
V	7a	N	6	1—3	5	4.7	0.29	10.2	3.34
A	33	N	2	8—10	5	4.1	0.30	3.1	2.01
	60	N	5	3—9	5	3.5	0.32	3.5	2.59
K	90	N	6	3—5	6	4.8	0.30	3.3	2.62
K	35	R	3	4—6	5	4.9	0.34	6.1	2.54
	87	N	6	3—5	5	4.5	0.29	2.6	2.40
K	23	R	1	4—6	5	5.0	0.32	2.0	2.37
V	19b	N	5	5—7	5	5.1	0.39	7.4	1.92
K	59	N	4	0—5	6	5.3	0.45	9.6	5.07
	58	N	6	3—7	6	4.9	0.25	6.9	2.76
V	14b	N	4	5—7	6	4.5	0.40	5.3	2.48
V	13b	N	4	5—7	6	4.5	0.40	5.4	2.45
V	12b	N	4	5—7	6	4.4	0.40	4.1	2.46
V	20b	N	5	5—7	6	5.5	0.42	6.9	1.83
	56	N	6	0—3	6	5.1	0.43	32.6	3.24
	88	N	6	7—10	6	5.2	0.30	4.0	2.41
	61	N	5	10—13	7	4.2	0.40	13.2	2.58
V	7b	N	6	5—7	7	5.0	0.40	9.1	2.51
	76	R	1	60—62	9	4.8	0.71	11.2	1.92
				Eutrophic *Sphagnum-Carex* peat					
	91	L	8	0—2	2	5.8	0.18	9.1	2.32
	62	L	8	0—2	3	4.4	0.18	18.4	1.96
	40	L	8	0—3	3	5.6	0.25	9.8	2.21
	95	L	8	3—5	3	5.8	0.36	7.7	2.15
K	5	L	8	3—5	4	5.4	0.27	5.3	2.54
	92	L	8	3—5	4	5.9	0.36	8.2	2.49
	63	L	8	3—7	5	4.7	0.32	4.9	2.30

1		2	3	4	5	6	7	8	9
	96	L	8	7—10	5	5.8	0.51	14.2	2.33
	93	L	8	7—10	6	5.8	0.41	8.9	2.66
	117	L	8	17—20	6	5.2	0.41	7.5	2.36
	64	L	8	8—10	7	4.3	0.38	5.1	2.16
	118	L	8	20—23	7	5.4	0.47	19.2	2.48
				Bryales-Carex peat					
K	9	L	7	0—2	1	4.9	0.16	9.9	1.96
K	1	L	7	0—2	1	5.5	0.14	9.0	2.53
K	10	L	7	2—3	2	5.2	0.24	15.6	2.98
	74	L	7	0—3	2	6.2	0.20	5.7	3.13
	122	L	8	14—17	2	4.9	0.22	8.2	2.55
	139	L	8	0—2	2	3.9	0.48	7.5	2.29
	39	L	7	0—2	2	4.7	0.23	4.2	3.16
	119	L	8	4—7	3	5.1	0.30	17.1	3.17
	120	L	8	7—10	3	5.0	0.25	6.0	2.22
	121	L	8	10—13	3	4.8	0.21	6.8	2.58
	129	L	8	20—23	3	4.8	0.27	5.9	1.96
	143	L	7	1—3	3	4.1	0.21	3.7	2.09
	113	L	8	4—7	3	5.6	0.28	6.7	2.37
	126	L	8	10—13	3	4.9	0.25	3.7	1.95
	127	L	8	14—17	3	4.9	0.24	4.8	1.97
	128	L	8	17—20	3	4.8	0.25	4.7	1.95
K	2	L	7	3—5	3	5.2	0.28	7.5	2.76
	97	L	7	0—2	3	3.9	0.26	4.3	2.02
	73	L	8	0—2	3	8.0	0.44	15.1	2.56
	125	L	8	4—7	4	4.9	0.30	4.4	2.56
	123	L	8	17—20	4	4.9	0.24	4.4	2.36
	114	L	8	7—10	4	5.4	0.29	7.5	2.37
	141	L	7	2—4	4	5.6	0.45	5.1	2.53
	75	L	7	0—2	4	5.4	0.24	7.1	3.10
	130	L	8	24—27	5	5.0	0.36	5.1	2.36
	98	L	7	3—5	5	4.4	0.34	3.3	1.98
	142	L	8	2—4	5	4.8	0.53	6.6	3.19
	115	L	8	10—13	5	5.4	0.37	6.5	2.05
	135	L	8	10—13	6	5.8	0.44	9.8	3.16
	116	L	8	14—17	6	5.3	0.39	7.0	2.14
	140	K	10	2—4	6	5.1	0.58	8.9	3.29
	99	L	7	7—10	6	4.9	0.45	4.6	2.27
	134	L	8	4—10	6	5.7	0.43	15.3	2.86
	136	L	8	14—17	7	5.7	0.42	11.8	2.79
K	11	L	7	5—7	7	5.0	0.37	10.6	3.62
K	3	L	7	7—9	7	5.3	0.34	4.4	2.76
				Carex-peat					
K	29	N	4	5—7	2	4.6	0.20	5.1	1.99
A	40	N	3	0—2	3	4.7	0.30	5.5	3.08
A	41	N	3	3—5	3	4.8	0.25	5.1	2.54
A	8	K	5	0—3	3	4.7	0.32	5.0	2.73
A	38	N	2	3—5	3	4.5	0.29	10.0	2.94

1		2	3	4	5	6	7	8	9
A	24	N	2	5—6	3	5.0	0.34	5.5	2.50
A	43	N	3	2—5	3	4.5	0.24	5.1	2.23
	38	K	7	0—2	4	4.9	0.36	6.7	3.16
K	13	N	4	1—3	4	4.9	0.28	5.1	3.47
K	14	N	4	5—7	4	5.1	0.26	4.9	2.68
K	25	N	6	1—3	4	4.6	0.21	4.5	2.33
K	26	N	6	5—7	4	4.2	0.20	3.1	2.40
	103	N	4	2—4	4	4.8	0.28	7.7	2.95
	109	N	6	1—3	4	4.6	0.24	24.8	2.16
	111	K		1—3	4	4.7	0.26	3.0	2.62
K	27	N	6	11—14	4	4.4	0.23	5.3	2.04
A	44	N	3	6—8	4	4.3	0.27	6.9	1.70
A	42	N	3	8—10	4	4.9	0.23	4.2	2.55
	110	N	6	2—4	5	4.6	0.24	3.6	2.56
K	36	N	2	4—6	5	4.9	0.34	6.1	2.54
A	17	N	2	8—10	5	4.1	0.31	5.5	2.23
K	30	R	4	2—5	5	4.8	0.38	4.9	2.73
K	41	R	4	2—6	5	4.2	0.28	3.5	3.61
	23	K			6	5.0	0.34	24.2	2.46
	26	L	9	2—4	6	6.1	0.34	14.2	2.32
K	20	N	4	6—8	6	5.4	0.30	4.8	2.88
	104	N	6	2—4	6	4.6	0.29	7.6	3.11
	131	L	8	27—30	6	5.0	0.35	8.2	3.04
	138	L	8	20—23	6	5.5	0.43	11.3	2.75
A	25	N	2	8—9	6	5.1	0.37	8.7	2.48
K	4	N	6	3—6	7	5.2	0.35	6.6	2.74
A	21	N	2	8—10	7	5.8	0.37	7.2	2.05
	137	L	8	17—20	7	5.6	0.39	12.9	2.64
K	19	N	4	3—5	7	5.4	0.46	8.1	3.52
A	50	N	3	3—5	7	4.6	0.31	5.3	2.05
	31	K	6	3—6	8	4.9	0.39	7.8	2.18
	30	K	6	0—3	8	4.6	0.54	9.1	2.40
	32	K	6	0—5	8	4.7	0.69	23.6	2.30
A	9	K	5	0—3	8	4.6	0.58	6.9	2.84
A	45	N	3	12—14	8	4.9	0.52	20.6	2.33
K	60	N	4	10—14	8	4.9	0.53	7.0	2.56

It may be of interest to examine the possible differences in the characteristics of the different kinds of peat on the basis of the data in Table 1. Therefore, the mean values of the degree of humification, pH, volume weight, ash content, and nitrogen content are calculated for the peat groups. As a measure of the distribution the confidence limits at the 95 per cent level are given. These data are collected in Table 2.

In the present material the group of Sp appears, on the average, to be of a lower degree of humification than the other groups, except that of the SCp. The Cp-group seems to represent a higher degree of humification than the other ones. Partly, this is connected with the sampling depth of the various kinds of peat:

Table 2. Mean values of the degree of humification, pH, volume weight, ash content, and nitrogen content for the different peat groups (with 95 % confidence limits)

Kind of peat	Number of samples	H	pH	Volume weight	Ash %	N %
Sp	32	2.6 ± 0.6	4.3 ± 0.2	0.21 ± 0.04	5.0 ± 1.0	1.50 ± 0.22
CSp	34	3.7 ± 0.6	4.5 ± 0.1	0.26 ± 0.04	7.2 ± 1.3	2.20 ± 0.22
SCp	62	3.1 ± 0.4	4.7 ± 0.1	0.31 ± 0.02	9.5 ± 1.5	2.43 ± 0.17
EuSCp	12	4.6 ± 1.1	5.4 ± 0.3	0.34 ± 0.07	9.9 ± 3.2	2.33 ± 0.13
BCp	36	4.1 ± 0.6	5.2 ± 0.2	0.32 ± 0.04	7.5 ± 1.2	2.60 ± 0.16
Cp	41	5.2 ± 0.6	4.9 ± 0.1	0.34 ± 0.07	8.2 ± 1.6	2.55 ± 0.14

the Sp-samples originate, on the average, from a less deep layer than all the other groups. Yet, the BCp-group with a lower average degree of humification than the Cp-group represents markedly deeper layers than the latter one. The total correlation coefficient between the sampling depth and the degree of humification was calculated and a highly significant, but not very close correlation, was found, the coefficient being r = 0.414***.

The average pH values of the different groups are in accordance with the corresponding data reported by Kivinen (12). Only the BCp samples in his material tend to be somewhat less acid than the present samples, the difference of the means is even highly significant. In the present material the Sp samples, as a group, have a lower pH than all the other kinds of peat, the BCp and EuSCp samples are less acid than the other groups, but no significant difference can be found between the CSp and SCp groups on one hand and between the SCp and Cp groups on the other hand.

In the volume weights the low degree of humification of the Sp samples appears. The volume weights of all the groups in which the *Carex*-residues dominates are equal and higher than those of the Sp and CSp samples. The ash content of the BCp group is rather low, yet significantly higher than that of the Sp group, which again appears to be the poorest kind of peat. Owing to the large variation in the ash content no significant difference can be found between the average values of the other kinds of peat. These means are also of the same order as those reported by Kivinen (12) for various peat groups, the only exception again being the BCp samples.

As to the Kjeldahl nitrogen content of the peat groups, the results agree well with the corresponding results by Kivinen (12). In the present material the nitrogen contents of the Cp, BCp and SCp groups do not significantly differ from each other, the nitrogen percentage in the CSp-group is lower than in these but higher than in the poor Sp-group and equal to that in the EuSCp samples. The low number of the EuSCp samples makes their group less representable than the larger ones. Generally the EuSCp seems to be like the SCp and differs from the latter only in its lower acidity.

Table 3. Phosphorus in the peat samples

Sample		Total P		Organic P			N/org. P	Inorganic P, ppm soluble in	
		ppm	kg/ha	ppm	% of tot.P	% of org. matter		0.5 N HAc	0.2 N H_2SO_4
1		2	3	4	5	6	7	8	9
Sphagnum peat									
	65	400	40	250	63	0.02	33	60	60
	144	220	30	130	59	0.01	68	28	40
K	31	480	80	320	67	0.03	76	46	70
K	32	390	60	300	77	0.03	49	24	50
K	21	430	80	300	70	0.03	29	37	50
K	34	730	130	550	75	0.06	19	5	60
A	4	190	40	140	74	0.01	46	7	10
K	37	840	180	590	70	0.06	25	55	90
K	6	970	210	660	68	0.07	18	21	140
A	27	380	90	290	76	0.03	25	8	40
	36	730	170	540	74	0.06	23	15	80
A	58	340	90	210	62	0.02	21	37	50
A	37	530	300	360	68	0.04	30	5	50
A	31	850	490	620	73	0.07	30	29	50
K	22	580	90	400	69	0.04	29	57	50
K	7	1180	400	890	76	0.09	17	14	160
V	6a	560	250	380	68	0.04	48	6	30
	66	470	80	320	68	0.03	30	30	20
A	5	360	170	270	75	0.03	43	5	0
V	6b	490	250	350	72	0.04	64	5	20
A	1	570	330	430	76	0.04	40	14	30
A	32	760	520	590	78	0.06	37	9	30
A	6	370	160	290	79	0.03	41	4	10
V	1a	880	540	640	73	0.07	30	11	20
V	15a	690	460	460	67	0.05	37	7	30
	67	680	280	500	73	0.05	41	16	20
	105	370	150	260	70	0.03	55	22	20
V	1b	830	550	650	78	0.07	33	9	20
A	2	620	610	520	84	0.05	34	15	30
	68	630	400	540	86	0.06	28	4	0
V	15b	490	400	370	75	0.04	53	3	20
A	3	710	540	560	79	0.06	33	1	10
Carex-Sphagnum peat									
V	24a	360	70	280	78	0.03	37	4	20
	100	460	100	260	57	0.03	66	—	20
V	23a	410	90	310	76	0.03	41	4	20
V	16a	520	120	350	67	0.04	27	14	50
	69	770	140	510	66	0.05	24	73	240
V	2a	670	200	500	75	0.05	21	8	30
K	38	760	350	550	72	0.06	41	50	60
	101	510	140	380	75	0.04	60	—	10

1		2	3	4	5	6	7	8	9
	107	790	250	530	67	0.06	62	9	30
V	24b	410	140	330	80	0.04	95	5	10
V	23b	420	160	360	86	0.04	82	5	10
	28	590	270	430	73	0.04	69	1	30
	37	880	580	700	80	0.08	43	9	40
A	52	700	460	490	70	0.05	41	1	30
K	39	840	420	700	83	0.07	30	14	20
V	21a	610	370	470	77	0.05	43	4	30
V	21b	540	300	430	80	0.05	67	7	10
A	28	440	260	330	75	0.03	34	4	20
	70	1310	650	1110	85	0.12	19	20	70
V	16b	770	450	610	79	0.06	37	6	20
V	22b	530	300	430	81	0.05	43	8	10
V	2b	1060	660	810	76	0.08	25	12	50
	34	1480	1000	1120	76	0.13	24	1	60
V	22a	870	640	640	74	0.07	38	12	50
	35	1280	970	1030	80	0.11	24	1	40
K	8	1810	1410	1570	87	0.17	15	5	70
K	33	770	380	660	86	0.07	40	10	20
	102	650	400	550	85	0.06	47	—	10
	29	570	370	410	72	0.04	67	0	10
A	29	550	390	460	84	0.05	37	3	20
	106	620	320	420	68	0.05	55	28	60
	71	1510	1090	1340	89	0.14	20	5	10
K	42	1290	1010	1110	86	0.13	21	9	30
A	46	1550	1520	1380	89	0.15	15	3	30
					Sphagnum-Carex peat				
K	28	930	370	680	73	0.07	26	7	70
V	3a	550	150	430	78	0.05	25	9	20
A	19	540	270	400	74	0.05	47	19	20
A	13	480	190	440	92	0.05	39	—	10
A	12	500	250	420	84	0.04	42	3	10
A	23	1260	960	860	68	0.09	31	7	60
V	19a	860	360	600	70	0.07	29	7	50
V	5a	530	260	340	64	0.04	60	5	30
K	12	1270	690	1000	79	0.11	34	4	50
A	53	520	440	400	77	0.05	49	1	20
	59	1070	490	780	73	0.10	21	8	150
A	47	1210	560	1010	83	0.11	19	4	20
V	3b	540	270	420	78	0.04	28	6	20
A	11	560	290	440	79	0.05	52	7	20
A	16	440	260	420	95	0.04	50	4	10
V	5b	550	330	420	76	0.05	58	3	10
A	35	710	440	580	82	0.06	42	4	20
V	10a	880	480	680	77	0.08	38	6	30
V	10b	690	330	550	80	0.06	43	4	20
V	9a	890	480	670	75	0.08	41	5	30
V	13a	670	340	450	67	0.05	64	8	30

1		2	3	4	5	6	7	8	9
K	18	570	310	440	77	0.05	103	5	50
V	9b	690	330	550	80	0.06	46	4	20
V	14a	680	390	470	69	0.05	69	7	20
V	20a	1150	760	880	76	0.09	18	—	50
K	24	450	310	360	80	0.04	70	8	10
A	49	1230	840	860	70	0.09	29	2	60
	86	830	350	560	67	0.06	43	—	30
	89	1280	560	840	66	0.09	28	—	100
V	11a	870	490	640	74	0.08	34	6	30
V	11b	700	340	550	79	0.06	51	4	10
V	8a	880	440	660	75	0.08	36	7	50
	57	1110	550	900	81	0.11	29	2	20
	33	1110	670	850	77	0.09	38	20	100
A	20	750	450	650	87	0.07	32	13	10
V	12a	700	420	510	73	0.06	64	8	30
V	17a	900	540	680	75	0.08	34	6	20
V	17b	810	490	640	79	0.07	35	2	20
V	18a	890	570	680	76	0.07	33	6	30
V	18b	810	500	670	83	0.07	33	3	10
A	15	680	460	550	81	0.06	37	6	10
	55	640	560	510	80	0.07	49	1	10
V	8b	660	320	530	80	0.06	45	3	10
V	7a	950	550	720	76	0.08	46	4	50
A	33	630	380	500	79	0.05	40	—	20
	90	730	440	560	77	0.06	47	—	10
	60	1100	710	890	81	0.09	29	7	20
K	35	1180	800	900	77	0.10	28	4	50
	87	570	330	450	79	0.05	53	—	10
K	23	610	390	470	77	0.05	50	25	40
V	19b	750	590	600	80	0.06	32	3	10
K	59	460	410	380	83	0.04	133	2	10
	58	1000	500	830	83	0.09	33	2	0
V	14b	570	450	390	69	0.04	64	3	10
V	13b	540	430	390	72	0.04	63	3	10
V	12b	530	420	410	77	0.04	60	3	10
V	20b	1080	910	920	85	0.10	20	3	10
	56	1030	890	830	80	0.12	39	1	90
	88	840	500	690	82	0.07	35	—	10
	61	1290	1030	990	77	0.11	23	2	30
V	7b	1010	810	880	87	0.10	29	3	20
	76	560	800	410	78	0.05	47	9	30
				Eutrophic *Sphagnum-Carex* peat					
	91	1470	530	1230	84	0.14	19	—	80
	62	1500	540	1110	74	0.14	18	15	100
	40	860	430	670	78	0.07	33	57	80
	95	810	580	650	80	0.07	33	—	20
K	5	550	300	470	85	0.05	54	18	40
	92	820	590	690	84	0.07	36	—	20

1	2	3	4	5	6	7	8	9
63	750	480	600	80	0.06	38	7	10
96	2050	2090	1910	93	0.22	12	—	30
93	770	630	650	84	0.07	41	—	20
117	670	550	590	88	0.06	40	—	20
64	500	380	400	80	0.04	54	2	0
118	1040	980	920	88	0.11	27	—	60
Bryales-Carex peat								
K 9	580	190	400	69	0.04	49	12	70
K 1	340	100	200	59	0.02	126	21	50
K 10	530	250	430	81	0.05	69	5	50
74	520	210	380	73	0.04	82	22	20
122	300	130	230	77	0.02	110	—	10
139	1190	1140	890	75	0.10	26	17	140
39	500	230	370	74	0.04	86	12	30
119	350	210	270	77	0.03	117	—	20
120	270	140	240	89	0.03	93	—	10
121	260	110	200	77	0.02	130	—	20
129	320	170	240	75	0.03	81	—	10
143	570	240	440	77	0.05	48	25	30
113	530	300	430	81	0.05	55	—	20
126	270	130	210	78	0.02	93	—	10
127	290	140	250	86	0.03	79	—	10
128	330	160	250	75	0.03	78	—	10
K 2	660	380	530	80	0.06	52	4	40
97	750	390	500	67	0.05	40	—	40
73	650	570	510	79	0.06	50	8	30
125	370	220	300	81	0.03	85	—	10
123	310	150	280	90	0.03	84	—	10
114	530	310	470	88	0.05	50	—	20
141	690	620	540	78	0.06	47	—	50
75	620	300	450	72	0.05	69	5	50
130	410	300	320	78	0.03	74	—	10
98	610	410	500	82	0.05	40	—	10
142	450	480	330	73	0.03	98	29	40
115	450	330	390	87	0.04	53	—	10
135	1120	990	970	87	0.11	33	—	20
116	540	420	460	85	0.05	47	—	10
140	860	1000	730	85	0.08	45	—	30
99	680	610	530	78	0.06	43	—	10
134	1130	970	980	86	0.11	29	—	20
136	900	760	780	87	0.09	36	—	20
K 11	610	450	490	81	0.05	74	3	20
K 3	520	350	420	81	0.04	66	4	30
Carex-peat								
K 29	850	340	630	74	0.07	32	5	50
A 40	810	490	650	80	0.07	47	4	20
A 41	470	230	370	79	0.04	69	3	10

1		2	3	4	5	6	7	8	9
A	8	570	370	510	90	0.05	54	2	0
A	38	550	320	400	73	0.04	73	7	20
A	24	850	580	720	85	0.08	35	3	10
A	43	1180	570	1010	86	0.11	22	2	10
	38	1410	1020	1060	75	0.11	30	9	140
K	13	1060	590	880	83	0.09	39	4	20
K	14	890	460	730	82	0.08	37	2	20
K	25	1140	480	930	82	0.10	25	4	20
K	26	1210	480	920	76	0.09	26	2	20
	103	1550	870	1150	74	0.12	26	7	110
	109	580	280	320	55	0.04	68	6	90
	111	1480	770	1270	86	0.13	21	3	20
K	27	1240	570	1080	87	0.11	19	2	20
A	44	1020	550	880	86	0.09	19	2	10
A	42	500	230	400	80	0.04	64	5	10
	110	890	430	740	83	0.08	35	2	20
K	36	1070	730	940	88	0.10	27	1	10
A	17	550	340	500	91	0.05	45	—	10
K	30	1120	760	830	74	0.09	33	1	20
K	41	670	380	500	75	0.05	72	6	30
	23	1350	1030	1020	76	0.14	24	6	100
	26	1340	910	1080	81	0.13	22	39	90
K	20	870	520	620	71	0.06	46	1	30
	104	710	410	520	73	0.05	60	5	50
	131	450	320	350	78	0.04	87	—	20
	138	660	570	580	88	0.06	48	—	20
A	25	910	670	800	88	0.09	31	2	20
K	4	630	440	520	82	0.06	53	4	30
A	21	660	490	590	89	0.06	35	5	10
	137	530	410	460	87	0.05	57	—	20
K	19	750	690	540	72	0.06	65	2	30
A	50	890	550	760	86	0.08	37	3	10
	31	750	580	650	87	0.07	34	1	10
	30	950	1030	820	86	0.09	29	2	20
	32	1250	1720	1070	86	0.14	22	1	20
A	9	830	960	680	82	0.07	42	3	20
A	45	2350	2440	1950	83	0.25	12	1	180
K	60	1230	1300	1090	89	0.12	22	2	30

According to this survey the present material appears to be satisfactorily typical for a study of Finnish peat soils. Only the BCp-group seems to be in some respects of a poorer quality than is generally suggested.

Total phosphorus

The total P content of the peat samples expressed both as ppm and as kg/ha in a 20 cm-layer is reported in Table 3. Quantities ranging from 190 to 2350 ppm or from 30 to 2440 kg/ha can be found. In order to obtain an idea of the differences between the various kinds of peat the corresponding mean values are computed. The minimum and maximum values are also given and the distribution is characterized by the confidence limits at the 95 per cent level.

		Total P ppm		Total P kg/ha	
		mean	min. max.	mean	min. max
32 Sp	samples	580 ± 80	190 — 1180	260 ± 70	30 — 610
34 CSp	»	800 ± 120	360 — 1810	470 ± 170	70 — 1520
62 SCp	»	800 ± 60	440 — 1290	490 ± 50	150 — 1030
12 EuSCp	»	980 ± 290	500 — 2050	670 ± 300	230 — 2090
36 BCp	»	560 ± 90	260 — 1190	390 ± 90	100 — 1140
41 Cp	»	950 ± 120	450 — 2350	660 ± 130	230 — 2440

The most striking result is the low average value for the total P content of the BCp-group expressed on the weight basis. It is equal to that of the Sp-group and significantly lower than the mean phosphorus content of Cp, SCp, and CSp samples. Owing to the higher volume weight of the BCp samples their P content expressed as kg/ha tends to be somewhat higher than the corresponding value for the Sp-group. Even then the BCp seems to be poorer in phosphorus than the Cp, but the difference between the BC-group and the CSp and SCp groups is less significant. Attention must, however, be paid to the fact that the figures calculated on the basis of the volume weight determined in this work on air-dry and ground samples do not correspond to the real conditions in nature.

The Cp and EuSCp groups tend to show the highest average content of total phosphorus. The difference between the total phosphorus in the Cp-group and the SCp-group is statistically significant. The variation in the CSp and EuSCp groups violates the demonstration of a significant difference between the P content of these kinds of peat and of that of the Cp-group. The poverty of the Sp and BCp in total P is indisputable.

These data are well in accordance with the results reported by Kivinen (12) of his own analyses and of the analyses performed by some other peat scientists in Finland. Only the poor BCp-group of this material forms an exception. The average phosphorus content of the 21 BCp samples analysed by Kivinen is about 700 ppm. Vahtera (19) in his thesis reports even higher phosphorus contents for the BCp: his average value of 24 samples is about 1400 ppm, as far as it is possible to estimate it on the basis of the distribution tables given. This quantity cannot, however, be typical for Finnish BCp. It is probable that the analyses performed by Vahtera are not reliable, since also the average phosphorus content which can be calculated for his 97 Sp samples seems to be higher than 1300 ppm, and one fifth of his 58 Cp samples contain more than 3000 ppm of total P.

The total P content of the present samples appears to be in no correlation with the land quality determined on the basis of the surface vegetation. The correlation coefficient for all the samples is r = 0.070. This, probably, arises from the fact that the sampling depth of the material varied considerably and the peat quality of the deeper layers does not any more exert a distinct effect upon the nutrition of the surface vegetation. If only the surface samples are chosen and the correlation coefficient between their total P content and the degree of land quality is calculated, a low but significant correlation coefficient, r = 0.361*** can be obtained. An even closer correlation is found if the BCp samples which all originate from peat lands of a high quality but which contain rather low amounts of total phosphorus, are excluded. This correlation coefficient is r = 0.481***.

In a previous paper (9) the dependence of the total P content of peat samples on the sampling depth was studied. It was found that even within the same profile the P content could vary quite irregularly, but often some tendency appeared to exist: in the peat lands of better quality the surface samples were higher in phosphorus than the deeper ones, and in the peat lands of lower quality an increase in the P content with the depth was detected.

In order to study whether the total phosphorus content of peat is connected with some of its other characteristics the total correlation coefficients between the total P and the total N, or the ash content, or the degree of humification were calculated. The following data were obtained:

Correlation coefficients between total P content and

	H	N %	Ash %
32 Sp samples	0.135	0.406*	0.382*
34 CSp »	0.573***	0.222	0.243
62 SCp »	0.108	0.049	0.109
12 EuSCp »	— 0.318	— 0.640*	0.700*
36 BCp »	0.377*	— 0.148	0.298
41 Cp »	— 0.019	0.308	0.346*
All the 217 »	0.317***	0.206*	0.289**

Although statistically even highly significant correlation coefficients between the total P content and the other characteristics of all the material could be found, these figures are, almost without exception, so low that no marked dependence between these quantities can be expected to exist. In addition to this, the coefficients calculated for the various peat groups do not encourage to imagine that the total P content of a peat would be connected with the total N or ash contents, generally not even with the degree of humification.

The present material corroborates the opinion that the Finnish virgin peat soils are mostly rather poor in phosphorus. Some exceptions were detected: in 26 of all the 217 samples a P content higher than 1200 ppm was found, but only in two of the samples the P content exceeded 2000 ppm. On the other hand, in 40 samples less than 500 ppm of total P occurred. Yet, the total amount of phosphorus is not enough to characterize the phosphorus conditions in a soil: the forms in which the phosphorus occurs can be more important, at least when the plant nutrition is in question.

Organic phosphorus

There is in the literature very little information of the organic phosphorus content of peat soils. In 1899 NANNES (14) isolated from peat an organic preparate with a high P content thus proving that phosphorus in peat soils occurs, at least partly in organic form. This had been suggested already by EGGERTZ and NILSON (4) although the method which they employed for the determination of organic P was unreliable. Since then only some scattered data concerning the occurence of organic P in peat lands are reported. SCHMOEGER (16) found in a peat sample 600 ppm of organic P, and amount which corresponded to 57 per cent of the total P content of the soil. DICKMAN and DETURK (2) obtained the same percentage for their peat soil which contained 1040 ppm of organic P. DMITRENKO (3) reported that in some meadow-bogs the organic P content varied from 920 to 1700 ppm. In a Swedish raised bog the organic P content estimated by an ignition method was in the 90—100 cm layer 65 ppm and in the 140—150 cm layer 130 ppm corresponding to the relative amounts of 71 and 84 per cent of the total P contents, respectively (13). In a previous publication the author studied the organic P content of 37 cultivated peat soils (5). The data varied from 170 to 1670 ppm and the relative amount of organic P of total P dissolved ranged from 30 to 80 per cent. Also some virgin peat samples were analysed, but the method of fractionation employed for these latter estimations probably yielded too high results.

It was emphasized in a previous paper (11) that the determination of total organic P in samples of virgin peat soils often requires a more drastic treatment than that which is needed when mineral soils or old cultivated peat soils are in question. In the same paper analyses for organic P were reported. In 32 samples of virgin peat soils the amount of organic P varied from 180 to 1180 ppm, and in the 8 samples of cultivated peat soils the corresponding limits were 600 and 1260 ppm.

In the present paper the organic P content of the samples was determined as an average of the results of an extraction method, particularly developed for the analyses of virgin peat samples, and an ignition method. The former method tends to yield too low estimations of the amount of organic P. The latter one, on the other hand, tends to give too high values. Hence, it can be supposed that the average of the results obtained by the respective methods is fairly reliable.

In these 217 peat samples (Table 3) the amount of phosphorus which occurs in organic form ranges from 130 ppm to 1950 ppm with an average value of 600 $\pm$ 40. The organic P content expressed as a percentage of the total P content ranges from 55 % to 95 % with an average of 78 $\pm$ 1 %.

The organic P content of the various peat groups was the following (the confidence limits of the means are given at the 95 per cent level):

		Org. P. ppm			Org. P % of tot. P		
		mean	min.	max.	mean	min.	max.
32 Sp	samples	430 ± 60	130 —	890	73 ± 2.2	59 —	86
34 CSp	»	630 ± 120	280 —	1570	77 ± 3.0	57 —	89
62 SCp	»	620 ± 50	340 —	1010	77 ± 1.6	64 —	95
12 EuSCp	»	820 ± 280	400 —	1910	83 ± 3.3	74 —	93
36 BCp	»	440 ± 70	200 —	980	79 ± 2.4	59 —	90
41 Cp	»	770 ± 100	320 —	1950	81 ± 2.2	55 —	91

The relation between the organic P content of the various peat groups appears to be similar to that which exists between the results obtained for the total P content of the samples. This arises from the fact that the correlation between the total and organic phosphorus contents of these peat samples is very close, the total correlation coefficient for the material being markedly higher than 0.9. The average contents of organic P are not very high when expressed as parts per millions but the corresponding relative amounts indicate that in all the peat groups the largest part of P occurs in organic form. A more detailed picture of the distribution of the organic P content within the various peat groups is presented in the Tables 4 and 5.

The data in Table 4 indicate that only 22 of the samples contain more than 1000 ppm of organic P. All the samples of Sp and BCp lie below this limit. To these groups also belong the three samples in which the organic P content is lower than 200 ppm.

As to the proportion of organic P of total P, the distribution of the samples of the various peat groups in the different classes appears to be more equal (Table 5). There seems, however, to be a tendency to lower percentages in the Sp samples and to higher percentages in the Cp samples as compared with those of the other peat groups. This may be connected with the fact that a large part of the Sp samples originates from the less humified surface layers and most of the Cp samples from

Table 4. Distribution of samples of various peat groups in classes of organic phosphorus content.

Org. P ppm	Sp	CSp	SCp	EuSCp	BCp	Cp	Total
<200	2	—	—	—	1	—	3
210—400	14	8	5	—	15	3	45
410—600	11	13	27	3	15	11	80
610—800	4	5	15	5	2	9	40
810—1000	1	1	13	1	3	8	27
1010—1200	—	4	2	1	—	8	15
1210—1400	—	2	—	1	—	1	4
1410—1600	—	1	—	—	—	—	1
1610—1800	—	—	—	—	—	—	—
1810—2000	—	—	—	1	—	1	2

Table 5. Organic phosphorus as a percentage of total phosphorus in various peat groups.

Org. P %	Sp	CSp	SCp	EuSCp	BCp	Cp	Total
51—55	—	—	—	—	—	1	1
56—60	1	1	—	—	1	—	3
61—65	2	—	1	—	—	—	3
66—70	10	5	8	—	2	—	25
71—75	9	7	9	1	7	9	42
76—80	8	10	29	4	10	6	67
81—85	1	5	11	4	8	9	38
86—90	1	6	2	2	8	15	34
91—95	—	—	2	1	—	1	4

deeper layers of peat lands. The author has found (9) that generally, at least within the same profile, the proportion of phosphorus occurring in organic form increases with the depth. Tables 1 and 3 reveals that all the samples in which the percentage of organic P of total P is 65 % or lower were collected from the surface layers not deeper than 3 dm. On the other hand, all the samples in which more than 91 per cent of total P occurs in organic form arises from deeper layers between 6 and 10 dm. This, of course, cannot mean that the proportion of organic P would depend only on the depth or on the age of the peat.

In order to study the different factors which control the occurence of peat phosphorus in organic form, the present material was submitted to further statistical examination. First the absolute amounts of organic P were studied. It has already been mentioned that this quantity closely depends on the total P content of peat. In addition to this, it can be supposed that the degree of humification could exert some effect upon the accumulation of organic P. Also the relations of N content and organic P content may be noteworthy. The total linear correlation coefficients between the amount of organic P and the total P content, or the degree of humification, or N content were for the various peat groups and for the total material the following:

Correlation coefficients between organic P ppm and

		total P ppm	H	N %
32 Sp	samples	0.968***	— 0.010	0.420*
34 CSp	»	0.988***	0.559***	0.243
62 SCp	»	0.955***	0.157	0.052
12 EuSCp	»	0.938***	— 0.200	— 0.111
36 BCp	»	0.977***	0.441**	0.307
41 Cp	»	0.981***	0.147	— 0.084
All the 217	»	0.934***	0.336***	0.184

When compared with the close correlation of organic P and total P contents the connection of the former with the degree of humification appears to be weak and the dependence of the former on the N content is insignificant. Even the effect of the degree of humification on the organic P content of these samples is indirect and arises from the connections between the total P content and the degree of humification: after the elimination of the effect of the two other factors the partial correlation coefficients between the organic P content (1) and the total P content (2) or the degree of humification (3) or the N content (4) were.

$$r_{12;\,34} = 0.927^{***} \quad r_{13;\,24} = 0.136 \quad r_{1';\,23} = -\,0.072$$

Consequently, of the characteristics of the peat samples examined here, only the total content of P appears to regulate the absolute amount of organic P. There may exist other factors which exert their effect on the accumulation of organic P in peat soils, but it seems probable that the generally rather low total P content is the minimum factor which impedes the effect of those other characteristics to become observable.

It can be supposed that the proportion of phosphorus occurring in organic form depends on the degree of humification and on the depth, on the acidity of peat and possibly also on the total P content of the samples. This material revealed the following correlation coefficients between the percentage of organic P of the total P and these other characteristics:

Correlation coefficients between the percentage of organic P of total P and

	H	Depth	pH	total P
32 Sp samples	0.567***	0.636***	— 0.108	0.309
34 CSp »	0.586***	0.362	— 0.016	0.326
62 SCp »	0.180	0.220	0.310*	— 0.075
12 EuSCp »	0.204	0.627	0.267	0.076
36 BCp »	0.576***	0.297	0.090	0.134
41 Cp »	0.290	0.243	0.073	0.038
All the 217 »	0.504***	0.334***	0.234*	0.222*

The low correlation between the percentage of organic P and the total P content of all the material disappears when the effect of the degree of humification is eliminated: the partial correlation coefficient is $r = 0.076$. The elimination of the degree of humification does not, on the other hand, change the correlation between the organic P percentage and the acidity: the partial correlation coefficient is $r = 0.228^{*}$. The elimination of the degree of humification also leads to the disappearance of the significant correlation between the proportion of organic P and the depth: the partial correlation coefficient is $r = 0.159$, but the elimination of the effect of depth only slightly lowers the correlation between the organic P percentage and the degree of humification: the partial correlation coefficient is $r = 0.427^{***}$.

In a previous paper (9) in which the distribution of P in various peat profiles was studied, the observation was made that the proportion of organic P was rather closely correlated both with the degree of humification and with the depth. Since both these characteristics were also closely correlated with each other the elimination of the effect of either one of them led to equally high partial correlation coefficients. Hence, it could not be concluded which of these factors was the primary one to regulate the accumulation of organic P in peat. The present results tend to suggest that the degree of humification probably plays the more important role in this connection. Yet, the examination of the respective correlation coefficients for the various peat groups shows that the degree of humification cannot be the main factor.

It is of interest to notice that the rather low correlation coefficient between the proportion of organic P and the pH value is positive. Generally, it has been supposed that the effect of the reaction would be the contrary, at least in mineral soils and in cultivated peat soils (5, 18). If this positive correlation found for the present material really would be of any significance it could be explained on the basis of the supposition that the biological turning over of inorganic P compounds into organic forms occurs more intensively under the less acid conditions. When mineral soils are in question, the fact is emphasized that under acid conditions the mineralization of organic P is slower than is the case in less acid soils. In virgin peat soils, however, the biological absorption may be the dominating process.

Theoretically it indeed seems that in most of these peat samples no net mineralization of organic phosphorus can be expected to be observed, because of their extremely low organic P content. The amount of organic P expressed as a percentage of organic dry matter is in the larger part of the samples markedly lower than the general limit of mineralization of organic P or about 0.2 per cent (5). Even if allowance is made to the fact that the carbon compounds of peat are not easily available for microorganisms and, hence, the limit value must be lower in peat than in materials containing more available sources of energy and carbon, it seems improbable that this limit could be markedly lower than about 0.1 per cent organic P of the organic material.

In the present peat samples the organic phosphorus content of organic dry matter presented in Table 3 gives the following average and limit values for various peat groups (the means are reported with the corresponding confidence limits at the 95 per cent level):

Organic P as a percentage of organic dry matter

		mean	min. — max.
32 Sp	samples	0.04 ± 0.007	0.01 — 0.09
34 CSp	»	0.07 ± 0.013	0.03 — 0.17
62 SCp	»	0.07 ± 0.005	0.04 — 0.12
12 EuSCp	»	0.09 ± 0.03	0.04 — 0.22
36 BCp	»	0.05 ± 0.008	0.02 — 0.11
41 Cp	»	0.08 ± 0.013	0.04 — 0.25
All the 217	»	0.07 ± 0.004	0.01 — 0.25

As it can be observed from the maximum value in the Sp-group there are no samples containing 0.1 per cent of organic P. Table 3 reveals that in the group of CSp seven samples exceed this limit, in the SCp-group their number is five, in the group of EuSCp four, in the BCp-group two and in the group of Cp it is ten. The mean values for all the groups, except for the EuSCp-group, are significantly lower than 0.1 per cent.

It can be supposed that the percentage of organic P of the organic dry matter increases with the degree of humification. On the basis of this material a positive correlation coefficient was obtained between these variables; r = 0.382***, which indicates a significant but not very close connection. As to the different peat groups the corresponding correlation coefficients varied markedly being the following:

Sp: r = 0,344	SCp: r = 0.159	BCp: r = 0.378*
CSp: r = 0.621***	EuSCp: r = — 0.243	Cp: r = 0.298

These coefficients do not significantly differ from the figures obtained for the dependence between the degree of humification and the organic P content of the dry matter. This, of course, could be expected because of the low ash content of most of the samples. In view of the marked variation in the total P content of the samples and the close dependence of the organic P content on it no answer to the question »does the organic P in organic dry matter increase or decrease by advancing humification» can be given by this material.

The close relation of P and N contents of soil organic matter has sometimes been emphasized (1, 15, 17, 18). According to a previous paper (5) this connection seems to be rather distinct in mineral soils, but in peat soils the ratio of N to organic P markedly varied: in 70 mineral soils N/org. P ranged from 5 to 16, in 30 cultivated peat soils the limits were 8 and 74. In the present material a low correlation between the N and organic P contents of the samples were found (cf. p. 159). Therefore, no constant number for the ratio of N/org.P can be expected in this material.

The data reported in Table 3 reveal that the ratio of N/org.P ranges from 12 to 133. The mean value is 45 ± 3. If the ratio in mineral soils is supposed to be, on the average, 10, a figure often used as a typical mean value, the ratio in peat soils appears to be approximately five times higher. This again emphasizes the fact that peat soils are relatively richer in nitrogen and poorer in phosphorus than the mineral soils.

In the various peat groups the means of N/org.P (with the confidence limits at 95 % level) and the minimum and maximum values are the following:

		N/org. P mean	N/org. P min. — max.
32 Sp	samples	38 ± 6	17 — 76
34 CSp	»	41 ± 6	15 — 95
62 SCp	»	43 ± 4	18 — 133
12 EuSCp	»	34 ± 11	12 — 54
36 BCp	»	68 ± 6	26 — 130
41 CP	»	40 ± 6	12 — 87

The BCp-group has the highest mean value of the ratio N/org.P, obviously owing to its low organic P content. No difference exists between the other peat groups. It was found that the degree of humification appears to be in no correlation with the ratio of N/org.P.

Easily soluble inorganic phosphorus

Before the results of inorganic P soluble in 0.5 N acetic acid or in 0.2 N sulphuric acid, reported in Table 3, are examined, it must be pointed out that the analyses were performed on air-dry and ground samples. This may mean that the figures obtained differ from the amounts of inorganic P soluble from the samples under natural conditions. Particularly the changes occurring in the colloids of peat during the drying are claimed to cause considerable changes in the solubility of inorganic P. However, only a few data are given to prove this opinion, and usually they are results obtained when the drying is performed at higher temperatures. In clay soils even drying at room temperature could either increase or decrease the amount of inorganic P soluble in 0.5 N acetic acid, but in a swamp peat sample analysed the difference in the quantities of P dissolved by this extractant from fresh and air-dried portions was almost insignificant (10). Therefore, for the present it can be supposed that these data obtained using the air-dried samples give at least an approximate idea of the easily soluble inorganic P in peat.

The treatment with 0.2 N sulphuric acid is rather intensive and usually the amounts of P dissolved are markedly higher than the quantities extracted by 0.5 N acetic acid. It has been assumed that acetic acid would not dissolve P retented by iron and its compounds, and thus gives a fairly reliable idea of the easily available part of soil P (cf. 6). The kind of P compounds or complexes the 0.2 N sulphuric acid extracts from peat cannot, for the present, be estimated.

Since the P extracted by the sulphuric acid obviously represents an indefinite part of the inorganic peat phosphorus no statistical examination of these data was performed. Generally, it can be said that in the Sp-group the inorganic P seems to be more easily soluble in 0.2 N sulphuric acid and particularly in 0.5 N acetic acid than in the other kinds of peat. This again can be connected with the fact that a large part of the Sp samples originated from the surface layers. It has been found (9) that in the same profile the solubility of inorganic P in diluted acid dropped drastically on going deeper.

On the average the amounts of inorganic P soluble in 0.2 N sulphuric acid appears to correspond to about 15 — 30 per cent of the total inorganic P in the peat samples. The percentages are highest in the Sp-group. The other groups do not seem to differ markedly from each other in this respect.

The 0.5 N acetic acid extracts on the average about 15 per cent of the total inorganic P in the Sp samples but only about 2 per cent of the inorganic P in the Cp-group. The other groups seem to stand between these extremes.

Discussion

Obviously the most distinct result of the present investigation is the discovery that the largest part of phosphorus in these virgin peat soils occurs in organic form. An average proportion of 78 ± 1 per cent of the total P content is detected.

The accumulation of organic P in peat soils may, of course, arise from various factors. On the basis of the present knowledge, it seems to the author most probable that phosphorus is generally a minimum factor in the »metabolism» of a peat land. This means that the need of P by the surface vegetation and by the microorganisms which live in the different peat layers is higher than the available sources, at least in peat lands without any support from outward. In addition to the requirements of the living organisms also the chemical and physicochemical retention ability of unsatisfied inorganic and organic complexes must be taken into consideration.

In a mineral soil or in an old cultivated peat soil the ratio of C : N : P in the organic matter is generally supposed to be approximately 100 : 10 : 1. In a virgin peat soil as those examined above this ratio may, on the average, be about 700 : 35 : 1. This indicates that a peat soil of this kind is still far from the end product of humification, and also that the nitrogen supply in peat is far better than the possibilities to find enough of phosphorus for an intensive humification.

The supposition that in a typical peat soil the greatest part of phosphorus is in the living material or in organic form in the residues of plants and microorganisms is corroborated by some of the results in the present paper. First, the proportion of organic P of total P is high and no correlation exists between these quantities: it means that even in peat soils with the highest total P content most of the phosphorus occurs in organic form. Second, the extremely low content of organic P, on the average far less than 0.1 per cent of organic dry matter, indicates that the synthetic processes of microorganisms probably dominate, even if allowance is made to the fact that the conditions in peat lands and the low availability of the carbon compounds in peat and in the residues of peat land plants decrease the limit value of mineralization of organic phosphorus. The positive correlation between the proportion of organic P and the pH-values also tends to indicate the dominance of the biological synthesis in the phosphorus metabolism in a peat soil.

Unpublished data obtained by the author also corroborate the supposition of the importance of the biological absorption in peat soils. It was found that in soils fertilized with mineral phosphates about one half of the phosphorus left in the soil could be accumulated as organic compounds. This, probably, was resulted both by the activity of plants and of microorganisms.

The present paper reports results of a statistical study of phosphorus in virgin peat soils. As such it is only a basis for further investigation in which the problems discussed here have to be treated in more detail.

Summary.

In the present paper the total and organic P content of virgin peat soils is studied on the basis of 217 peat samples mostly collected from Northern Finland

and consisting of 32 Sp, 34 CSp, 62 SCp, 12 EuSCp, 36 BCp, and 41 Cp samples. The material was found to be satisfactorily typical for a study of Finnish peat soils as to the pH, ash and N contents. Only the BCp samples were, in some respect, of a poorer quality than in general.

The total P content of the 217 samples ranged from 190 to 2350 ppm or from 30 to 2440 kg/ha. In the Sp and BCp groups the mean P content was equal, 580 ± 80 ppm and 560 ± 90 ppm resp., and significantly lower than the corresponding value in all the other groups which was 950 ± 120 ppm in the Cp-group, 980 ± 290 in the EuSCp-group, 800 ± 60 in the SCp-group, and 800 ± 120 ppm in the CSp-group.

A low but significant correlation was found to exist between the degree of land quality estimated on the basis of the surface vegetation and the P content of the surface samples: r = 0.361***. When the BCp samples were excluded an even closer correlation was detected: r = 0.481***.

The correlation coefficient between the total P content and the degree of humification was r = 0.317***, that between the total P and the ash contents r = 0.289**, and that between the total P and N contents r = 0.206*.

The organic P content of the 217 samples ranged from 130 to 1950 ppm with an average of 600 ± 40 ppm. The Sp and BCp groups showed significantly lower means, 430 ± 60 ppm and 440 ± 70 ppm resp., than the other groups with averages of 630 ± 120 ppm in the CSp-group, 620 ± 50 ppm in the SCp-group, 770 ± 100 ppm in the Cp-group and 820 ± 280 in the EuSCp-group.

The organic P content was very closely correlated with the total P content: the total correlation coefficient was r = 0.934***. The connection with the degree of humification was not distinct: the total correlation coefficient was r = 0.336***, but the partial correlation coefficient after the elimination of the effects of total P and N contents was only r = 0.136. No significant correlation existed between the organic P content and the N content, r = 0.184.

The organic P content of the 217 samples expressed as a percentage of the total P content ranged from 55 to 95 per cent with an average of 78 ± 1 per cent.

The proportion of organic P of total P was correlated with the degree of humification, the total correlation coefficient was r = 0.504***, the partial correlation coefficient after the elimination of the effect of the sampling depth was r = 0.427***. No correlation with the sampling depth existed after the elimination of the effect of the degree of humification: the partial correlation coefficient was r = 0.159, whereas the total correlation coefficient was r = 0.334***. A low correlation existed between the percentage of organic P of total P and the pH value even after the elimination of the effect of the degree of humification, r = 0.228*, but the connection with the total P content appeared to be only indirect and arised from the effect of the degree of humification, the total correlation coefficient was r = 0.222*, the partial correlation coefficient r = 0.076.

The amount of organic P expressed as a percentage of the organic dry matter ranged from 0.01 to 0.25 per cent with an average of 0.07 ± 0.004.

The ratio of N/org.P ranged from 12 to 133 with an average of 45 ± 3. Owing to the low P content of the BCp-group its mean ratio was significantly higher than that of the other groups. The degree of humification did not show any correlation with the ratio of N/org.P.

The solubility of inorganic P in 0.5 N acetic acid and in 0.2 N sulphuric acid was highest in the Sp-group. On the average approximately from 15 to 30 per cent of total inorganic P was extracted by the latter solution. The acetic acid extracted only about 2 per cent of the inorganic P in the Cp-group but about 15 per cent in the Sp-group.

The phosphorus conditions in virgin peat soils was discussed and it was attempted to explain the results obtained on the basis of the supposition that phosphorus is a minimum factor in the metabolism of peat.

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SELOSTUS:

LUONNONTILAISTEN TURVEMAITTEN FOSFORISTA

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Tutkimuksessa on yritetty selvittää luonnontilaisten turvemaitten fosforin määrää ja koostumusta. Tutkimusaineistona oli 217 turvenäytettä, jotka oli kerätty etupäässä maamme pohjoisosista ja jotka edustivat eri turvelajeja ja suotyyppejä.

Näytteiden kokonaisfosforin pitoisuus vaihteli 190—2350 mg/kg ja 30—2440 kg/ha. Rahkaturpeitten ja ruskosammalsaraturpeitten ryhmät sisälsivät keskimäärin selvästi vähemmän fosforia kuin muut turvelajit. Pintanäytteiden ja soitten boniteetin välillä oli havaittavissa merkitsevä, joskin heikohko vuorosuhde, korrelaatiokerroin oli $r' = 0.361$***. Tilastollisesti merkitsevä korrelaatiokerroin saatiin myös kokonaisfosforin pitoisuuden sekä maatumisasteen välille, $r = 0.317$***, samoin kokonaisfosforin pitoisuuden ja tuhkapitoisuuden välille $r = 0.289$**. Kokonaisfosforin pitoisuuden ja Kjeldahltypen pitoisuuden välillä oli myös havaittavissa merkitsevä riippuvuus, $r = 0.206$*.

Näytteiden orgaanisen fosforin pitoisuus vaihteli 130—1950 mg/kg, keskiarvo oli 600 ± 40 mg/kg. Erot eri turvelajien välillä olivat samanlaiset kuin kokonaisfosforin pitoisuuden kohdalla. Orgaanisen fosforin pitoisuuden ja kokonaisfosforin pitoisuuden riippuvuus oli erittäin voimakas: $r = 0.934$***.

Orgaanisen fosforin suhteellinen määrä vaihteli 55—95 % kokonaisfosforista ja oli keskimäärin 78 ± 1 %. Tämä suure ei osoittautunut riippuvaksi kokonaisfosforin pitoisuudesta eikä näytteen ottosyvyydestä. Sen sijaan havaittiin verrattain voimakas korrelaatio orgaanisen fosforin suhteellisen määrän ja maatumisasteen välillä: osittaiskorrelaatiokerroin syvyyden vaikutuksen eliminoinnin jälkeen oli $r = 0.427$***. Heikko, joskin tilastollisesti merkitsevä korrelaatio voitiin todeta myös orgaanisen fosforin suhteellisen määrän ja pH:n välillä; maatumisasteen vaikutuksen eliminoinnin jälkeen saatu osittaiskorrelaatiokerroin oli $r = 0.228$*.

Orgaanisen fosforin määrä ilmoitettuna prosentteina orgaanisesta kuiva-aineesta oli hyvin alhainen: 0.01—0.25 %, keskimäärin 0.07 ± 0.004 %.

Suhde N/org.P vaihteli 12—133 keskiarvon ollessa 45 ± 3. Ruskosammalsaraturveryhmän keskimääräinen N/org.P oli selvästi suurempi kuin muitten ryhmien. Maatumisasteella ei näyttänyt olevan vaikutusta suhteen arvoon.

0.2 n rikkihappo uutti noin 15—30 % turvenäytteiden epäorgaanisen fosforin kokonaismäärästä. 0.5 n etikkahappo uutti vain pari prosenttia saraturpeiden epäorgaanisesta fosforista, mutta noin 15 % rahkaturpeiden epäorgaanisesta fosforista.

Saatujen tulosten perusteella oletettiin, että fosfori on eräs nimitekijöistä turvemaitten metabolismissa.