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EFFECT OF LIMING ON PHOSPHORUS FERTILIZER REQUIREMENT IN CEREALS AND LEY

ANTTI JAAKKOLA, HEIKKI HAKKOLA, JAAKKO KÖYLIJÄRVI and PAAVO SIMOJOKI

JAAKKOLA, A., HAKKOLA, H., KÖYLIJÄRVI, J. & SIMOJOKI, P. 1977. **Effect of liming on phosphorus fertilizer requirement in cereals and ley.** Ann. Agric. Fenn. 16: 207—219. (Agric. Res. Centre, Inst. Agric. Chem. and Phys., SF-01300 Vantaa 30, Finland.)

The trial series consisted of four field trials lasting 7—11 years. The trials were carried out on gyttja clay, silt, loam and Carex peat. The experimental factors consisted of liming (0, 2, 8 and 32, and in one trial 48 t/ha of ground limestone at the start of the trials), and phosphorus fertilization (0, 200 and 800 kg/ha of superphosphate annually). Cereals and ley for hay were cultivated in free crop sequence.

Liming clearly raised the pH-value of the soil in all the trials. Its effect on the yield varied. In the trials on gyttja clay and loam, there was a rise in the mean yield level of the trial period. On peat soil liming did not affect the yield. The mean yield increase of the trial period brought about by phosphorus fertilization was evident in all the trials. The smaller superphosphate application, 200 kg/ha/a, was almost as effective as the larger one, 800 kg/ha/a.

It was not possible to determine with certainty the effect of liming on the phosphorus fertilization requirement. Heavy liming apparently reduced the requirement in the gyttja clay trial, in which it raised the pH-value from 5,5 to 6,9. The reduction was not statistically significant, however. Heavy liming increased the amount of phosphorus extractable in acid ammonium acetate in the trials on mineral soils, but did not do so in the peat soil trial. From the point of view of the plants' phosphorus supply, its significance remained undetermined.

Index words: phosphorus fertilization, phosphorus in soil, liming, soil acidity.

On acid soils liming improves the solubility of the soil phosphorus and reduces the retention of superphosphate to a sparingly soluble form (SALONEN 1940, KAILA 1965, 1967 etc.). This presumably decreases the phosphorus fertilization requirement. On the other hand, the improvement in growth induced by liming indicates an increase in the requirement of nutrients, including phosphorus. In some earlier field trials performed in Finland, the yield increase caused by phosphorus fertilization has generally decreased, even if only slightly, when the soil has been limed (SALONEN 1953, KERÄNEN and MARJANEN 1972). Individual experiments have even shown reversed results. In these experiments the maximum amounts of ground limestone used in liming have been 4 t/ha. In the present trial series the writers have also attempt to define the effect of very heavy liming on the phosphorus fertilizer requirement of cereals and ley.

MATERIAL AND METHODS

The trial series consisted of four field trials (Table 1). Three of the trial fields were on mineral soil and one on peat soil. The soil of two fields was relatively acid (Trials 1 and 4) while that of the other two was only mildly acid (Trials 2 and 3).

Table 1. The location of the trials and the soil in the experimental fields.

	Trial 1	Trial 2	Trial 3	Trial 4
Location	Mietoinen	Laukaa	Laukaa	Ruukki
Soil type	Gyttja clay	Silt	Loam	Carex peat
pH (water)	5,2	6,0	5,6	5,2
Contents extractable in acid ammonium acetate:				
Ca mg/l	1230	—	975	1630
P mg/l	5,9	—	6,2	6,3
K mg/l	300	—	120	66

The experimental factors of the two-factor trials were liming (L) and phosphorus fertilizing (P). The amounts used were as follows:

L liming
L_0 no liming
L_2 2 t/ha ground limestone
L_8 8 t/ha » »
L_{32} 32 t/ha » »
L_{48} 48 t/ha » » , only in Trial 3.

P phosphorus fertilizing
P_0 no phosphorus fertilizing
P_1 200 kg/ha superphosphate
P_4 800 kg/ha »

The liming was performed at the start of the trial, the phosphorus fertilization annually. A free crop sequence was followed. The nitrogen and potassium fertilization varied from

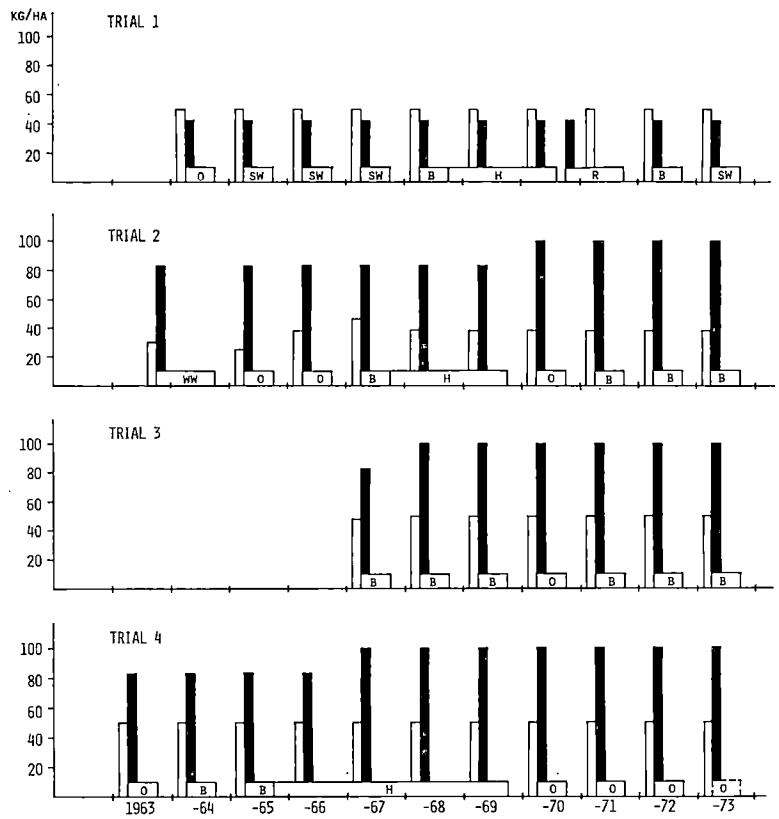

Fig. 1. Nitrogen (white columns) and potassium (black columns) fertilization together with crop sequence in the field trials.

B barley R rye
H ley for hay SW spring wheat
O oats WW winter wheat

trial to trial and, partly, also from year to year (Fig. 1). There were four replicas, arranged in separate blocks. In Trial 1 the treatments were randomized within blocks, the other trials applied the split plot method with the limed (L) levels as the main plots and the phosphorus fertilized levels (P) as subplots. The duration of two of the trials was 10 years, the other two lasting 7 and 11 years respectively. In the latter trial the yield was harvested for 10 years only owing to crop failure in the final year.

The grain yields of the cereals were harvested and weighed per plot. Straw was also removed from the plots. The leys were cut at the usual haymaking time — the turn of June/July. In certain cases the aftermath was also harvested, weighed and counted together with the main yield. To render the results from the different plants more comparable, the yields were converted into food units (F.u.). The food unit yields were calculated according to the following dry matter food unit values:

rye	1,17	F.u./kg
wheat	1,17	» »
barley	1,17	» »
oats	0,98	» »
grass	0,52	» »
grass, aftermath	0,70	» »

When Trials 1—3 were completed in 1973, grain and straw samples were taken from each plot for nutrient determination. Samples were also taken from the plant stand of Trial 4, which had not ripened and was not harvested. From the samples, the nitrogen was determined by Kjeldahl-digestion, the phosphorus, the potassium, calcium and magnesium from the ash extract.

Soil samples representing the plough layer of each plot were taken once during the trial period from each trial. After the conclusion of the trials, in the autumn of 1973, soil samples were taken per plot from the plough layer as well as the subsoil. From the soil samples the pH (water suspension) and the calcium, potassium, magnesium and phosphorus extractable in acid ammonium acetate (pH 4,65) were determined. In accordance with general practice, the contents are given per volume unit (mg/l) of air-dried ground soil.

Statistical mathematical testing of the results was done by analysis of variance. When the effect of the liming was significant at a minimum confidence of 95 % and examination was made whether the change in the result (e.g. in the yield or the nutrient content of the soil) was proportional or not to the amount of lime used. This was done by determining the linear regression equation between the amount of lime and the result obtained and by calculating the deviations from the values indicated by the equation. In cases where the effect of the phosphorus fertilization was significant a further examination was made whether an increase in the annual application of superphosphate from 200 to 800 kg/ha was of significance, or whether the result was due solely to phosphorus fertilization in general, the effect of which was described by $(\frac{P_1 + P_4}{2})$ compared to P_0.

RESULTS

Yield

In Trials 1 and 3 liming increased the mean yield throughout the trial period (Table 2). In both trials the yield increase per ground limestone ton was 11 F.u./ha/a. The depence of the results on different liming levels did not differ significantly from linear correlation.

In all four trials phosphorus fertilization contributed towards increasing the mean yield. Only in Trial 4 was it possible to determine with certainty that 800 kg/ha of super-

Table 2. Average yields over the whole experimental period in different trials, F.u./ha/a.

	L_0	L_2	L_8	L_{32}	L_{48}	$LSD_{0,05}$
Trial 1						
P_0	3180	3280	3530	3720		190
P_1	3380	3490	3580	3700		190
P_4	3430	3570	3540	3770		190
$LSD_{0,05}$	190	190	190	190		
Trial 2						
P_0	1900	1740	2070	1770		140
P_1	2200	2180	2170	2210		140
P_4	2280	2410	2250	2370		140
$LSD_{0,05}$	340	340	340	340		
Trial 3						
P_0	2670	2920	2920	3230	3160	610
P_1	2960	2930	3040	3470	3550	610
P_4	3200	3100	3100	3420	3580	610
$LSD_{0,05}$	310	310	310	310	310	
Trial 4						
P_0	2370	2300	2430	2230		210
P_1	2630	2520	2630	2500		210
P_4	2730	2640	2710	2590		210
$LSD_{0,05}$	120	120	120	120		

L_0 no lime
L_2 2 t/ha of lime
L_8 8 » » »
L_{32} 32 » » »
L_{48} 48 » » »

P_0 no superphosphate
P_1 200 kg/ha/a of superphosphate
P_4 800 » » »

phosphate per year was a more effective fertilizer than 200 kg/ha.

The mean effect of the phosphorus fertilization throughout the trial period did not depend significantly on the amount of ground limestone administered at the start of the trial.

The yield level varied from year to year apparently depending on local weather conditions at each trial site and on the plant cultivated (Fig. 2). The effect of liming varied likewise from year to year, even in Trials (2 and 4) in which the mean effect of liming was not significant. In the course of Trial 1, the mean yield increase brought about by the ton of lime dropped from 21 F.u./ha to 3 F.u./ha. In Trial 2 liming caused an increase in the yield to start with, but in the 8th and 9th years a clear drop in yield was registered. In this trial, owing to other unfavourable growth factors, the yield level of the final trial year was so low that the treatments did not induce any changes. In Trial 3 yield boosting-effect of liming evidently decreased with time. In Trial 4 liming was clearly responsible for a drop in the yield in the final trial year. It was not possible, however, to establish any consistent negative trend over a period of time.

The effect of phosphorus fertilization likewise varied clearly in different years in all the trials (Fig. 3). In trials 2—4 the yield increase attributable to phosphorus fertilization, in general progressed with time. Owing to variations due to differing yield levels, however, it is impossible to prove this by any simple statistical test. There was a clear deficiency in phosphorus in each trial field since phosphorus fertilization caused an increase in the yield in all trials as early as the first trial year.

There was no significant annual variation in the interaction of the liming and phosphorus

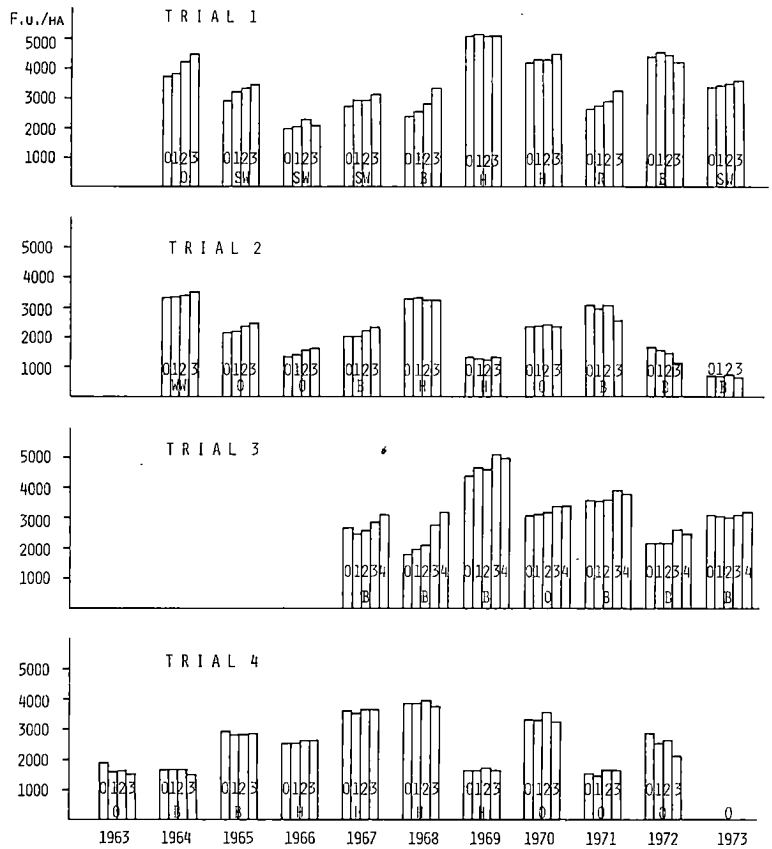

Fig. 2. Average yields in different years at increasing lime levels.

0 no liming (L_0)
1 2 t/ha of ground limestone (L_2)
2 8 » » » » (L_8)
3 32 » » » » (L_{32})
4 48 » » » » (L_{48})

Letters referring to crops: see text for Fig. 1.

fertilization in any of the trials. As an examination of this interaction was the chief purpose of the trial series, it was performed separately for each trial year despite the fact that the possibility of a wrong conclusion would in this way clearly exceed the 5 per cent used in the testing. Interaction between the liming and the phosphorus fertilization, or the variation in the effect of phosphorus fertilization at different liming levels (or vice versa) was significant in the following cases:

Trial 1. 1967 spring wheat and 1970 ley (1st cutting)
Trial 3. 1971 barley
Trial 4. 1968 ley (1st cutting)

In Trial 1 in 1967 and in Trials 3 and 4 the variations caused by phosphorus fertili zation at different liming levels were inconsistent and apparently accidental. In Trial 1 in 1970, the ley yield of the 1st cutting in the different treatments was as follows (F.u./ha):

	L_0	L_2	L_8	L_{32}
P_0	2000	2200	2130	2190
P_1	2290	2390	2340	2070
P_4	2500	2330	2200	2150

The yield increase caused by phosphorus fertilization decreased when the amount of lime was increased. Indeed, particularly in plots that have been given the larger applica-

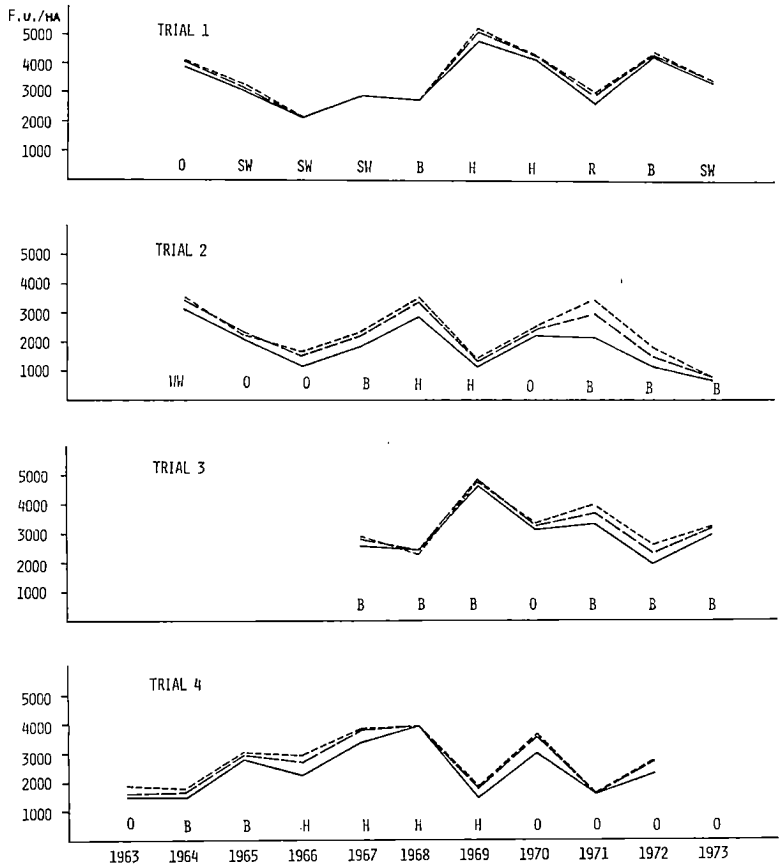

Fig. 3. Average yields in different years at increasing superphosphate levels.
———— no phosphorus application (P_0)
— — — — — 200 kg/ha of superphosphate per year (P_1)
- - - - - - - - - 800 » » » » » (P_4)
Letters referring to crops: see text for figure 1.

tion of superphosphate, 800 kg/ha, it seemed as if liming had caused a drop in the yield. The differences according to the liming were not significant, however.

Nutrient content of the yields

The nutrient contents of the grain and straw of the spring wheat harvested during the final trial year (1973) in Trial 1 did not depend on the phosphorus fertilization. Liming, on the other hand, caused differences in some contents. The mean contents at the different liming levels are shown in Table 3. Very heavy liming raised the calcium as well as the potassium contents of grain and straw. It appears that the uptake of these nutrients increased simultaneously, since the yield appeared to be larger owing to liming, though, admittedly, not significantly so.

In Trials 2 and 3, in which barley was cultivated during the final year, the nutrient content of grain and straw was likewise unaffected by phosphorus fertilization.

Liming accounted for a drop in the nitrogen content of the straw in both trials (Table 4). In Trial 2, the nitrogen content, though lowered, was nevertheless higher than in the straw from unlimed plots in Trial 3. Poor

Table 3. D.M. yields and nutrient contents of spring wheat at different lime levels (1973, Trial 1).

			L_0	L_2	L_8	L_{32}
	Grain yield,	kg/ha	2860k	2910k	2940k	3020k
N	in grain,	g/kg	27,9a	27,9a	28,4a	29,6a
	in straw,	»	6,9a	7,0a	6,9a	7,6a
P	in grain,	g/kg	4,3a	4,3a	4,2a	4,3a
	in straw,	»	0,7a	0,9a	0,8a	0,9a
K	in grain,	g/kg	4,6a	4,5a	5,0a	4,9a
	in straw,	»	13,7a	14,8c	14,0b	14,8c
Ca	in grain,	g/kg	0,33a	0,33a	0,33a	0,36b
	in straw,	»	1,93a	1,97a	2,04a	2,55b
Mg	in grain,	g/kg	1,26a	1,30a	1,32a	1,33a
	in straw,	»	0,63a	0,63a	0,62a	0,70a

Yields or nutrient contents not followed by a common letter differ significantly (P = 0,05).

L_0 no lime
L_2 2 t/ha of lime in 1963
L_8 8 » » » » »
L_{32} 32 » » » » »

Table 4. D.M. yields and nutrient contents not barley at different lime levels (1973, trials 2 and 3).

			Trial 2				Trial 3				
			L_0	L_2	L_8	L_{32}	L_0	L_2	L_8	L_{32}	L_{48}
	Grain yield,	kg/ha	620a	600a	620a	580a	2630k	2620k	2570k	2650k	2730k
N	in grain,	g/kg	18,9a	16,6a	20,2a	18,4a	17,7k	18,1k	17,5k	17,2k	18,1k
	in straw,	»	12,0b	11,6b	11,0ab	10,2a	8,3m	8,7m	7,2l	6,9kl	6,1k
P	in grain,	g/kg	4,3a	4,5a	4,8b	4,7b	3,6k	3,8k	3,8k	4,0l	4,3m
	in straw,	»	1,6a	1,9a	2,3b	2,3b	0,8k	1,1k	0,7k	0,8k	0,8k
K	in grain,	g/kg	4,8a	4,6a	4,9a	4,9a	4,5k	4,5k	4,4k	4,0k	4,6k
	in straw,	»	12,6b	11,2a	10,4a	10,3a	15,8k	15,0k	14,4k	14,8k	14,0k
Ca	in grain,	g/kg	0,48a	0,51b	0,53b	0,56c	0,41k	0,41k	0,43l	0,45l	0,43l
	in straw,	»	4,57a	5,04ab	5,39bc	5,71c	3,89k	3,87k	3,65k	3,87k	3,68 k
Mg	in grain,	g/kg	1,25a	1,25a	1,25a	1,26a	1,17k	1,17k	1,19k	1,15k	1,17 k
	in straw,	»	2,03a	2,02a	1,92a	1,94a	0,93k	0,92k	0,86k	0,82k	0,80 k

Yields or nutrient contents in either trial not followed by a common letter differ significantly (P = 0,05).

L_0 no lime
L_2 2 t/ha of lime in 1963 (Trial 2) or 1966 (Trial 3)
L_8 8 » » » » » » » » »
L_{32} 32 » » » » » » » » »
L_{48} 48 » » » in 1966 (Trial 3)

growth, evidenced by the small grain yield in Trial 2, appears to account for the high nitrogen content of the straw.

Heavy liming raised the phosphorus content in the grain in both trials, while it produced this effect only in the straw of the poorly

Table 5. Nutrient contents in whole crop oats (1973, Trial 4) at different lime and superphosphate levels, g/kg in D.M.

	L_0	L_2	L_8	L_{32}	P_0	P_1	P_4
N	19,5a	19,2a	20,0a	19,7a	20,6k	19,5k	18,8k
P	3,0b	2,7ab	2,7ab	2,4a	2,3k	2,5k	3,3l
K	21,3a	21,5a	19,4a	20,1a	20,2k	20,1k	21,5k
Ca	2,37a	1,99a	2,00a	1,90a	1,69k	2,02k	2,49l
Mg	1,62a	1,54a	1,46a	1,71a	1,44k	1,59k	1,72k

Contents of a nutrient at different levels of lime or of superphosphate differ significantly (P = 0,05) if they are not followed by a common letter.

L_0 no lime
L_2 2 t/ha of lime in 1962
L_8 8 » » » » »
L_{32} 32 » » » » »

P_0 no superphosphate
P_1 200 kg/ha/a of superphosphate
P_4 800 » » »

grown crop in Trial 2. Even without liming this straw had a much higher phosphorus content than the straw from the other trial.

The potassium content of the straw in the poorly grown barley crop (Trial 2) was below that of Trial 3 and it showed a further drop when the soil was limed.

Liming did not change the calcium content of the straw in Trial 3, however, there was an increase in the grain calcium content. In the poorly grown crop in Trial 2, the calcium contents of the grain as well as the straw, which were clearly higher than in Trial 3, were even higher when the soil had been given lime.

Liming did not significantly affect the magnesium content of the grain and straw. In the poorly grown crop in Trial 2, the contents were clearly higher than in Trial 3, which had given a good yield.

In Trial 4 the phosphorus and calcium contents of the whole oat crop that had grown in 1973, after the conclusion of the actual trial period, rose thanks to superphosphate fertilizer application (Table 5). There also seemed to be an increase in the magnesium content but the difference was not significant. Liming, which in this trial had not affected the size of the yields, did, nevertheless, lower the phosphorus content of the whole oat crop and possibly even the calcium content, although the latter difference was not significant. The yields of the whole oat crop were not weighed so that it is not known whether the treatments changed the yield.

Nutrient contents of the soil

The effect of superphosphate fertilizing on the calcium content extractable from the soil was minimal. In consequence, Fig. 4 shows only the mean calcium content at different superphosphate levels as compared to the pH level of the plough layer, which had been raised by liming at the start of the trials.

In all trials liming clearly raised the content of calcium extractable in acid ammonium acetate. In Trials 1 and 3 a drop in the calcium content of the plough layer was established at the highest liming levels (32 and 48 t/ha of ground limestone) between the years 1969 and 1973. In the same trials in 1973 the calcium content of the subsoil was larger the more the soil had been limed. This points to increasing calcium leaching with increased liming.

The contents of phosphorus extractable in acid ammonium acetate were affected by superphosphate fertilization in the plough layer samples at both sampling times. Heavier fertilization (P_4, 800 kg/ha/a of superphosphate) accounted very clearly for a heavier phosphorus content in the plough layer than with

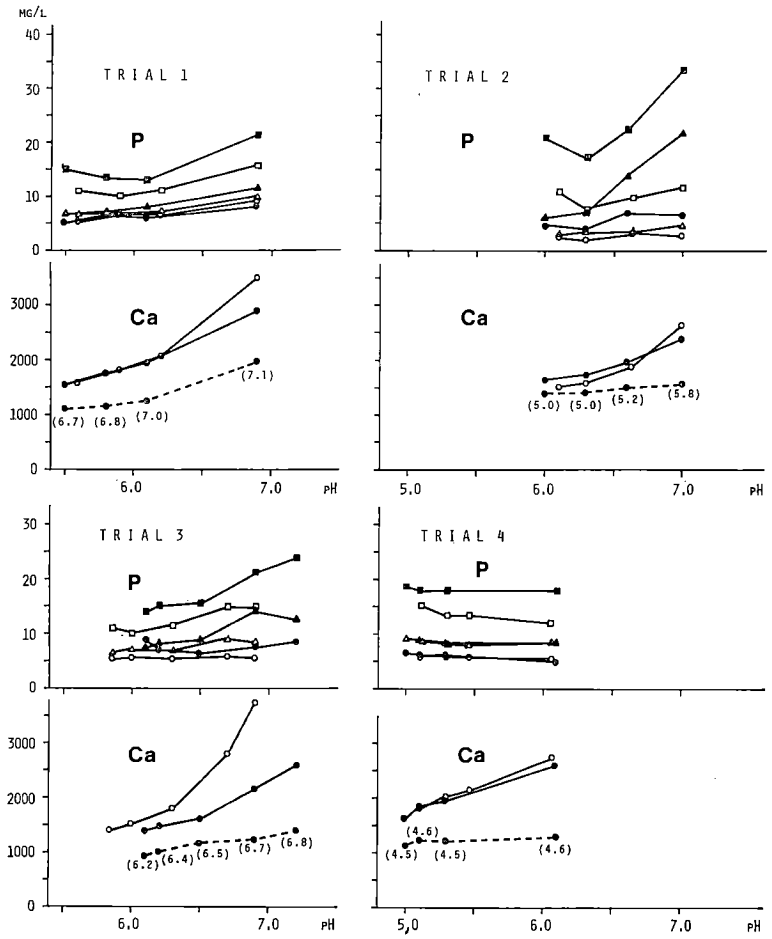

Fig. 4. Dependence of calcium (Ca) and phosphorus (P) in soil extractable with acid ammonium on the plough layer pH (water suspension) varying because of liming.

○ ●	no phosphorus application (P_0)
△ ▲	200 kg/ha of superphosphate per year (P_1)
□ ■	800 » » » » » (P_4)
----------●---------- (pH)	subsoil with pH in parentheses
○ △ □	sampling in 1968 (Trial 2), 1969 (Trials 1 and 3) or 1970 (Trial 4)
● ▲ ■	sampling in 1973 (all trials)

a smaller application (P_1, 200 kg/ha/a) or no phosphorus fertilization (P_0). The difference between P_0 and P_1 was in some cases so small that it was impossible to determine with certainty. Between the samplings the phosphorus content of the soil increased in areas that had been fertilized with superphosphate, apart from Trial 4 on the plots that had been given the smaller dose of superphosphate.

In Trials 1, 2 and 3 the effect of liming on the contents of phosphorus extractable from the soil was very clear in areas that had been given the largest amounts of superphosphate. In Trial 4, on the other hand, no effect was discernible. In Trial 3 liming raised the phosphorus content throughout the pH-area (ap-

proximate pH 6—7,2). In Trial 1, on the other hand, the minimum level of the phosphorus content was approximately pH 6, and in Trial 2 pH 6,3. The differences in the soil phosphorus content in relation to liming when the smaller dose of superphosphate was given, and in particular when no phosphorus fertilizer was applied, were generally small, but there is no indication that liming would not have had the same effect as in the areas that have been given the large dose of phosphorus fertilization.

The increase in the phosphorus content of the soil brought about by superphosphate fertilization was largest in Trials 2 and 3. During the entire trial period the difference in the soil phosphorus content (mg/l) between soil that had received no superphosphate fertilization and soil that had had the heaviest application was as follows per increase of 100 kg/ha fertilizer phosphorus:

	Trial 1	Trial 2	Trial 3	Trial 4
pH 6,1	1,1	2,0	1,0	1,7
pH 6,9	1,9	3,4	2,8	—

DISCUSSION

The field trial material was relatively limited, only four field trials, so that the result obtained is hardly generally representative. The soil types of the trial fields, gyttja clay, two silty soils and Carex peat, belonged, however, to three groups that usually differ clearly in their characteristics, and this naturally increased the chances for finding differences.

Yield

In each trial liming had a very clear effect in neutralizing the acidity of the soil. The consequent conditions for improving soil productivity differed in the different trials, however, in that the original acidity of the soil was clearly too heavy only in Trial 1. In fact it was only in this trial that a clear improvement in yield was obtained. In Trial 2, with a heavy dose of lime, 32 and 48 t/ha, there were already drops in the yield towards the end of the 10 and 7 year trial periods. In Trial 4 on peat soil, liming produced no results. The effect of liming on peat soil does, in fact, often remain insignificant (cf. e.g. TUORILA et al. 1939).

Phosphorus fertilization increased yields in all the trials. The yield increases were, however, often relatively small compared to the random variation, nor were they obtained every year by any means. Evidently growth was being inhibited by other growth factors, thus obliterating the effect of the phosphorus fertilization. It is possible that in certain cases nitrogen and potassium fertilizer applications were too meagre. Weather conditions and the soil were, however, probably the main cause. It is possible that by cultivating plants more exacting than grass and cereals the effect of phosphorus fertilization could have been demonstrated more clearly and conditions improved for showing the differences produced by liming. It is also possible, however, that the differences obtained in this way would not have been applicable to grass and cereal cultivation and since these are the commonest crops the express object of the research would have miscarried. The yield difference between the phosphorus fertilization levels (200 and 800 kg/ha of superphosphate annually) was in general small, and the chances for establishing the change caused by liming in this difference were slight.

The effect of phosphorus fertilization on the yields changed significantly only in a couple of the trial years when liming was increased. It can not be concluded decisively that liming will change the yield increase obtained by phosphorus fertilization solely on the basis of the four field trials described here. Nevertheless, since that change pointed in the

same direction in all the clear cases — a decrease in the phosphorus response due to liming — and as similar results have been obtained in a number of other field trials (SALONEN 1953, KERÄNEN and MARJANEN 1972 etc.), it seems probably that the effect of liming in reducing the yield increase caused by phosphorus fertilization is factual, at least under some circumstances. In the present trials the differences in the mean yield responses to 800 kg/ha/a superphosphate between unlimed and limed (32 t/ha) plots, with their ranges (P = 0,95), were as follows:

Trial	Yield increase caused by 800 kg/ha/a of superphosphate fertilizer		Difference (2) – (1)
	no lime (1)	lime 32 t/ha (2)	
1	250	50	−200 ± 270
2	380	600	200 ± 480
3	530	190	−340 ± 440
4	360	360	0 ± 170

Judging by these results the negative interaction between liming and fertilization was likely in Trials 1 and 3, and unlikely in Trials 2 and 4. Apparently this is attributable to the different pH-areas in the trials (cf. Fig. 4) as well as to the soil type.

Nutrient content of the yield

The nutrient contents of the yield samples from the different trials taken in the final trial year are not comparable since the plants cultivated were not the same, and in Trials 2 and 3, where both crops were barley, there was an explicit difference in size in the yield level.

In Trials 1—3 liming did not affect the grain yield of the yield sample year; the size of the yield in Trial 4 is not known. Liming raised the calcium content of the grain in Trials 1, 2 and 3, and the calcium content of the straw in Trials 1 and 2. It is evident that in the trials on mineral soils the uptake of calcium was increased by liming. In the peat soil trial (4), on the other hand, liming did not significantly affect the calcium except that the trend seemed to be towards a lowering in calcium content.

In the trials on silt and loam soils (2 and 3) the effect of liming on the phosphorus content of the yield was the same as on its calcium content; in the trial on gyttja clay no effect was discernible while the phosphorus content was reduced in the peat soil in Trial 4. It seems evident that the uptake of phosphorus by the plant changed in the same direction as the content. This was also the case in Trial 4, in which the liming, judging by results from previous years, in fact tended to reduce the yield.

Phosphorus fertilization affected the yield nutrient contents in the final trial year only in the trial on peat soil, in which the calcium and phosphorus contents clearly increased with 800 kg/ha superphosphate fertilization. The increase in the phosphorus content in plant material grown on peat soil seems to point to a relatively high degree of availability of the phosphorus fertilizer.

It should be noted that in Trials 2—4 the calcium and the phosphorus in the yields reacted similarly to the treatments. In the gyttja clay trial (1), on the other hand, the phosphorus content did not seem to change despite a rise in the calcium content due to liming. This may be attributable to a greater phosphorus retention in gyttja clay than in other soils.

State of nutrients in soil

In addition to a clear change in the pH-value of the soil in Trials 1, 2 and 3, heavy liming brought about a distinct change in the amount of phosphorus extractable in acid ammonium acetate in soil that had been treated with the larger dose of superphosphate fertilizer (800 kg/ha/a). There is no evidence that the phosphorus accumulated from the smaller dose of superphosphate fertilizer (200 kg/ha/a) would not have shown a similar change. This de-

pendence could not be shown clearly, however, as the changes were small. In these trials the pH-value of the soil and the content of phosphorus extractable in acid ammonium acetate evidently followed a trend similar to that noted by e.g. LAKANEN and VUORINEN (1963) and LAKANEN et al. (1970). In Trial 4, on the other hand, liming did not affect the extractability into acid ammonium acetate of the soil's own phosphorus or the phosphorus that had accumulated from the fertilizer. The pH-area in this trial differed from the other trials and occurred, as in the results obtained by LAKANEN et al. (1970), in an area with a minimum phosphorus solubility.

The fact that no clear dependence was established between the pH-value and the extractable phosphorus content may be partly due to the Carex peat in question containing low quantities of iron and aluminium compounds, whose phosphorus retention capacity is highly dependent on the pH-value.

From the practical point of view the significance of the changes in the extractable phosphorus content caused by liming has as yet not been established since it has not been possible to determine how far the extractable phosphorus in the soil and the phosphorus uptake by the plant depend on each other and how this interdependence is affected by the pH-value of the soil.

Judging by the determinations and yield results obtained in the final trial year, the effect of phosphorus fertilization on the plant's uptake of phosphorus was slight in Trials 1—3. Phosphorus leaching was hardly significant in these mineral soil trials. It appears that phosphorus fertilization increased the total content of phosphorus in the soil compared to non-phosphorus fertilized (P_0) soil on P_1-level by 17,4 kg/ha and on P_4-level by 69,6 kg/ha per annum. Assuming that the amount of soil was 2 000 000 l/ha it was calculated that of the fertilizer phosphorus »accumulated in the soil» at pH 6,1, 2,2 % in Trial 1, 4,0 % in Trial 2, and 2,1 % in Trial 3 were extracted in the acid ammonium acetate.

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SELOSTUS

Kalkituksen vaikutus viljan ja nurmen fosforilannoitustarpeeseen

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Maatalouden tutkimuskeskus

Koesarjaan kuului neljä 7—11 vuotta kestänyttä kenttäkoetta liejusavella, hiesumaalla (2 koetta) ja saraturpeella. Koetekijöinä olivat kalkitus (0, 2, 8 ja 32 sekä yhdessä kokeessa 48 t/ha kalkkikivijauhetta kokeiden alkaessa) ja fosforilannoitus (0, 200 ja 800 kg/ha superfosfaattia vuosittain). Kokeissa viljeltiin viljoja ja heinänurmea vapaassa järjestyksessä.

Kalkitus nosti maan pH-arvoa selvästi kaikissa kokeissa. Vaikutus satoon oli vaihteleva. Keskimääräinen satotaso nousi liejusaven ja toisen hiesumaan kokeessa. Turvemaalla kalkitus ei vaikuttanut satoon. Fosforilannoitus lisäsi satoa selvästi kaikissa kokeissa. Pienempi superfosfaattiannos, 200 kg/ha/a, oli melkein yhtä tehokas kuin suurempi annos 800 kg/ha/a.

Kalkituksen vaikutusta fosforilannoitustarpeeseen ei voitu todeta varmasti. Runsas kalkitus näytti vähentävän fosforilannoitustarvetta liejusaven kokeessa, jossa se nosti pH-arvon 5,5:stä 6,9:ään. Lannoitustarpeen väheneminen ei ollut tilastollisesti merkitsevä. Runsas kalkitus lisäsi maasta happameen ammoniumasetaattiin uuttuvan fosforin määrää kivennäismaiden kokeissa, mutta ei turvemaan kokeessa. Tämän merkitys kasvien fosforinsaannin kannalta jäi epäselväksi.

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THE EFFECT OF SULPHUR ON THE YIELD AND CHEMICAL COMPOSITION OF TIMOTHY

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TÄHTINEN, H. 1977. **The effect of sulphur on the yield and chemical composition of timothy.** Ann. Agric. Fenn. 16: 220–226. (Agric. Res. Centre, Inst. Agric. Chem. and Phys., SF-01300 Vantaa 30, Finland.)

The effect of sulphur application on the yield, its total nitrogen and total sulphur content and the N/S ratio, was investigated in field trials, using timothy to be cut for hay as the test plant.

Sulphur fertilizer applied in the form of gypsum increased the yield considerably in some trial fields. Sulphur fertilization increased the sulphur content significantly only in stands deficient in this element. In such cases, nitrogen content decreased at the same time, probably owing to dilution caused by the substantial yield increase brought about by sulphur fertilization. In the stands where sulphur application did not increase the yield, it did not influence the sulphur and nitrogen contents either. The yield increase obtained with sulphur clearly seemed to depend more on the N/S ratio than on the sulphur content of the yield.

The experiments showed that there are areas in Finland where the application of sulphur fertilizer is necessary to produce an abundant yield and good quality forage in timothy cultivation.

Index words: sulphur content, N/S ratio, diagnosis of sulphur deficiency, gypsum, *Phleum pratense* L.

INTRODUCTION

Most sulphur occurs in the soil in organic form and the rate of decomposition of organic matter determines the mineralization of the sulphur. Part of it occurs as sulphate, and it is in this form, almost exclusively, that plants take up sulphur from the soil. The content of soluble sulphur in the soil is apt to vary during the growing season. Sulphur is leached out of top soil by rain, but, on the other hand, abundant sulphur is brought by rain, especially in industrial areas. Sulphur is also absorbed directly from the atmosphere into the soil. A survey of sulphur balance in cultivated soils in Finland was presented by KORKMAN (1973). According to a recent study, plants take in sulphur directly from the atmosphere through their stomata in the form of sulphur dioxide and in this way satisfy a considerable part of their need in areas deficient in sulphur (SIMAN and JANSSON 1976).

Consequently, it has proved difficult to determine the need for sulphur fertilization by different means of soil analyses. Plant analyses have given fairly good results in determining sulphur deficiency. In plants, sulphur occurs mainly in the protein, as sulphate. In

certain plants, for example in the crucifers, sulphur is also present in substantial quantities as volatile organic sulphur compounds.

Plants utilize sulphur primarily for forming protein. Only sulphur exceeding the amount required by the protein accumulates in the cells as sulphate. Therefore, in cases of sulphur deficiency, almost all the sulphur present in the plants is contained in the protein (DeLoch 1960, Dijkshoorn et al. 1961, Stewart and Porter 1959). Unless there is sufficient sulphur, a plant cannot fully utilize nitrogen fertilizer applied, the production of protein decreases and non-protein nitrogen increases (O'Connor and Vartha 1969, Stewart and Porter 1969). When sulphur is limited, yield is low, and the quality of the protein deteriorates (Saalbach et al. 1961, Saalbach 1966).

The diagnostic criteria most commonly applied to assess the sulphur requirements of plants have been total sulphur content and sulphate sulphur content or the total nitrogen/total sulphur ratio. Less frequently, the N/S ratio of the organic matter or protein and total phosphorus/total sulphur ratio have been used. Metson (1973) published a comprehensive review of the literature on the above subjects. Amide-N content has also been proposed as a criterion for assessing the sulphur requirements of plants (Rendig et al. 1976).

It is possible to determine the critical level indicating sulphur deficiency for many cultivated plants. As the excess sulphur needed to form organic matter accumulates in the plant cells, especially in the form of sulphate, the S-content has not always proved a reliable index of sulphur deficiency. In some studies, sulphate sulphur content has indicated the S-status better than the S-content, but in either case the critical level depends on the nitrogen supply of the plant. The sulphur requirements of gramineous plants appear to be better indicated by the N/S ratio than by the S-content (Metson 1973, Rasmussen et al. 1977). However, especially with timothy, very few studies have been made of cultivated graminae, comparing the contents with yield increases resulting from the application of sulphur (Korkman 1973).

In Finland there are areas where sulphur fertilization is essential to maintain plant growth (Salonen et al. 1965, Korkman 1973). Yield increases have been obtained with sulphur fertilization in trials carried out mainly in northern Finland, in a region where approximately 12 kg of sulphur per hectare is introduced into the soil annually by rain and snowfall. In southern Finland, the corresponding value, registered far from sources of emission, is 18 kg (Haapala 1972).

The present study deals with the influence of sulphur fertilization applied as gypsum on the size of the yield, its S-content and its N/S-ratio, and is based on the results of field trials using timothy as the test plant. Timothy was selected for the experiments because in northern Finland ley constitutes the main crop. On the basis of the results, the significance of the S-content and N/S ratio as an index of the sulphur requirement of timothy is examined.

MATERIAL AND METHODS

The field trials were established on first or second year timothy stands. The basal dressing was applied with multinutrient fertilizer (N—P—K—S 12,0—6,5—14,9—0). The sulphur fertilizer used was a relatively fine-ground (< 0,15 mm 50 %, < 2 mm 5 %) gypsum containing 17,0 % S. The multinutrient fertilizer levels contained 0, 48 and 96 kg of nitrogen and the gypsum 0, 34 and 68 kg of sulphur per hectare, so that the N/S of the fertilization was 1:0,7 throughout. All the fertilizers were broadcast in the spring, the NPK basal dressing annually and the gypsum at the beginning of the experiment. The trial was arranged in four

randomized blocks on 50 m² plots in 1969, except for trial 4, which was set up in 1970. In a couple of the trial sites, the field had to be ploughed because of outwintering, and the grass was re-established in the second year, when sulphur fertilization was also renewed. The ley was cut when the timothy began to flower, and the botanical composition of the yield was then determined. An analysis was made of the S (ANON. 1965, SALONEN et al. 1962) and N using the Kjeldahl method.

RESULTS AND DISCUSSION

Significant yield increases were obtained with multinutrient fertilizer in all the experiments (Table 1). Doubling the amounts of fertilizer also increased yield significantly, except in trial 5. A significant increase in yield was obtained in trials 1 and 2, in which sulphur fertilization was renewed the second year. In these trials the beneficial effect of the sulphur was not reduced in the year following the application. Gypsum generally has hardly any residual effect in coarse mineral soils. In fine-ground gypsum the sulphate appeared to remove from the top soil down to below the root system layer, in some cases by the end of the first growing season (BARROW 1966). On the other hand, in soils with a high sulphate-absorbing capacity, the influence was likely to persist over a period of several years (DICKSON and ASHER 1974, DURING and COOPER 1974). In trials 3—5, sulphur fertilization caused, on average, a slight decrease in yield. The difference was significant only in the first year of trial 3. The interaction of the amount of NPK fertilizer and sulphur fertilization was significant only in trial 2 in 1972. In that year, the sulphur perceptibly enhanced the effect of the NPK fertilization, the ratio of the sulphur to the other nutrients remaining the same at the different fertilization levels. In many studies, the effect of the nitrogen has been observed to depend on a sufficient supply of sulphur.

In trial 2 and 3, the proportion of wild grasses increased at the expence of timothy in unfertilized test plots in the second and third year crops. In no trial did sulphur fer-

Table 1. Hay yields obtained from timothy stands in diffetent trials.

Treatment kg/ha		Hay yield kg/ha								
		Trial 1		Trial 2		Trial 3			Trial 4	Trial 5
N[1])	S[2])	1970	1971	1970	1971	1969	1970	1971	1970	1969
0	0	955	1100	1785	1010	2050	2335	1215	4305	5110
48	0	1960	2910	1700	1285	5620	5635	3715	5935	9070
48	34	2085	3760	4095	2850	5030	5645	3560	5840	8710
96	0	2265	3600	3050	2135	6800	6565	5850	6670	9140
96	68	2515	4160	4920	5350	6540	6630	5760	6495	9030
Significance:										
NPK level		**	*	***	***	***	***	***	**	—
S-fertilization		(*)	**	***	***	*	—	—	—	—
NPK × S interaction		—	—	—	—	—	—	—	—	—

[1]) as multinutrient fertilizer
[2]) In trials 1 and 2, S applied twice in 1969 and 1970.

tilization either improve overwintering or influence the composition of plant species. In some investigations with leguminous plants sulphur has been observed to improve winter hardiness, and in many studies it has been found to increase the proportion of legumes and to reduce that of weeds in the stands (BEATON et al 1966, METSON 1973).

With gypsum fertilization it was even possible to eliminate quite a marked sulphur deficiency. In experiments abroad, gypsum has been observed to have a rapid effect although its availability is affected by the particle size of the product (MCLACHLAN and DEMARCO 1968, MORTENSON et al. 1968, BEATON and HUBBARD 1969).

In all the trials the N-content of timothy rose significantly with NPK fertilization (Table 2). Without fertilization, the N-content varied between 0,89 and 1,95. The values of the plant samples taken from normally developed stands of trials during the first years of the experiment are included although the yield results were omitted from the data because of gaps caused by damage during the winter. The N-content was highest in the NPK treatments deficient in sulphur. The same effect has been observed to be produced by nitrogen fertilization in studies with cereals (O'CONNOR and VARTHA 1969, KORKMAN 1973). In sulphur-deficient soils, sulphur fertilization reduced the N-content of timothy significantly. This was accounted for by the dilution attributable to the substantial increase in yield obtained through the application of sulphur fertilizer. According to KANG and OSINAME (1976), unless the yield increase obtained with sulphur is very marked, sulphur fertilization can raise the N-content of the yield specifically in soils deficient in sulphur. In the present study, when the sulphur supply was sufficient, sulphur fertilization did not affect the N-content of the timothy.

The S-content of timothy in soils deficient

Table 2. Total nitrogen and total sulphur contents of timothy in dry matter, and ratio of total nitrogen to total sulphur.

Treatment kg/ha		Trial 1			Trial 2			Trial 3			Trial 4	Trial 5
N	S	1969	1970	1971	1969	1970	1971	1969	1970	1971	1970	1969
							N-%					
0	0	1,03	1,49	1,51	1,43	1,95	1,50	1,09	1,12	1,44	1,28	0,89
48	0	1,25	2,00	1,70	2,09	2,41	1,82	1,51	1,12	1,55	1,59	1,18
48	34	1,34	1,42	1,87	1,16	1,66	1,48	1,61	1,60	1,49	1,58	1,22
96	0	1,61	1,65	1,95	2,08	2,13	2,00	1,72	1,34	1,79	1,64	1,62
96	68	1,47	1,71	1,92	1,38	1,85	1,74	1,73	1,30	1,65	1,81	1,97
							S-%					
0	0	0,09	0,13	0,10	0,10	0,11	0,08	0,15	0,16	0,17	0,15	0,12
48	0	0,09	0,12	0,11	0,10	0,12	0,08	0,14	0,16	0,15	0,15	0,11
48	34	0,12	0,16	0,16	0,16	0,19	0,11	0,16	0,18	0,16	0,19	0,12
96	0	0,09	0,12	0,10	0,10	0,10	0,09	0,12	0,15	0,17	0,14	0,13
96	68	0,14	0,18	0,16	0,17	0,19	0,13	0,13	0,18	0,16	0,21	0,16
							N/S					
0	0	11,4	11,5	15,1	14,3	17,7	18,8	7,3	7,0	8,5	8,5	7,4
48	0	13,9	16,7	15,5	20,9	20,1	22,8	10,8	7,0	10,3	10,6	10,7
48	34	11,2	8,9	11,7	7,3	8,7	13,4	10,1	8,9	9,3	8,3	10,2
96	0	17,9	13,8	19,5	20,8	21,3	22,2	14,3	8,9	10,5	11,7	12,5
96	68	10,5	9,5	12,0	8,1	9,7	13,4	13,3	7,2	10,3	8,6	12,3

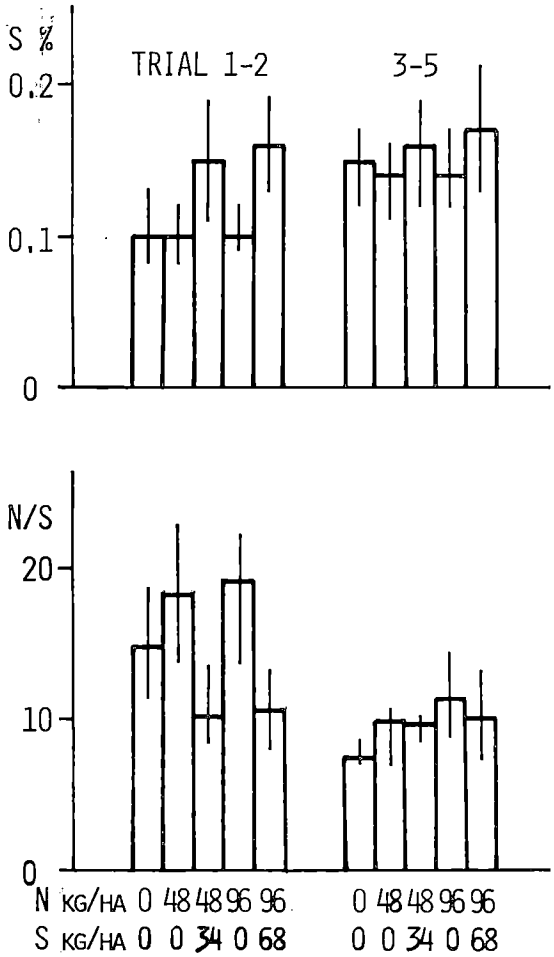

Fig. 1. Average sulphur content (S) of timothy and the nitrogen/sulphur ratio (N/S) in yields obtained with different fertilization in sulphur-deficient soils (trials 1 and 2) and sulphur-sufficient soils (trials 3—5). The range is marked by a vertical line.

in sulphur (trials 1 and 2) was under 0,13 % (Table 2, Fig. 1). In studies carried out with several other gramineous plants, the sulphur content has been registered as below 0,12 % when sulphur supply is limited, although higher critical values have also been reported (METSON 1973). In the present trials, sulphur fertilization increased the S-content of timothy significantly only in soils deficient in sulphur, raising it to the same level as in other trials. No significant difference between the amounts of sulphur appeared, the N/S ratio in the fertilization remaining the same.

In sulphur-deficient soil without sulphur fertilization, NPK fertilization had no significant effect on the sulphur content of the yield. According to the trials conducted by LEGGETT and EPSTEIN (1956), phosphate and nitrate have scarcely any effect on the uptake of sulphate by roots (cf. DIJKSHOORN et al. 1961). In these stands receiving sufficient sulphur, the S-% varied from 0,10 to 0,21 and sulphur fertilization did not significantly affect the S-%. Nitrogen fertilization, in particular, has a marked effect (METSON 1973). The sulphur content of gramineous plants also depends on the time of harvesting, decreasing during the growing season (WHITEHEAD 1966, RASMUSSEN et al. 1977). The S-contents registered in the present study agree with the S-contents of timothy obtained in field experiments carried out in different parts of the country (SALONEN et al. 1965, KORKMAN 1973).

When using multinutrient fertilizer without sulphur on soils deficient in sulphur, the N/S ratio varied between 13,8 and 22,8 (Table 2, Fig. 1). The highest values show that the forage contains insufficient amounts of sulphur for ruminants. In sulphur-deficient soils without fertilization the ratio was slightly lower, in only two samples below 13,8. In sulphur-deficient soils, sulphur fertilization reduced the N/S ratio. According to earlier studies, by sulphur fertilization it is possible not only to increase the yield but also improve the nutritive value of the forage. When the sulphur supply was sufficient, the N/S ratio was, except one value, under 14 (range: 7,0—14,3) in the stands in trials 1 and 2 receiving sulphur fertilizer and in trials 3—5. Sulphur fertilization had a significant effect on the ratio only in soils deficient in sulphur (trials 1 and 2). In studies conducted with different gramineous plants, the critical values of the N/S ratio of the sulphur need have most frequently been 12—14 (METSON 1973). According to DIJKSHOORN and VAN WIJK (1967) also, the N/S ratio of the protein of gramineous plants that have grown normally is approxi-

mately 14, with no appreciable difference being observed between the different grass species. The critical value of nearly 14 for sulphur deficiency in timothy revealed in the present study agrees with results of trials mentioned above with other gramineous plants.

According to these results, plant analysis appears to be of practical use in determining the sulphur requirements of timothy. The differences between stands receiving sulphur and stands deficient in it are more distinct with respect to the N/S ratio than the S-content of timothy. The present material is too limited, and the deficiency in sulphur registered conspicuous, however, so that additional data would be needed to determine the critical value for timothy.

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SELOSTUS

Rikkilannoituksen vaikutus timotein satoon ja kemialliseen koostumukseen

HILKKA TÄHTINEN

Maatalouden tutkimuskeskus

Tämä työ liittyy rikkilannoitustutkimuksiin, joilla pyritään selvittämään rikkilannoituksen tarvetta maassamme. Rikkilannoituksella on aikaisemmin saatu sadonlisäyksiä lähinnä Pohjois-Suomessa, jossa tärkein viljelykasvi on timotei. Selostettavilla kenttäkokeilla selvitetään rikin merkitystä timoteinurmien lannoituksessa sekä mahdollisuutta todeta rikkilannoituksen tarve kasvianalyysien perusteella.

Aineisto käsittää viisi 1—3-vuotista kenttäkoetta, joista punnittiin heinäsato ja määritettiin timotein kokonaistyppi- ja -rikkipitoisuudet sekä laskettiin N/S-suhde.

Kipsinä annettu rikkilannoitus lisäsi muutamilla koepaikoilla voimakkaasti satoa. Rikkilannoitus kohotti merkitsevästi rikkipitoisuutta ainoastaan rikin puutteessa olevissa kasvustoissa. Tällöin sadon typpipitoisuus samalla aleni todennäköisesti rikillä saadun voimakkaan sadonlisäyksen aiheuttaman laimenemisvaikutuksen takia. Kasvustoissa, joissa rikkilannoitus ei lisännyt satoa, ei rikkilannoitus vaikuttanut rikki- ja typpipitoisuuksiin.

Tulosten mukaan näyttää kasvianalyysi soveltuvan timotein rikintarpeen ilmaisijaksi. Rikillä saatava sadonlisäys näytti riippuvan selvemmin timotein N/S-suhteesta kuin rikkipitoisuudesta.

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ACID AMMONIUM ACETATE AND ACID AMMONIUM ACETATE/EDTA AS EXTRACTANTS FOR PHOSPHORUS-32, ALUMINUM AND IRON IN SOILS

ARJA PAASIKALLIO and ULLA HÄKKINEN

PAASIKALLIO, A. & HÄKKINEN, U. 1977. **Acid ammonium acetate and acid ammonium acetate/EDTA as extractants for phosphorus-32, aluminum and iron in soils.** Ann. Agric. Fenn. 16: 227–237. (Agric. Res. Centre, Isotope Lab., SF-01300 Vantaa 30, Finland.)

The effect of some soil factors on the adsorption and extraction of radioactive phosphorus-32 with acid ammonium acetate/0,02 M EDTA was studied in 445 samples of various soil types. The amount of applied ^{32}P adsorbed by the soil was about 90 %, except in Sphagnum peats where it was about 50 %. Factors affecting the adsorption of ^{32}P were soil texture and pH in coarse mineral soils, soil texture in clay soils, K and Al in humus soils and Al and/or Fe in peat soils. The amount of ^{32}P extracted by acid ammonium acetate/EDTA ranged from 9 to 22 %. In mineral and humus soils, native soil P was a significant factor explaining the variation in the extraction of ^{32}P. Other factors affecting the extraction of ^{32}P in mineral soils were generally similar to those which affected its adsorption. In peat soils none of the factors studied were significant.

In another series of soils containing 129 samples the extractability of ^{32}P, aluminum and iron with acid ammonium acetate and acid ammonium acetate/EDTA was compared and the effect of soil factors on the extraction of ^{32}P with these extractants was studied. The extraction of ^{32}P, Al and Fe with acid ammonium acetate/EDTA from low P mineral soils was 7, 6 and 48 fold, respectively, and from high P mineral soils 4, 10 and 105 fold, as compared to extraction with acid ammonium acetate. The corresponding values for ^{32}P, Al and Fe in low P organic soils were 10, 8 and 49 and in high P organic soils 2, 19 and 237, respectively. Significant factors affecting the extraction of ^{32}P with both extractants in all soils were native soil P and, in mineral soils, particle size also. The extraction of ^{32}P with acid ammonium acetate/EDTA was further affected by Fe in mineral soils and by Al and Fe in organic soils, while the extraction of ^{32}P with acid ammonium acetate was affected by pH in mineral soils and bulk density in organic soils.

Index words: acid ammonium acetate/EDTA, phosphorus-32, iron, aluminum.

INTRODUCTION

Acid ammonium acetate (Aaa), which is used in Finland to estimate plant available phosphorus, has a relatively low phosphorus extraction power (VUORINEN and MÄKITIE 1955). The addition of EDTA to the extractant (Aaa/EDTA) increases the phosphorus extraction power primarily because EDTA can bind various metals, e.g. aluminum and iron,

in soils and thereby release the phosphorus associated with these metals.

VIRO (1955a, b) used 0,05 M EDTA solution as a phosphorus extractant in Finnish forest soils. Most of the other studies of phosphorus extraction with EDTA have been carried out with more dilute EDTA solutions. ALEXANDER and ROBERTSON (1972) used 5 mM EDTA solution and found that EDTA extractable phosphorus showed significant positive correlation with A-value and with 0,015 M H_2SO_4 + 0,03 M NH_4F and 0,5 N $NaHCO_3$ extractable phosphorus. HANNA et al. (1962), AHMED and ISLAM (1975) and OLSEN (1975) found a high correlation between phosphorus extracted with a water solution of EDTA and plant phosphorus.

Aaa/0,02 M EDTA has been used to some extent for extracting several trace elements from Finnish soils (LAKANEN and ERVIÖ 1971, SILLANPÄÄ et al. 1975 and SIPPOLA and TARES 1978). The extractant has not been used in the routine analysis of soil phosphorus because determination of phosphorus from a strong EDTA solution has proved tedious. Since the problem of determining phosphorus from EDTA extracts has been solved (NNADI et al. 1975), it would be possible to use this extractant in phosphorus extractions, but more detailed studies for interpretating the results would be necessary.

This paper reports the effect of various soil factors on the adsorption and extraction of phosphorus-32 using acid ammonium acetate and acid ammonium acetate/0,02 M EDTA as extractants and compares the extractability of phosphorus-32, aluminum and iron with these extractants from soils of various phosphorus contents.

MATERIAL AND METHODS

Two series of soil samples (445 and 129) representing typical cultivated soils in Finland were used in this study. Some of the properties of the first series are shown in Table 1 and Fig. 1 and of the second series in Tables 3 and 4 in which the value 12 mg P/ litre of soil

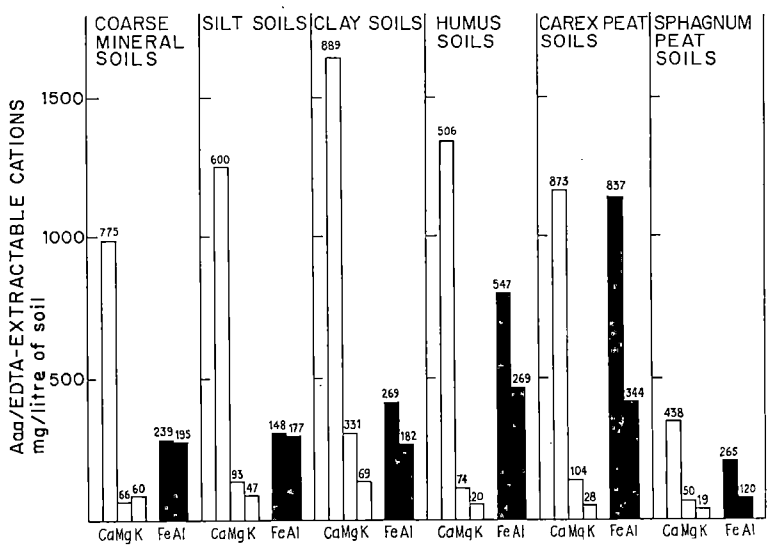

Fig. 1. The content of acid ammonium acetate/EDTA (Aaa/EDTA) extractable cations Ca, Mg, K, Fe and Al in various soil groups. The figures above the columns show standard deviations.

Table 1. Analytical data of soil groups (a = mean value, b = standard deviation).

Soil groups		P Aaa-extr.	Humus	N	Mineral composition Clay	Silt		Fine-sand	Sand	pH	Bulk density
					< 2 μ	2–20 μ		20–200 μ	200–2000 μ		
						fine	coarse				
		mg/l	%	%		%					g/cm³
Coarse mineral soils (n = 156)	a	7,2	4,68	—	7,5	4,3	7,4	47,2	33,3	5,46	1,21
	b	8,3	3,06		7,5	4,5	7,4	21,7	35,0	0,71	
Silt soils (n = 69)	a	5,7	5,85	—	25,2	26,3	26,3	17,5	4,1	5,53	0,94
	b	5,9	2,20		7,1	8,1	6,4	9,6	2,6	0,50	
Clay soils (n = 117)	a	4.6	7,36	—	48,5	16,5	14,1	16,1	4,9	5,63	0,99
	b	3,7	2,39		12,9	6,6	5,5	9,8	3,6	0,50	
Humus soils (n = 22)	a	5,0	25,89	0,734			—			5,14	0,72
	b	3,7	7,70	0,258						0,61	
Carex peat soils (n = 44)	a	3,6	62,29	1,698			—			4,64	0,39
	b	2,6	13,01	0,460						0,53	
Sphagnum peat soils (n = 37)	a	4,3	72,56	0,988			—			4,13	0,15
	b	2,8	6,31	0,425						0,40	

was used in dividing the mineral soils into low and high P soils. The corresponding value for organic soils was 20 mg P/ litre of soil.

The particle size distribution was determined by dry and wet sieving and by the pipette method, organic carbon colorimetrically after sulphuric acid — potassium dichromate wet digestion and the total nitrogen by the Kjeldahl method. Humus content was calculated from the content of organic carbon using the coefficient 1,72.

Ca, K, Mg, P, Fe and Al were extracted from all soils with acid ammonium acetate (pH 4,65) and with acid ammonium acetate/ 0,02 M EDTA (LAKANEN and ERVIÖ 1971), P only with the former. The soil-extractant mixture was shaken for one hour, centrifuged and filtered. The cations were determined from the extract by atomic absorption spectrophotometry and P colorimetrically by the molybdenum blue method. Soil pH was determined from the soil-water suspension (1: 2,5).

The adsorption and extraction of P in the first series of soils were studied by adding to the soils neutral carrier-free radiophosphorus, the activity of which was 220—280 nCi ^{32}P/ml (soil-water in vol. ratio 1:5). The soils were shaken for 18 hours, centrifuged and the radioactivity was measured from a 10 ml of supernatant without filtering. The adsorption percentage was calculated by comparing the activity of ^{32}P remaining in the soil (= the amount of ^{32}P added to soil minus the amount of ^{32}P extracted from soil) with the activity of the standard ^{32}P solution. The activity remaining in the soil was immediately extracted with acid ammonium acetate/EDTA, as before, and the radioactivity was measured from the supernatant. The extraction percentage was calculated by comparing the amount of ^{32}P extracted with the amount of ^{32}P adsorbed by the soil. Because ^{32}P was extracted immediately after centrifuging and decanting the adsorption solution, the extraction percentage was corrected taking into account the volume of water and its activity remaining in soils where adsorption was lower than 80 %. The correction had the greatest effect on the extraction percentages of Sphagnum peats.

The extraction of P from the second series

of soils was studied by adding neutral carrier-free radiophosphorus solution to soils, 120 μCi ^{32}P/100 ml of soil. In addition the soils were moistened with water, mixed well and allowed to stand for 2—3 days, after which they were air-dried, ground and an amount corresponding to a volume of 10 ml was weighed. Soils were extracted using both extractants (vol. ratio 1:5). The radioactivity was counted from 5 ml of the supernatant and the standard solution. The extraction percentage was calculated by comparing the amount extracted with the amount of ^{32}P added to soil. Fe and Al determinations were made from the same solutions. All radioactivity measurements were made using a two channel gammaspectrometer (Wallac GTL 500, Turku) with a NaI (Tl) well crystal.

In the first series of soils, the effect of various soil factors on the adsorption and extraction of ^{32}P and, in the second series of soils, their effect on the extraction of ^{32}P with both extractants was studied by means of stepwise multiple regression analysis.

RESULTS AND DISCUSSION

The adsorption of ^{32}P by various soils and its extraction with acid ammonium acetate/EDTA (Aaa/EDTA)

The soils (the first series) adsorbed about 90 % of added ^{32}P, apart from Sphagnum peat soils in which adsorption was about 50 %. The extraction of ^{32}P by Aaa/EDTA ranged from 9 to 22 %, depending on soil type (Fig. 2). The relatively high adsorption of ^{32}P in Sphagnum peat soils might be due partly to the high degree of decomposition of peat soils. On the other hand about a fourth of the original Sphagnum peat soils had to be rejected because after the necessary corrections their extraction percentages were negative. The adsorption percentage of these soils was usually below 20.

The most important factor explaining significantly the variation in the adsorption of ^{32}P in all mineral soils was soil texture. Adsorption increased with decreasing sand content (Table 2). In all soil groups except clay soils, Al and/or Fe and in coarse mineral soils and Carex peats also soil pH was a significant factor explaining the variation in the adsorption of ^{32}P.

In the extraction of ^{32}P with Aaa/EDTA from mineral soils, native soil P and soil texture were the most important factors explaining the variation (Table 2). In humus soils, the only explanatory factor was the native soil P, and in peat soils there were no significant factors. In coarse mineral soils the increase in the adsorption and the decrease in the extraction of ^{32}P as soil pH increased

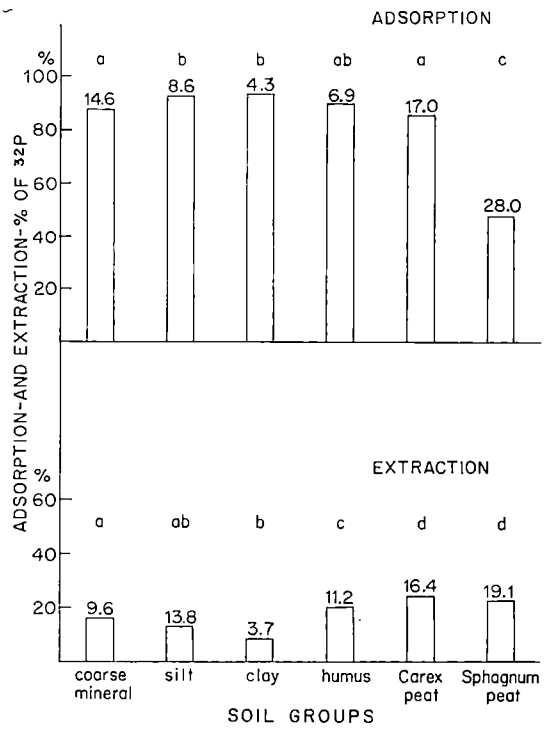

Fig. 2. The percentage ^{32}P adsorption and extraction with acid ammonium acetate/EDTA in various soil groups. Mean values not followed by the same letter differ significantly at 95 % level. The figures above the columns show standard deviations.

Table 2. Significant factors (independent variables) in the multiple regression equations of ^{32}P adsorption and extraction with acid ammonium acetate/EDTA (dependent variables), correlation coefficients, t-values and the degree of determination (R^2 in per cent).

Dependent variable:		Adsorption of ^{32}P					Extraction of ^{32}P				
Soil groups	Step	Independent variables	r	t-value	R^2 %		Step	Independent variables	r	t-value	R^2 %
Coarse mineral soils (n = 214)	1	sand	−0,392***	−4,95***			1	P	0,294***	4,89***	
	2	pH	0,249**	3,37***			2	finesand	0,269**	4,04***	
	3	Al	0,153*	3,14**			3	pH	−0,057	−3,52***	
	4	Ca	0,102	−2,84**							
		Total			21,9			Total			18,2
Clay soils (n = 116)	1	sand	−0,225**	−2,54*			1	clay	−0,357***	−4,24***	
	2	fsilt	0,208*	2,35*			2	P	0,360***	3,89***	
							3	Fe	0,211*	2,45*	
		Total			9,5			Total			27,8
Humus soils (n = 22)	1	K	−0,503*	−3,05**			1	P	0,531**	2,80*	28,3
	2	Al	0,323	2,15*							
		Total			40,0						
Carex peat soils (n = 44)	1	Al	0,372*	3,63***							
	2	Fe	0,415**	2,51*				—			
	3	pH	0,350*	2,23*							
		Total			41,0						
Sphaghum peat soils (n = 37)	1	Fe	0,343*	2,18*	11,8			—			

Table 3. Analytical data of the mineral and organic soils grouped according to the content of acid ammonium acetate (Aaa) extractable P (a = mean value, b = standard deviation).

Soil groups		Aaa-extractable					Bulk density g/cm³
		P	Ca	Mg	K	pH	
			mg/litre of soil				
MINERAL SOILS							
Aaa-extr. P:							
≦ 12 mg/l	a	5,9	1 417	203	154	5,85	1,03
(n = 68)	b	3,5	805	168	88	0,51	0,15
> 12 mg/l	a	50,4	2 590	201	234	6,55	1,06
(n = 27)	b	36,1	1 352	245	150	0,74	0,11
TOTAL	a	18,5	1 750	203	177	6,05	1,04
(n = 95)	b	27,8	1 118	191	114	0,67	0,14
ORGANIC SOILS							
Aaa-extr. P:							
≦ 20 mg/l	a	6,9	1 759	262	130	5,13	0,53
(n = 25)	b	4,4	692	181	172	0,48	0,17
> 20 mg/l	a	182,3	3 570	390	456	6,32	0,43
(n = 9)	b	137,2	1 430	207	533	1,02	0,37
TOTAL	a	53,3	2 239	296	216	5,44	0,50
(n = 34)	b	103,7	1 225	194	334	0,84	0,24

was evidently due to the soil pH values, which were below the solubility minimum of P, i.e. pH 5,8 (LAKANEN and VUORINEN 1963).

Most of the soil factors which affected both the adsorption and extraction of ^{32}P, e.g. soil type, texture, pH, Fe and Al, are generally

known to affect the solubility of soil P. However, the significant factors in the regression equations explained only a small part of the variation in the adsorption and extraction of ^{32}P.

Aaa/EDTA extracted considerably more Fe from Carex peat and humus soils than from other soil groups, while the differences between soil types in the content of Al were smaller (Fig. 1). The findings of SILLANPÄÄ et al. (1975) and SIPPOLA and TARES (1978) agree with these results.

The extractability of ^{32}P, Al and Fe with acid ammonium acetate/EDTA (Aaa/EDTA) and acid ammonium acetate (Aaa)

In the second series of soils the amounts and ratios of ^{32}P, Al and Fe extracted with Aaa/EDTA and Aaa, differed significantly between low P and high P soils, only the differences in the contents of Aaa/EDTA extractable Fe in mineral soils were not significant (Table 4). The amounts of ^{32}P were higher (and the ratios lower) and the amounts of Al and Fe lower (and the ratios higher) in high P than in low P soils.

In low P mineral soils the extractability of ^{32}P, Al and Fe with Aaa/EDTA was 6,5, 6,3 and 47,6 times the extractability with Aaa. From high P mineral soils, compared with Aaa, Aaa/EDTA extracted about twice as much Fe as from the former soils. In low P organic soils the extraction power of Aaa/EDTA compared with that of Aaa was only slightly higher than in low P mineral soils, and in high P organic soils the ratios were 1,9, 18,8 and 237,4, respectively.

LAKANEN and ERVIÖ (1971) and SILLANPÄÄ et al. (1975) have reported higher values for Fe extracted with Aaa than the values given in Table 4. However, iron was added to soils in the first mentioned study and SILLANPÄÄ et al. used a wider extraction ratio (1:10) than in this study.

Table 4. The amounts of ^{32}P, Al and Fe extracted with acid ammonium acetate/EDTA (Aaa/EDTA) and acid ammonium acetate (Aaa) and their ratios in mineral and organic soils grouped according to the content of Aaa-extractable P (a = mean value, b = standard deviation).

Soil groups		^{32}P extraction-%		^{32}P Aaa/EDTA / Aaa	Al mg/l of soil		Al Aaa/EDTA / Aaa	Fe mg/l of soil		Fe Aaa/EDTA / Aaa
		Aaa/EDTA	Aaa		Aaa/EDTA	Aaa		Aaa/EDTA	Aaa	
MINERAL SOILS										
Aaa-extr. P:										
≤ 12 mg/l	a	13,4	2,1	6,5	274	49,2	6,3	371	11,1	47,6
(n = 68)	b	8,5	1,2	2,6	139	34,0	2,4	209	8,0	38,6
> 12 mg/l	a	25,9	7,1	4,2	157	21,1	10,3	337	5,2	104,8
(n = 27)	b	10,1	4,1	1,7	95	17,2	6,9	157	4,3	84,7
TOTAL	a	17,0	3,6	5,8	240	41,2	7,4	361	9,4	63,9
(n = 95)	b	10,6	3,3	2,6	138	32,7	4,6	195	7,6	61,0
ORGANIC SOILS										
Aaa-extr. P:										
≤ 20 mg/l	a	26,0	2,7	10,0	481	60,3	8,2	1 267	29,9	48,5
(n = 25)	b	12,2	1,4	2,3	202	26,5	2,0	781	23,6	15,7
> 20 mg/l	a	65,3	44,6	1,9	104	7,4	18,8	368	2,2	237,4
(n = 9)	b	18,2	27,9	0,8	61	3,4	18,3	231	1,6	288,3
TOTAL	a	36,4	13,7	7,9	381	46,3	11,0	1 029	22,6	98,5
(n = 34)	b	22,3	23,3	4,1	243	32,8	10,3	875	23,6	165,8

Table 5. Significant factors (independent variables) in the multiple regression equations of ^{32}P extraction with acid ammonium acetate/EDTA (Aaa/EDTA) and acid ammonium acetate (Aaa) (dependent variables), correlation coefficients, t-values and the degree of determination (R^2 in per cent).

Soil groups	Dependent variable	Step	Independet variables	r	t-value	R^2 %
MINERAL SOILS (n = 95)	Aaa/EDTA-extractable ^{32}P	1	P	0,645***	10,30***	
		2	d.p.size(1	−0,303**	− 6,52***	
		3	Fe	0,303**	5,26***	
			Total			64,5
	Aaa-extractable ^{32}P	1	P	0,872***	15,15***	
		2	d.p.size(1	−0,149	− 5,09***	
		3	pH	0,570***	3,14**	
			Total			82,4
ORGANIC SOILS (n = 34)	Aaa/EDTA-extractable ^{32}P	1	Al	−0,735***	− 7,12***	
		2	P	0,716***	5,52***	
		3	Ca	0,294	− 5,25***	
		4	Fe	−0,478**	− 2,88**	
			Total			85,5
	Aaa-extractable ^{32}P	1	P	0,774***	6,77***	
		2	bulk density	−0,483**	− 3,01**	
			Total			69,1

1) d.p.size = decreasing particle size

The dependence of the acid ammonium acetate/EDTA (Aaa/EDTA) and the acid ammonium acetate (Aaa) extractable ^{32}P upon the content of P, Al, Fe and pH in soil

In the second series of soils the significant factors in the regression equations explained a considerable amount of the variation in the extraction of ^{32}P with both extractants (Table 5) while in the soils of the first series they explained only a small part of this variation. Besides the difference in the number of samples used in the two experiments, the variation was probably partly due to the different extraction techniques and perhaps also to the greater variation in native soil P in the second series of soils. ^{32}P extracted with both extractants and native soil P was usually strongly correlated in all mineral and organic soils as was Aaa/EDTA extractable ^{32}P and Al in all organic soils; other correlations between ^{32}P and soil factors were considerably lower (Table 6).

In all mineral soils the most important factors explaining the variation in the extraction of ^{32}P with both extractants were native soil P and particle size (Table 5). In mineral soils the content of native soil P and the amounts of ^{32}P extracted were in significant positive correlation with exception of the Aaa extractable ^{32}P in low P soils (Table 6). This was probably due to the poor extraction power of Aaa so that the variation in the amounts of ^{32}P remained small (the standard deviation of ^{32}P was 1,2). In all organic soils, too, native soil P was an important factor explaining the variation in the extraction of ^{32}P with both extractants.

The ratio of Aaa/EDTA to Aaa extractable ^{32}P increased with increasing native soil P in low P mineral soils (Fig. 3A), primarily due to the increase in the amount of Aaa/EDTA extractable ^{32}P. The ratio decreased in the same direction in high P mineral soils (Fig. 3B), and this, on the other hand, was due to the relatively faster increase of Aaa than Aaa/EDTA extractable ^{32}P.

Generally, the Aaa/EDTA extractable ^{32}P was more dependent on the Fe and/or Al content of soils than the Aaa extractable ^{32}P, which, on the other hand, was affected more by the soil pH or bulk density (Table 5). In

Table 6. Correlations of the various extractions of phosphorus (a, b, c) and soil pH (d) with ^{32}P, Al and Fe. Significances of correlation coefficients at 95*, 99** and 99.9*** per cent levels. (a = P extracted with Aaa, b = ^{32}P extracted with Aaa, c = ^{32}P extracted with Aaa/EDTA)

Soil groups		^{32}P			Al			Fe			pH
		Aaa/EDTA	Aaa	Aaa/EDTA / Aaa	Aaa/EDTA	Aaa	Aaa/EDTA / Aaa	Aaa/EDTA	Aaa	Aaa/EDTA / Aaa	
MINERAL SOILS											
Aaa-extr. P:											
≦ 12 mg/l	a	0,641***	0,119	0,655***	0,538***	−0,066	0,597***	0,465***	0,146	0,162	−0,269*
(n = 68)	b			−0,120		0,003	−0,124		0,080	−0,301*	0,053
	c			0,664***	0,324**		0,316**	0,467***		−0,137	−0,228
	d			−0,345**	−0,397***	−0,334**		−0,322**	−0,587***		
> 12 mg/l	a	0,616***	0,833***	−0,630***	−0,343	−0,602***	0,547**	0,325	−0,190	0,477*	0,539**
(n = 27)	b			−0,661***		−0,602***	0,378		−0,065	0,286	0,595**
	c			−0,182	−0,257		0,169	0,280		0,058	0,425*
	d			−0,553**	−0,619***	−0,600***		0,567**	0,190		
TOTAL	a	0,645***	0,872***	−0,367***	−0,315**	−0,401***	0,616***	0,081	−0,279**	0,554***	0,546***
(n = 95)	b			−0,446***		−0,375***	0,455***		−0,231*	0,377***	0,570***
	c			0,146	−0,066		0,378***	0,303**		0,199	0,282**
	d			−0,490***	−0,537***	−0,476***		−0,088	−0,477***		
ORGANIC SOILS											
Aaa-extr. P:											
≦ 20 mg/l	a	0,260	0,059	0,415*	−0,300	−0,254	−0,087	−0,018	−0,134	0,284	−0,243
(n = 25)	b			−0,185		−0,573**	0,366		−0,317	0,673***	−0,429*
	c			0,245	−0,429**		0,343	−0,064		0,618***	−0,531**
	d			−0,379	−0,073	0,079		−0,218	−0,095		
> 20 mg/l	a	0,441	0,427	−0,407	−0,514	−0,387	−0,368	−0,421	−0,248	−0,344	0,271
(n = 9)	b			−0,982***		−0,677*	0,176		−0,882**	0,331	−0,474
	c			−0,969***	−0,922***		0,030	−0,852**		0,219	−0,488
	d			0,479	0,245	−0,107		0,683*	0,682*		
TOTAL	a	0,716***	0,774***	−0,682***	−0,575***	−0,566***	0,138	−0,428*	−0,405*	0,195	0,585***
(n = 34)	b			−0,765***		−0,622***	0,465**		−0,452**	0,581***	0,336*
	c			−0,673***	−0,735***		0,399*	−0,478**		0,500**	0,265
	d			−0,619***	−0,451**	−0,438**		−0,357*	−0,359*		

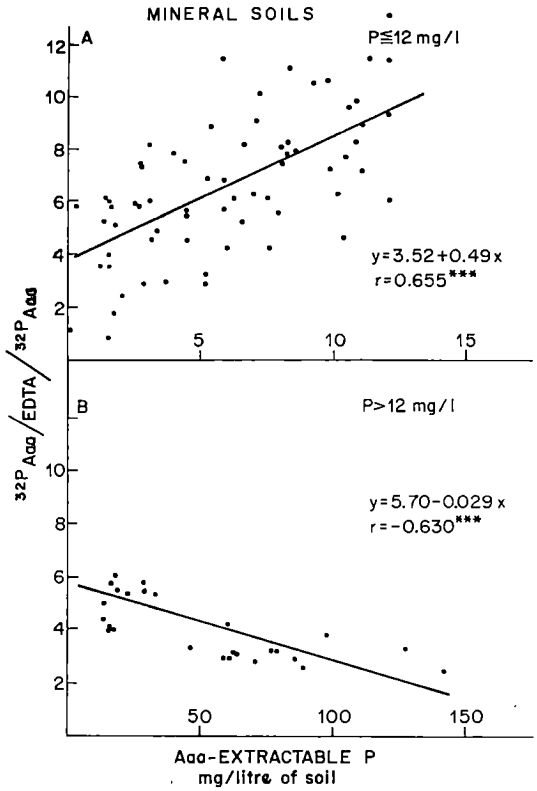

Fig. 3. The ratio of acid ammonium acetate/EDTA (Aaa/EDTA) extractable ^{32}P to acid ammonium acetate (Aaa) extractable ^{32}P as a function of Aaa extractable P in low P and high P mineral soils.

extracting ^{32}P with Aaa/EDTA, Fe was a significant positive factor on the regression equation in all mineral soils and both Al and Fe were significant negative factors in all organic soils. According to KAILA (1959) the significant factors affecting the retention capacity of P in peats were in the following sequence: acid soluble Al and Fe, the degree of decomposition and volume weight. In this study the correlations between ^{32}P and Fe were generally negative, the only positive correlation being between Aaa/EDTA extractable ^{32}P and Fe in mineral soils, especially when the native soil P was low (Table 6).

In all mineral soils, when extracting ^{32}P with Aaa, pH was a significant positive factor explaining the variation in the content of ^{32}P. However, increasing pH increased ^{32}P extraction only in high P soils (Table 6), where soil pH was above the solubility minimum of P.

Al extracted with both extractants decreased with increasing pH in all soil groups as did Fe in organic soils as a whole. However, in all mineral soils Aaa/EDTA extractable Fe and pH had no significant correlation, although separately, in low P soils it had a negative and in high P soils a positive correlation with pH. According to NORVELL (1972) pH should not affect the stability of Fe-EDTA chelates when soil pH is lower than 6.3. Generally, EDTA extractable Fe is not found to be reliable in predicting the plant requirement of Fe. According to BORGGAARD (1976) this may be due to the extraction time being too short (1 hour).

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SELOSTUS

Hapan ammoniumasetaatti ja hapan ammoniumasetaatti/EDTA fosfori-32:n, alumiinin ja raudan uuttonesteinä

ARJA PAASIKALLIO ja ULLA HÄKKINEN

Maatalouden tutkimuskeskus

Hapan ammoniumasetaatti/0,02 M EDTA (Aaa/EDTA) uuttaa maasta hivenaineita ja fosforia huomattavasti enemmän kuin hapan ammoniumasetaatti (Aaa). Fosforin pidättymistä maahan ja sen uuttumista Aaa/EDTA:lla tutkittiin radioaktiivisen fosfori-32:n (^{32}P) avulla 445 pintamaanäytteestä (aineisto I). Lisäksi tutkittiin alumiinin, raudan ja maahan lisätyn ^{32}P:n uuttumista Aaa:lla ja Aaa/EDTA:lla sekä eri maaperätekijöiden vaikutusta ^{32}P:n uuttumiseen 129 maanäytteestä (aineisto II).

Aineisto I:n maiden ominaisuudet on esitetty taulukossa 1 ja kuvassa 1. ^{32}P:sta pidättyi maahan yleensä noin 90 %, rahkaturvemaihin kuitenkin vain noin 50 % (kuva 2). Aaa/EDTA uutti maahan pidättyneestä ^{32}P:sta 9—22 % maalajista riippuen. Maalaji oli tärkeä ^{32}P:n pidättymiseen ja uuttumiseen vaikuttava tekijä kivennäismailla (taulukko 2). ^{32}P:n pidättyminen maahan kasvoi yleensä maan pH:n ja/tai alumiinipitoisuuden ja turvemailla myös rautapitoisuuden kasvaessa. ^{32}P:n uuttumista lisäsi myös maan fosforipitoisuuden kasvu. Nämä maaperätekijät selittivät kuitenkin vain pienen osan ^{32}P:n pidättymisen ja uuttumisen vaihtelusta.

Aineisto II:n kivennäismaat ja orgaaniset maat jaettiin kahteen ryhmään niiden happamalla ammoniumasetaatilla uuttuvan fosforipitoisuuden perusteella. Rajana oli kivennäismailla fosforipitoisuus 12 mg P/l maata ja orgaanisilla mailla 20 mg P/l maata. Maiden ominaisuudet on esitetty taulukoissa 3 ja 4. Vähän fosforia sisältävistä kivennäismaista Aaa/EDTA uutti ^{32}P:ta, alumiinia ja rautaa 7, 6 ja 48 kertaa ja paljon fosforia sisältävistä kivennäismaista 4, 10 ja 105 kertaa enemmän kuin Aaa. Vähän fosforia sisältävistä orgaanisista maista Aaa/EDTA uutti Aaa:han verrattuna näitä alkuaineita suunnilleen saman verran kuin vähän fosforia sisältävistä kivennäismaista ja paljon fosforia sisältävistä orgaanisista maista 2, 19 ja 237 kertaa enemmän kuin Aaa (taulukko 4). Yleensä Aaa/EDTA uutti paljon enemmän rautaa kuin alumiinia Aaa:han verrattuna. Vähän fosforia sisältävistä maista uuttui Aaa/EDTA:lla Aaa:han verrattuna enemmän fosforia ja vähemmän alumiinia ja rautaa

kuin paljon fosforia sisältävistä maista. Aaa/EDTA:lla ja Aaa:lla uuttuvien ^{32}P-määrien suhde kasvoi vähän fosforia sisältävillä kivennäismailla mutta pieneni paljon fosforia sisältävillä kivennäismailla maan fosforipitoisuuden kasvaessa (kuva 3).

^{32}P:n uuttumiseen merkitsevästi vaikuttavat maaperätekijät, jotka selittivät yleensä 65—85 % ^{32}P:n uuttumisen vaihtelusta, on esitetty taulukossa 5. Eri uuttonesteillä uuttuva ^{32}P-määrä kasvoi kummassakin maaryhmässä maan fosforipitoisuuden kasvaessa. Kivennäismailla kummallakin uuttonesteellä uuttuva ^{32}P-määrä pieneni maan hiukkaskoon pienetessä. Kivennäismailla Aaa/EDTA:lla uuttuva ^{32}P-määrä kasvoi rautapitoisuuden kasvaessa ja orgaanisilla mailla se pieneni rauta- ja alumiinipitoisuuden kasvaessa. Aaa:lla uuttuviin ^{32}P-määriin maan alumiini- ja rautapitoisuudella ei ollut vaikutusta. ^{32}P:n, alumiinin, raudan ja pH:n väliset korrelaatiot on esitetty taulukossa 6. Parhaiten korreloivat keskenään kummallakin uuttonesteellä uuttuva ^{32}P ja maan Aaa-liukoinen fosfori kummassakin maaryhmässä sekä Aaa/EDTA:lla uuttuva ^{32}P ja alumiini orgaanisissa maissa.

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Seria PHYTOPATHOLOGIA N. 65 – Sarja KASVITAUDIT n:o 65

HENDERSONIA, PHAEOSEPTORIA AND STAGONOSPORA ON GRAMINEAE IN FINLAND

KAIHO MÄKELÄ

MÄKELÄ, K. 1977. **Hendersonia, Phaeoseptoria and Stagonospora on Gramineae in Finland.** Ann. Agric. Fenn. 16: 238–255. (Agric. Res. Centre, Inst. Pl. Path., SF-01300 Vantaa 30, Finland.)

About 4630 samples of 47 grass species and 2040 samples of four cereals collected throughout Finland during 1966–1974 were examined. Nine septorioid species were discovered. The species found on both cereals and other grasses were *Hendersonia crastophila* Sacc. and *Phaeoseptoria festucae* Sprag. *H. crastophila* was found to be very common on grasses but less common on cereals, whilst *P. festucae* was more common on cereals than on grasses. *P. poae* Sprag. was moderately common on non-cereals throughout the country. All other fungi species found were rare and occurred infrequently on non-cereals; they included *Hendersonia culmicola* Sacc. and *H. simplex* Schroet. as well as *Stagonospora smolandica* Eliass. and *S. subseriata* (Desm.) Sacc. on some grass species. *Hendersonia phragmites* Desm. was found to be moderately common on *Phragmites communis*, as was *Phaeoseptoria airae* (Grove) Sprag. on *Deschampsia caespitosa*.

Index words: *Hendersonia, Phaeoseptoria, Stagonospora,* grasses, cereals.

INTRODUCTION

Hendersonia Berk. em. Sacc., *Stagonospora* Sacc. and *Phaeoseptoria* Speg. belong to the order *Spahaeropsidales* (*Coelomycetes*) (AINSWORTH et al. 1973). These fungi occur on numerous *Gramineae* species. *Hendersonia* species are saprophytes or very weak parasites. All the *Phaeoseptoria* species are saprophytes, while most of the *Stagonospora* species are parasitic (SPRAGUE 1950, JORSTAD 1967). *Hendersonia* species have multiseptate, fuliginous, broadened conidia, whilst those of the *Phaeoseptoria* species are elongate (SPRAGUE 1943b, 1950, JORSTAD 1967). The *Stagonospora* species have multiseptate, hyaline, guttulate, cylindrical, broadened conidia (SPRAGUE 1950, JØRSTAD 1967).

Since the work done by KARSTEN (1884a, b) on *Hendersonia* species, only very sporadic studies have been made in Finland on the occurrence of these fungi on grasses and cereals (MÄKELÄ 1972, 1975).

MATERIAL AND METHODS

The present study is based on about 4630 grass samples gathered from leys, field borders, meadows and forests throughout the country during 1966—1973, and cereal samples gathered from agricultural fields in 1970—1973. The material comprised four cereal species and 47 species of other grasses.

A great number of samples of cultivated grasses were taken from the Viikki experimental fields, Helsinki and the Experiment Stations of the Agricultural Research Centre throughout the country in 1966—1970. The samples of wild grasses and cereals were gathered at random all over the country, chiefly in 1971—1973. The grass samples were collected between the spring thaw and the first real snowfall of the autumn. The bulk of the cereal samples was gathered when the grain was at the milkyripe stage, chiefly from late July to early August.

In addition to these specimens of grasses and cereals, collections at the Department of Plant Pathology, University of Helsinki (HPP), and Mr. Pentti Alanko's private herbarium were examined.

The nomenclature of the vascular plants is according to HULTEN (1971). Abbrevations of the biological provences are in accordance with HEIKINHEIMO and RAATIKAINEN (1971). Pentti Alanko = P.A., Hilkka Koponen = H.K. and Kaiho Mäkelä = K.M. collected the samples.

Microscopic slides were prepared from all the samples. The slides were preserved in lactic acid — lactophenol solutions, in which the fungi were also measured and photographed.

The species

Hendersonia crastophila Saccardo, Michelia I:211, 1878

Reported from many European countries, e.g. Italy, Denmark, Great Britain (SACCARDO 1884, LIND 1913, GROVE 1937, WEBSTER 1955). Found in Norway on 18 grass species, including *Agropyron caninum*, *A. repens*, *Calamagrostis arundinacea*, *Dactylis glomerata*, *Deschampsia caespitosa*, *Festuca pratensis*, *Phleum pratense* and *Poa pratensis* (JORSTAD 1967). Common in the USA, found on about 40 grasses (SPRAGUE 1950). Cereal hosts include *Avena sativa*, *Hordeum vulgare*, *Secale cereale* and *Triticum aestivum* (SPRAGUE 1950, JORSTAD 1967), but according to FRANDSEN (1943) only oats.

WEBSTER (1955) considers it possible that *Hendersonia crastophila* is the conidial stage of *Pleospora vagans* Niessl.

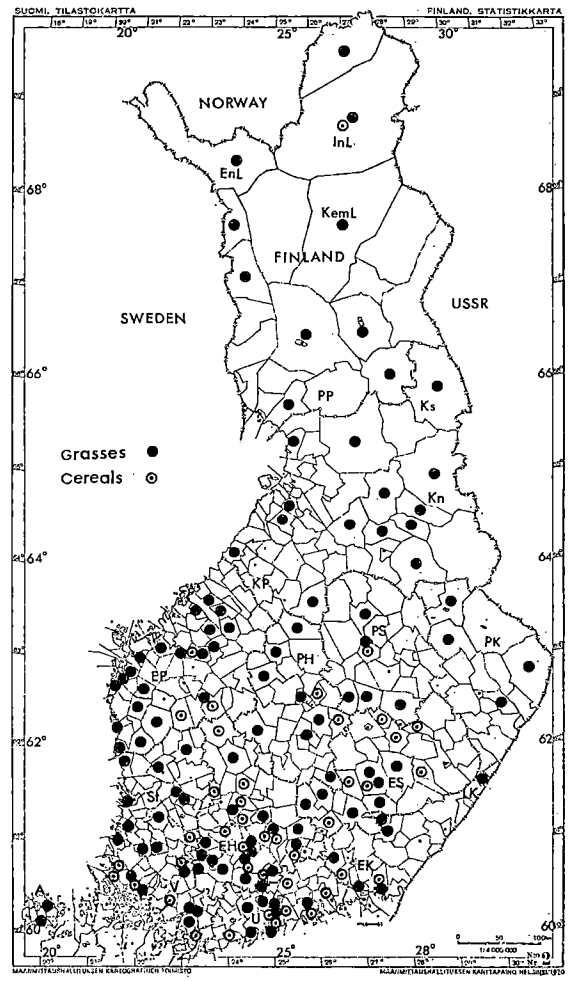

Fig. 1. Occurrence of *Hendersonia crastophila* on grasses and cereals in Finland

Table 1. Size of conidia of *Hendersonia crastophila*

Hosts	No. of isolates measured	No. of conidia measured	Length µm mean	Length µm range	Width µm mean	Width µm range	No. of septa mean	No. of septa range
Agropyron caninum	5	45	39,0	29—50	4,3	3—6	6,8	5— 9
A. repens	29	187	39,9	22—72	4,4	3—6	6,7	3—13
Agrostis stolonifera	6	56	44,3	28—58	4,2	3—7	6,8	3— 9
A. tenuis	45	393	41,0	24—65	4,2	3—7	7,0	3—11
Alopecurus geniculatus	2	16	38,3	30—43	4,4	4—5	7,5	7—10
A. pratensis	5	31	34,1	20—48	4,4	3—5	5,9	3— 9
Anthoxanthum odoratum	5	45	39,3	28—54	4,0	3—6	6,5	3— 8
Avena sativa	4	21	40,3	28—57	4,5	3—6	6,4	3— 8
Bromus inermis	2	11	35,8	30—46	5,1	4—6	7,0	7— 7
Calamagrostis arundinacea	11	92	39,2	22—62	4,4	3—7	6,9	5—12
C. canescens	2	14	44,6	36—62	3,9	3—5	6,4	3— 9
C. epigeios	23	181	41,7	22—67	4,4	3—8	6,8	3—13
C. lapponica	1	7	33,6	28—42	4,6	4—5	—	5— 7
C. pupurea	7	128	45,4	28—71	4,2	3—6	6,0	5—11
Dactylis glomerata	26	119	35,9	18—60	4,3	3—8	6,2	3— 9
Deschampsia caespitosa	12	76	42,4	28—63	4,5	3—6	7,1	4—11
D. flexuosa	3	25	42,3	30—62	4,4	3—6	6,9	5— 8
Elymus arenarius	2	20	39,4	28—68	4,5	4—5	7,1	7— 9
Festuca ovina	4	33	32,1	24—42	3,6	2—5	6,7	5— 9
F. pratensis	21	134	40,0	22—64	4,0	3—6	6,7	3— 9
F. rubra	31	240	40,6	20—59	4,2	3—7	7,2	3—11
Glyceria fluitans	3	12	46,8	34—57	4,2	4—5	8,8	7—14
Hierochloë australis	4	25	38,8	27—48	4,9	4—6	6,7	4— 7
H. odorata	3	30	34,4	23—55	4,3	3—6	6,1	4— 7
Hordeum vulgare	20	64	44,8	26—78	4,8	4—8	6,7	3— 8
Melica nutans	1	10	49,7	40—60	4,5	4—5	7,0	6— 8
Milium effusum	4	35	33,5	26—40	4,4	3—7	5,3	3— 7
Molinia coerulea	3	30	45,7	29—64	4,1	4—5	6,3	4— 8
Nardus stricta	1	10	29,2	25—34	3,3	—	4,3	3— 6
Phalaris arundinacea	7	62	45,6	34—59	4,7	3—8	7,0	3—11
Phleum pratense	17	119	39,7	30—55	4,8	3—8	6,5	3— 8
Phragmites communis	5	86	44,2	31—55	4,8	4—6	6,6	3— 9
Poa nemoralis	1	10	41,7	34—48	4,4	4—5	7,0	6— 7
P. palustris	2	18	37,6	30—50	4,3	4—6	7,0	6— 7
P. pratensis	5	45	38,1	30—58	4,3	3—5	7,2	5—10
Secale cereale	10	56	42,1	28—63	4,5	3—6	6,7	4—12
Triticum aestivum	12	69	38,7	27—63	4,2	2—7	6,6	3— 8
Total	344	2 555		18—78		2—8		3—14
Mean			40,0		4,4		6,7	

In the present study the fungus was found to be very common, occurring on 39 grass species in 60 localities all over the country (Fig. 1). It was found fairly commonly on cereals in 42 localities in southern and central Finland. It occurred on 7,6 % of all the grass samples and on 2,5 %, or more infrequently, of the cereal samples, with the exception of spring wheat (5,9 %) (Table 7). It was observed many times on *Agropyron*, *Agrostis*, *Calamagrostis*, *Poa species*, *Deschampsia caespitosa* and *Festuca rubra*. The collections were made between April 4 and November 24 (January 1), mostly in July and August, from the dry parts of living leaves or dry leaves, sheaths or culms. Pycnidia 50—170 µm, mostly 125 µm in diam., thin-walled (Figs. 2, 10). Conidia pale brown in mass, hyaline when young, later yellow-yellowish brown, cylindrical, straight or curved, flattened on one side, tapering towards a pointed apex (Figs. 2, 10), (18—) 29,2—49,7 (—78) × (2—) 3,3—5,1 (—8) µm, (3—) 4,3—8,8 (—14) septate, usually 39,5 × 4,4 µm, 7 septate, the size varying according to the host (Table 1).

According to SPRAGUE (1950) the conidia are 28—40 × 3,8—4,4 µm in size, typically are 7 septate, and the pycnidia are very large, 180—300 µm. In Norwegian material, on 22 different *Graminae* species, the conidia varied

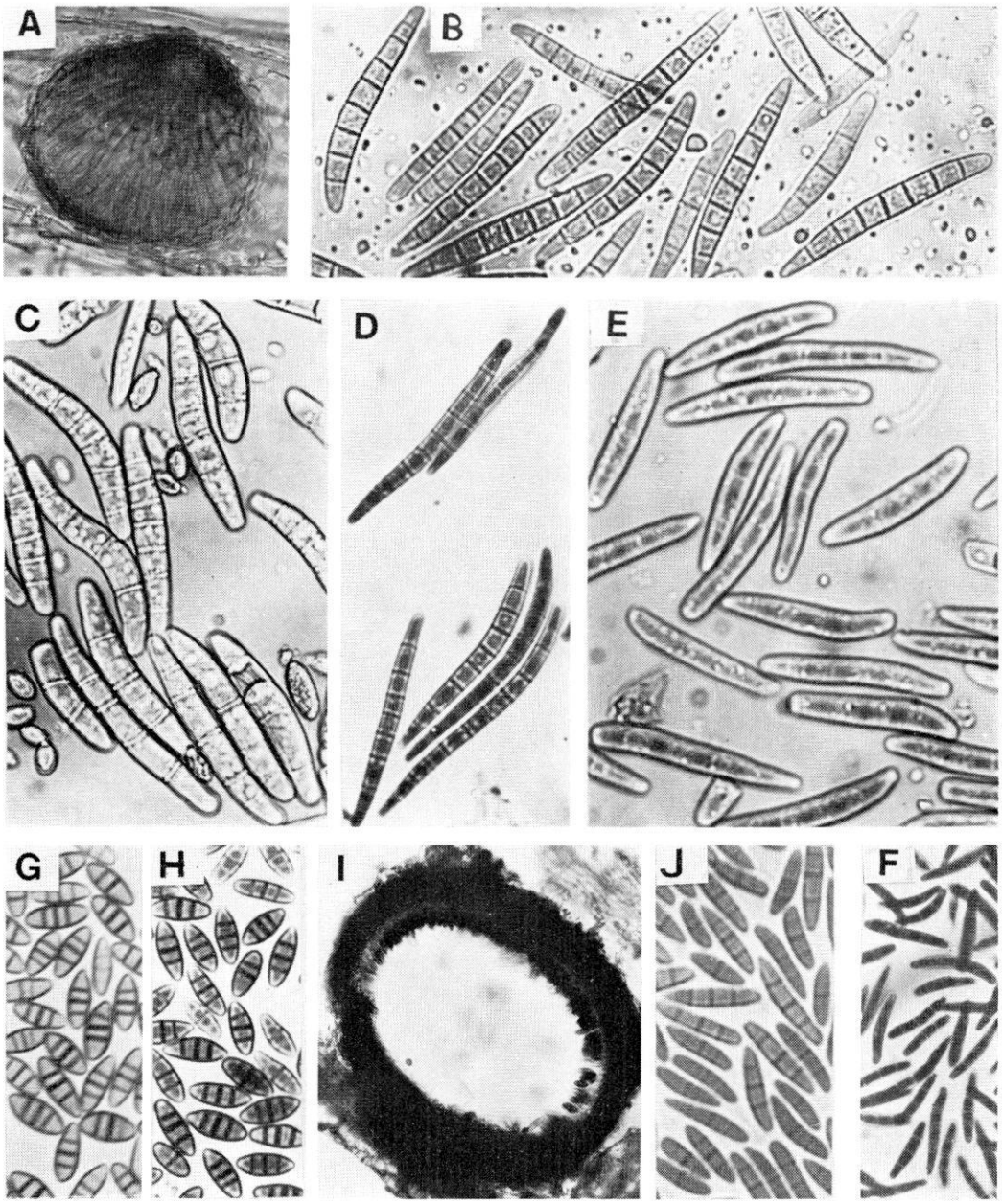

Fig. 2. Pycnidia and conidia. — A—D *Hendersonia crastophila*, A on *Calamagrostis lapponica*, B on *C. epigeios*, C on *Triticum aestivum*, D on *Agrostis tenuis*, E, F *H. culmicola*, E on *Deschampsia caespitosa*, F on *Festuca pratensis*, G—I *H. phragmites* on *Phragmites communis*, J *H. simplex* on *Dactylis glomerata*

Material: A: Kn. Paltamo 9. VIII. 1973 (H.K.); B: St. Kokemäki 21. VIII. 1972 (H.K.); C: U. Elimäki 21. X. 1975 (J. Kurtto); D: EP. Teuva 19. VIII. 1972 (H.K.); E: U. Vantaa 28. V. 1972 (H.K.); F: InL. Inari 31. VII. 1968 (K.M.); G: PH. Karstula 29. VI. 1973 (H.K.); H, I: St. Mellilä 1. VI. 1972 (J. Kurtto); J: U. Helsinki 31. V. 1972. (K. M.). A, I: X 200, B, C, E: X 1 000, D. J: X 750, F, G, H: X 500.

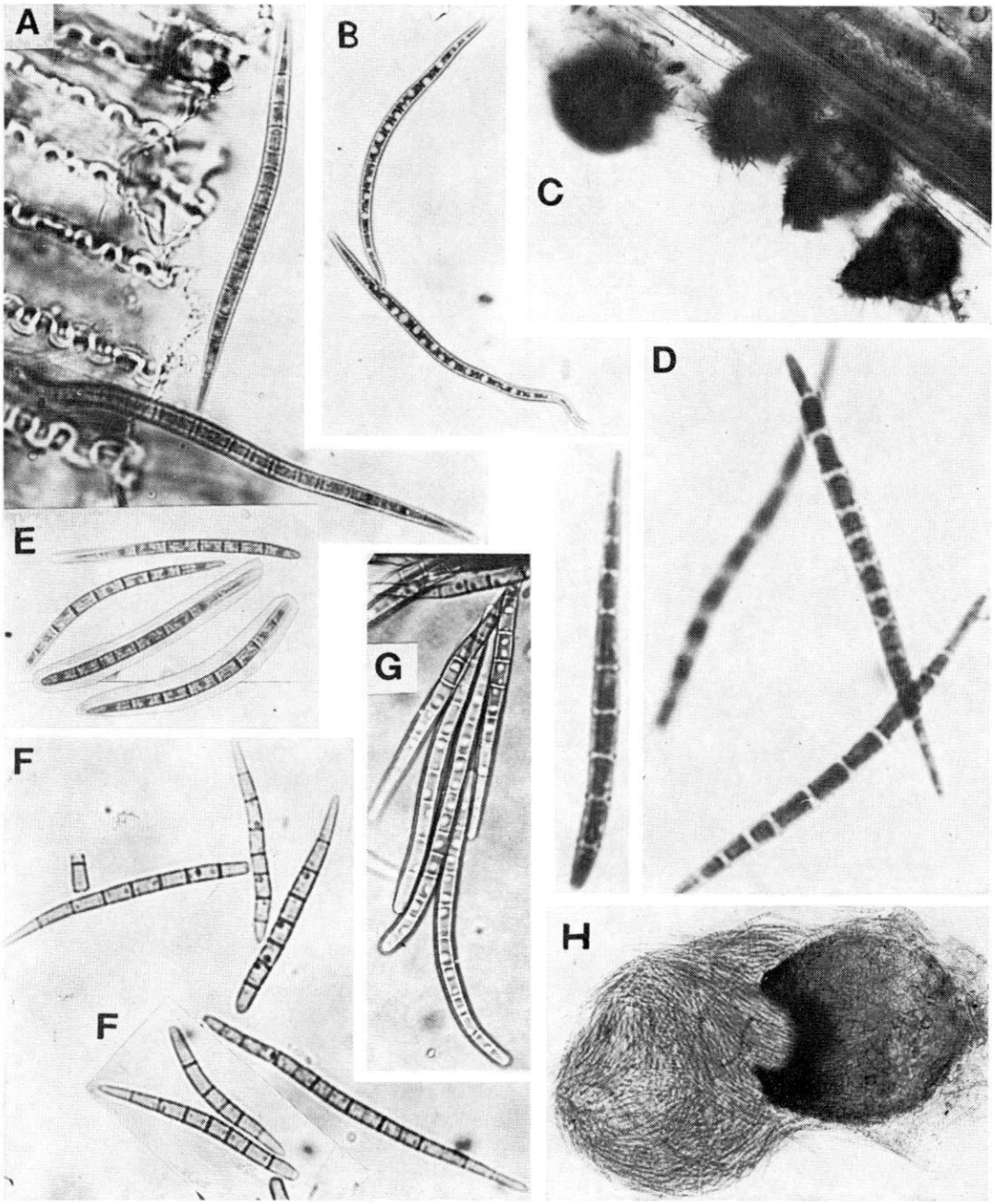

Fig. 5. Pycnidia and conidia. — A, B *Phaeoseptoria airae* on *Deschampsia caespitosa*, C—H *P. festucae*, C, F on *Triticum aestivum*, D, G, H on *Hordeum vulgare*, E on *Festuca rubra*

Material: A: EP. Närpiö 19. VIII. 1972 (H.K.); B: EH. Humppila 16. VIII. 1972 (P.A.); C: V. Pusula 18. VII. 1972 (J. Kurtto); D: U. Artjärvi 18. VIII. 1971 (J. Kurtto); E: KP. Kaustinen 17. VIII. 1972 (H.K.); F: U. Kirkkonummi 18. VII. 1972 (J. Kurtto); G, H: U. Vehmaa. A, D, G: X 1 000, B, E, F: X 750, C: X 100, H: X 200.

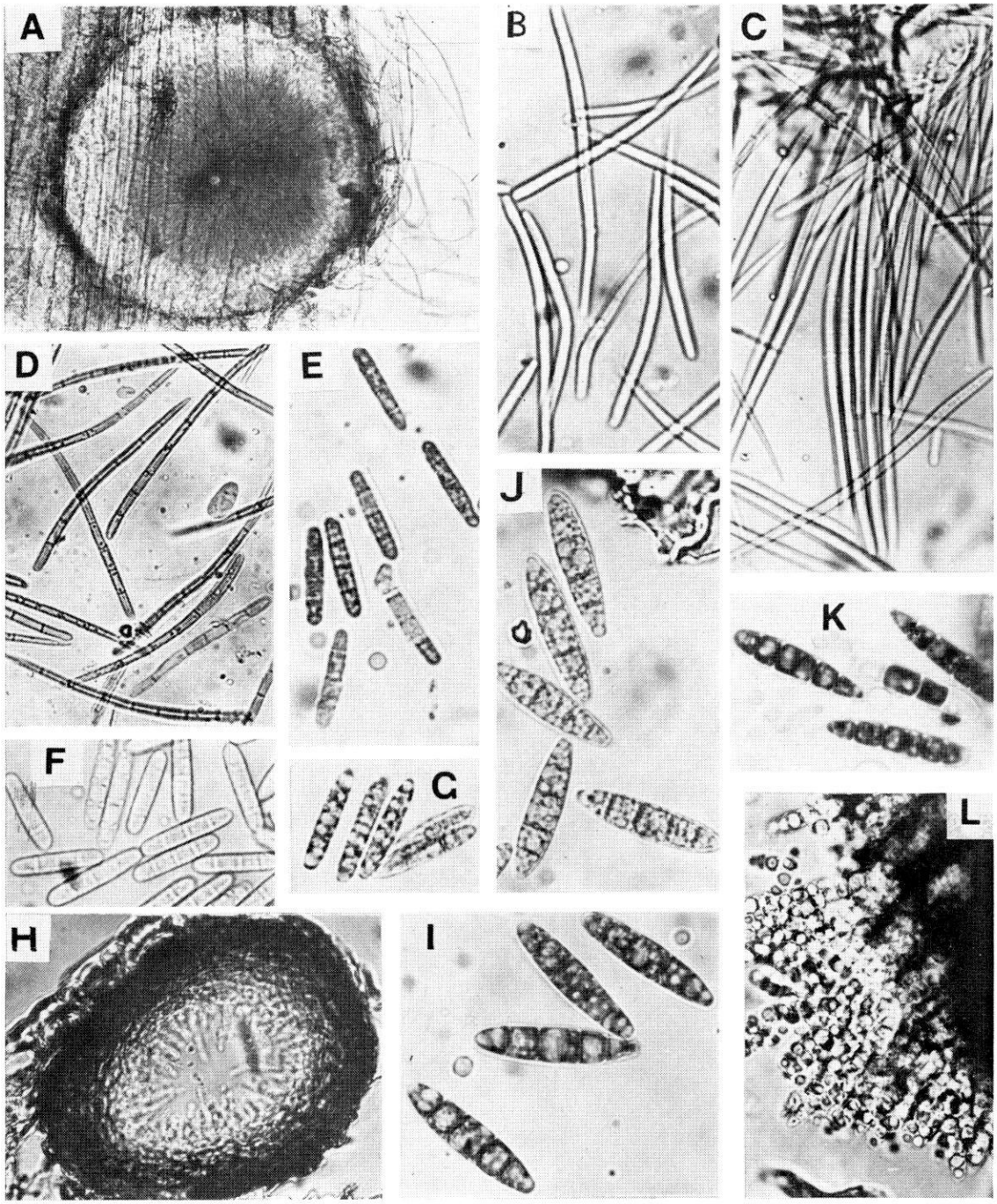

Fig. 8. Pycnidia and conidia. — A—D *Phaeoseptoria poae*, A, B on *Festuca rubra*, C on *Deschampsia caespitosa*, D on *Poa pratensis*, E—H *Stagonospora smolandica*, E on *Festuca ovina*, F—H on *Deschampsia caespitosa*, I—L *S. subseriata*, I, J, L on *Festuca ovina*, K on *Calamagrostis arundinaceae*

Material: A, B: U. Helsinki 19. VII. 1972 (K.M.); C: Kn. Puolanka 9. VIII. 1973 (H.K.); D: U. Tuusula 29. V. 1970 (K.M.); E: ES. Ristiina 11. IX. 1972 (H.K.); F: U. Helsinki 2. VIII. 1972 (H.K.); G, H: U. Helsinki 8. VIII. 1972 (H.K.); I: St. Merikarvia 13. VIII. 1972 (H.K.); J: EP. Vöyri 17. VIII. 1972 (H.K.); K: EH. Forssa 10. V. 1969; L: EH. Ruovesi 23. VII. 1973 (H.K.). A, H: X 200, B—G, I—K: X 1 000, L: 500.

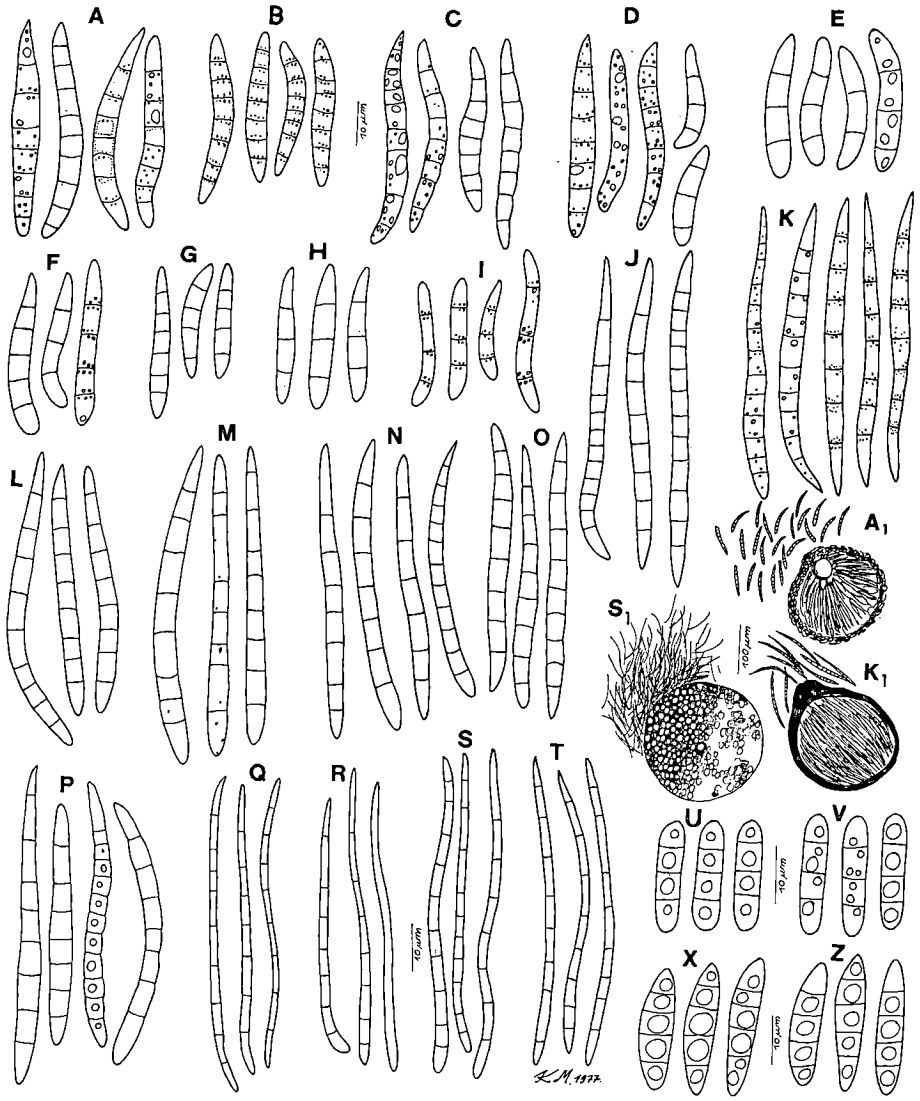

Fig. 10. Pycnidia and conidia. — A, A_1—D *Hendersonia crastophila*, A, A_1 on *Agrostis stolanifera*, B on *Dactylis glomerata*, C on *Festuca rubra*, D on *Phleum pratense*, E—G *H. culmicola*, E on *Agrostis tenuis*, F on *Calamagrostis epigeios*, G on *Poa pratensis*, H, I *H. simplex*, H on *Alopecurus pratensis*, I on *Festuca rubra*, J, K, K_1 *Phaeoseptoria airae*, J on *Deschampsia caespitosa*, K, K_1 on *D. flexuosa*, L—P *P. festucae*, L on *Agrostis tenuis*, M on *Poa pratensis*, N on *Festuca rubra*, O on *Triticum aestivum*, P on *Hordeum vulgare*, Q—S, S_1, T *Phaeseptoria poae*, Q on *Dactylis glomerata*, R on *Festuca rubra*, S, S_1 on *Poa pratensis*, T on *Phleum pratense*, U, V *Stagonospora smolamdica*, U on *Festuca pratensis*, V on *Agrostis tenuis*, X, Z *S. subseriata*, X on *Festuca ovina*, Z on *Molinia coerulea*.

Material: A, A_1: U. Helsinki 10. XI. 1967 (K.M.); B: U. Helsinki 30. VIII. 1966 (K.M.); C: EH. Asikkala 22. IX. 1966; D: InL. Inari 1. IX. 1968 (E. Metsäpelto); E, F, G: U. Helsinki 2. VIII. 1972 (H.K.); H: EH. Asikkala 15. VI. 1972 (J. Kurtto); I: InL. Inari 1. IX. 1968 (E. Metsäpelto); J: PK. Kiihtelysvaara 11. VIII. 1973 (K.M.); K, K_1: EP. Vöyri 17. VIII. 1972 (H.K.); L: Kn. Suomussalmi 9. VIII. 1973 (K.M.); M: EH. Urjala 7. VIII. 1972 (P.A.); N: KP. Pyhäjärvi 22. IX. 1966; O: St. Kiikka 8. VIII. 1973 (A. Kurppa); P: PH. Keitele 16. VII. 1972 (P. Heinänen); Q; EH. Hämeenlinna 14. V. 1967 (K.M.); R: InL. Inari 28. VI. 1968 (K.M.); S, S_1: KP. Veteli 23. IX. 1966; T: U. Helsinki 11. V. 1967 (K.M.); U: PK. Liperi 11. VIII. 1973 (K.M.); V: EP. Kauhava 15. VIII. 1972 (H.K.); X: EH. Merikarvia 13. VIII. 1972 (H.K.); Z: Kn. Paltamo 10. VIII. 1973 (H.K.).

between 19—67 × 2,5—6 µm, were 7 (9—12) septate, and the pycnidia measured 60—180 µm (JORSTAD 1967). In the present study the size of the conidia varied more than in the above mentioned studies.

Material examined

Agropyron caninum St, EH, EP. *A. repens* V, U, St, EH, ES, EP, PH, KP, Kn, PP. *Agrostis stolanifera* U, St, Kn, PP. *A. tenuis* A, V, U, St, EH, ES, EP, PH, PS, KP, PP, Kn, KemL, InL. *Agrostis sp.* U, EH. *Alopecurus geniculatus* U, KP. *A. pratensis* V, U, St, EH, ES, Kn, InL. *Anthoxanthum odoratum* U, EH, ES, EP, Kn. *Avena sativa* U, EH, PS, InL. *Bromus inermis* U. *Calamagrostis arundinacea* U, EH, PS. *C. canescens* EH, Kn. *C. epigeios* U, St, EH, ES, EP, PP. *C. lapponica* Kn. *C. purpurea* U, ES, EP, PH, KP. *Calamagrostis* sp. U, EH, PK. *Dactylis glomerata* V, U, EH. *Deschampsia caespitosa* V, U, St, EH, ES, EP, PH, PS, PK, KP, PP, Kn, Ks, EnL, KemL. *D. flexuosa* St, Kn. *Elymus arenarius* KP. *Festuca ovina* U, ES, EP, PH, KP. *F. pratensis* V, U, EH, ES, PK, PP, Ks, KemL, InL. *F. rubra* A, U, EK, St, EH, ES, EP, PH, PK, KP, PP, KemL, InL. *Glyceria fluitans* EP. *Hierochloë australis* U. *H. odorata* ES. *Holcus* sp. U. *Hordeum vulgare* V, U, St, EK, EH, ES, EP, PH. *Melica nutans* EH. *Milium*

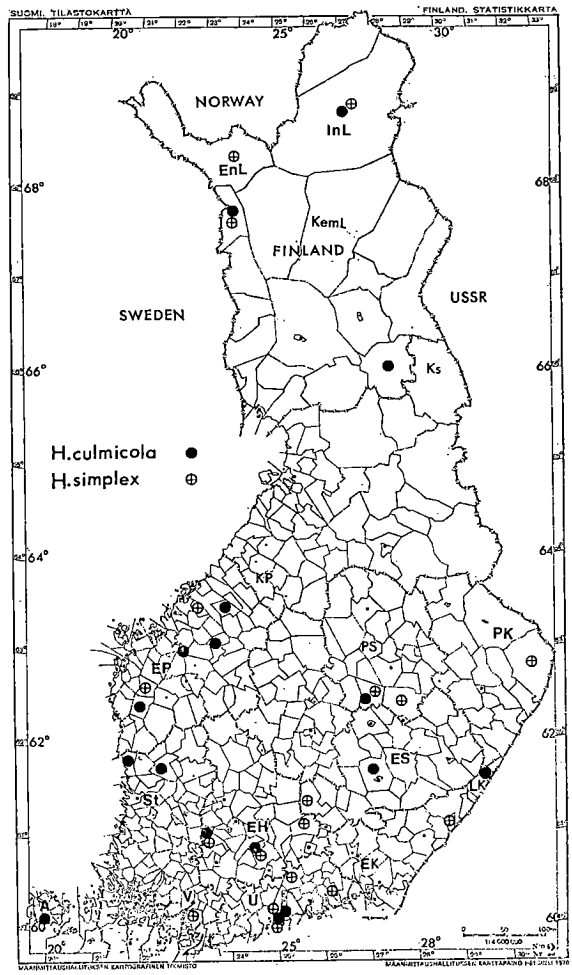

Fig. 3. Occurrence of *Hendersonia culmicola* and *H. simplex* on grasses in Finland.

Table 2. Size of conidia of *Hendersonia culmicola*

Hosts	No. of isolates measured	No. of conidia measured	Length µm mean	Length µm range	Width µm mean	Width µm range	No. of septa mean	No. of septa range
Agrostis tenuis	7	53	27,0	18—37	3,7	3—4,5	3,8	3—6
Alopecurus prantensis	4	18	35,8	26—42	2,6	2—3	—	3—7
Dactylis glomerata	3	30	21,3	16—31	3,2	3—4	3,7	3—7
Festuca ovina	3	34	26,2	21—34	3,1	2—4	3,5	2—6
F. pratensis	4	36	24,8	12—38	3,3	2—4	2,7	1—5
F. rubra	3	26	25,4	16—40	3,1	3—4	3,9	1—7
Lolium perenne	3	29	26,3	16—40	4,0	4—5	5,7	3—7
Phalaris arundinacea	3	25	29,3	20—38	3,1	3—4	4,1	3—7
Poa pratensis	3	25	28,8	20—38	3,1	3—4	4,5	3—7
Total	33	276		12—42		2—4,5		1—7
Mean			27,2		3,2		4,0	

effusum EH, EnL. *Molinia coerulea* U, Kn. *Nardus stricta* EP. *Phalaris arundinacea* U, EH, ES, EP. *Phleum alpinum* Kn. *P. nodorum* EP. *P. pratense* U, St, EH, PH, PS, KP, InL. *Phragmites communis* U, EH. *Poa nemoralis* U. *P. palustris* U, EH. *P. pratensis* A, U, St, EH, LK, PH, PK, KemL, InL. *Secale cereale* V, U, St, EH, ES. *Triticum aestivum* V, U, St, EH, ES, EP, InL (grasses: ca. 350 samples from 117 localities, cereals: ca. 50 samples from 42 localities).

Hendersonia culmicola Saccardo, Michelia 1: 210, 1878; Syll. Fung. III: 437, 1884

Reported in Norway on about 15 grass species throughout the country, e.g. on *Agrostis tenuis*, *Dactylis glomerata*, *Deschampsia caespitosa*, *Festuca pratensis*, *Phlem pratense* and *Poa pratensis* (JORSTAD 1967, ÅRSVOLL 1975). Common in Great Britain on many grasses, but variation very wide (GROVE 1937). Also collected on about 25 grass species in the USA (SPRAGUE 1950).

In this study the fungus was found very infrequently, i.e on 9 grass species in 16 localities throughout the country (Fig. 3). The sasples were collected between June 15 and November 8, mostly in August. The species occurred on 0,5 % of all the grass sasples, but was not found on cereals Table 7). Observed e.g. on *Agrostis tenuis*, *Festuca* species and *Poa pratensis*.

Pycnidia 60—220 μm in diam. Conidia pale brown in mass, hyaline when young, later yellowish brown, cylindrical, straight or curved with rounded or pointed apex (Figs. 2, 10) (12—) 21,3—35,8 (—42) × (2—) 2,6—4,0 (4,5) μm, (1—) 2,7—5,7 (—7) septate, mostly 27,2 × 3,1 μm, 4 septate (Table 2).

According to SPRAGUE (1950) the conidia are 17—35 × 1,9—4,6 μm in size, are 0—7 septate, and the pycnidia measure 100—185 μm. In Norwegian material on different hosts the size of the conidia varied between 14—41 × 2—4 μm, were usually 3 septate out up to 7 septate, and the pycnidia were 90—200 μm, in diam. (JORSTAD 1967).

Material examined

Agrostis tenuis EH, ES, PS, Ks, InL. *Alopecurus pratensis* U, EH. *Dactylis glomerata* U. *Festuca ovina* EP, KP. *F. pratensis* U, ES. *F. rubra* St, EP. *Lolium perenne* U. *Phalaris arundenacea* St. *Poa pratensis* U, St, LK, KemL. (22 samples from 16 localities).

Hendersonia phragmites Desm., Ann. Sci. Nat. Ser. 3,20: 224, 1853. Saccardo Syll. Fung. III: 437, 1884

Reported on *Phragmites communis* in France (SACCARDO 1884). Also found in Norway on *Elymus arenarius* and *Glyceria maxima* (JORSTAD 1967).

In this study the species was found accidentally on three specimens of *Phragmites communis* in three localities (Table 7). Pycnidia black, thickwalled, 80—120 μm in diam. Conidia ovate, yellow-brown or red-brown, in mass black-brown (Fig. 2), (10—) 17,3 (—26) × (5—) 5,9 (—8) μm, (2—) 3 (—4) septa.

The original description gives the size of the conidia as 15—20 × c 7 μm, they are 3 septate and the pycnidia are 170 μm (SACCARDO 1884). In JORSTAD's (1967) collections the conidia were 9—35 × 3—6,5 μm, 1—3 (—7) septate, ranging very widely between different specimens.

Material examined

Phragmites communis St. Mellilä 1. VI. 1972 (J. Kurtto; PH. Karstula 29. VI. 1973 (H.K.), Kivijärvi 30. VI. 1973 (H.K.).

Table 3. Size of conidia of *Hendersonia simplex*

Hosts	No. of isolates measured	No. of conidia measured	Length µm mean	Length µm range	Width µm mean	Width µm range	No. of septa mean	No. of septa range
Agropyron repens	2	15	18,2	12—24	3,7	3—4	3	3—3
Agrostis sp.	1	10	18,2	15—21	3,7	3—4	3	3—3
Alopecurus pratensis	2	8	16,8	14—20	2,9	2—4	3	3—3
Calamagrostis sp.	2	66	18,8	13—22	3,9	3—4	3	3—3
C. arundinacea	6	36	20,4	14—28	3,4	3—4	3	3—3
C. epigeios	2	20	20,4	18—24	3,6	3—4	3	3—3
C. purpurea	1	8	23,8	20—28	3,6	3—4	3	3—3
Dactylis glomerata	1	20	19,1	16—21	3,9	3—4	3	2—3
Deschampsia caespitosa	1	10	16,7	15—18	3,2	3—4	3	3—3
Festuca ovina	2	17	20,7	18—27	3,6	1—4,5	3	3—3
F. rubra	2	26	16,4	12—22	3,0	2—4	2,9	1—3
Total	22	236		12—28		1—4,5		1—3
Mean			19,0		3,5		3,0	

Hendersonia simplex Scroeter. Jahr. — Berl. Schles. Ges. Vaterl. Cultur, 58 (1880): 177. Syn. *Septoria simplex* (Schroet.) Sacc. Syll. Fg., III: 560, 1884

Described orignally on *Melica nutans* in Sweden. (SCHROETER 1880). Recorded in Norway on 17 grasses, including *Agropyron*, *Agrostis*, *Festuca* and *Poa* species (JØRSTAD 1967). According to SPRAGUE (1950), *H. simplex* is synonymous with *H. culmorum*. ÅRSVOLL (1975) agrees with him, whilst JØRSTAD (1967) prefers to reckon them as separate species for the time being, though it is not always possible to differentiate between them clearly.

In this study the species was found to be very uncommon, occurring on 10 grass species in 18 localities throughout the country (Fig. 3) between May 1 and September 9. It occurred on 0,5 % of all the grass samples, but was not found on the cereals (Table 7). Observed e.g. on *Calamagrostis* species.

Pycnidia 90—300 µm in diam. Conidia brownish in mass, hyaline when young, later yellow, straight or curved, with rounded or pointed apex (Figs. 2, 10), (12—) 16,4—23,8 (—28) × (1—) 29—3,9 (—4,5) µm, (1) 3 septate, mostly 19 × 3,5 µm, 3 septate (Table 3).

In the present study the conidia were broader and the pycnidia larger than in JØRSTAD's (1967) material, in which the

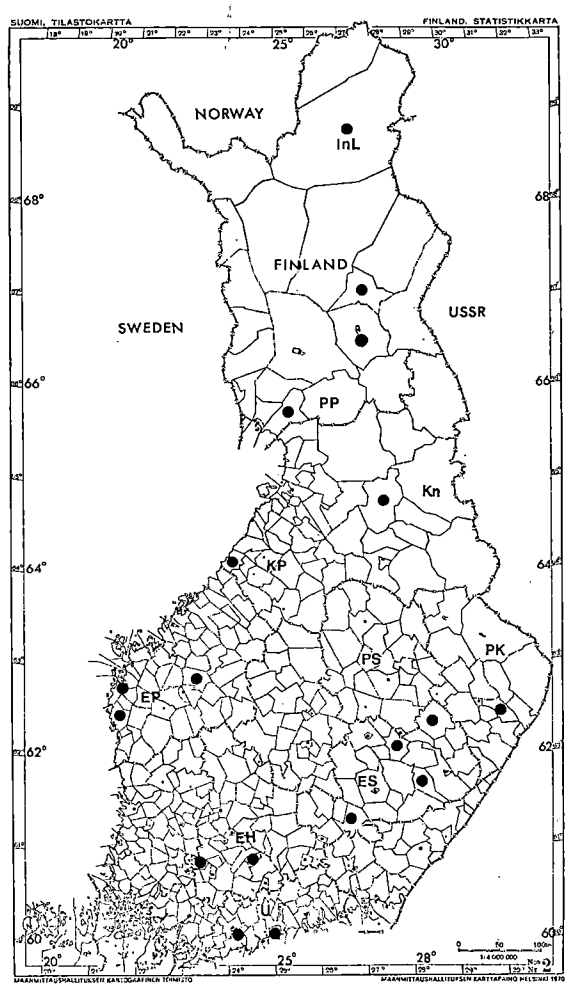

Fig. 4. Occurrence of *Phaeoseptoria airae* on grasses in Finland.

conidia varied between 11—35 × 2—3,5 μm, with 1—3 septate and the pycnidia measuring 80—200 μm in diam.

Material examined

Agropyron repens V, EK. *Agrostis* sp. U. *Alopecurus pratensis* InL. *Calamagrostis* sp. EH, PK. *C. arundinacea* U, EH, PS. *C. epigeios* EH, PK. *C. purpurea* KP. *Dactylis glomerata* U. *Deschampsia caespitosa* U. *Featuca ovina* KemL, EnL. *F. rubra* U, EP (ca. 20 samples from 18 localities).

Phaeoseptoria airae (Grove) Sprague, Mycologia 35: 485, 1943. Syn. *Septoria alopecuri* Syd. Var. Airae Grove, Brit. Stem -a. Leaf — Fungi 1: 425, 1935

Reported on *Deschampsia caespitosa* in England (Grove 1935), in Norway (Jørstad 1967) and in the USA (Sprague 1943). According to Webster (1956) this fungus in cultures isolated conidia from *D. caespitosa* yielded perithecia of *Leptosphaeria microscopica* Karst.

In the present study it was found on two grasses, and was most common throughout the country on *Deschampsia caespitosa* (Fig. 4, Table 7), between May 11 and August 11.

Pycnidia 150—210 μm in diam (Fig. 10). Conidia filiform-fusoid, mostly flexuous, tapering towards an acute apex, brown in mass, hyaline or yellow when viewed singly (Figs. 5, 10), measuring (32—) 62,1 (—89) × (3) 3,7 (—4) μm, (5—) 9,2 (—17) septate on *D. caespitosa* and (70—) 74,7 (—80) × (4—) 4,1 (—5) μm, (4—) 7,1 (—9) septate on *D. flexuosa*.

In the original description the conidia are 60—75 × 2,5—3 μm in size, faintly pseudoseptata (Grove 1935), and in Jørstad's (1967) material 42—100 × 3,5—4,5 μm, with the septa mostly obscure, but up to 13 seen.

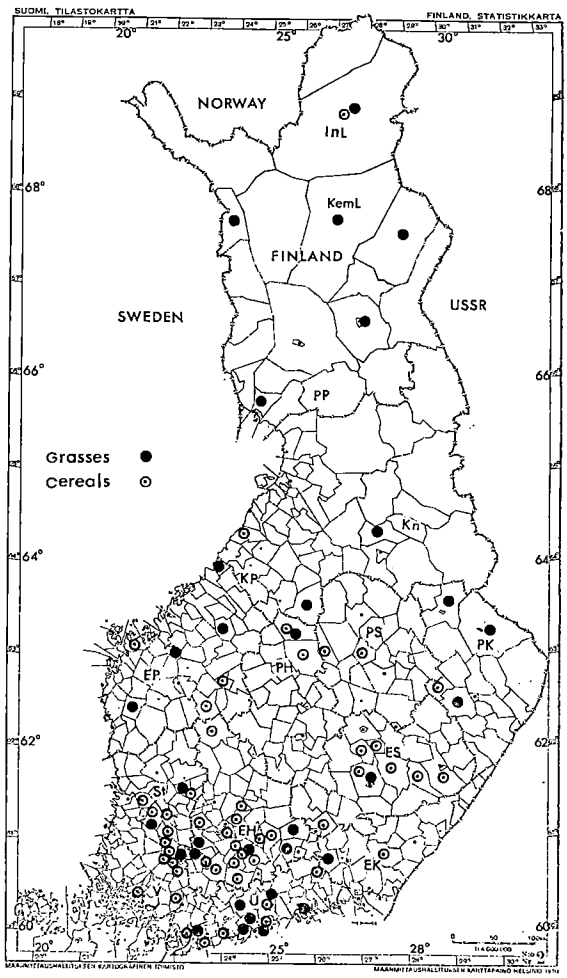

Fig. 6. Occurrence of *Phaeoseptoria festucae* on grasses and cereals in Finland

Material examined

Deschampsia caespitosa U. Helsinki 11. V. 1967 (K.M.), Siuntio 24. V. 1972 (K.M.); EH. Humppila 16. VIII. (P.A.), Hämeenlinna 15. IX. 1968 (K.M.); ES. Mäntyharju 9. IX. 1972 (H.K.), Sulkava 24. VII. 1972 (H.K.); EP. Lapua 31. VII. 1970 (P.A.), Närpiö 19. VIII. 1972 (H.K.), Petolahti 18. VIII. 1972 (H.K.); PS. Heinävesi 5. VII. 1972 (H.K.), Joroinen 5. VII. 1972 (H.K.); PK. Puolanka 8. VIII. 1973 (H.K.); PP. Kemijärvi 7. VIII. 1973 (H.K.), Simo 5. VIII. 1973 (H.K.); KemL. Pelkosenniemi 20. VII. 1970 (P. Ilonoja); InL. Inari (2 specimens) 13. VI. 1969 (Arvi Salo-

Table 4. Size of conidia of *Phaeoseptoria festucae*

Hosts	No. of isolates measured	No. of conidia measured	Length µm mean	Length µm range	Width µm mean	Width µm range	No. of septa mean	No. of septa range
Agropyron repens	3	12	58,2	43—72	3,3	2—6	8,7	8—13
Agrostis tenuis	5	30	62,5	50—84	3,3	2—6	9,1	7—11
Alopecurus pratensis	1	10	72,2	58—80	4,0	—	14,6	11—17
Anthoxanthum odoratum	1	20	54,0	50—66	4,1	4—5	10,0	7—11
Dactylis glomerata	7	77	61,0	44—98	3,4	2—5	7,1	5—13
Festuca pratensis	2	12	59,0	52—64	3,3	2—4	6,5	6— 7
F. rubra	8	75	60,5	42—82	4,1	3—6	8,3	3—13
Hordeum vulgare	31	206	64,6	36—96	4,3	2—6	8,3	4—13
Secale cereale	15	40	61,8	43—95	4,3	2—6	8,7	5—15
Triticum aestivum	16	62	66,9	42—89	4,6	3—6	8,8	6—15
Total	89	544		36—98		2—6		3—17
Mean			62,0		3,9		9,0	

nen), 14. VII. 1969 (K.M.). *D. flexuosa* Kn. Puolanka 8. VIII. 1973 (H.K.).

Phaeoseptoria festucae, Sprague, Mycologia 35: 487, 1943

Described on *Festuca rubra* in the USA (SPRAGUE 1943a). Found in Norway on *Agropyron repens, Agrostis stolonifera* and *Triticum aestivum* (JØRSTAD 1967). According to WEBSTER (1955) the perfect stage is *Leptosphaeria microscopica* Karst.; the fungus occur on many grass species in Great Britain.

In this study the fungus was found to be rare but moderately common on 12 grass species in 33 localities throughout the country, and also on three cereals in 52 localities in southern and central parts of Finland (Fig. 6). Found in 1,1 % of all the grass samples e.g. *Festuca rubra, Deschampsia caespitosa, Agrostis tenuis, Dactylis glomerata* and *Poa pratensis,* being more common on cereals (3,1 %) particularly on spring wheat (7,2 %), but not on oats (Table 7). The samples were collected between April 13 and November 10 (January 13), mostly in July and August.

Pycnidia (50—) 130 × 160 (—280) µm in diam, brown or black (Fig. 5). Conidia obclavate-filiform, mostly flexuous, apices acuta, black in mass, yellow or pale brown when viewed singly (Figs. 5, 10), measuring (36—) 54,0—72,2 (—98) × (2—) 3,3—4,6 (—6) µm (3—), 8,3—14,6 (—17) septate, mostly 62,0 × 3,9 µm 9 septate (Table 4).

On the original specimen the size of the conidia is 50—85 × 2,8—4,8 µm, with 8—11 septa and pycnidia 55—100 µm in diam. (SPRAGUE 1943). According to JØRSTAD (1967) the size of the fungus varies very much, and on *Triticum aestivum* the conidia are 32 × 80 × 3—4,5 µm, with 3—9 septa and pycnidia 110—210 µm in diam.

Material examined

Agropyron repens U, EH. *Agrostis borealis* KemL. *A. tenuis* U, Kn. *Alopecurus pratensis* U, St. *Anthoxanthum odoratum* ES. *Dactylis glomerata* U, EH, InL. *Deschampsia caespitosa* U, EH, InL. *D. flexuosa* EP. *F. ovina* St. *F. pratensis* U, EH, PK, InL. *F. rubra* V, U, St, EH, EP, PK, KP, PP, KemL. *Hordeum vulgare* V, U, EK, St, EH, ES, EP, PH, PS, PK, KP, InL. *Poa pratensis* EH, PH, InL. *Secale cereale* V, U, St, EH, ES, EP, PH. *Triticum aestivum* V, U, St, EH, ES, KP, PS (grasses: ca 50 samples from 33 localities, cereals: 65 samples from 50 localities).

Phaeoseptoria poae Sprague, Mycologia 40: 190, 1948

Described on *Poa canbyi* in the USA (SPRAGUE 1948). Reported on *Deschampsia caespitosa, D. flexuosa, Festuca arundinacea* and *Poa nemoralis*

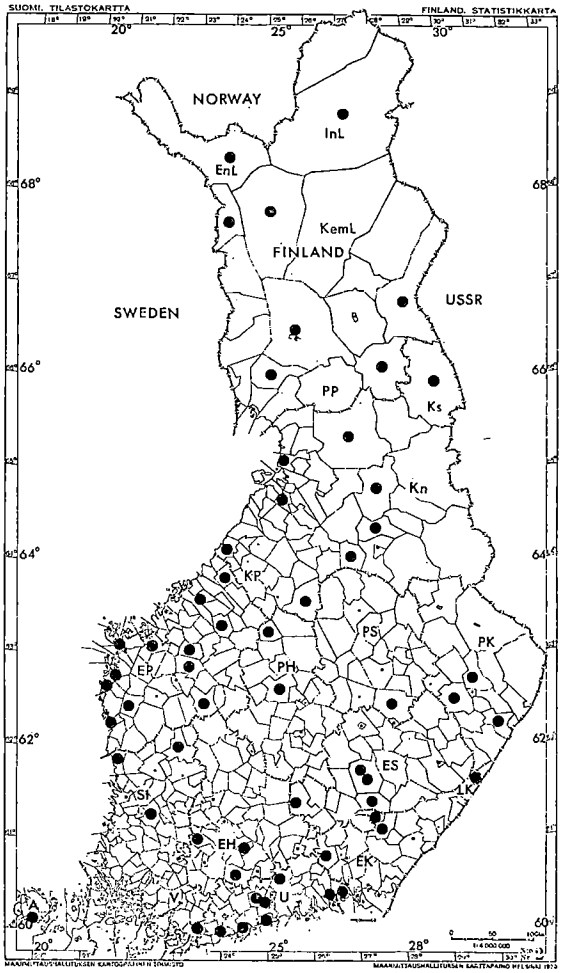

Fig. 7. Occurrence of *Phaeoseptoria poae* on grasses in Finland.

in Norway (JORSTAD 1967). In Finland found on *Poa pratensis* (MÄKELÄ 1972).

In this study the fungus was found to be moderately common on 20 grass species collected in 60 localities throughout the country (Fig. 7) between April 3 and November 24, mostly in July and August. It occurred on 3,5 % of all the grass samples, but was not found on the cereals (Table 7). Observed to be common on *Poa annua* and *P. pratensis;* also occuring many times on *Festuca rubra*, *Deschampsia*, *Calamagrostis* and *Alopecurus* species (Table 7).

Pycnidia brown, globose, 110—240, mostly 170 μm in diam. (Figs. 8, 10). Conidia hyaline to light yellow, in mass golden brown, straight or flexuous, tapering towards a pointed apex (Figs. 8, 10); (21—) 50,6—67,0 (—91) × (1,5—) 1,9—2,9 (—5) μm, (3—) 6,5—8,1 (—12) septa, mostly 55,6 × 2,3 μm, 7 septa (Table 5).

According to SPRAGUE (1950), the conidia measure 50—77 × 2,1—2,4 μm. In Norwegian material on different grass species the size of the conidia varied between 31—90 × 2—3,5 μm; the septa were often obscure, up to 10 in number, mostly 7 or 8 (JORSTAD 1967).

Material examined

Agrostis tenuis A, EH, ES, EP. *Alopecurus geniculatus* InL. *A. pratensis* EH, InL. *Anthoxanthum odoratum* U, LK. *Calamagrostis arundinacea* U, EH. *C. epigeios* St, EH, EP. *Calamagrostis* sp.: U, ES, PH. *Dactylis glomerata* U, EH, ES, EP, KP, Kn, PP, InL. *Deschampsia caespitosa* U, EH, EP, KP, Kn, EnL, InL. *D. flexuosa* St, EH, ES, EP, KP, PS, Kn, Ks, KemL, InL. *Deschampsia* sp. U. *Elymus arenarius* KP. *Festuca ovina* InL. *F. pratensis* U, EH, PP, KemL, InL. *F. rubra* U, St, EH, Es, LK, EP, PK, KP, PP, KemL, InL. *Lolium multiflorum* U, InL. *L. perenne* U, ES, InL. *Phleum pratense* U, EH, ES, InL. *Poa alpina* U, *P. annua* U, ES, EP, KP, PK, Ks, InL. *P. compressa* V, *P. pratensis* U, St, EH, ES, LK, EP, PH, KP, Kn, PP, InL. *Poa* sp. U, ES, PK, Ks (ca. 165 samples from 60 localities).

Stagonospora smolandica Eliasson, Sv. Bot. Tidskr. 9: 410, 1915

Described on *Agrostis tenuis* in Sweden (ELIASSON 1915). Found in Norway on the same grass species (JORSTAD 1967).

In this study the fungus was found very infrequently occurring on 6 grass species in 15 localities throughout the country, but not in northern Finland (Fig. 9). Observed in

Table 5. Size of conidia of *Phaeoseptoria poae*

Hosts	No. of isolates measured	No. of conidia measured	Length µm mean	Length µm range	Width µm mean	Width µm range	No. of septa mean	No. of septa range
Agrostis tenuis	4	27	59,6	44—70	2,3	1,5—3	8,1	7—11
Alopecurus geniculatus	1	16	52,1	37—59	2,3	2—3	7,0	7— 7
A. pratensis	3	39	55,9	30—68	2,4	2—3	7,4	5—11
Anthoxanthum odoratum	1	10	52,3	39—57	1,9	1,5—2	7,0	6— 8
Calamagrostis arundinacea	3	22	55,0	40—70	2,5	2—4	6,5	6— 7
C. epigeios	1	10	53,8	46—62	2,0	2—2	—	—
Dactylis glomerata	9	119	50,6	32—72	2,2	2—4	7,3	4— 9
Deschampsia caespitosa	7	89	51,6	21—85	2,3	2—4	7,6	7— 9
D. flexuosa	13	123	60,9	40—91	2,4	2—3	7,4	6—10
Festuca pratensis	10	101	51,2	28—70	2,6	2—4	6,5	4— 9
F. rubra	6	61	55,7	40—72	2,4	1,5—4	6,8	4— 8
Lolium multiflorum	1	25	67,0	48—82	2,0	2—2	7,3	7— 8
L. perenne	1	17	60,0	36—75	2,9	2—4	7,0	4— 8
Phleum pratense	13	164	55,8	32—78	2,4	2—4	6,8	4—12
Poa annua	1	20	60,5	40—68	2,4	2—3	7,0	7— 8
P. pratensis	27	316	53,2	31—76	2,4	2—5	7,0	5— 8
Total	101	1 159		21—91		1,5—5		3—12
Mean			56,0		2,3		7,5	

0,3 % of all the grass samples, e.g. on *Agrostis tenuis*, *Calamagrostis*, *Deschampsia* and *Festuca* species, but not found on the cereals, (Table 7). Collected between July 5 and August 19, mostly in August.

The pycnidia were 80—175 µm in diam. (Fig. 8). Conidia hyaline, usually with four large guttules, straight, with rounded ends (Figs. 8, 10), (12—) 12,4—21,0 (—23 × (2—) 2,8—4,3 (—6) µm, (1—) 2,1—3,0 (—5) septate, mostly 17,5 × 3,7 µm, 3 septate (Table 6). The fungus was also found on *Nardus stricta* and resembled *S. smolandica* except that the conidia were 2 septate and measured 20—24 × 6—8 µm.

In the original description the size of the conidia is given as 19—22 × 3 µ, and it has 3 septatis (ELIASSON 1915). According to JØRSTAD (1967) the conidia vary between 15—21,5 × 3—3,5 µm, with 3 septa.

Material examined

Agrostis tenuis EH. Urjala 11. VIII. 1972 (H.K.); ES. Juva 19. VIII. 1972 (H.K.); EP. Isojoki 19. VIII. 1972 (H.K.); Leppävirta 11. VIII. 1973 (H.K.); KP. Evijärvi 16. VIII. 1972 (H.K.), Kauhava 15. VIII. 1972 (H.K.; Kn. Paltamo 17. VII. 1972 (H.K.); PP. Pudasjärvi

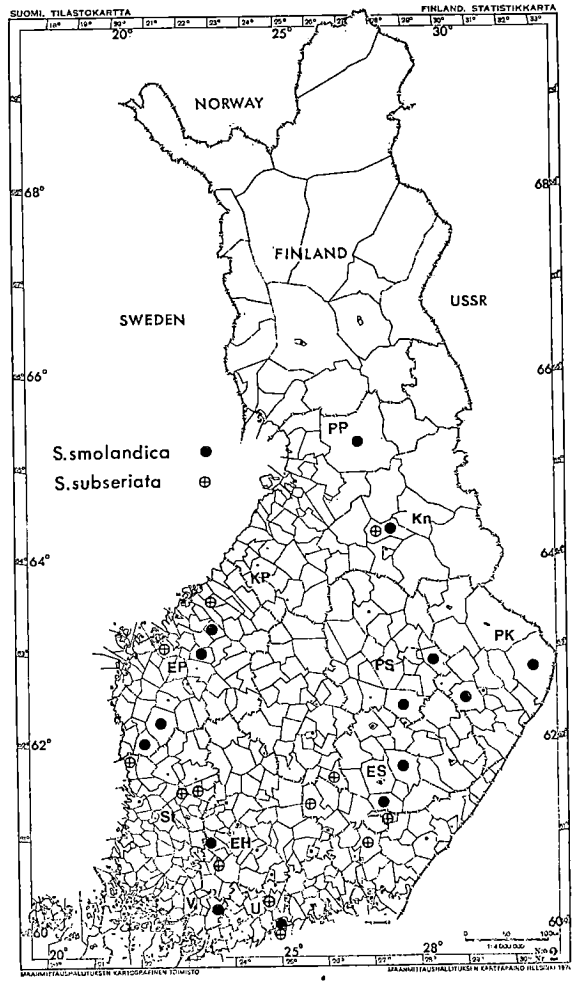

Fig. 9. Occurrence of *Stagonospora smolandica* and *S. subseriata* on grasses in Finland.

Table 6. Size of conidia of *Stagonospora smolandica*

Hosts	No. of isolates measured	No. of conidia measured	Length µm mean	Length µm range	Width µm mean	Width µm range	No. of septa mean	No. of septa range
Agrostis tenuis	8	60	18,2	14—21	4,0	3—6	2,8	2—4
Calamagrostis epigeios	1	5	12,4	12—13	2,8	2—3	3,0	3—3
Deschampsia caespitosa	1	10	21,0	19—23	3,8	3—4	2,1	2—3
D. flexuosa	2	18	16,5	12—21	3,1	2—4	3,0	3—3
Festuca pratensis	1	6	18,2	16—20	4,3	4—5	3,0	3—3
F. rubra	2	25	18,4	16—20	4,0	3—4	3,0	3—3
Total	15	124		12—23		2—6		2—4
Mean			17,5		3,7		2,8	

8. VIII. 1973 (H.K.). *Calamagrostis epigeios* EP. Kauhajoki 19. VIII. 1972 (H.K.). *Calamagrostis* sp.: PK. Ilomantsi 29. VII. 1972 (H.K.). *Deschampsia caespitosa* U. Helsinki 8. VIII. 1972 (H.K.). *D. flexuosa* V. Suomusjärvi 18. VII. 1972 (H.K.); EH. Urjala 10. VIII. 1972 (H.K.); ES. Ristiina 26. V. 1972 (J. Kurtto). *Festuca pratensis* PK. Liperi 11. VIII. 1973 (K.M.). *F. rubra* EH. Urjala 10. VIII. 1972 (H.K.); PS. Heinävesi 5. VII. 1972 (H.K.).

Stagonospora subseriata (Desm.) Saccardo, Syll. Fung. III: 454, 1884. Syn. *Hendersonia subseriata* Desmazieres, Ann. Sci. Nat., Ser. 3,6: 69, 1846

Reported on *Molinia coerulea* in France and also on other grasses in Belgium and Germany (SAGGARDO 1884). Found on dry leaves of grasses, especially *Molinia coerulea* and *Deschampsia caespitosa*, in Britain (GROVE 1935), and also in Norway (JORSTAD 1967). Found in a few places in the USA, e.g. on *Phleum prarense* and *Poa pratensis* (SPRAGUE 1950).

In the present study it was found occasionally, occuring on three grass species in 13 localities in southern and central Finland (Fig. 9). Observed in 0,3 % of all the grass samples, mostly on *Festuca ovina* (Table 7). Collected between May 10 and August 21, mostly in August.

Pycnidia 100—200 µm in diam Conidia hyaline, broad oblong-fusoid, often rounded apex, with guttules (Figs. 8, 10), on *Festuca ovina*, 13 isolates (23—) 27,7 (—32) × (4—) 6,1 (—8) µm, (2—) 3,9 (—5) septate, on *Molinia coerulea*, one isolate (33—) 34,7 (—37) × (8—) 8,5 (—9) µm, 4 septate.

According to SPRAGUE (1950) the size of the conidia is 20—45 × 6—8 µm, it is 3—4 septate, and in GROVE's (1935) material varied between 25—40 × 6—7 µm, with 3—6 septa.

Material examined

Calamagrostis arundinacea EH. Forssa 10. V. 1969 (P.A.). *Festuca ovina* EH. Forssa 10. V. 1969 (P.A.): U. Nurmijärvi 19. VIII. 1973 (H.K.); St. Hämeenkyrö 21. VIII. 1972 (H.K.), Merikarvia 13. VIII. 1972 (H.K.) (two specimens), Suodenniemi 21. VIII. 1972 (H.K.); EH. Sysmä 31. VII. 1972 (K.M.), 9. IX. 1972 (H.K.); ES. Valkeala 6. VII. 1972 (H.K.), Joutsa 31. VII. 1972 (H.K.), Suomenniemi 28. VI. 1972 (H.K.); EP. Vöyri 17. VIII. 1972 (H.K.); KP. Kruunupyy 17. VIII. 1972 (H.K.). *Molinia coerulea* Kn. Paltamo 10. VIII. 1973 (H.K.).

Table 7. Occurrence of *Hendersonia*, *Phaeoseptoria* and *Stagonospora* species (%) on various hosts

	No. of samples researched	*Hendersonia crastophila*	*H. culmicola*	*H. phragmites*	*H. simplex*	*Phaeoseptoria airae*	*P. festucae*	*P. poae*	*Stagonospora smolandica*	*S. subseriata*	*Stagonospora spp.*	Total
Agropyron caninum	28	18										18
A. repens	230	12			1		2					15
Agrostis spp.	69	10			1						1	12
A. borealis	9						11				11	22
A. canina	7											17
A. stolonifera	30	17										21
A. tenuis	363	14	1				1	1	2		2	15
Alopecurus geniculatus	21	10						5				17
A. pratensis	195	5	2		1		2	2			5	15
Anthoxanthum odoratum	55	9					2	4				2
Brachypodium pinnatum	6											32
Bromus inermis	48	2										23
Calamagrostis spp.	50	14			4			6	2		6	5
C. arundinacea	74	10			8			4		1		17
C. canescens	41	5										7
C. epigeios	176	12			1			2	1		1	
C. lapponica	15	7										13
C. neglecta	11											11
C. purpurea	86	11			1						1	42
Dactylis glomerata	593	4	0,2		0,2		2	3			2	17
Deschampsia caespitosa	158	18			1	12	3	6	1		1	50
D. flexuosa	157	3				1	1	9	2		1	
Elymus arenarius	6	33						17				29
Festuca spp.	1											
F. capillata	106	6	3		2		1	1		11	10	34
F. ovina	534	3	0,4				1	2	1		2	9
F. pratensis	269	13	1		1		6	7	1		1	30
F. rubra	8	38										38
Glyceria fluitans	2											
Hierochloë alpina	11	27									9	36
H. australis	10	30									20	50
H. odorata	1	(100)										(100)
Holcus sp.	17							12			6	18
Lolium multiflorum	142		1					3				4
L. perenne	46	2									2	4
Melica nutans	18	17									11	28
Milium effusum	16	19								6		25
Molinia coerulea	55	2										2
Nardus stricta	30	23	3								7	33
Phalaris arundinacea	19	5										5
Phleum alpinum	5	20										20
P. nodosum	545	5						3				8
P. pratense	34	15		9								24
Phragmites communis	94							4				4
Poa spp.	3							33				33
P. alpina	34							29			3	32
P. annua	1							(100)				(100)
P. compressa	15	13										13
P. nemoralis	8	25										25
P. palustris	151	12	3				2	22			2	41
P. pratensis	4 632	7,6	0,5	0,1	0,5	0,4	1,1	3,5	0,4	0,3	1,5	15,9
Grasses total												
Avena sativa	415	1										1
Hordeum vulgare	803	3					4					7
Secale cereale	341	3					4					7
Triticum aestivum	481	3					4					7
(Spring wheat)		(5,9)					(7,2)					
(Winter wheat)		(0,4)					(1,2)					
Cereals total	2 040	2,5					3,1					5,6

CONCLUSIONS

Among the grass species most frequently infected by *Hendersonia-*, *Phaeoseptoria-* and *Stagonospora* species were *Deschampsia caespitosa* (42 %), *Poa pratensis* (41 %) and *P. annua* (32 %), *F. ovina* (34 %) and *F. rubra* (30 %) as well as *Agrostis tenuis* (21 %) (Table 7). The fungi were found to occur rarely on *Bromus inermis*, *Nardus stricta*, *Lolium perenne*, *Melica nutans*, *Calamagrostis canescens*, *Phleum pratense* and *Festuca pratensis*. On the cereals, *H. crastophila* and *P. festucae* were found most commonly on spring wheat, and most rarely on oats.

The greatest number of these fungi, seven species, were found on *Deschampsia caespitosa*, *Festuca ovina* and *F. rubra*. About 60 % of the grasses studied revealed only one or two fungi species.

The fungi occurring commonly on grasses throughout Finland were *Hendersonia crastophila*, *Phaeoseptoria festucae* and *P. poae*; all occurred on several hosts. Species with scattered occurrence throughout the country were *H. culmicola*, *H. simplex* and *P. airae*. Fungi found only in southern and central Finland were *Stagonospora smolandica* and *S. subseriata* on grasses, as well as *H. crastophila* and *P. festucae* on cereals.

The greatest number of these fungi species were found on dead or necrotic plant tissue. Pycnidia were scattered singly, rarely in groups e.g. sometimes *P. festucae* (Fig. 5). Obviously these fungi are of little economic importance.

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SELOSTUS

Hendersonia-, Phaeoseptoria- ja Stagonospora -lajien esiintymisestä heinäkasveilla

KAIHO MÄKELÄ

Maatalouden tutkimuskeskus

Tutkitut yhdeksän sienilajia esiintyivät kaikki heinillä, kaksi niistä myös viljoilla. *Hendersonia crastophila* oli hyvin yleinen heinillä, mutta paljon harvinaisempi viljoilla. Sensijaan *Phaeoseptoria festucae* esiintyi yleisemmin viljoilla kuin heinillä. *P. poae* oli melko yleinen heinillä kautta maan. Kaikkia muita lajeja esiinty vähänlaisesti; *H. culmicola*, *H. simplex*, *Stagonospora smolandica* ja *S. subseriata* useilla heinälajeilla, *H. phragmites* järviruo'olla ja *P. airae* nurmilauhalla Sienten taloudellinen merkitys on ilmeisesti vähäinen

ANNALES AGRICULTURAE FENNIAE, VOL. 16: 256–276 (1977)
Seria PHYTOPATHOLOGIA N. 66 – Sarja KASVITAUDIT n:o 66

SEPTORIA AND SELENOPHOMA SPECIES ON GRAMINEAE IN FINLAND

KAIHO MÄKELÄ

MÄKELÄ, K. 1977. **Septoria and Selenophoma species on Gramineae in Finland.** Ann. Agric. Fenn. 16: 256–276. (Agric. Res. Centre, Inst. Pl. Path., SF-01300 Vantaa 30, Finland.)

Between 1966 and 1974, about 4650 samples of 48 grass species and 2040 samples of four cereals collected throughout Finland were examined. Ten *Septoria* species were found. Five are reported for the first time in Finland: *S. elymi* Ell. & Ev. on *Agropyron* species, *S. macropoda* Pass. and *S. oudemansii* Sacc. on *Poa* species, *S. tenella* Cke & Ell. on *Festuca* species and *S. triseti* Speg. on *Agrostis* species. These were found to occur sporadically throughout the country. *S. nodorum* (Berk.) Berk. & Br. was common on wheat, moderately common on barley, very rare on rye, and occurred on 27 grass species; *S. avenae* Frank f.sp. *triticea* T. Johnson was common on barley, moderately common on wheat, and occurred on 20 grass species; *S. avenae* Frank f.sp. *avenae* Shaw was found sporadically on *Avena* species; *S. tritici* Rob. was common on winter wheat in spring; *S. secalis* Prill. & Delacr. was moderately common on rye. *Selenophoma donacis* var. *stomaticola* (Bäuml.) Sprague & A. G. Johnson was found sporadically on barley, oats, wheat and on eleven grass species in northern Finland.

Index words: *Septoria* species on *Gramineae*, *Selenophoma* species on *Gramineae*.

INTRODUCTION

Several *Septoria* and some *Selenophoma* species are known to cause serious leaf spot diseases on cereals and grasses all over the world (SPRAGUE 1950). The present concept of *Septoria* is largely based on a description proposed by SACCARDO (1884). Later GROVE (1935) established the popular conception of the genus as outlined by Saccardo. The genus *Selenophoma* was first defined by MAIRE (1906).

In recent times these fungi have been studied extensively by SPRAGUE (1944, 1950) and SPRAGUE and JOHNSON (1950) in the USA, and also by FRANDSEN (1943) and JORSTAD (1967) in Scandinavia. In Finland, these fungi have been little investigated to date.

This study is part of a research project dealing with leaf spot diseases on cereals and grasses, and specifically with the pathogens causing these diseases (cf. MÄKELÄ 1972a, 1972b, 1975).

MATERIAL AND METHODS

This study is based on cereal samples collected during the 1971—1973 growing season from 2040 fields all over the country. The bulk of the cereal samples was gathered when the grain was at he soft dough stage, usually from late July to early August. Samples of winter wheat and rye were also gathered in May. The samples of grasses (about 4650 samples) were gathered througout the country from leys, the margins of fields, forests and seashores. The observations were made and samples collected from spring to autumn during 1966—1974.

The fungi were determined as follows: Diseased leaves were kept on moist blotting paper in Petri dishes for a few days, after which the fungi were examined with a stereomicroscope. Microscopic slides were prepared from all samples. The slides were preserved in a lactic acid-lactophenol solution, in which the fungi were also measured and photographed.

In addition to these specimens of grasses and cereals, collections of the University of Helsinki, Department of Plant Pathology, HPP, and Mr. Pentti Alanko's herbarium were examined.

Abbreviations of the Finnish biological provinces are in accordance with HEIKINHEIMO and RAATIKAINEN (1971).

The collectors were Pentti Alanko = P.A., Hilkka Koponen = H.K., and Kaiho Mäkelä = K.M.

RESULTS AND CONCLUSION

Septoria avenae Frank f.sp. **avenae** Shaw; perfect stage *Leptosphaeria avenaria* Weber f.sp. *avenaria* Shaw. Can. J. Bot. 35: 97, 1957a, syn. *Phaeosphaeria avenaria* (Weber) O. Eriksss. f.sp. *avenaria*.

S. avenae f.sp. *avenae* causes speckled blotch or leaf spot on oats. The fungus is widespread on oats (FRANDSEN 1943, SPRAGUE 1950). *S. avenae* has been found also on various grasses (SPRAGUE 1950). In Europa it has been found on oats in Scotland (NOBLE and MONTGOMERIE 1956, RICHARDSON and NOBLE 1970), Germany (MÜLLER 1963) and Scandinavia (FRANDSEN 1943, JORSTAD 1967). Nevertheless, the fungus is of little economic importance.

The perfect stage has been found on oats (WEBER 1922a, JORSTD 1930, HUFFMAN 1955, SHAW 1957a).

In this study, *S. avenae* f.sp. *avenae* occurred rarely on oats in the southern parts of the country (Fig. 1). The fungus was ancountered in only 3 per cent of the 415 fields examined (MÄKELÄ 1975).

Pycnidia of the fungus were found on ripening and withering leaves and measured (100) 146 (162) μm in diam. Mecroconidia were cylindrical, rounded at the ends, eleven isolates measuring (23) 37,1 (56) × (2,4) 3,4 (5,4) μm, (3) 4,1 (6) -septate (Figs. 3 and 11). According to SPRAGUE (1950), the conidia vary in size, 25—45 × 3—4 μm, and according to JORSTAD (1967) 22—47 × (2,5) 3—4 μm.

The perfect stage was found on only a few samples of overwintered oat stubble (KOPONEN and MÄKELÄ 1975).

Material examined

Avena sativa V, U, EH, EP, PS (22 localities, over 400 samples) (MÄKELÄ 1975). *A. fatua* U. Mäntsälä 9. IX. 1970 (K.M.).

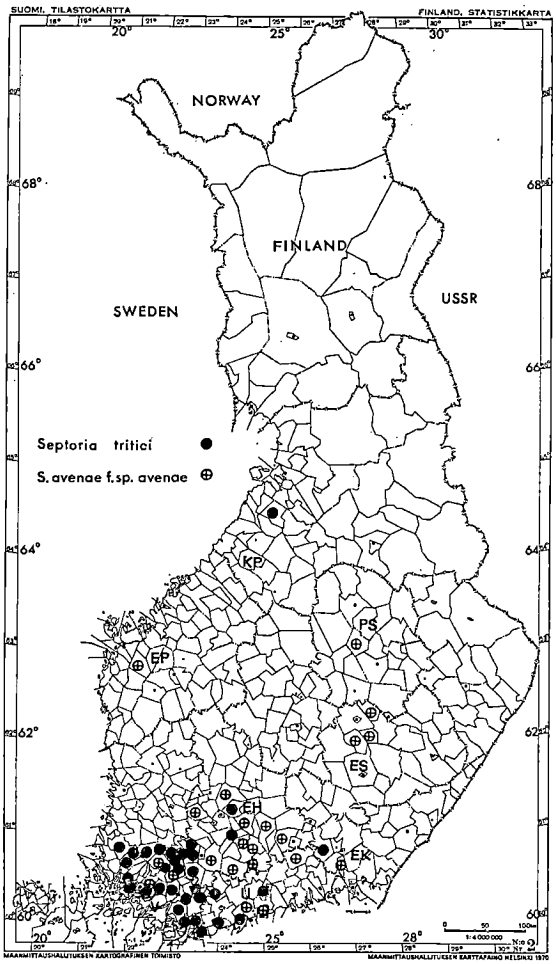

Fig. 1. The occurrence of *Septoria avenae* f. sp. *avenae* on *Avena sativa* and *S. tritici* on *Triticum aestivum* by localities in Finland.

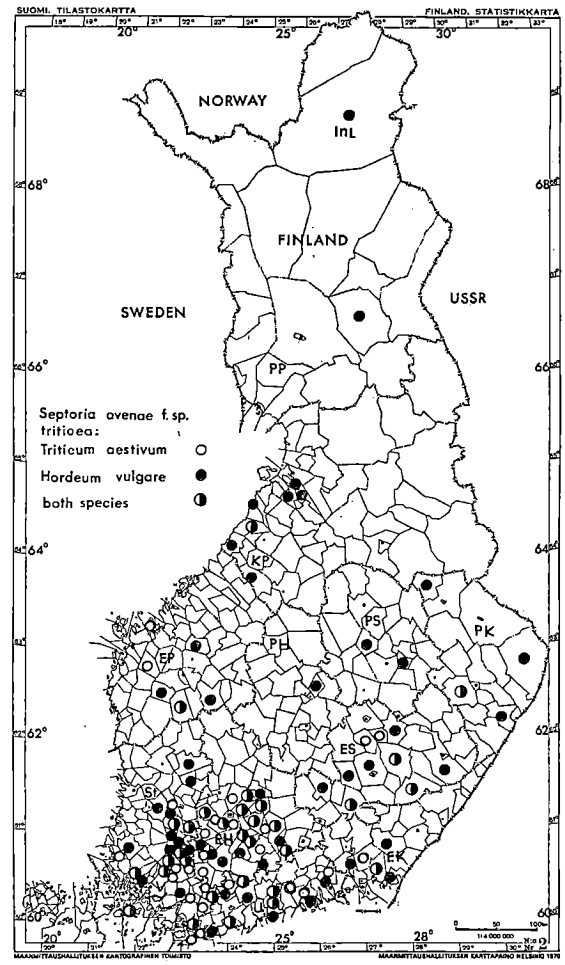

Fig. 2. The occurrence of *Septoria avenae* f. sp. *triticea* on *Hordeum vulgare* and *Triticum aestivum* by localities in Finland.

Septoria avenae Frank f.sp. **triticea** T. Johnson; perfect stage *Leptosphaeria avenaria* Weber f.sp. *triticea* T. Johnson, Can. J. Res. 25 C: 259, 1947, syn. *Phaeosphaeria avenaria* (Weber) O. Eriksss. f.sp. *triticea*.

The fungus has been found on wheat and barley in Canada (JOHNSON 1947, SHAW 1957a), in the USA (SPRAGUE 1950, HOSFORD et al. 1969) and in Scotland (RICHARDSON and NOBLE 1970, RICHARDSON 1972) as well as on wheat in Austria (KIETREIBER 1962). The fungus infects also oats, rye and certain grasses, particularly *Agropyron* and *Elymus* species (JOHNSON 1947, SPRAGUE 1950).

The perfect stage has been found on wheat (JOHNSON 1947, SHAW 1957b, HOSFORD et al. 1969).

In this study *S. avenae* f.sp. *triticea* was found on barley throughout the country as far north as Inari, Lapland. Both on barley and wheat, however the disease occurred most commonly in the southern parts of Finland, which comprise the main areas of cultivation in the country (Fig. 2). The fungus was found, on average, in 15 per cent of the 803 fields and in about 45 per cent of the 251 localities studied. The fungus was rather more com-

Table 1. Size of conidia of *Septoria avenae* f.sp. *triticea* on various hosts.

Host	No. of isolates	Size of conidia, µm
Agropyron caninum	6	(20) 28,5 (38) × (3) 3,6 (4)
A. repens	29	(18) 31,6 (44) × (2,7) 3,2 (4)
Agrostis tenuis	12	(22) 31,7 (46) × (2) 3,2 (4,5)
Alopecurus pratensis	12	(22) 31,7 (49) × (2) 3,0 (4)
Calamagrostis epigeios	2	(21) 30,8 (40) × (2) 2,9 (3)
Dactylis glomerata	2	(26) 33,4 (42) × (2) 3,3 (4)
Festuca pratensis	10	(16) 28,8 (48) × (2) 2,8 (5,5)
Hordeum vulgare	39	(15) 31,4 (47) × (2) 3,2 (6)
Phalaris arundinacea	6	(20) 26,6 (34) × (2) 3,3 (4,5)
Phleum pratense	2	(18) 28,2 (34) × (3) 3,4 (4)
Triticum aestivum	29	(17) 33,0 (54) × (2) 3,2 (4,5)

mon on two-rowed varieties (29 %) than on six-rowed varieties (12 %).

As well as on barley, the fungus was encountered on wheat in 23 per cent of the 222 spring wheat fields and in 14 per cent of the 259 winter wheat fields examined. The fungus occurred in about a third of the localities studied.

Pycnidia of *S. avenae* f. sp. *triticea* were found in greatest abundance on ripening and withering leaves, on yellowish brown or brown necrotic lesions.

Pycnidia were light brown, measuring (70) 150 (290) µm in diam. (Fig. 3). Macroconidia were cylindrical, rounded at the ends, straight or slightly curved, of mean dimensions in two cereal species and 68 isolates (15) 31,4—33,0 (54) × (2) 3,2 (6) µm, (2) 4,0 (6) -septate.

As well as on cereals, *S. avenae* f. sp. *triticea* was found on 102 samples of 20 grass species. The fungus occurred on grasses, however, rather rarely and sporadically throughout the country (Fig. 5). Pycnidia were found on withering leaves between April 10 and October 17. They measured 85—150 µm in diam. On 20 grass species the conidia varied in size, being (16) 24,2—37,6 (49) × (2) 2,0—4,0 (5,5) µm, (2) 4,0 (6) -septate, mostly 30,1 × 3,2 µm, 4,0 -septate (Table 1, Figs. 3 and 11).

According to JOHNSON (1947), the size of conidia on *Triticum aestivum* was (18) 26—42 (53) × (2,3) 2,8—3,5 (4,2) µm. In various Norwegian *Gramineae*, the size of *Septoria phyllachoroides* Pass. Conidia vary, 18—48 × 2—3,5 (4) µm, 1—3 -septate (JORSTAD 1967, p. 48). According to JORSTAD (1967), *S. phyllachoroides* resembles very closely *S. avenae* f.sp. *triticea*. In fact, it seems difficult to maintain them as different species.

The perfect stage, was found occasionally on *Agropyron repens*, *Hordeum vulgare*, *Secale cereale* and *Triticum aestivum* (KOPONEN and MÄKELÄ 1975).

Material examined:

Agropyron caninum — U: Helsinki 15. VIII. 1972 (P.A.), 8. X. 1972 (P.A.), Nurmijärvi; EH: Urjala 15. VII. 1972 (P.A.), 8. IX. 1972 (P.A.); EP: Vöyri. *A. repens* — V: Korppoo. Nauvo, Raisio, Tenhola; U: Espoo 10. IX, 1973 (P.A.) Helsinki (8 specimens), Inkoo, Kirkkonummi; St: Eurajoki, Kankaanpää; EH: Asikkala, Hattula, Hämeenlinna, Tammela; ES: Mäntyharju; PH: Äänekoski; PK: Ilomantsi; KP: Lappajärvi; Kn. Sotkamo. *Agrostis gigantea* — U: Helsinki. *A. stolonifera* — V: Lohja; LK: Simpele. *A. tenuis* — U: Helsinki (6 specimens); St: Kokemäki; EH: Sysmä; EP: Korsnäs; Kn: Paltamo; PP: Pudasjärvi; InL: Inari. *Agrostis* sp. — V: Tenhola; U: Helsinki, Kirkkonummi, Nurmijärvi; EH: Hämeenlinna. *Alopecurus geniculatus* — U: Helsinki. *A. pratensis* — V: Halikko, Kodisjoki, Muurla, Salo, Tenhola; U: Helsinki (3 specimens), Kirkkonummi, Pornainen, Porvoo commune, Siuntio 15. VII. 1967 (P.

A.), Tuusula; St: Oripää, Pori; EH: Asikkala, Hämeenlinna. *Anthoxanthum odoratum* — U: Helsinki; EH: Urjala; ES: Ristiina; Ks: Salla. *Calamagrostis epigeios* — U: Helsinki (2 specimens). *C. lapponica* — Kn: Paltamo. *C. purpurea* — PK: Ilomantsi. *Calamagrostis* sp. — EH: Hämeenlinna. *Dactylis glomerata* — V: Korppoo; U: Helsinki. *Festuca capillata* — U: Tuusula *F. pratensis* — V: Tenhola; U: Helsinki (7 specimens), Tuusula, Vantaa (2 specimens); EH: Hämeenlinna, Ypäjä; ES: Mikkeli (5 specimens); InL: Inari. *F. rubra* — PK: Pielisjärvi. *Hierichloë odorata* — U: Helsinki; LK: Uukuniemi. *Hordeum vulgare* — V, U, EK, St, EH, ES, EP, PH, PS, PK, KP, PP, InL (ca. 800 samples from 82 localities) (MÄKELÄ 1975). *Molinia coerulea* — PK: Ilomantsi. *Phalaris arundinacea* — V: Masku; U: Helsinki, Kirkkonummi, Snappertuna; EH: Urjala 13. VIII. 1972 (P.A.); EP: Mustasaari. *Phleum nodorum* — EP: Teuva. *P. pratense* — U: Helsinki; InL: Inari. *Triticum aestivum* — V, U, EK, St, EH, ES, EP, PS, PK, KP, (ca. 480 samples from 56 localities) (MÄKELÄ 1975).

Septoria elymi Ellis and Everhart, J. Mycol. 7: 132, 1893, syn. cf. FRANDSEN 1943: 66, SPRAGUE 1944: 65, JORSTAD 1967: 36.

Septoria elymi is known to attack *Agropyron* and *Elymus* species in the United States, Europe, and Asia (WEBER 1923, FRANDSEN 1943, SPRAGUE 1944, 1950, HOWARD et al. 1951, JORSTAD 1967).

In this study, *S. elymi* was found sporadically on dead leaves or leaf parts of *Agropyron caninum* (five of 28 specimens studied). Pycnidia varied from 80—133 μm, conidia filiform, straight or curved, septa indistinct, (20) 37,2 (46) × (1) 1,6 (2) μm (Fig. 11).

According to SPRAGUE (1944, 1950), the conidia measure 25—50 × 1,2—2,1 μm, and in JORSTAD's (1967) *A. caninum* material, this size varies extremely, 11—43 × 1—1,5 μm.

Material examined:

Agropyron caninum — EH: Urjala 11. VIII. 1972 (P.A.) (5 specimens).

Septoria macropoda Passer, Fung. Parm. Sept. no 141, 1879 (SACCARDO 1884: 561, ALLESCHER 1901: 853), syn. cf. SPRAGUE 1944: 52, JORSTAD 1967: 41.

The species has been divided into three variants differing from each other in host range and size of conidia (SPRAGUE 1944, 1950, 1954). Of these variants the following is described from Europe (JORSTAD 1967): *S. macropoda* Pass. var. *septulata* (Ganz. Frag.) Sprague, Phytopath. 32: 738, 1942, syn. SPRAGUE 1944: 53, JORSTAD 1967: 41.

Septoria macropoda and its variants are known to attack many species of *Poa*, particularly in the United States and Europe (SPRAGUE 1944, 1950, FRANDSEN 1943, HOWARD et al. 1951, JORSTAD 1962, 1967).

In Finland, *S. macropoda* was found infrequently and sporadically throughout the country (Fig. 7) on faded leaves or leaf parts of *Poa* species. The fungus was found on 15 specimens of three grass species: on *Poa annua* L. (six. of 34 specimens studied), *P. compressa* (one specimen), and *P. pratensis* L. (seven of 151 specimens). The specimens with conidia were collected between April 13 and September 20, the bulk in August.

Pycnidia were 80—140 μm in diam., conidia filiform, straight or flexuous, septa mostly indistinct (Figs. 6 and 11). The size of conidia varies a little on *Poa annua*, (27) 40,7 (56) μm × (0,5) 1,4 (2) μm, and on *P. pratensis* (27) 41,7 (60) μm × (1) 1,5 (2) μm, whilst on *P. compressa* the conidia were smaller (23) 26,3 (28) μm × 0,5—1 μm.

According to JORSTAD (1967), the conidia on *P. annua* measured 16—52 × 1—1,5 μm and on *P. pratensis* 25—53 × 0,7—2 μm. He considers all the Norwegian collections on *Poa* species to be *Septoria macropoda*. The present author, too, arrives at the same con-

clusion for the Finnish collections. On the other hand, SPRAGUE (1944, 1950) considers the fungus on *P. annua*, with conidia measuring 30—40 × 1,0—1,5 µm, to be *S. macropoda* and the fungus on *P. pratensis*, with conidia measuring 40—60 × 1,3—1,7 µm, to be *S. macropoda* var. *septulata*.

Material examined:

Poa annua — ES: Mikkeli commune 10. IX. 1972 (H.K.); EP: Kristiinankaupunki 19. VIII. 1972 (H.K.), Kruunupyy 16. VIII. 1972 (H.K.); PK: Liperi 5. VII. 1972 (H.K.); Ks: Posio 7. VIII. 1973 (H.K.); InL: Inari 22. VII. 1968 (K.M.). *P. compressa* — V: Pohja 7. IX. 1958 (P.A.). *P. pratensis* — U. Helsinki 3. VIII. 1972 (H.K.); EH: Hämeenlinna 13. IV. 1968 (K.M.); ES: Mikkeli commune 30. VII. 1972 (H.K.); PH: Saarijärvi 2. VII. 1973 (H.K.); PK: Nurmes 20. IX. 1966 (K.M.); PP: Pudasjärvi 8. VIII. 1973 (H.K.); Kn: Vuolijoki 10. VIII. 1973 (H.K.). *Poa* sp. — ES: Ristiina 26. VI. 1972 (H.K.).

Septoria nodorum Berkeley, Gard. Chron. 1845: 601 (SACCARDO 1884: 561), syn cf. SPRAGUE 1950: 244, JORSTAD 1967: 43. Perfect stage: *Leptosphaeria nodorum* Müller) Hedjaroude.

The species has been divided into two *formae speciales* (SMEDEGÅRD-PETERSEN 1974).

The fungus causes glume blotch on wheat. It is primarily an ear pathogen (WEBER 1922b, FRANDSEN 1943, HOPP 1957, JORSTAD 1967, BRÖNNIMANN 1968). *S. nodorum* occurs also on barley (SPRAGUE 1950, JORSTAD 1967, HANSEN and MAGNUS 1969, HOLMES and COLHOU 1970, RICHARDSON 1972, SMEDEGÅRD-PETERSEN 1974), and on rye (WEBER 1922b, SPRAGUE 1950, KOLK 1966, BECKER 1957) as well as on certain grass species (WEBER 1922b, SPRAGUE 1950, BECKER 1957, HOPP 1957, JORSTAD 1967, TETEREVNIKOVA-BABAYAN and BOKHYAN 1970, WILLIAMS and JONES 1973).

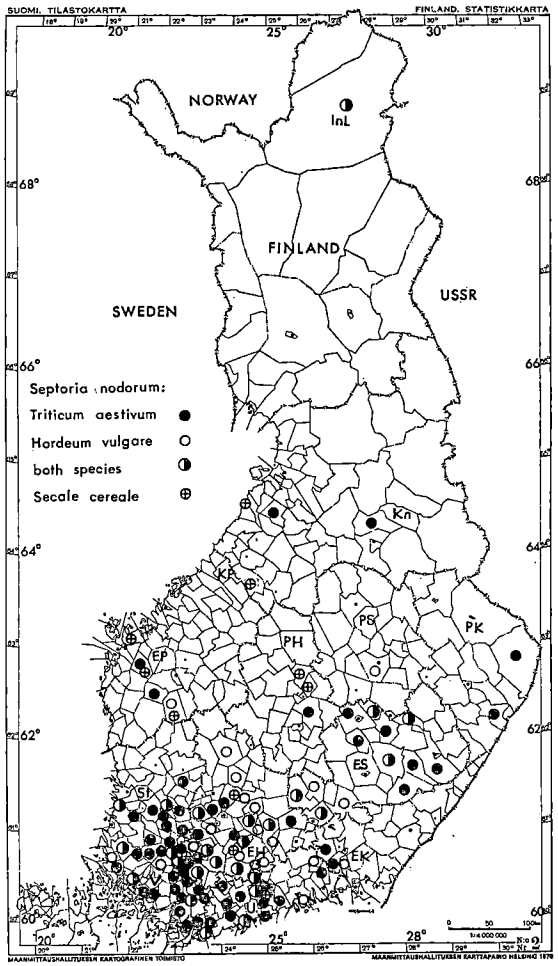

Fig. 4. The occurrence of *Septoria nodorum* on *Triticum aestivum*, *Hordeum vulgare* and *Secale cereale* by localities in Finland.

S. nodorum occurs widely in most of the world's wheat growing areas (SPRAGUE 1950, C.M.I. map 283). In Scandinavia, the fungus is nowadays quite common on wheat and occurs also on barley and rye. But only on wheat does it appear to be a parasite of economic importance (JORSTAD 1930, 1945, 1967, FRANDSEN 1943, KOLK 1966, HANSEN and MAGNUS 1969, LEIJERSTAM 1972, SMEDEGÅRD-PETERSEN 1974).

In Finland, *S. nodorum* has been found in recent years on barley and on various grasses (MÄKELÄ 1972a, 1972b).

The perfect stage has been found on wheat (MÜLLER 1952, LUCAS and WESTERN 1967) and on barley (SMEDEGÅRD-PETERSEN 1974).

In this study, *Septoria nodorum* was found to occur mainly on cereals. It was the most common species on spring and winter wheat and was moderately common on two-rowed barley. The fungus was found on wheat in 60—70 per cent, and on barley in about 40 per cent of the localities and for both cereals in a third of the fields examined. However, on six-rowed barley and winter rye the fungus was found to be very rare occurring, in only 6—10 per cent of the localities and 2—4 per cent of the fields studied. The fungus occurred on cereals in the southern and central parts of the country, and occasionally as far north as Inari (Fig. 4).

Pycnidia of S. *nodorum* were found in greatest abundance on ripening and withering leaves, on brownish leaf spots as well as on ears of wheat (Fig. 6). Pycnidia were yellow or brown, measuring (90) 145 (300) μm in diam. (Fig. 6). Conidia were short, cylindrical, straight or bent, of mean dimensions in three species and 63 isolates (10) 18,9—20,2 (29) × (1,5) 2,6—3,3 (4,5) μm, (1) 2,6—2,9 (5) -septate (Table 2, Figs. 6 and 11). The shape and size of the conidia were very similar on different cereals.

As well as on cereals, *S. nodorum* was found on 124 samples of 27 grass species. Even so, the fungus occurred on grasses rather rarely and sporadically throughout the country (Fig. 5). Pycnidia were found on withering leaves between March 24 and November 25. They measured (70) 150 (390) μm in diam. Conidia varied in size somewhat in 27 grass species

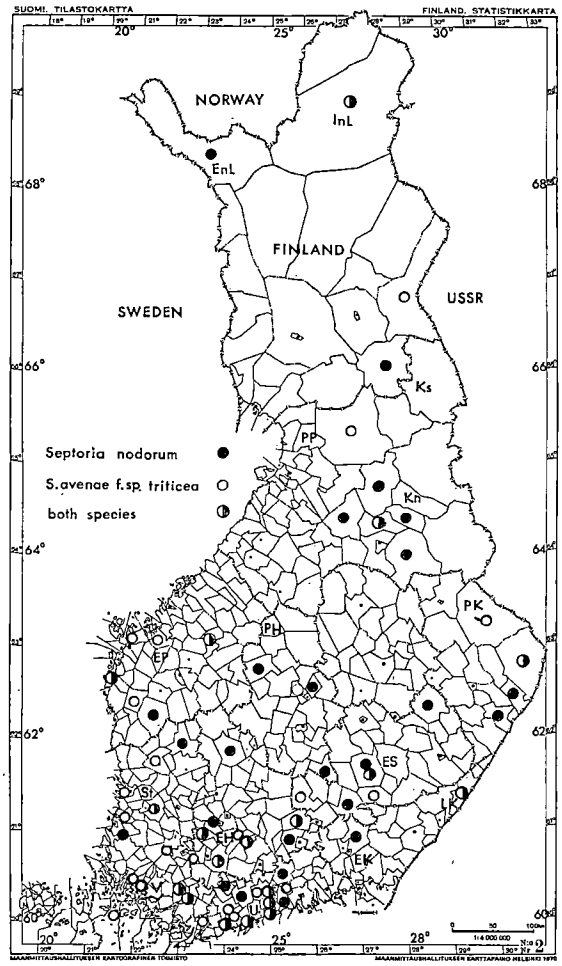

Fig. 5. The occurrence of *Septoria avenae* f. sp. *triticea* and *S. nodorum* on grass species by localities in Finland.

Table 2. Size of conidia of *Septoria nodorum* on various hosts.

Host	No. of isolates	Size of conidia, μm
Agropyron repens	7	(14) 20,8 (29) × (2) 3,8 (6)
Agrostis tenuis	13	(16) 21,3 (26) × (2) 3,7 (5)
Alopecurus pratensis	8	(14) 17,1 (24) × (2) 3,2 (4)
Calamagrostis epigeios	3	(12) 17,3 (22) × (2,5) 3,2 (4,5)
Dactylis glomerata	8	(11) 16,7 (24) × (1,8) 2,1 (3,8)
Deschampsia caespitosa	10	(14) 21,7 (29) × (2) 3,1 (4,5)
Festuca pratensis	11	(13) 17,9 (24) × (2) 2,9 (4)
F. rubra	5	(15) 19,6 (29) × (2) 2,9 (4)
Hordeum vulgare	30	(12) 19,4 (27) × (2) 2,7 (4,5)
Phleum pratense	13	(13) 18,8 (26) × (2) 3,0 (4,5)
Poa pratensis	4	(14) 20,9 (26) × (2,5) 3,1 (3,8)
Secale cereale	4	(12) 19,9 (24) × (2) 3,3 (4,5)
Triticum aestivum	29	(10) 19,7 (29) × (2) 2,9 (4,5)

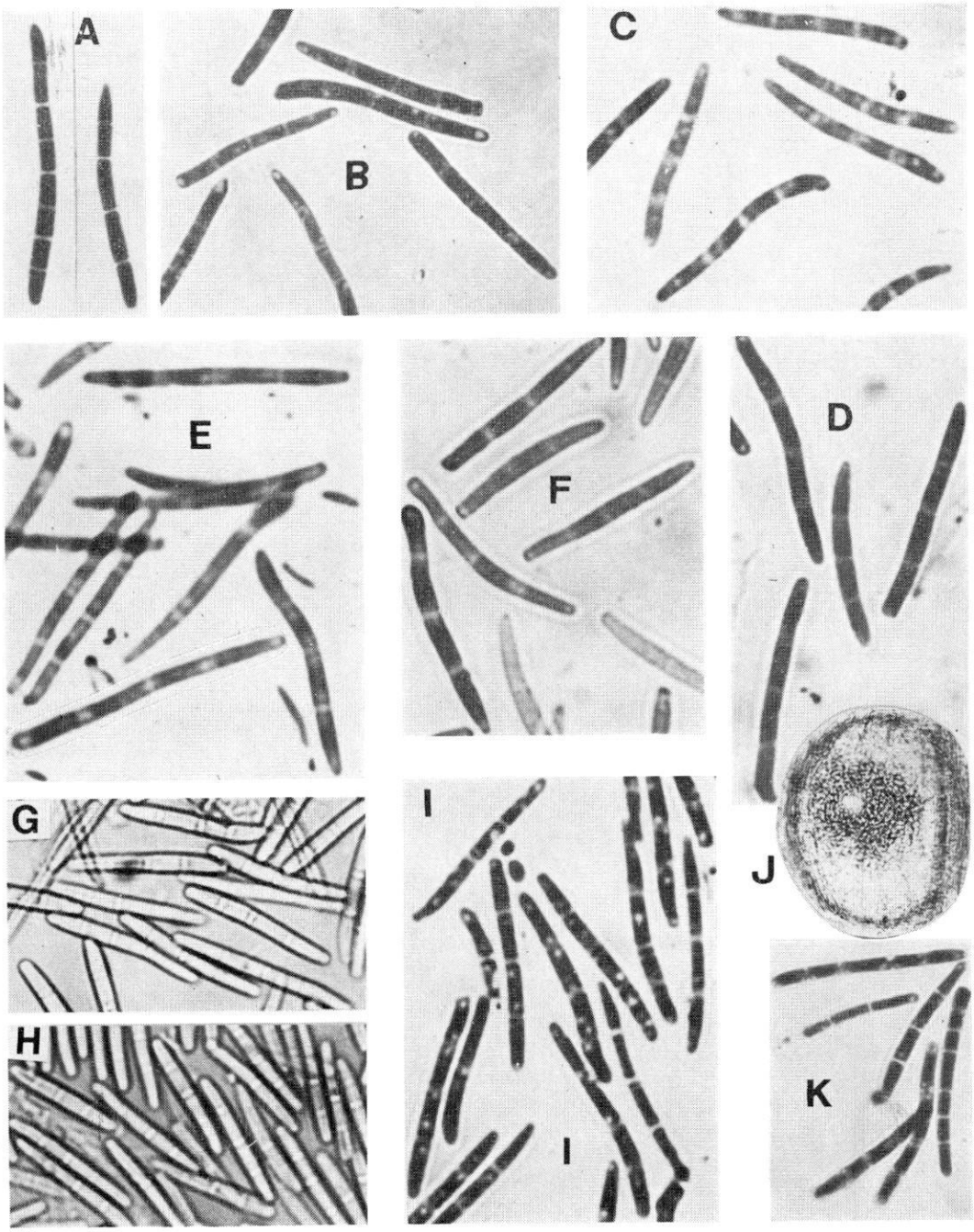

Fig. 3. A, B: *Septoria avenae* f. sp. *avenae* on *Avena sativa*; C-K: *S. avenae* f. sp. *triticea*, C, D: on *Agropyron repens*, E: on *Agrostis tenuis*, F: on *Alopecurus pratensis*, G: on *Dactylis glomerata*, H: on *Festuca pratensis*, I: on *Hordeum vulgare*, J, K: on *Triticum aestivum*. A-G, I, K: ×1000, H: ×750, J: ×150.

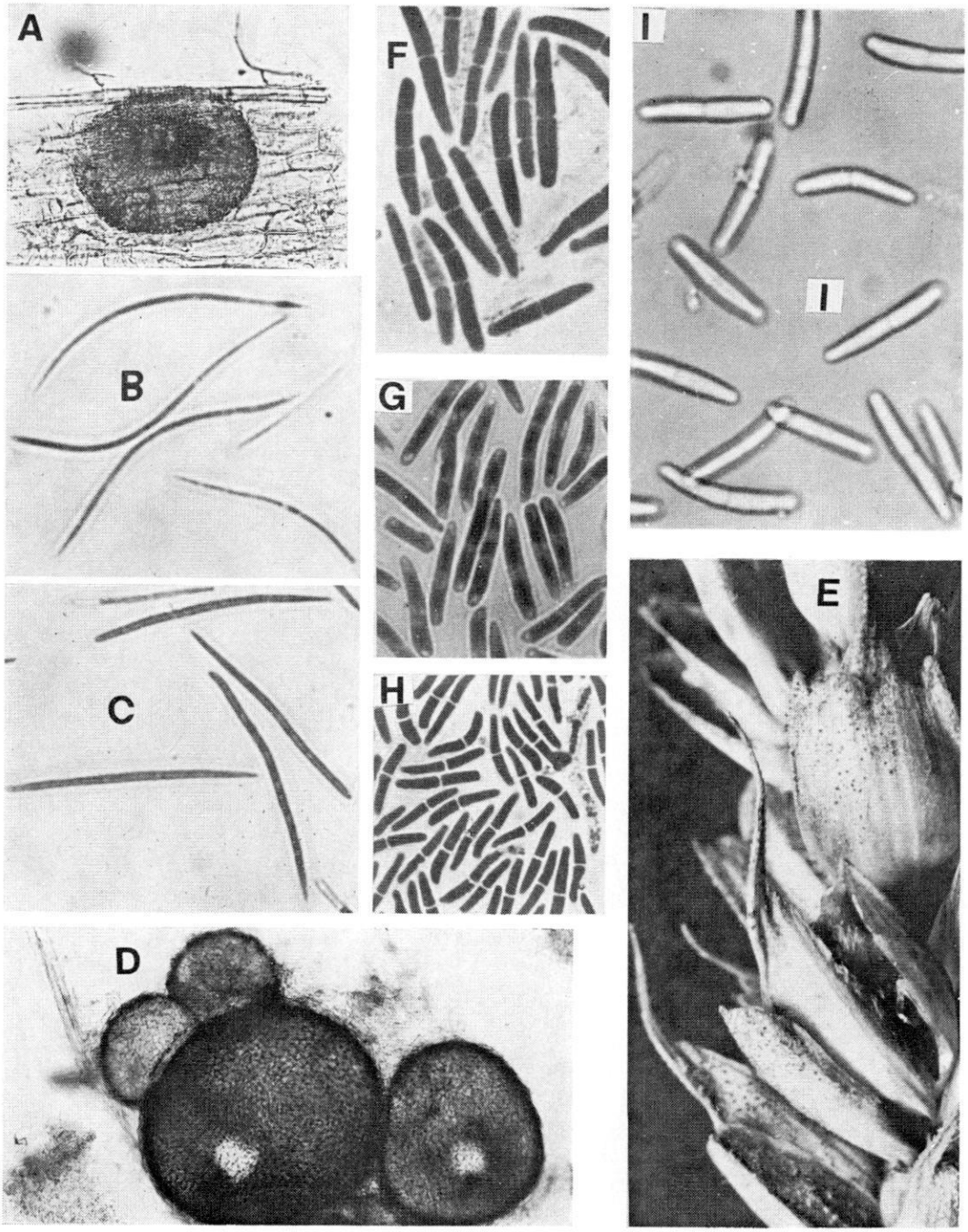

Fig. 6. A-C: *Septoria macropoda*, A, B: on *Poa annua*, C: on *P. pratensis;* D-H: *S. nodorum*, D, F, G: on *Hordeum vulgare*, E, H: on *Triticum aestivum;* I: *S. oudemansii* on *Poa pratensis*. A: ×200, B, C, F, G, I: ×1000, H: ×500, E: ×5, D: ×150.

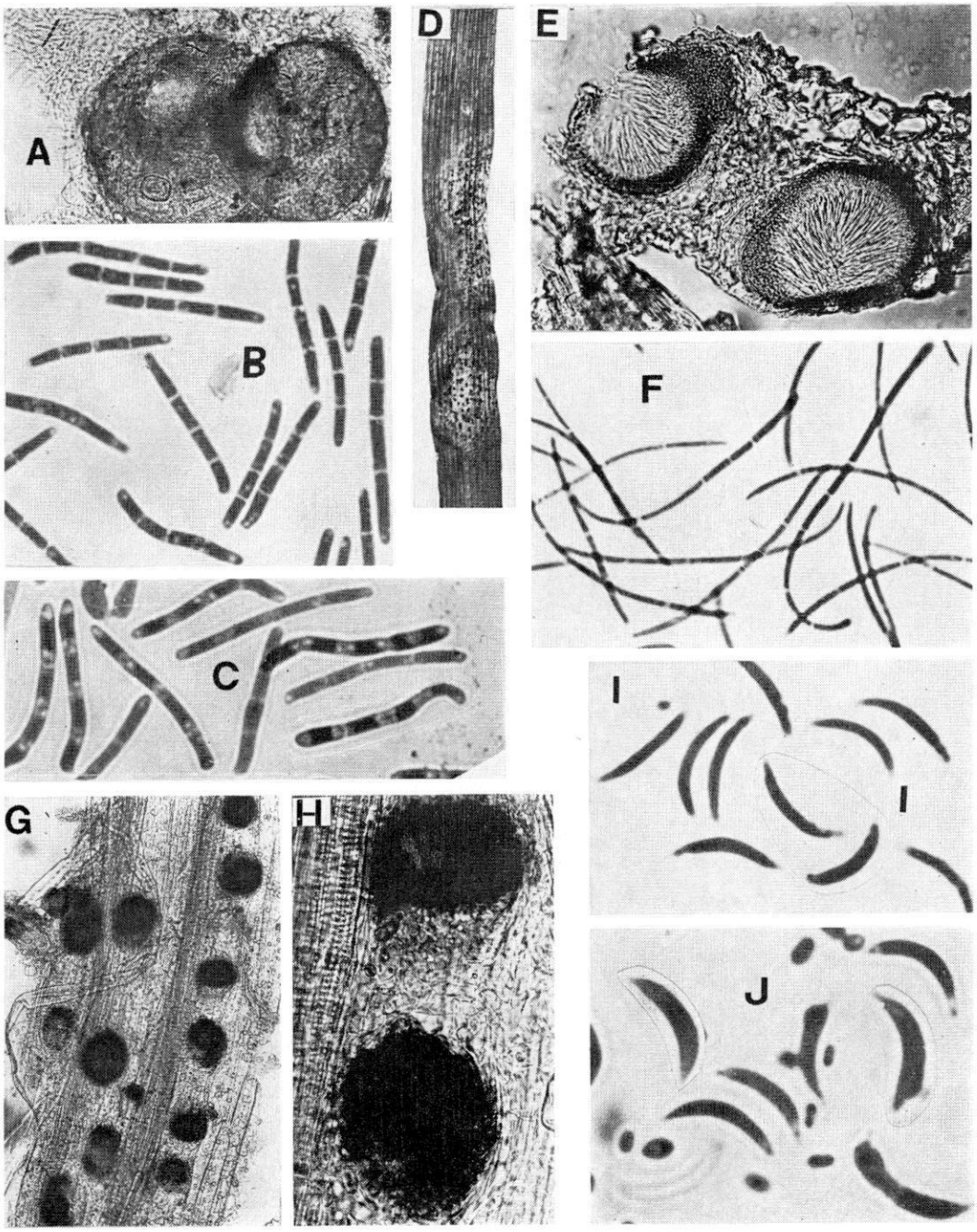

Fig. 9. A-C: *Septoria secalis* on *Secale cereale*, D-F: *S. tritici* on *Triticum aestivum*, G-J: *Selenophoma donacis* var. *stomaticolae* G, H: on *Hordeum vulgare*, I: on *Avena sativa*, J: on *Triticum aestivum*. A, E: ×150, B, C, F: ×1000, D: ×1, G: ×40, H: ×200, I, J: ×1500.

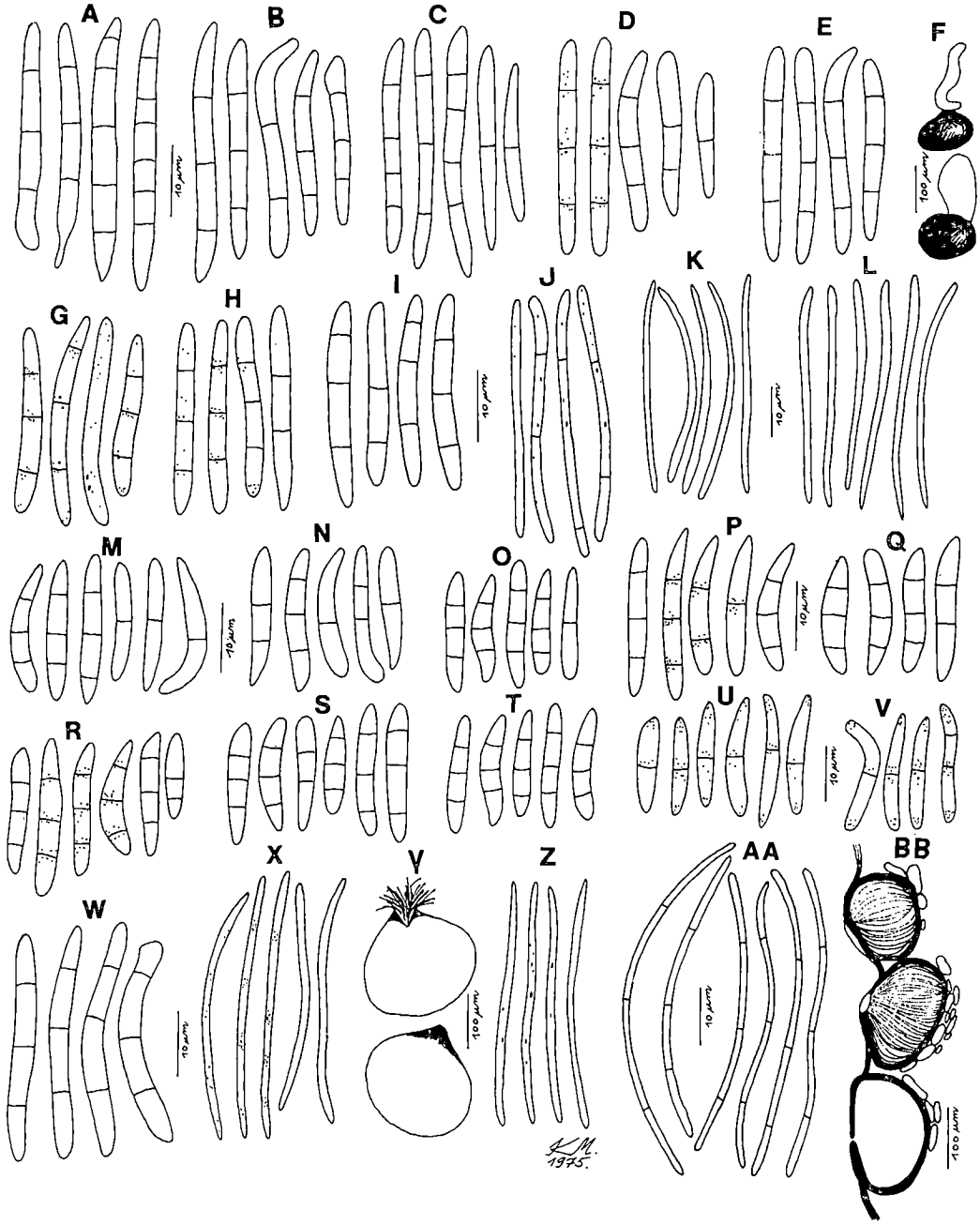

Fig. 11. A: *Septoria avenae* f. sp. *avenae*, B-I: *S. avenae* f. sp. *triticea*, J: *S. elymi*, K-L: *S. macropoda*, M-T: *S nodorum*, U-V: *S. oudemansii*, W: *S. secalis*, X, Y: *S. tenella*, Z: *S. triseti*, AA, BB: *S. tritici*; on *Avena sativa* A; on *Agropyron caninum* J; on *A. repens* D, O; on *Agrostis tenuis* E, P, Z; on *Alopecurus pratensis* G; on *Dactylis glomerata* Q; on *Deschampsia caespitosa* R; on *Festuca pratensis* H, S; on *F. rubra* X-Y; on *Hordeum vulgare* B, N; on *Phleum pratense* I; on *Poa annua* K; on *P. nemoralis* V; on *P. pratensis* L, T, U; on *Secale cereale* W; on *Triticum aestivum* C, F, M, AA, BB.

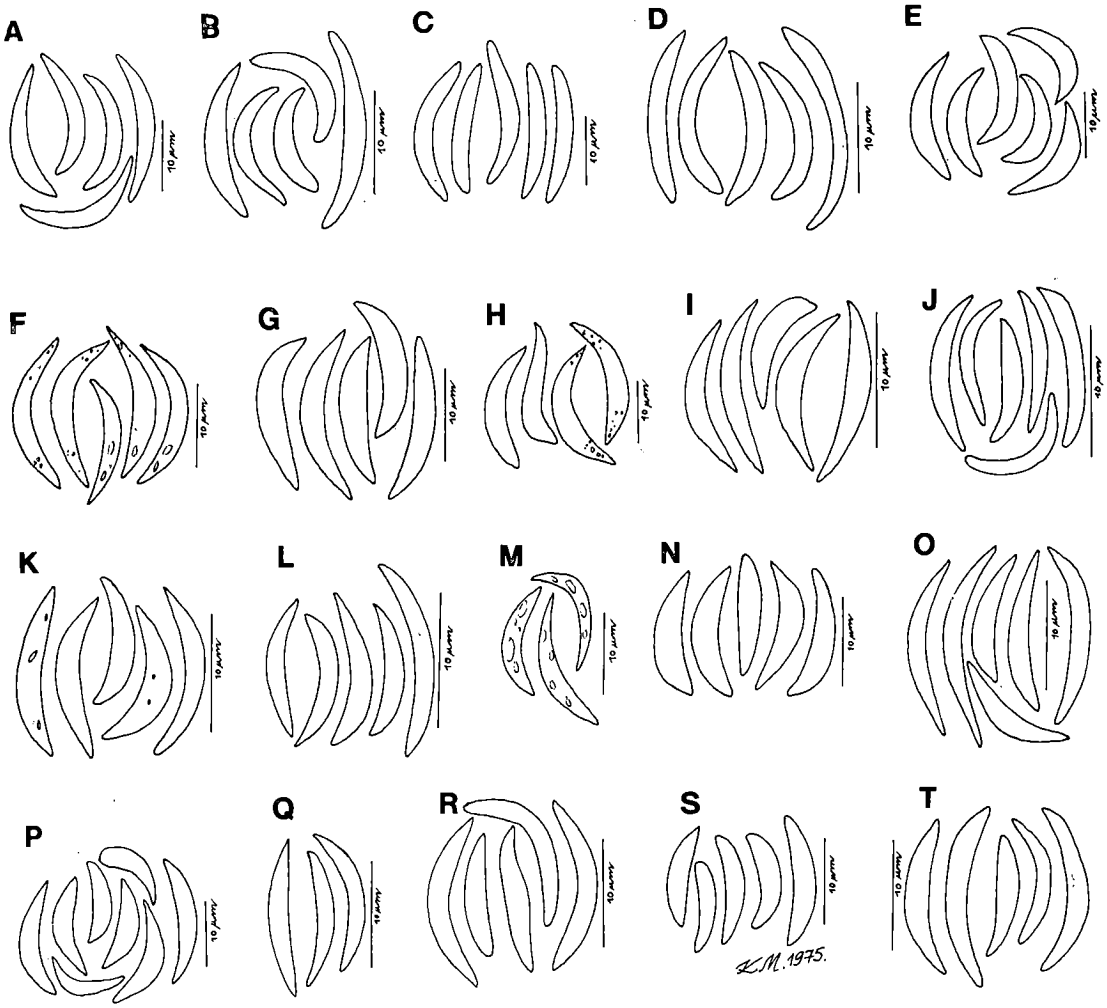

Fig. 13. Conidia of *Selephoma donacis* var. *stomaticola*. A: on *Agropyron repens;* B: on *Agrostis tenuis;* C: on *Alopecurus pratensis;* D: on *Anthoxanthum odoratum;* E: on *Calamagrostis* sp.; F, G, H: on *Dactylis glomerata;* I: on *Deschampsia caespitosa;* J: on *Festuca pratensis;* K: on *F. rubra;* L, M, N: on *Phleum pratense;* O: on *Avena sativa;* P, Q: on *Hordeum vulgare;* R, S, T: on *Triticum aestivum*.

and 124 isolates, (10) 16,5—21,7 (29) × (2) 2,1—4,0 (6) μm, (2) 3,4—4,1 (5) -septate, mostly 19,2 × 3,2 μm, 3,5-septate (Table 2).

According to SPRAGUE (1950), the size of conidia is 15—32 × 2—4 μm and of pycnidia 160—210 μm in diam. On various hosts in Norway, the size of conidia varies, 12—35 × 2—3,5 μm and of pycnidia 50—160 μm in diam. (JORSTAD 1967). In the present study, conidia are rather similar in size, but perhaps a little broader and pycnidia larger than in the materials described above.

The perfect stage was found occasionally on overwintered dead leaves and culms of grasses and cereals in southern Finland, mainly in spring (25. V—6. VI; 3. VIII), on the following species: *Agrostis stolonifers*, *A. tenuis*, *Calamagrostis* sp., *Dactylis glomerata*, *Deschampsia caespitosa*, *Festuca rubra*, *Hordeum vulgare*, *Phleum pratense*, *Secale cereale* and *Triticum aestivum* (KOPONEN and MÄKELÄ 1975).

Material examined:

Agropyron caninum — St: Merikarvia. *A. repens* — V: Kiikala, Paimio, Perniö, Vihti; U: Espoo, Helsinki, Inkoo, Kirkkonummi, Snappertuna; EK: Imatra; St: Mellilä; EH: Forssa, Koski Hl, Ruovesi, Tammela, Viiala; PH: Karstula; PK: Ilomantsi, Tuupovaara; Kn: Paltamo; PP: Ii. *Agrostis stolonifera* — U: Helsinki; LK: Simpele; Kn: Paltamo. *A. tenuis* — U: Helsinki (3 specimens), Inkoo, Vantaa; St: Parkano; ES: Mikkelin commune; EP: Kauhajoki; PK: Ilomantsi; KP: Lappajärvi; EnL: Karesuvanto; InL: Inari (2 specimens). *Agrostis* sp. — U: Helsinki; EH: Hämeenlinna; ES: Valkeala; PS: Heinävesi; PK: Tuupovaara. *Alopecurus pratensis* — V: Kodisjoki, Muurla; U: Helsinki; EH: Asikkala, Hämeenlinna; InL: Inari. *Anthoxanthum odoratum* — PH: Sumiainen; PK: Ilomantsi; EnL: Enontekiö. *Bromus inermis* — U: Helsinki; InL: Inari. *Calamagrostis arundinacea* — EH: Mäntsälä. *C. canescens* — Kn: Paltamo. *C. epigeios* — V: Pusula; EH: Hollola, Mäntsälä. *C. purpurea* — PK: Ilomantsi; InL: Inari. *Calamagrostis* sp. — EH: Hämeenlinna (2 specimens). *Dactylis glomerata* — V: Mietoinen; U: Helsinki (10 specimens, 26. IX. 1971, P.A.); EH: Hämeenlinna, Jaala; ES: Mikkeli; InL: Inari. *Deschampsia caespitosa* — U: Helsinki, Vantaa; EK: Imatra; EH: Sysmä; ES: Mäntyharju: EP: Alavus 27. VIII. 1972, P.A., Jurva, Korsnäs; PS: Heinävesi; PK: Ilomantsi; KP: Kalajoki, Lappajärvi; PP: Ii, Simo; Kn: Paltamo, Puolanka. Ristijärvi; EnL: Enontekiö; InL: Inari. *D. flexuosa* — U: Sipoo; ES: Mäntyharju. *Festuca ovina* — U: Helsinki, Tuusula; EH: Urjala; KemL: Kolari; EnL: Enontekiö. *F. pratensis* — V: Mietoinen, Salo; U: Helsinki (5 specimens), Inkoo; PP: Rovaniemi commune; InL: Inari. *F. rubra* — U: Helsinki, Tuusula; St: Kokemäki, Parkano; EH: Hattula, Hämeenlinna, Urjala; ES: Mikkeli; LK: Simpele; EP: Jurva; Kn: Paltamo; InL: Inari, Utsjoki. *Festuca* sp. — U: Helsinki ; ES: Valkeala. *Hordeum vulgare* — V, U, St, EH, ES, EP, PS, InL: (ca. 800 samples from 43 localities) (MÄKELÄ 1975). *Lolium multiflorum* — InL: Inari. *L. perenne* — U: Helsinki. Tuusula; St: Kokemäki; InL: Inari. *Melica nutans* — U: Tuusula; EH: Joutsa. *Molinia coerulea* — PK: Ilomantsi. *Nardus stricta* — ES: Mikkelin commune; PH: Karstula (2 specimens); PK: Ilomantsi; Kn: Vaala; Ks: Posio. *Phleum nodorum* — U: Helsinki; EP: Teuva. *P. pratense* — U: Helsinki (7 specimens), Tuusula, Vantaa; St: Kokemäki; EH: Hämeenlinna, Urjala 8. VIII. 1972, P.A.; ES: Mikkeli; InL: Inari. *Poa annua* — U: Helsinki. *P. palustris* — U: Helsinki; EH: Hattula. *P. pratensis* — U: Helsinki (3 specimens), Tuusula; KP: Kruunupyy. *Poa* sp. — U: Inkoo; PK: Tohmajärvi. *Secale cereale* — U, St, EH, EP, PH, KP, about 340 samples from 11 localities (MÄKELÄ 1975). *Triticum aestivum* — V, U, St, EH, ES, EP, PH, PS, PK, KP, Kn, InL, about 480 samples from 81 localities (MÄKELÄ 1975).

Septoria oudemansii Saccardo, originally described as *S. poae* Oud. Aanwinsten Fl.

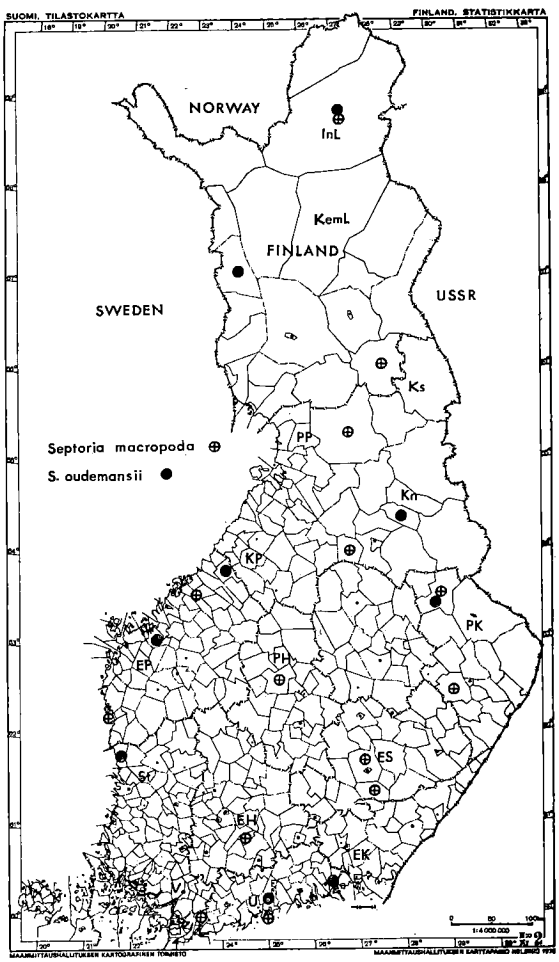

Fig. 7. The occurrence of *Septoria macropoda* and *S. oudemansii* on *Poa* species by localities in Finland.

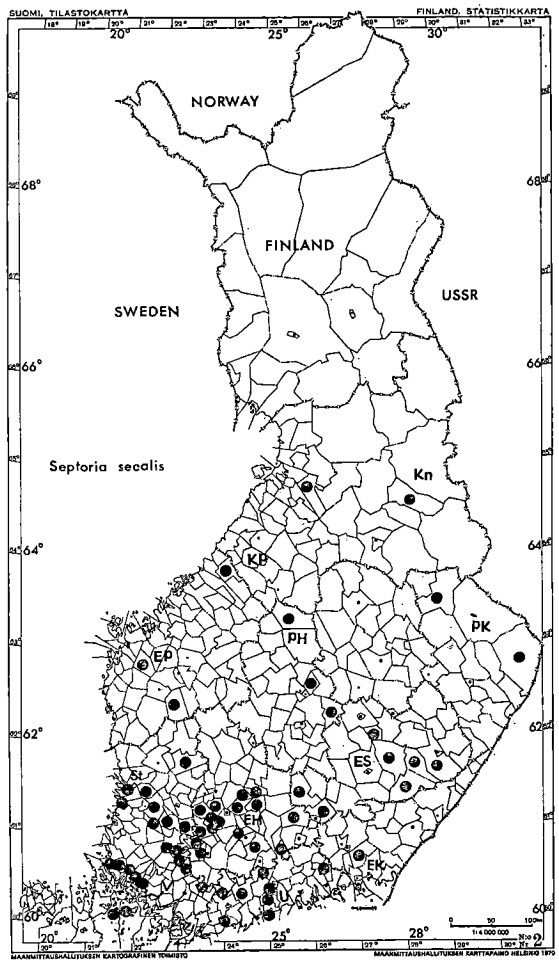

Fig. 8. The occurrence of *Septoria seca is* on *Secale cereale* by localities in Finland.

Myc. Nederl. p. 9, 1877, Syll. Fung. III: 563, 1884. syn. cf. ALLESCHER 1901: 917, SPRAGUE 1944: 57, JØRSTAD 1967: 45.

Septoria oudemansii Sacc. is an obscure but widespread parasite on *Poa* species in North America and Europe (ALLESCHER 1901. FRANDSEN 1943, SPRAGUE 1944, 1950, HOWARD et al. 1951, JØRSTAD 1967).

In the present study, *S. oudemansii* was found rarely and sporadically throughout the country (Fig. 7) on withered leaves or leaf parts of *Poa* species. The fungus was found on *Poa pratensis* (eight of 151 specimens studied), and *P. nemoralis* L. (two of 15 specimens). The specimens with conidia were collected between June 8 and September 22.

Pycnidia were 80—180 μm in diam., conidia cylindrical, often with one septum (Figs. 6 and 11), on *P. pratensis* (12) 16,5 (20) × (1,8) 2,0 (3,0) μm, 2— (3—) -septate, and on *P. nemoralis* (16) 24,7 (32) × (1,0) 2,0 (3,0) μm, 2— (3—) -septate. In this study the size of the conidia is rather similar to, but of pycnidia greater than in FRANDSEN's (1943) and JØRSTAD's (1967) material.

Material examined:

Poa pratensis — U: Helsinki 2. VIII. 1972, Ruotsinpyhtää IX. 1966 (K.M.); St: Merikarvia 14. VIII. 1972 (H.K.); PK: Nurmes IX. 1966 (K.M.); KP: Kannus IX. 1966 (K.M.); Kn: Ristijärvi IX. 1966 (K.M.); KemL: Kolari VIII. 1966 (K.M.); InL: Ivalo VIII. 1966 (K.M.). *P. nemoralis* — U: Helsinki commune 8. VI. 1968 (P. A.); EP: Vöyri 18. VIII. 1972 (H.K.).

Septoria secalis Prillieux and Delacroix, Bull. Soc. Myc. Fr. 5: 125, 1889 (SACCARDO 1892: 386, ALLESCHER 1901: 853, SPRAGUE 1944: 84, 1950: 253).

The fungus causes leaf blotch on rye in the USA and Europe (WEBER 1923, JØRSTAD 1930, 1945, 1967, FRANDSEN 1943, SPRAGUE 1950, RICHARDSON and NOBLE 1970).

In this study, *S. secalis* occurred, only on winter rye, throughout the country as far north as North Ostrobothnia (Muhos) and Kainuu (Hyrynsalmi) (Fig. 8). The disease was found to occur most commonly in the southwestern and southern parts of Finland, which are the country's main areas of rye cultivation.

S. secalis was found on average in 26 per cent of the 341 fields and in about half of the 112 localities studied. Most specimens of the fungus were collected in July (25. V—8. VIII).

Pycnidia of *S. secalis* were found in greatest abundance on ripening and withering leaves, on brown necrotic spots.

Pycnidia were brown, measuring (72) 155 (279) μm in diam. Macroconidia were cylindrical, rounded at the ends, (20) 34,4 (54) μm × (2,5) 3,2 (5,0) μm, 3-septate (Figs, 9 and 11). According to SPRAGUE (1944, 1950), the conidia measure 25—50 × 2,0—3,5 μm, mostly 35 × 2,5 μm, while JØRSTAD (1967) in Norway gives a size of 20—45 × 2—3 (3,5) μm.

The fungus is clearly of no economic importance (cf. WEBER 1923, JØRSTAD 1930, FRANDSEN 1943).

Material examined:

Secale cereale — V, U, EK, St, EH, ES, EP, PH, PS, PK, KP, Kn, PP; about 340 samples from 60 localities (MÄKELÄ 1975).

Septoria tenella Cooke and Ellis, Grevillea 8: 11, 1879 (SACCARDO 1884: 562, syn. SPRAGUE 1944: 87, JØRSTAD 1967: 49). SPRAGUE

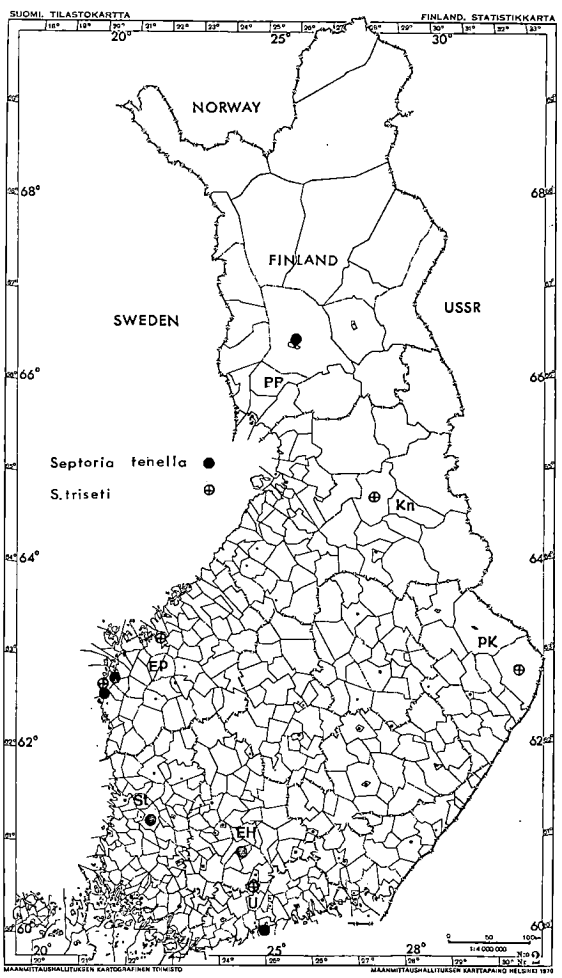

Fig. 10. The occurrence of *Septoria tenella* on *Festuca* species and *S. triseti* on *Agrostis* spec es by localities in Finland.

(1944) unites *S. festucae* Died. with *S. tenella*, whilst JØRSTAD (1967) considers them as two different species.

Septoria tenella is known to attack *Festuca* species in the United States, Europe and Asia (SACCARDO 1884, SPRAGUE 1944, 1950, 1954, HOWARD et al. 1951, JØRSTAD 1967).

In this study, *S. tenella* was found sporadically and infrequently throughout the country (Fig. 10). The fungus was found on *Festuca rubra* (six of 269 specimens studied) and *F. pratensis* (two of 534 specimens).

Pycnidia were 80—190 *µm* in diam., conidia filiform, straight or flexuous, on *F. rubra* (17) 39,9 (60) × (0,5) 1,6 (2,0) µm, and on *F. pratensis* (30) 36,1 (40) × (1,0) 1,3 (1,5) µm, without visible septa (Fig. 11). According to SPRAGUE (1944), the conidia are exceedingly variable, measuring from 5—70 × 0,8—2,1 µm. The most frequent size is 25—45 × 1—1,5 µm, 0- to 2-septate. On Norwegian *F. pratensis*, the size of conidia is 26—72 × 1—1,5 µm (JØRSTAD 1967).

Material examined:

Festuca pratensis — U: Helsinki 9. IX. 1968 (K.M.); PP: Rovaniemi 22. IX. 1966 (K.M.). *F. rubra* — U: Helsinki 2. VIII. 1972 (H.K.) 2 specimens; St: Kokemäki 21. VIII. 1972 (H.K.); EH: Hämeenlinnan 24. III. 1967 (K. M.); EP: Korsnäs 18. VIII. 1972 (H.K.), Petolahti 18. VIII. 1972 (H.K.).

Septoria tritici Roberge, DESMAZIERES, Ann. Sci. Nat. Bot. Ser. 2, 17: 107, 1842 (SACCARDO 1884: 561), syn. cf. FRANDSEN 1943: 14,S PRAGUE 1944: 26.

The fungus causes speckled leaf-blotch, mainly on winter wheat in the spring (JØRSTAD 1945, 1967, NILSSON 1950, SPRAGUE 1950, SANDERSON 1964, RICHARDSON and NOBLE 1970), but also on spring wheat (LEBEDEVA 1960, COOKE and JONES 1971), on other *Triticum* species, on *Secale cereale* L. (WEBER 1922b, SPRAGUE 1950) and on certain grass species (ALLESCHER 1901, WEBER 1922b, GROVE 1935, TETEREVNIKOVA-BABAYAN and BOKHYAN 1970, WILLIAMS and JONES 1973).

S. tritici is widespread and important, particularly in moist conditions (FRANDSEN 1943, SPRAGUE 1950, SANDERSON 1964, TETEREVNIKOVA-BABAYAN and BOKHYAN 1967, RICHARDSON and NOBLE 1970). In Scandinavia the fungus has been known in Denmark and Sweden since last century (cf. FRANDSEN 1943) and in Norway since 1931 (JØRSTAD 1945, 1967). Nowadays the fungus is little known.

In the present study, *S. tritici* occurred only on winter wheat, but is common particularly in the south-western parts of Finland, where most of the winter wheat is grown (Fig. 1). The fungus was encountered in 38 per cent of the 259 fields and in about half of the 93 localities studied. Most of the specimens of *S. tritici* were collected in May (8. V—8. VI).

Pycnidia of the fungus were found on brown — greyish brown — yellowish brown leaf spots (Fig. 9). Pycnidia were blackish brown, flattened, measuring (62) 117 × 129 (204) µm in diam. (Figs. 9 and 11). Macroconidia were obclavate — filiform, slightly curved, (24) 55,5 (82) × (1) 2,0 (3) µm, (1) 3,2 (6) -septate (Figs. 9 and 11). In the present study, the size of the fungus is rather similar to that reported by JØRSTAD (1967).

Material examined:

Triticum aestivum (winter wheat) — V, U, St, EH, KP; about 260 samples from 34 localities (MÄKELÄ 1975).

Septoria triseti Spegazzini, Fung, Fueg. no 421, 1887 (SACCARDO 1892: 385, SPRAGUE 1944: 105).

Septoria triseti is known occur most abundantly on *Agrostis tenuis*, less on some other *Agrostis* species in the United States and

Argentina (SACCARDO 1884, SPRAGUE 1944, 1950, HOWARD et al. 1951).

In this study, *S. triseti* was found sporadically and infrequently in the southern and central parts of the country (Fig. 10). The fungus was found on *Agrostis tenuis* (four of 363 specimens studied), and *A. canina* (one of seven specimens). The specimens with conidia were collected between July 3 and August 17.

Pycnidia were yellowish brown, 80—150 (300) μm in diam., conidia filiform; straight, bent or curved, on *A. tenuis* (22) 26,8 (30) × 0,5 μm (Hyvinkää, Oravainen), (38) 50,7 (55) × 1 μm (Korsnäs), and on *A. canina* (26) 30,2 (35) × 1 μm (Fig. 11). According to SPRAGUE (1944, 1950), the conidia measure 16—43 (18—35) × 0,8—2,0 (1,3—1,7) μm, 0- to 1- septate.

In the present study, *S. triseti* resembles *S. phleina* Baud. & Picb. and *S. calamagrostis* (Lib.) Sacc. (cf. SPRAGUE 1944, 1950, JØRSTAD 1967).

Material examined:

Agrostis canina — PK: Ilomantsi 3. VII. 1972 (H.K.). *A. tenuis* — U: Hyvinkää 6. VIII. 1972 (H.K.); EP: Oravainen 17. VIII. 1972 (H.K.), Korsnäs 16. VIII. 1972 (H.K.); Kn: Puolanka 8. VIII. 1973 (H.K.).

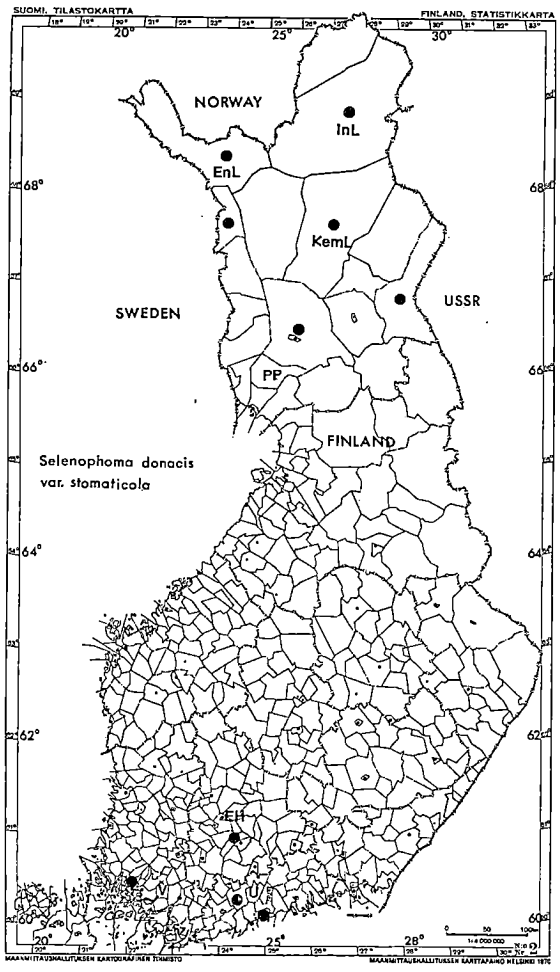

Fig. 12. The occurrence of *Selenophoma donacis* var. *stomaticola* on *Graminae* by localities in Finland.

Selenophoma Maire

Selenophoma donacis (Pass.) Sprague & A. G. Johnson, Mycologia 32: 415, 1940, syn. *Septoria oxyspora* Penz. et Sacc. F. Mortol. Tav. IV, Fig. 13, Saccardo. Syll. Fung. III: 565, 1884, syn cf. SPRAGUE and JOHNSON 1947: 740, 1950: 12.

Selenophoma donacis var. *stomaticola* (Bäuml.) Sprague & A. G. Johnson, Mycologia 37: 639, 1945, syn. cf. SPRAGUE and JOHNSON 1947: 740, 1950: 20. *Selenophoma* is a genus of *Sphaeropsidales* (AINSWORTH 1967).

The fungus produces leaf spots, eye spot, halo spot, on numerous species of *Graminea* in Europe, North America, Asia, and Australasia (GROVE 1935, SAMPSON and WESTERN 1942, FRANDSEN 1943, SPRAGUE 1950, SPRAGUE and JOHNSON 1950, SHAW 1953b, LATCH and WENHAM 1959, JØRSTAD 1962, 1967, HANSEN and MAGNUS 1969).

In Finland, the fungus has been known since 1887 on *Phragmites communis* Trin. in EH: Mustiala, by the name *Septoria curva* Karst. (KARSTEN 1887: 103). Since this time the species has been recorded infrequently.

In the present study, all the Finnish material examined seems to belong to the *S. donacis* var. *stomaticola*, which nevertheless intergrades with the main form (cf. SPRAGUE 1950: 207,

SPRAGUE and JOHNSON 1947: 740, 1950: 12, 20). The situation is similar in Norway and Iceland (JØRSTAD 1962, 1967).

The fungus occurred sporadically, mostly in northern Finland, but very occasionally also in the southern parts of the country (Fig. 12). The fungus was found on 22 specimens of eleven grass species and on six specimens of three cereals. The specimens with conidia were collected between June 2 and October 12.

Lesions were light coloured, with minute golden brown or black pycnidia 40—150 μm in diam., often in rows between the veins (Fig. 9). Conidia were falcate with an acute apex, septate, (9) 12—15 (22) × (1) 2,2—2,4 (5) μm, very similar on all hosts (Figs. 9 and 13). In this study, the size of conidia is quite similar to values reported earlier (PETRAK 1929, GROVE 1935, SPRAGUE and JOHNSON 1950, JØRSTAD 1967).

The fungus is of negligible importance in Finland.

Material examined:

Agropyron repens — InL: Inari 1. IX. 1968 (Eila Metsäpelto). *Agrostis tenuis*. — KemL: Muonio 27. VII. 1973 (H.K.). *Alopecurus pratensis* — U: Helsinki 2. VI. 1969; InL: Inari 1. IX. 1968 (Eila Metsäpelto). *Anthoxanthum odoratum* — Ks: Salla 3. VIII. 1973; EnL: Kilpisjärvi 29. VII. 1973 (H.K.). *Avena sativa* — InL: Inari 8. IX. 1973 (K.M.). *Calamagrostis* sp. U: Helsinki 15. VI. 1967 (K.M.). *Dactylis glomerata* — U: Helsinki 20. VI. 1967, 12. X. 1972; InL: Inari 1. IX. 1968, 15. IX. 1969, 16. IX. 1970, 7. VIII. 1973 (K.M.). *Deschampsia caespitosa* — V: Masku 25. VII. 1972; KemL: Sodankylä 2. VIII. 1973 (H.K.). *Festuca pratensis* — InL: Inari 22. VII. 1968 (K.M.). *F. rubra* — InL: Inari 7. VIII. 1973 (K.M.). *Hordeum vulgare* — KemL: Sodankylä 2. VIII. 1973; InL: Inari 8. IX. 1973 (K.M.). *Phleum pratense* — V: Vihti 15. VIII. 1968; U: Helsinki 10. VI. 1968; PP: Rovaniemi 1. X. 1969; InL: Inari 7. VIII. 1973 (K.M.). *Poa pratensis* — EH: Tyrväntö 24. VI. 1965 (P.A.). *Triticum* sativum — InL: Inari 7. VIII. 1973, 8. IX. 1973, 24. IX. 1974 (K.M.).

DISCUSSION

In this investigation the material used consisted of plant samples collected from the wild or from cultivation. The bulk of the cultivated grass samples was collected from 1968 to 1970, and most of the wild grasses and the cereals from 1971 to 1973. On account of the rather start period of collection and abundance of material collected, the material provides a fairly reliable index of the fungal flora, its occurrence, abundance and its internal relations. On the other hand, a material collected over a longer period might have revealed a larger number of species.

The determination of *Septoria* species is often difficult. There have been few taxonomic investigations in recent years. SPRAGUE's detailed studies have been made mostly in the United States, where the grass flora is very different from in Europe (cf. JØRSTAD 1967). FRANDSEN's (1943) investigations in Denmark were made before there of SPRAGUE, so ffrhat the nomenclatures differ. In the Norwegian investigations of JØRSTAD (1967), too, in which the grass flora is similar to that of Finland. There is uncertainly in the nomenclature of many species of *Septoria*. JØRSTAD does not accept Spragues nomenclatural system unreservedly. In any case, JØRSTAD's account does not have any illustrations.

The identification of species is rendered still more difficult by the large amount of intraspecific variation, which is due to varying age of the fungus, environmental factors and different hosts. On the other hand morphologically, similar species can be distinguished on the basis of their physiological characteris-

tics, pathogenicity and host range (cf. SPRAGUE 1944, JØRSTAD 1967).

In the present investigation, the identification of fungus species was made with the aid of extensive microphotographi, drawings and measurements as well as infection experiments in the case of the *Septoria* species of cereals (cf. MÄKELÄ 1975).

This present study reveals that in Finland *Septoria* fungi occur commonly on cereals, particularly on wheat and barley. However there fungi are much rarer on wild grasses. The situation is similar in other Northern countries (FRANDSEN 1943, JØRSTAD 1967).

Septoria nodorum occurred on wheat as a leaf and ear pathogen (FRANDSEN 1943, JØRSTAD 1967, BRÖNNIMANN 1968). The fungus also occured on barley, but is apparently of little significance (cf. HANSEN and MAGNUS 1969, RICHARDSON 1972). As well as on cereals, the fungus was found to occur, though rarely, on numerous grasses (cf. SPRAGUE 1950, HOPP 1957, JØRSTAD 1967, TETEREVNIKOVA-BABAYAN and BOKHYAN 1970, WILLIAMS and JONES 1973). The fungus is regarded as being a very weakly specialised species (WEBER 1922a, HOPP 1957, BRÖNNIMANN 1968). This opinion is supported by the laboratory inoculation tests made by the author (MÄKELÄ 1975).

Septoria avenae f.sp. *triticea* occurred rather commonly on barley and wheat, and rarely on numerous grass species. The fungus is apparently a pathogen of minor importance in Finland, and is considered to be a weak parasite (JOHNSON 1947, SHAW 1957b).

The perfect stages (*Leptosphaeria avenaria* and *L. nodorum*) were found on all cereals and on numerous grass species, as were the corresponding *Septoria* species. In other countries, the same *Septoria* species (*S. nodorum*, *S. tritici*) occur on cereals and grasses (WEBER 1922b, SPRAGUE 1950, JØRSTAD 1967). Evidently both species can survive on grasses, too, and it seems possible that both may overwinter in this way (TETEREVNIKOVA-BABAYAN and BOKHYAN 1970, WILLIAMS and JONES 1973). The present investigation did not clarify the role the perfect stage and grasses play in the survival and transmission of these fungi.

The other eight *Septoria* species found in this study occurred only on certain cereal or grass species or genera.

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Kymmenestä todetusta *Septoria*-lajista *S. nodorum* esiintyi yleisenä vehnällä, melko yleisenä ohralla ja harvinaisena rukiilla, sekä lisäksi 27:llä heinälajilla. *S. avenae* f. sp. *triticea* oli yleinen ohralla, melko yleinen vehnällä ja esiintyi sitäpaitsi 20:llä heinälajilla. *S. tritici* oli yleinen syysvehnällä keväällä. *S. secalis* esiintyi melko yleisenä rukiilla ja *S. avenae* f. sp. *avenae* harvinaisena kauralla. Satunnaisena esiintyivät myös *S. elymi* juolavehnillä, *S. macropoda* ja S. *oudemansii* nurmikka-lajeilla, *S. tenella* nadoilla ja *S. triseti* rölleillä. Taloudellista merkitystä on ennenmuuta *S. nodorum*illa ja *S. tritici*llä vehnän tautien aiheuttajina.

Selenophoma donacis var. *stomaticola* esiintyi harvinaisena viljoilla ja heinillä varsinkin maan pohjois-osissa.

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QUINTOZENE IN SOME SOILS AND PLANTS IN FINLAND

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Residues of quintozene (pentachloronitrobenzene, PCNB) and its metabolites or technical impurities pentachlorobenzene (PECB), hexachlorobenzen (HCB), tecnazene (tetrachloronitrobenzene, TCNB), pentachloroaniline (PCA) and methylthiopentachlorobenzene (MTPCB) were analysed in 19 soil samples and 9 plant samples. In general, the residues were higher in the soil of forest tree nurseries (PCNB maximum 27,0 mg/kg) than in agricultural soil (PCNB maximum 12,2 mg/kg). PCA and MTPCB were found in all treated soils, the highest residues being 2,4 and 2,15 mg/kg, respectively. The highest TCNB residue was 6,0, the highest HCB 0,21 and the highest PECB 0,09 mg/kg.

The PCNB residues in plants treated in the autumn and sampled half a year later were, in general, smaller than the residues in the soil in which they were growing, the highest residue being 0,14 mg/kg in one winter wheat sample. Not all the metabolites or impurities were found in plants.

Index words: Quintozene, pentachloroaniline, tetrachloronitrobenzene, hexachlorobenzene, pentachlorobenzene, methylthiopentachlorobenzene, soil, persistence.

Quintozene (pentachloronitrobenzene, PCNB) is known to be relatively stable pesticide (e.g. EDVARDS and THOMPSON 1973). Its half-life in soil has been estimated to be about 400 days (BECK and HANSEN 1974). These authors found residues of quintozene and its metabolites and technical impurities pentachlorobenzene (PECB), hexachlorobenzene (HCB), tecnazene (tetrachloronitrobenzene, TCNB), pentachloroaniline (PCA) and methylthiopentachlorobenzene (MTPCB) in soils treated with quintozene.

In Finland quintozene has been used since the 1950's specially to protect winter wheat, winter rye and grasses as well as clover against winter killing fungi. In forest tree nurseries quintozene has been used to protect the seedlings against black snow mold (*Herpotricha nigra* Hartig) and snow blight (*Phacidium infestans* Karst.)

The amount of quintozene used during the period 1968—1976 totalled 182,5 tons (active ingredient) (MARKKULA and TIITTANEN 1969—1975, TIITTANEN and BLOMQVIST 1976, 1977) the annual distribution being as follows:

Year	Tons	Year	Tons
1968	21,4	1972	19,8
1969	25,4	1973	16.3
1970	33,5	1974	11,2
1971	30,5	1975	17,4
		1976	7,0

On average 40 % of the preparations were dusts and 60 % wettable powders. Wettable

powders are mainly used in cereal cultivations, and dusts in forest tree nurseries. In cereal cultivation the amount used is 4—6 kg a.i. per hectare. Winter wheat and rye are treated in the autumn, just before the permanent snow cover arrives. Quintozene has been used mainly in central Finland. In 1970, when most quintozene was sold, the quantity of wettable powders (17,1 tons a.i.) was enough to treat about 3 000 hectares of winter cereals.

Practically all the forest tree nurseries are treated at least once a year the normal amount being 5—10 kg a.i. per hectare.

MATERIAL AND METHODS

Forest tree nurseries

The soil samples weighing about 1 kg each and consisting of ten subsamples, were taken in June 1976 from the areas of three nurseries in southern Finland (Table 1). The amount of PCNB used in each sampling site was known with a comparatively high degree of accuracy.

Table 1. Residues of quintozene and its metabolites in soil and plants. The three forest tree nurseries, Haapastensyrjä, Oitti and Röykkä, are situated in southern Finland. The soil type was peat (samples 1—6) or mixed peat and sand (samples 7 and 8) Samples 9—19 were located in southern or central Finland as follows: 9 Agric. Res. Centre, Vantaa; 10—11 Central Finland Exp. Sta., Laukaa; 12—15 Häme Exp. Sta., Pälkäne; 16—19 Kotkaniemi Exp. Farm of Kemira Company, Vihti.
PCNB = pentachloronitrobenzene, PCA = pentachloroaniline, TCNB = tetrachloronitrobenzene, HCB = hexachlorobenzene, PECB = pentachlorobenzene, MTPCB = methylthiopentachlorobenzene.

Sample	Locality		Quintozene treatments		PCNB residues recovered as % of the total use	Residues mg/kg					
			Years	Total a.i. kg/ha		PCNB	PCA	TCNB	HCB	PECB	MTPCB
Forest tree nurseries											
1	Haapastensyrjä		1971—1974	20—40	100	27,0	2,4	0,05	0,21	0,09	2,15
2	Haapastensyrjä		1972—1974	15—30	8	1,46	1,3	0,006	0,06	0,06	0,71
3	Haapastensyrjä		1975	7	14	0,90	0,33	6,0	0.001	0,001	0,12
4	Haapastensyrjä		Untreated	0		0	0	0	0	0	0
5	Oitti		Several years, last one in 1970	20—40	0,1	0,05	0,10	0	0,057	0,008	0,028
6	Oitti		Untreated	0		0	0	0	0	0	0
7	Röykkä		1973—1975	30	12	3,55	0,53	0,007	0,043	0,009	0,43
8	Röykkä		Untreated	0		0	0	0	0	0	0
Fields											
9	Vantaa	soil	1975	5	16	0,21	0,04	0,004	0,002	0,0015	0,03
		rye				0,003	0,001	0	0	0	0
10	Laukkaa	soil	1975	5	12	0,30	0,07	0	0,004	0,004	0,06
		rye				0,003	0,03	0,001	0,006	0,03	0,002
11	Laukaa	soil	Untreated	0		0	0	0	0	0	0
		rye				0	0	0	0	0	0
12	Pälkäne	soil	1975	5	2	0,04	0,03	0,003	0,003	0,006	0,003
		rye				0,07	0	0,002	0,006	0,006	0
13	Pälkäne	soil	Untreated	0		0	0	0	0	0	0
		rye				0	0	0	0	0	0
14	Pälkäne	soil	1975	5	4	0,10	0,20	0.002	0,006	0,008	0,021
		clover				0,005	0	0	0	0,003	0
15	Pälkäne	soil	Untreated	0		0	0	0	0	0	0
		clover				0	0	0	0	0	0
16	Vihti	soil	1966—1975	50	48	12,2	0,75	0,07	0,123	0.0025	0,72
		wheat				0,14	0,40	0,002	0,0002	0,004	0,15
17	Vihti	soil	1975	5	37	1,85	0,33	0,013	0,048	0,094	0,18
		wheat				0,05	0,025	0,001	0,02	0,0025	0
18	Vihti	soil	1970—1973	20	0.4	0,07	0.03	0.002	0 004	0,002	0
19	Vihti	soil	untreated	0		0	0	0	0	0	0

The soil was stored at a temperature of −30°C until December 1976 when the analyses were started.

Cereals and clovers

In June 1976 samples weighing about 2 kg and consisting of ten subsamples were taken from the 20 cm soil layer of 11 fields on four localities. Like in forest tree nurseries, the use of PCNB on these fields was known relatively well. Samples were intentionally taken from the fields known to be treated for a long time or only once. Two of the fields (16 and 17 in Table 1) were exceptionally sampled in July 1977 and analysed immediately.

Samples of cereals and clovers (about 1 kg each) were taken from the same areas as soil samples at the same time.

Both the soil and the plants sampled in June 1976 were stored at −30°C until December 1976 when analyses were started.

Chemicals

The solvents were *pro analysi* quality and freshly distilled. PCNB, TCNB, HCB and PECB, which were used as reference and standard compounds, were commercial chemicals, and their purity was calculated by^1 H NMR and MS. PCA was prepared from PCNB by catalytic hydration using palladium on carbon as catalyst.

Extraction

The soil samples (50 g) were homogenized in a 150 ml mixture (1:1) of diethyl ether and petroleum spirit (bp. 40°C). The homogenate was sedimented over 24 hours and dried over sodium sulphate.

Cereal and clover samples (10—50 g) were peeled and extracted in a Soxhlet apparatus for 6 hours into a mixture of diethyl ether and petroleum spirit (1:1). The extracts were dried over anhydrous sodium sulphate and evaporated *in vacuo* down to 1—4 ml and, depending on the original concentration of the residues, diluted with hexane to 2—50 ml.

Gas-liquid chromatography

The concentrates were examined by GLC using a Carlo Erba 2 300 instrument, provided with a nickel-type EC detector. The chromatograms (see Fig. 1) were recorded using both a 50 m OV-101 and a 40 m Silar 5CP glass capillary column, i.d. 0,3 mm, at 150°C, and 4 ml hydrogen per minute as the carrier gas. The sensitivity of the method was 10—100 pg per μl.

Identifications

The identification of MTPCB was based on its mass spectrum (MW = 294—304), which was recorded with a GLC—MS system. The rest of the compounds were identified according to their similar retention times to the reference compounds in two glass capillary GLC

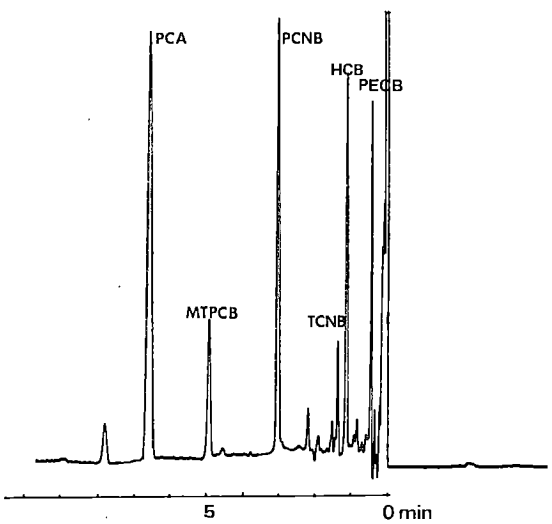

Fig. 1. The gas chromatogram (OV-101 column at 160°C) for the sample No 4 in Table 1.

columns (OV-101 and Silar 5CP), working with various temperature programme.

Recoveries

The compounds were added to the soil and plant samples at concentrations of 0,1—0,01 ppm. After 2 days the samples were analyzed and the GLC peak areas were compared with those obtained from standard solutions. The recoveries were as follows:

	soil	plant
PECB	58 %	46 %
HCB	81	53
TCNB	75	68
PCNB	59	68
PCA	75	70

In calculating the amounts of the residues of MTPCB the mean values of the recoveries (i.e. 70 % for the soil samples and 61 % for the plant samples) were used.

RESULTS AND CONCLUSIONS

PCNB residues, varying from 0,05 to 27,0 mg/kg, were found in all the forest tree nurseries known to have been treated by PCNB (Table 1). The weight of a 20 cm thick peat and sand soil layer of one hectare is not known exactly but if it is estimated to be about half of the weight of mineral soil (= 2 million kg per hectare), the highest PCNB residue is equal to 27 kg of PCNB per hectare. The total amount of PCNB used in this area was 20—40 kg a.i. per hectare, so that all the PCNB used was left in soil. In other areas PCNB residues were smaller (0,05 to 3,55 mk/kg) and only 0,1 % to 14 % of PCNB was left in soil.

Residues in cereal and clover fields were in general smaller than those in forest tree nurseries (0,04 to 12,2 mg/kg). The highest residue found in field 16 in Table 1, which was treated during ten succeeding years with 50 kg a.i. of PCNB, was equal to about 25 kg of PCNB in an area of one hectare (= 2 million kg of soil). Approximately half of the total amount of PCNB used in this area was left in soil. In field 17, where PCNB residue was 1,85 mg/kg, about 37 % of the total amount of PCNB used was left but in other fields this figure was smaller.

PCNB residues in cereals and clover were small, the highest being 0,14 mg/kg in winter wheat growing on field 16. The Finnish Pesticide Regulation Unit has suggested a tolerance of 1,0 mg/kg for PCNB in agricultural products.

All the metabolites and impurities found by BECK and HANSEN (1974) were present in these soil samples, too. In general, PCA and MTPCB residues were higher than those of HCB, TCNB or PECB, which did not exceed 0,1 mg/kg.

It seems to be evident that PCNB has not been accumulated in agricultural soils even after use of several years. However, the high PCNB residue found in one forest tree nursery, 27 mg/kg, justifies the author's oppinion that the soil of forest tree nurseries treated with PCNB should not be used as soil-improving agent in fields or glass-houses where vegetables are cultivated.

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SELOSTUS

Kvintotseenin jäämät maassa ja kasveissa

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Suomessa käytetään kvintotseenia eli PCNB:tä vuosittain useita tonneja talvituhosienien torjuntaan syysviljoissa, apilanurmissa ja metsäpuiden taimistoissa. Enimmillään PCNB:n käyttö oli 1970, jolloin sen levitysmäärä kohosi 33,5 tonniin. Kvintotseeni tiedetään melko pysyväksi torjunta-aineeksi. Sen puoliintumisajaksi maassa on Tanskassa laskettu noin 13 kuukautta. Tämän vuoksi tutkittiin eräiden metsäpuutaimistojen kasvualustojen sekä peltomaiden kvintotseenipitoisuutta 1976. Tutkittaviksi valittiin erityisesti sellaisia alueita, joilla tiedettiin kvintotseenia käytetyn verraten runsaasti ja pitkään. Samoilla pelloilla kasvaneista syysviljoista ja apilasta otettiin myös näytteet, joiden kvintotseenipitoisuus tutkittiin.

Metsäpuutaimistoiden suurin kvintotseenipitoisuus oli 27 mg ja pienin 0,05 mg maakilossa. Kaikilta alueilta, joilla kvintotseenia tiedettiin käytetyn, löytyi sen jäämiä. Alueella, jolta suurin määrä löytyi, oli ilmeisesti kaikki neljän vuoden aikana käytetty kvintotseeni jäljellä taimien kasvualustassa. Muilla alueilla sitävastoin oli jäljellä enintään 14 % käytetystä kvintotseenista.

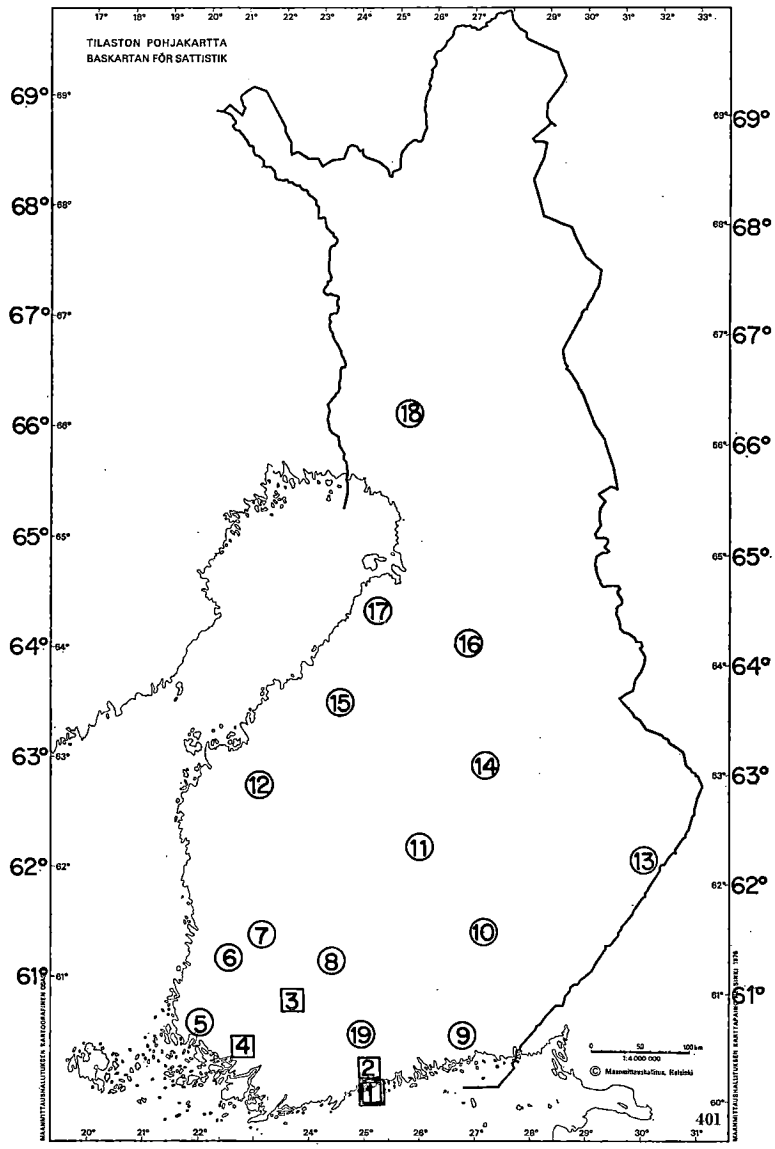
Vilja- ja apilapeltojen kvintotseenipitoisuudet olivat pienemmät kuin metsäpuutaimistojen kasvualostojen jäämät. Peltomaan suurin löydetty kvintotseenipitoisuus oli 12,2 mg/kg. Kaikista käsitellyistä pelloista löydettiin kvintotseenia mutta enimmilläänkin oli alueella käytetystä kvintotseenista jäljellä hieman vähemmän kuin puolet.

Syysviljoissa ja apilassa, jotka oli käsitelty kvintotseenilla syksyllä 1975, siis puoli vuotta ennen näytteiden keruuta, olivat kvintotseeni jäämät enintään 0,14 mg/kg. Suomessa ei ole voimassa virallisesti vahvistettuja torjunta-aineiden enimmäispitoisuuksia maataloustuotteissa, mutta Kasvinsuojelulaitos on valvontatyössään käyttänyt epävirallisena hyväksyttävänä

enimmäispitoisuutena WHO:n ja FAO:n suosittamaa rajaa, joka on 1 mg/kg.

Kaikista kvintotseenilla käsitellyistä alueista ja lähes kaikista kasveista löydettiin myös vaihtelevia määriä pentaklooribentseeniä (PECB taulukossa 1), heksaklooribentseeniä (HCB), teknatseenia (TCNB), pentakloorianiliinia (PCA) ja metyylitiopentaklooribentseeniä (MTPCB), jotka ovat kvintotseenia sisältävien kauppavalmisteiden epäpuhtauksia tai kvintotseenin hajoamistuotteita. Pentakloorjaniliinia ja metyylitiopentaklooribentseeniä oli maassa yleensä enitten: niiden suurimmat pitoisuudet olivat 2,4 ja 2,15 mg/kg. Muita epäpuhtauksia ja hajoamistuotteita oli enintään 0,1 mg/kg.

Vaikka metsäpuutaimistojen kasvualustojen kvintotseenimäärät olivat yleensä pienet, yhdeltä alueelta löytynyt verraten suuri kvintotseenimäärä antaa aiheen varoa käyttämästä taimistojen kvintotseenilla käsiteltyä kasvuturvetta maanparannusaineena sellaisissa puutarhoissa tai kasvihuoneissa, joissa viljellään vihanneksia tai muita syötäväksi tarkoitettuja kasveja.



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