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ANNALES AGRICULTURAE FENNIAE VOL. 15: 245—253 (1976)

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THE EFFECTS OF LIME AND PHOSPHORUS ON COPPER UPTAKE BY OATS AND ON THE RESPONSE TO COPPER FERTILIZATION

HILKKA TÄHTINEN

TÄHTINEN, H. 1976. **The effects of lime and phosphorus on copper uptake by oats and on the response to copper fertilization.** Ann. Agric. Fenn. 15: 245—253. (Agric. Res. Centre, Inst. Agric. Chem. and Phys., SF-01300 Vantaa 30, Finland).

The effects of liming and phosphate fertilization, their interaction on the grain and straw yield of oats, copper uptake and the response to copper fertilization were studied in pot experiments, using acid peat soil deficient in copper and phosphorus.

The size of the grain yield clearly depended on copper fertilization. No grains at all formed without copper. On copper deficient soils, liming only increased straw yield, inhibiting still further any slight kernel formation. When growth was not limited by lack of copper, liming slightly reduced both the grain yield and yield increases brought about by copper fertilization. Excessive phosphate fertilization on copper deficient soils lowered both yields and copper uptake by oats. When copper was applied, phosphate fertilization improved the grain and straw yield increases as well as copper uptake, and reduced the copper content of the grain. On one hand an increase in phosphorus improved the yield increases brought about by copper, on the other hand copper enhanced the favourable effects of phosphorus. The most striking effects, however, were produced by copper fertilization. Providing the copper content of the plants was adequate, an increase in the amount of copper applied did not improve grain yield significantly. Nevertheless, the copper content of the grain rose considerably when available copper was increased. The copper content of the soil depended significantly on copper fertilization alone. The three factor interaction Cu × P × Ca was not significant. The dependence of all the yield components on copper fertilization and liming were not affected by the amount of phosphate applied. Liming did not alter the relationship between the effects of copper and of phosphate fertilization.

Index words: Cu × Ca-interaction, Cu × P-interaction, Cu deficiency, Cu uptake.

INTRODUCTION

The availability of copper depends on soil acidity; as the pH rises the availability of soil copper decreases (HENKENS 1962, MISRA and TIWARI 1966). On copper deficient soils, liming has aggravated deficiency symptoms, lowered yields and reduced plant uptake of copper (SCHARRER and SCHAUMLÖFFEL 1960, HENKENS 1962, YOUNTS and PATTERSON 1964). Phosphate and nitrogen fertilization have also affected grain yield size and quality adversely on copper deficient soils (FLEMING and DELANEY 1961, VETTER and TEICHMANN 1968, BORCHMANN and FIBIAN 1971, DEKOCK et al. 1971, THIEL 1972, WAPAKALA 1973).

In Finland, copper deficiency symptoms appear most often on peat soils and on coarse mineral soils. Copper deficient soils are often in need of liming. Accordingly, this study was made to investigate the dependence of copper uptake by oats on lime and phosphorus, and on their interaction in an acid peat soil deficient in copper. The study was based on pot experiments.

MATERIAL AND METHODS

The soil was taken from a region (Muhos) where yield responses to copper fertilization had been obtained. The soil was acid, nutrient-poor Carex peat, characterized by the following soil analysis results: $pH_{(H_2O)}$ 4,20, acid ammonium acetate extractable Ca 400, P 4,2, K 20 and Mg 97 mg/l of soil (KURKI et al. 1965). Also, the copper content of the soil was low; Cu extractable in acid ammonium acetate/0,02 M EDTA was 0,3 mg/l (LAKANEN and ERVIÖ 1971).

The experiment was a 3 × 2 × 2 factorial with no replicates. There were three series: I 1966—68, II 1968—71 and III 1972—73. The experimental treatments (mg/pot) were: three copper levels 0 (Cu_0), 25 (Cu_1) and 50 (Cu_2) copper as $CuSO_4 \cdot 5H_2O$ and two levels of lime 0 (Ca_0) and 9610 (Ca_2) calcium as $CaCO_3$ and two levels of phosphate 218 (P_1) and 872 (P_2) phosphorus as $Ca(H_2PO_4)_2$.

The copper and lime were applied at the beginning of the series, the phosphorus annually. Basic fertilizer was given yearly at the following rates per pot: 1000 mg N (NH_4NO_3), 1660 K (KCl) and 1289 Mg ($MgSO_4 \cdot 7H_2O$) and micronutrients at rates of 10 mg H_3BO_3, 50 mg $MnSO_4 \cdot H_2O$, 50 mg $ZnSO_4 \cdot 5H_2O$, 10 mg $Na_2MoO_4 \cdot 2H_2O$ and 10 mg Fe-EDTA. No magnesium was given in 1969. The plant used in the experiments was Pendek oats. It was harvested ripe, except from the treatments with no copper, which remained green throughout. All treatments were harvested at the same time, however. Copper content of the grain and straw were determined in series II from 1968—70. Changes in soil acidity were measured yearly, after harvesting. Also, changes in nutrient contents caused by the experimental treatments were determined at the end of the series. Significance levels of the effects of lime, copper and phosphate fertilization and of the various interactions were tested using the analyses of variance.

RESULTS

Copper deficiency symptoms were most serious in oat stands without copper fertilization. The turgor pressure of young leaves fell, the leaf tips were bleached and twisted, and finally hung shrivelled and dry. The internodes were very short, and growth was stunted.

In all the pots receiving copper, the oats generally headed at the same time, in different years 4—12 days earlier than in the pots receiving none. Only during two years, did liming delay heading in oats which had received copper by one or two days, delaying ripening somewhat, too. Observations made in 1968 showed that there were 2—3 times as many tillers at harvesting time in the no-copper treatments as in the copper treatments, and that absence of copper resulted in a few small panicles only, which were nearly always

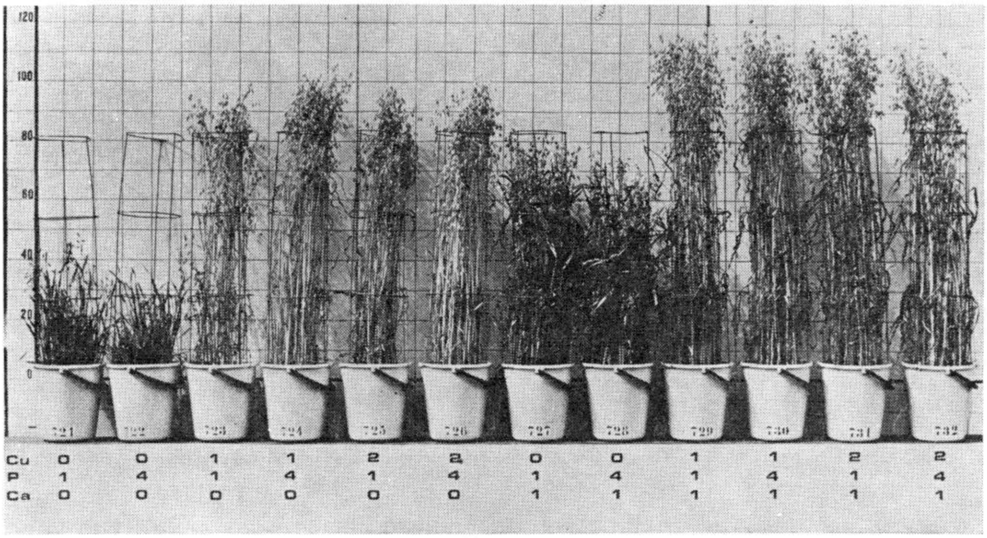

Fig. 1. Pot experiment on copper, phosphorus and lime (Photo by T. Kanerva 4. 8. 1966.)

empty (Table 1, Fig. 1). The plants receiving copper developed normally.

The grain yield was highly dependent upon copper fertilization (Tables 2 and 4). When copper was omitted, no yield at all or only a few small grains developed without lime. Liming improved grain yield slightly only when copper fertilization had been used. When lime was applied without copper, grain yield consisted of a few grams. An increase in copper from the lower to the higher level had no significant effect on yields. The interaction of lime and copper was not significant. An increase in phosphorus in the absence of copper reduced the poor grain development still further, although when copper was applied the effect of phosphorus on the grain yield was positive.

The straw yield was determined mainly by lime (Tables 2 and 4). The interaction of copper and phosphorus and of copper and lime were also significant. In the absence of copper, an increase in phosphorus decreased the straw yield, but with copper the

Table 1. Number of tillers and grain and straw yields in various treatments in 1968 for series I (3rd year) and II (1st year).

Treatment	Tillers no./pot		Grain g/pot		Straw g/pot	
	I	II	I	II	I	II
$Ca_0Cu_0P_1$	161	202	1)	2)	31,6	23,4
$Ca_0Cu_1P_1$	51	59	44,0	45,7	37,0	40,8
$Ca_0Cu_2P_1$	52	60	39,3	38,9	34,5	36,2
$Ca_0Cu_0P_4$	166	181	2)	2)	25,1	31,9
$Ca_0Cu_1P_4$	60	84	49,0	62,6	41,6	55,9
$Ca_0Cu_2P_4$	60	80	51,5	53,8	43,2	56,7
$Ca_1Cu_0P_1$	110	283	12,5	1)	80,2	80,3
$Ca_1Cu_1P_1$	70	81	50,9	62,8	68,0	63,7
$Ca_1Cu_2P_1$	64	77	45,7	59,6	48,5	60,9
$Ca_1Cu_0P_4$	177	249	0,5	0,1	62,4	82,0
$Ca_1Cu_1P_4$	71	89	47,6	62,1	49,0	61,5
$Ca_1Cu_2P_4$	75	80	53,5	63,9	53,4	63,8

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1) No grain yield
2) Grain yield $<0,05$

Table 2. Average grain and straw yields.

Treatment	Yield g/pot/year Grain	Straw
$Ca_0Cu_0P_1$	0,0[1]	38,9
$Ca_0Cu_1P_1$	43,9	41,4
$Ca_0Cu_2P_1$	43,5	39,7
$Ca_0Cu_0P_4$	0,0[1]	34,0
$Ca_0Cu_1P_4$	52,5	49,2
$Ca_0Cu_2P_4$	54,2	50,1
$Ca_1Cu_0P_1$	2,7	73,3
$Ca_1Cu_1P_1$	52,4	56,5
$Ca_1Cu_2P_1$	50,8	54,3
$Ca_1Cu_0P_4$	0,1	59,3
$Ca_1Cu_1P_4$	53,7	55,5
$Ca_1Cu_2P_4$	56,1	57,6

[1] Grain yield <0,05

effect of phosphorus was positive. Copper fertilization increased the straw yield only on unlimed soils, but still did not raise it as high as in the limed treatments. On the other hand, liming increased the straw yield most effectively when no copper had been applied.

The copper content of the yield was determined only for series II, from 1968—70 (Table 3). Since no grains formed in the absence of copper, as far as copper is concerned the test (Table 4) measures the effects of copper fertilization on copper content. Provided large amount of phosphate fertilizer had not been applied, the copper content of oat grain corresponded to the level of normal development in the pot experiments, even at the lower rate of copper application (Gupta and MacLeod 1970). The effects of copper applied were reflected significantly in the copper content of the grain. In the limed treatments, where the pH was slightly above five, the copper content of the grain was generally slightly lower than in the unlimed treatments. An increase in phosphorus fertilization reduced the copper content of the grain significantly if insufficient attention had been paid to copper fertilization. Copper content of the straw yield depended mainly on copper fertilization. However, there were no significant differences between different copper levels. The highest copper content of grain resulted from copper fertilization without lime, the lowest with phosphate fertilization.

Uptake of copper in the yield (Fig. 2 and Table 4). The level of copper applied affected significantly copper uptake of the grain. Despite the fact that liming increased grain yield, copper uptake of the grain was less in the limed treatments than in those unlimed. The increase in total copper uptake increased most strongly with the level of copper applied, and least with the level of phosphate applied. The increase in copper uptake caused by copper fertilization was significantly lower on limed than on unlimed soil. The effects of liming were reflected in a copper-lime interaction in the material.

Table 3. Copper contents of grain and straw from 1968—70 (series II).

Treatment	Cu ppm					
	Grain			Straw		
	1968	1969	1970	1968	1969	1970
$Ca_0Cu_0P_1$	—	—	—	2,21	1,40	1,67
$Ca_0Cu_1P_1$	2,93	2,48	2,21	1,87	2,07	2,87
$Ca_0Cu_2P_1$	4,92	4,33	4,24	3,67	2,80	3,33
$Ca_0Cu_0P_4$	—	—	—	1,77	1,07	1,67
$Ca_0Cu_1P_4$	2,28	1,28	2,38	2,33	2,27	2,73
$Ca_0Cu_2P_4$	3,76	3,50	3,50	3,33	2,87	3,33
$Ca_1Cu_0P_1$	—	—	—	2,00	1,33	2,33
$Ca_1Cu_1P_1$	2,38	2,15	2,15	2,67	2,13	3,00
$Ca_1Cu_2P_1$	3,08	2,68	2,38	3,00	2,33	3,51[1]
$Ca_1Cu_0P_4$	—	—	—	1,73	1,33	1,67
$Ca_1Cu_1P_4$	1,93	1,75	1,70	3,40	2,27	3,75
$Ca_1Cu_2P_4$	2,93	3,10	2,50	3,60	2,80	8,40

[1] Results of analysis missing. Estimated value (Cochran and Cox 1966).

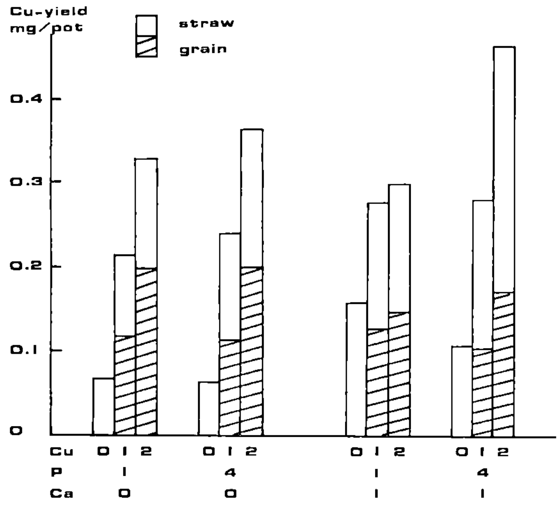

Fig. 2. Average copper uptake of grain and straw from 1968—70 (series II).

Soil analyses. Soil pH was measured each year after harvest. Of the various treatments, only liming affected soil acidity significantly (Fig. 3). After the first year, the pH of the limed soil was on average 1,6 pH units higher than that of the unlimed soil. In subsequent years, the difference narrowed a little, even though the pH of the unlimed treatments dropped slightly.

Liming was naturally the most important factor determining calcium contents at the end of the experiment (Table 5). The interaction of lime and copper fertilization was significant. The content of soil soluble phosphorus depended both on the amounts of lime and of phosphorus applied. Since liming increased yields and thus the phosphorus uptake of the yield, the level of soluble phosphorus in the soil accordingly decreased significantly. Even a small amount of phosphorus raised the phosphorus content of the soil from an original value of 4,2 mg/l at the

Table 5. Average soil calcium, copper and phosphorus contents at the end of series I—III.

Treatment	Cu mg/l soil	Ca mg/l soil	P mg/l soil
$Ca_0Cu_0P_1$	0,52	520	12,0
$Ca_0Cu_1P_1$	4,21	500	11,9
$Ca_0Cu_2P_1$	8,91	480	11,7
$Ca_0Cu_0P_4$	0,32	600	67,6
$Ca_0Cu_1P_4$	4,13	580	59,3
$Ca_0Cu_2P_4$	8,72	600	62,2
$Ca_1Cu_0P_1$	0,46	1730	6,1
$Ca_1Cu_1P_1$	4,24	1950	6,1
$Ca_1Cu_2P_1$	9,07	2020	7,0
$Ca_1Cu_0P_4$	0,38	1900	39,1
$Ca_1Cu_1P_4$	4,54	2100	51,1
$Ca_1Cu_2P_4$	8,92	1970	46,0
Significances:	Cu***	Ca*** P** Cu × Ca*	P*** Ca**

Table 4. Treatments affecting significantly the yield, the copper content and the amount of copper of the yield.

	Cu	P	Ca	Years	P × Cu	Cu × Ca	Years × Cu	P × Ca	Years × Ca
Yield:									
grain	***	***	***	***	**		***	*	
straw			***	***	***	***		**	*
total	***	*	***	***	***	***		***	**
Cu-content:									
grain[1])	***	***	**	*	***			*	
straw	***			*					
Cu-yield:									
grain[1])	***	**		**	*				
straw	**	**		*		*			
total	***	**		*		*			

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[1]) Results for copper indicate the significance of the difference between copper fertilization treatments.

Significances: * $0,01 < P \leq 0,05$
** $0,001 < P \leq 0,01$
*** $P \leq 0,001$

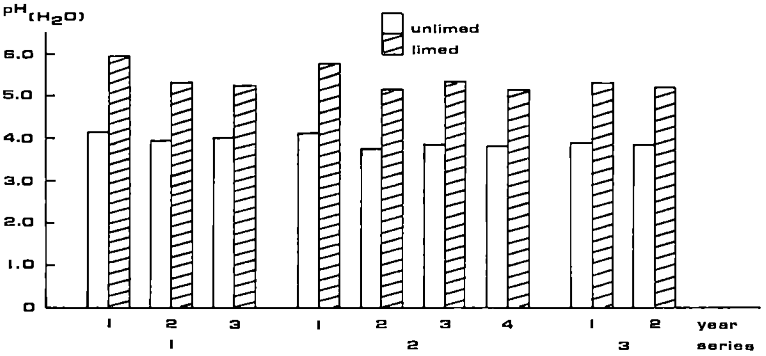

Fig. 3. Average effect of liming upon pH in different series at the end of the growing season.

beginning of the experiment to 9,1, while a large amount brought it up to 54,2, the increase being greater in the unlimed soil. Only copper fertilization had a significant effect on the copper content of the soil. Omitting copper, the copper content was 0,5 mg Cu/l. Even a low level of copper raised this value to an average of 4,3 and a high level to 8,9.

DISCUSSION

The experimental soil was very low in copper. Even during the early part of the growing season, deficiency symptoms appeared which were attributed to poor lignification of cell walls (Rahimi 1972, Rahimi and Bussler 1973 a, Pissarek 1974). The normal development of cereals requires sufficient available copper during the early part of the growing season, and the copper requirement is greatest during tillering. After heading, the plant takes up hardly any copper, and copper needed in seed formation is mobilized from the vegetative part to the seeds (Rademacher 1940). The deficiency symptoms noted here were similar to those presented in e.g. the paper by Rahimi and Bussler (1973 b). Tillers were produced very abundantly. This abnormal production of tillers caused by a deficiency of copper occurs in oats and barley, but not in wheat (Smilde and Henkens 1967). Copper deficiency was found to delay the development of oats. In this study, hardly any grains formed in the absence of copper; on the other hand even a small amount of copper sufficed for normal development in the pot experiments (Gupta and Macleod 1970). An increase in applied copper did not increase the grain yield, but did increase the copper content of the grain as well as that of the straw. This effect was reflected also in the copper content of the soil.

Liming without copper fertilization only increased the straw yield, which then tripled. Only when copper had been applied, did the grain yield increase slightly with liming. When lime was applied, the pH rose to slightly over five, and both the copper content and copper uptake of the grain developed were lower than in unlimed treatments, irrespective of the amount of copper applied. Correspondingly, the effect of copper fertilization was less. A reduction in the solubility of copper caused by the change in pH may account for this result (Peech 1941, Lucas 1948, Misra and Tiwari 1966). The detrimental effect of liming on the availability of copper to plants has been noticed in many previous studies (Scharrer and Schaumlöffel 1960, Henkens 1962, Younts and Patterson 1964). When liming has brought about increases in grain yield on soils low in copper, this has been attributed to the stimulating effect of lime upon the root system, enabling the plant to take up copper from a larger volume of soil (Younts and Patterson 1964). In these pot experiments, liming only increased the amount of copper taken up by the vegetative growth, and prevented copper from being translocated from the vegetative parts of oats to the grain. Copper extractable in ammonium acetate/0,02 M EDTA at the end of the experiments was not significantly dependent on liming.

As in earlier studies, the harmful effects of phosphorus upon yield and copper uptake on copper deficient soils were noted. The results vary somewhat according to the plant species, and relatively few experiments have been made with cereals. The mechanism involved is not fully understood. Binding of copper by the soil, prevention of copper translocation into the roots or from the roots into the aerial parts, or a greater tendency for copper to be bound by plant protein have been suggested as reasons. In these experiments, the last explanation seems unlikely, since when copper was omitted, yield and its copper content were slightly lowered by phosphorus. However, neither the amount of protein nor its quality in the yields was studied. Phosphorus had no significant effect on acid ammonium acetate/0,02 M EDTA extractable copper of the soil. It has been observed in some studies that copper availability does not decrease as the application of phosphorus is increased, rather the amount of readily soluble copper even increases with phosphate fertilization (Bingham and Garber 1960, DeKock et al. 1971). In a recent study of the effects of phosphorus on copper uptake by cereal roots or on the translocation of copper from the roots to the aerial parts, no conclusive results were obtained (Dahi 1973). The mobilization of copper from the vegetative parts to the grain in cereals is reduced by phosphate fertilization (Dahi 1973). The effect of phosphorus on treatments adequately supplied with copper was positive. Phosphorus increased both the yields and the copper uptake. Correspondingly, the yield increases brought about by phosphorus could be further improved by copper fertilization.

The effects of liming and phosphate fertilization on copper uptake, and also the effect of nitrogen mentioned above, indicate that consideration should be given to appropriate copper fertilization on copper deficient soils.

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SELOSTUS

Kalkituksen ja fosforilannoituksen vaikutus kauran kuparin saantiin ja kuparilannoituksen tehoon

HILKKA TÄHTINEN

Maatalouden tutkimuskeskus

Kalkituksen ja fosforilannoituksen vaikutusta ja niiden yhteisvaikutusta kauran jyvä- ja olkisatoon, kuparinottoon ja kuparilannoituksen tehoon tutkittiin happamalla kupari- ja fosforiköyhällä turvemaalla astiakokeissa.

Jyväsadon määrä riippui ratkaisevasti kuparilannoituksesta. Ilman kuparia ei jyviä muodostunut juuri lainkaan. Kalkitus lisäsi kupariköyhällä maalla ainoastaan olkisatoa ja alensi muutenkin melkein olematonta jyvien muodostusta. Ellei vilja ollut kuparin puutteessa, kalkitus hieman alensi sekä jyväsatoa että kuparilla saatavaa sadonlisäystä. Liiallinen fosforilannoitus kuparin puutteessa olevalla maalla alensi sekä satoa että kauran kuparinsaantia. Kuparilannoitusta käytettäessä fosforilannoitus lisäsi kuparilla saatavaa jyvä- ja olkisatoa ja sadon ottamaa kuparimäärää ja alensi jyvien kuparipitoisuutta. Fosforilannoituksen lisääminen lisäsi kuparilla saatavaa sadonlisäystä ja toisaalta kuparilannoitus paransi fosforilannoitteen vaikutusta. Ratkaisevin vaikutus jyväsatoon oli kuitenkin kuparilannoituksella. Kun kuparipitoisuus oli kasveissa riittävä, ei kuparimäärän lisääminen lisännyt merkitsevästi jyväsatoa. Sen sijaan jyvien kuparipitoisuus nousi huomattavasti kuparin käyttömäärää lisättäessä. Maan kupariluku riippui merkitsevästi ainoastaan kuparilannoituksesta. Kolmen tekijän yhteisvaikutus Cu × P × Ca ei ollut merkitsevä. Kaikkien tutkittujen satotekijöiden riippuvuus kuparilannoituksesta ja kalkituksesta pysyi samana fosforin käyttömääristä riippumatta. Kalkitus ei muuttanut kupari- ja fosforilannoituksen vaikutusten välistä riippuvuutta.

ANNALES AGRICULTURAE FENNIAE, VOL. 15: 254—262 (1976)

Seria PHYTOPATHOLOGIA N. 62 — Sarja KASVITAUDIT n:o 62

THE EFFECT OF FIVE FUSARIUM SPECIES ON THE GROWTH AND DEVELOPMENT OF SPRING WHEAT AND BARLEY

JUHANI UOTI

UOTI, J. 1976. **The effect of five Fusarium species on the growth and development of spring wheat and barley.** Ann. Agric. Fenn. 15: 254—262. (Agric. Res. Centre, Inst. Plant Path., SF-01300 Vantaa 30, Finland).

Spring wheat and barley seeds were inoculated separately with the spores of five different *Fusarium* species. Growth and development of the infected cereals was followed in a field test throughout the growing season. *F. culmorum* (W.G.Sm.) Sacc. was found to be the most destructive of the five species, causing severe seedling blight, foot and root rot and a marked reduction in yield in both cereals. *F. avenaceum* (Fr.) Sacc., *F. graminearum* Schw., *F. poae* (Pk.) Wr. and *F. tricinctum* (Cda) Sacc. all caused slight reduction in yield, but generally their effect was much less marked than *F. culmorum*. *F. poae* occurred most abundantly in the seed harvested, but its occurrence did not seem to be attributable to the inoculation. Soil type affected only slightly the occurrence of *Fusarium* species.

Index words: *Fusarium*, inoculation, spring wheat, barley.

INTRODUCTION

Seed-borne *Fusarium* is often responsible for serious seedling blight (de TEMPE 1964). Typically, *Fusarium* species not only strongly affect germination as such but may kill the young shoot after it seems well established (COLHOUN and PARK 1964). At a later stage, in addition to the seed-borne *Fusarium*, soil-borne *Fusarium* may infect the seedlings, causing foot and root rot (COOK 1968). Seedlings which have survived but are weakened by the fungi are easily attacked by soil-borne *Fusarium*. Head blight is also often caused by these fungi. Wet seasons particularly promote head infections (MISHRA 1973).

Although the number of species occurring on and in cereal grain may vary, certain *Fusarium* species seem to be dominant. According to UOTI and YLIMÄKI (1974) *F. avenaceum* (Fr.) Sacc., *F. culmorum* (W.G.Sm.) Sacc., *F. graminearum* Schw., *F. poae* (Pk.) Wr. and *F. tricinctum* (Cda) Sacc. were among the *Fusarium* species most frequently found in spring cereal seeds in 1972 in Finland. The observations made by MÄKELÄ (1973 and 1975) revealed primarily the same species of the *Fusarium* family occuring commonly in the leaf sheaths of cereals during the growing seasons 1971—1973.

In the present study spring wheat and barley seeds were inoculated separately with five *Fusarium* species. The seeds were then sown in the field, and the effect of each species on shooting, foot and root rot, head blight and yield was studied.

MATERIAL AND METHODS

The work was carried out at the Institute of Plant Pathology of the Agricultural Research Centre in Vantaa during the growing season of 1973. Commonly cultivated varieties of spring wheat (Ruso) and barley (Karri) were selected for the experiment. The seed samples were examined beforehand in the blotter test and were found to be only slightly contaminated with fungal organisms. In an official seed test, the samples obviously would have been labelled as healthy.

The fungus material used for the inoculation was isolated from cereal seed samples harvested in 1972. They were isolated and cultured as described earlier by Uoti and Ylimäki (1974). The cultures used for the inoculation were three weeks of age, and were producing spores abundantly. The fungus spores were diluted in sterile water, counting the spore concentration to 10 000—40 000 per milliliter using the Thoma hemacytometer. Two different strains of each five *Fusarium* species were well mixed. The spore suspension of the two strains was then poured over the seeds. This was done in Petri dishes using 100 ml of spore suspension and 50 g of seeds. The seeds were kept in the Petri dishes for 24 hours. Uninoculated or control seeds were kept in sterile water, similarly, for the same period of time. Next day the seeds were allowed to dry for two hours in a thin layer on filter paper. The seeds were then immediately sown, by hand, outdoors. This was done on May 22nd.

The seeds were at a density of 100 seeds per row, three rows or 300 seeds forming a plot. The size of the plot was 0,5 m^2. Four replicas were made. Four soil types were included: sand, loam, clay and peat. Each soil type formed one block consisting of all inoculation treatments and both cereals; the blocks were framed with wooden boards. Thus, the treatments included: inoculated or control, inoculated with the species of *F. avenaceum*, *F. culmorum*, *F. graminearum*, *F. poae* and *F. tricinctum*.

Shooting percentage was counted about three weeks after sowing. Yield was harvested by collecting all the heads from the plot by hand at normal harvest time, barley on August 17th and spring wheat August 28th. The heads were carefully treshed and the grain yield weighed after drying the seeds.

Foot and root rot analysis was by visual estimation of one hundred plants collected at random from each plot after harvest. In addition, short pieces of barley straw cut from the foot of the plants were placed on filter paper in a Petri dish, and the fungal growth in these was observed. At the same time *Fusarium* species were determined. The

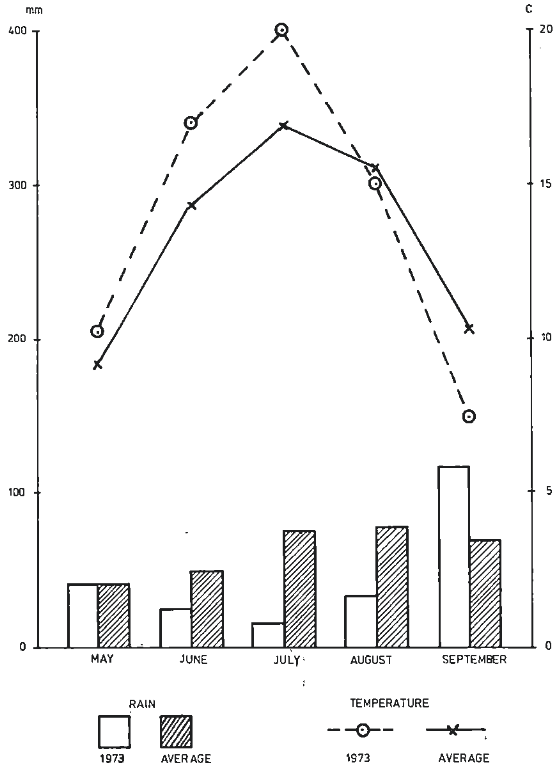

Fig. 1. Total rainfall (mm) and mean temperature (C) during the summer months at Tikkurila, Vantaa in 1973 compared to the average of 30 years.

occurrence of seed infection in the grain harvested was determined as described by Uoti and Ylimäki (1974).

Weather conditions during the summer months at Tikkurila are shown in Fig. 1. The trial plots received additional water by sprinkler irrigation, approximately 30 mm in May and early June 10 mm three times.

RESULTS

Shooting and yield

All the *Fusarium* species used for inoculation reduced shooting to some extent in both cereals, but more in spring wheat than in barley. All the species also caused yield reductions compared with the control. Generally, differences between the yields were smaller than between the shooting percentages. This was true for both cereals. *F. culmorum* proved the most strongly pathogenic. The loss of yield in spring wheat was quite considerable whereas barley suffered somewhat less. The effect of the other four *Fusarium* species was much less marked. Soil type had only a minor effect. Shooting percentages were lowest on loam soil, but under the prevailing conditions it still gave the highest yields with species other than *F. culmorum*. The results for spring wheat are shown in Table 1 and for barley in Table 2.

In a separate trial, different isolates of each five species were tested for pathogenicity on spring wheat in sandy soil only. In Fig. 2

Table 1. The effect of *Fusarium* species and soil type on shooting and yield of spring wheat.

Treatment	Shooting percentage					Yield g/m^2 (rf)				
	Sand	Loam	Clay	Peat	Mean	Sand	Loam	Clay	Peat	Mean
Uninoculated	89	81	82	90	85	268=100	107	99	93	267
F. avenaceum	80	62	74	78	74	89	91	93	75	235
F. culmorum	48	27	32	39	36	57	21	17	27	81
F. graminearum	84	67	76	81	77	66	86	71	66	193
F. poae	86	68	77	88	80	93	99	68	62	215
F. tricinctum	88	67	76	88	80	85	101	85	69	228
Mean	79	62	70	77	—	218	226	192	175	—
F-values	Soil type 20,03*** Treatment 211,89***					Soil type 9,26** Treatment 63,68***				

Table 2. The effect of *Fusarium* species and soil type on shooting and yield of barley.

Treatment	Shooting percentage					Yield g/m^2 (rf)				
	Sand	Loam	Clay	Peat	Mean	Sand	Loam	Clay	Peat	Mean
Uninoculated	94	92	93	96	94	425=100	95	74	98	390
F. avenaceum	80	80	78	87	83	75	81	70	86	331
F. culmorum	66	48	48	65	57	42	48	68	44	189
F. graminearum	92	87	88	91	89	76	72	69	71	306
F. poae	93	87	90	91	90	77	75	76	77	324
F. tricinctum	92	84	91	92	90	77	88	78	73	335
Mean	88	80	81	87	—	316	325	291	318	—
F-values	Soil type 10,99** Treatment 110,64***					Soil type 1,23° Treatment 27,53***				

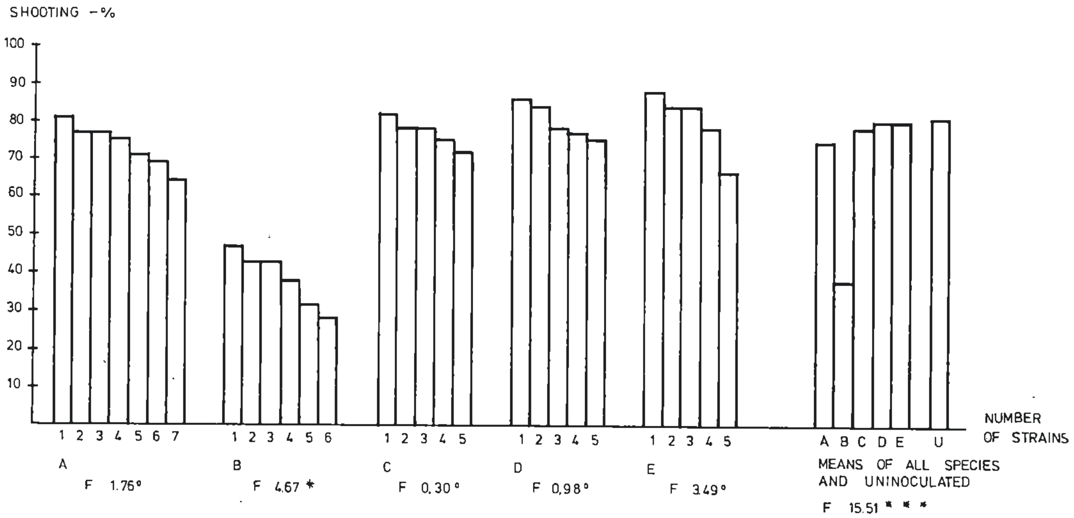

Fig. 2. The effect of different isolates (1—7) of *Fusarium* species on shooting (%) of spring wheat in sandy soil. *Fusarium avenaceum* (A), F. *culmorum* (B), F. *graminearum* (C), F. *poae* (D), *F. tricinctum* (E).

the observations made on shooting are summarized. The isolates differed only slightly within each species. Only among the strains of *F. culmorum* was the variation statistically significant. On the other hand, the average effect of these five species was much the same as in the main trial.

Foot and root

The results of visual estimation for foot and root rot in spring wheat and barley gave basically very much the same picture as the results for shooting and yield (Fig. 3). The degree of infection in spring wheat was generally higher than in barley. In both cereals inoculation with *F. culmorum* resulted in heavier infection than inoculation with any other *Fusarium* species.

Soil types did not influence the results very much. The soil-borne infection probably had been strong enough to cause almost the same level of infection in control plants as in plants grown from seeds and inoculated with *Fusarium* species other than *F. culmorum.*

Fungal growth in the cut pieces of barley

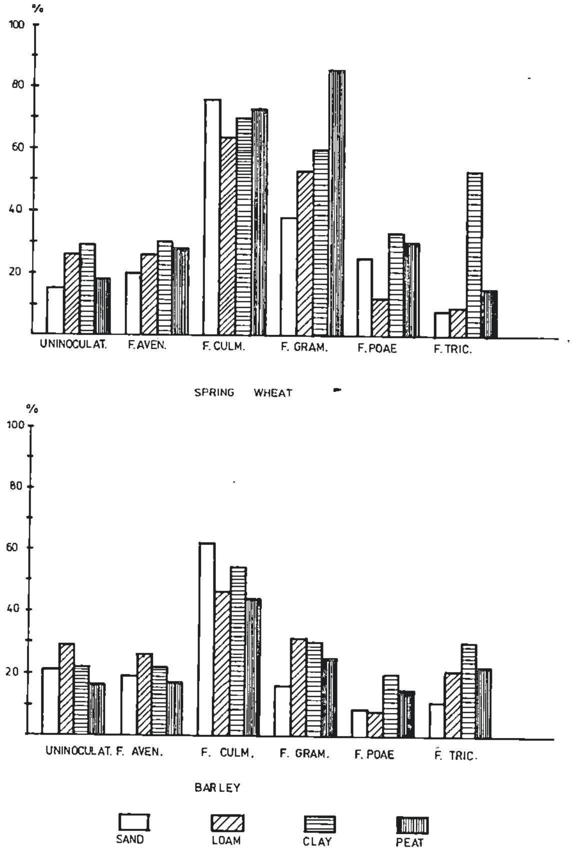

Fig. 3. The effect of *Fusarium* species and soil type on the occurrence (%) of foot and root rot in spring wheat and barley.

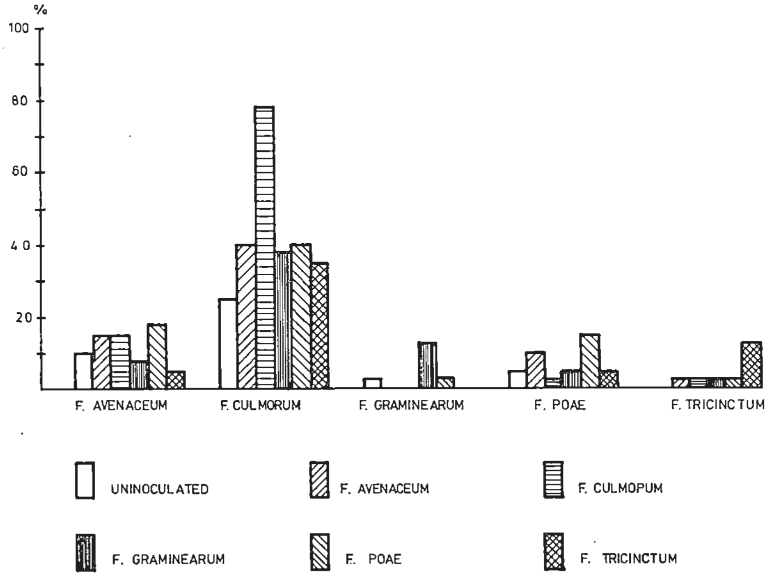

Fig. 4. The occurrence (%) of *Fusarium* species in barley straw grown in sandy soil inoculated with the different species of *Fusarium*.

Table 3. The effect of the inoculation on the occurrence of the *Fusarium* species and the germination of the harvested spring wheat seeds.

Occurrence of *Fusarium* species	Number of seeds in percentage infected by the species of *Fusarium*						F-value
	Uninoculated	Inoculated with the species of					
		F. avenaceum	*F. culmorum*	*F. graminearum*	*F. poae*	*F. tricinctum*	
F. avenaceum	2,8	6,9	6,0	5,9	3,6	1,3	3,64*
F. culmorum	5,0	2,3	10,6	1,8	2,5	2,9	3,15*
F. graminearum	0,0	0,0	0,1	0,1	0,1	0,3	2,09°
F. poae	10,1	7,8	10,6	7,3	6,1	7,4	1,97°
F. tricinctum	1,8	1,3	3,8	1,9	1,5	2,0	1,62°
Total *Fusarium*	22,5	21,9	32,0	24,8	19,1	16,5	2,81*
Germination-%	96,4	93,9	89,0	96,3	97,3	95,3	3,47**

Table 4. The effect of the inoculation on the occurrence of the *Fusarium* species and the germination of the harvested barley seeds.

Fusarium species	Number of seeds in percentage infected by the species of *Fusarium*						F-value
	Uninoculated	Inoculated with the species of					
		F. avenaceum	*F. culmorum*	*F. graminearum*	*F. poae*	*F. tricinctum*	
F. avenaceum	6,0	10,8	8,6	7,3	8,1	9,6	1,01°
F. culmorum	2,4	1,8	4,0	3,4	2,0	3,9	0,70°
F. graminearum	0,0	0,1	0,0	0,1	0,1	0,0	0,69°
F. poae	24,9	23,6	32,9	28,0	28,3	26,8	2,13°
F. tricinctum	4,3	6,5	6,4	5,3	4,1	8,3	2,09°
Total *Fusarium*	39,3	41,3	50,9	43,4	42,3	47,4	2,51*
Germination-%	82,4	85,4	72,6	81,4	78,9	71,8	5,33**

Table 5. The effect of soil type on the occurrence of *Fusarium* species and the germination of the harvested spring wheat seeds.

Fusarium species	Number of seeds in percentage infected by the species of *Fusarium*				F-value
	Sand	Loam	Clay	Peat	
F. avenaceum	3,9	6,8	2,9	4,0	1,13°
F. culmorum	3,2	4,8	5,5	3,2	0,43°
F. graminearum	0,1	0,6	0,4	0,0	2,33°
F. poae	7,5	8,0	11,0	6,3	3,05*
F. tricinctum	1,6	3,8	1,6	1,1	1,55°
Total *Fusarium*	21,0	27,3	25,8	17,1	1,81°
Germination-%	97,7	92,2	94,8	94,1	6,58*

Table 6. The effect of soil type on the occurrence of *Fusarium* species and the germination of the harvested barley seeds.

Fusarium species	Number of seeds in percentage by the species of *Fusarium*				F-value
	Sand	Loam	Clay	Peat	
F. avenaceum	5,7	9,4	9,3	9,2	0,24°
F. culmorum	4,0	2,8	2,4	2,3	0,73°
F. graminearum	0,2	0,0	0,0	0,1	1,00°
F. poae	27,1	25,9	31,0	25,6	1,07°
F. tricinctum	4,0	7,7	4,8	6,8	0,68°
Total *Fusarium*	41,8	45,6	46,3	42,6	0,35°
Germination-%	81,3	76,2	76,0	81,4	0,48°

straw revealed that in inoculation with *F. culmorum* had caused a marked increase in the occurrence of the same species after the harvest (Fig. 4). Generally, *F. culmorum* was found most frequently regardless of the *Fusarium* species originally used in the inoculation.

Occurrence of the Fusarium species in the seeds harvested

Certain *Fusarium* species occurred abundantly in the seeds of both cereals harvested. *F. poae* was quite dominant in both cereals, regardless of which species of *Fusarium* was originally inoculated (Tables 3 and 4). Only *F. culmorum* in spring wheat and *F. avenaceum* in barley clearly showed the highest percentages in those seed lots harvested from the plots inoculated with the same species. The higher the total infection was the lower the germination percentage.

Soil type had more effect than inoculation on the occurrence of the *Fusarium* in seeds. In spite of inoculation with any *Fusarium* species, loam and clay soils caused the highest infection in total. The type of the cereal affected the occurrence of some *Fusarium* species even more than the soil type. Thus *F. poae* always occurred most abundantly in barley. Also, in total, barley was contaminated with *Fusarium* species more than spring wheat (Tables 5 and 6).

DISCUSSION

In practical farming chemical seed treatment is quite important in preventing losses caused by seed-borne *Fusarium* fungi (LINE et al. 1973). Still commonly applied, mercurial seed dressing only partially controls the seed-borne infection. According to SALAMA and MISHRICKY (1973) surface desinfection does not totally eliminate fusarial contamination. Although the seed dressing generally provides some control against the soil-borne fungi, it is not effective enough. This has been suggested by JAMALAINEN (1962) in his studies with *Fusarium nivale*.

Seedling blight is the first sign of fusarial infection during the growth of cereals. Heavy seed infection with *Fusarium* fungi may cause serious yield reduction (COLHOUN 1972). Particularly, later plants which have survived the attack of seed-borne *Fusarium* but are weakened by the fungi are often infected by soil-borne *Fusarium*. These, in turn, are the major cause of foot and root rot (MALALASEKERA et al. 1973). The same authors have shown in their studies with *F. culmorum* that the fungus introduced with the seed inoculation proceeds up the coleoptile during seedling development. Infection of the leaves may, however, be caused by secondary spore infection. SALAMA and MISHRICKY (1973) presented the view that in maize *Fusarium* may grow from the germinating seed up to the developing head. Head and ensuing seed infection also reduce yield (COLHOUN 1972).

Of the five *Fusarium* species included in the present study, only *F. culmorum* was shown clearly to be strongly pathogenic. This species is particularly harmful during the early growth of cereals. COLHOUN (1970) also reported that *F. culmorum* was more damaging to seedlings than any other *Fusarium* species. Although pathogenicity varied within all the five *Fusarium* species, even the least pathogenic strain of *F. culmorum* killed more wheat seedlings than the most pathogenic strain of any other *Fusarium* species.

The analysis of foot and root rot was not clearly attributable to the inoculation. Obviously the soil-borne fungi mixes with seed-borne inoculum at this stage of development. Nonetheless, the importance of *F. culmorum* as a major cause of foot and root rot is quite evident.

Infection in the harvested seeds also depends very little on the original inoculation. *F. poae* occurred abundantly in all seeds, whereas *F. graminearum* was completely absent. It seems possible that in this case most of the head infection had occurred via air-borne spores. The small size of the spores of *F. poae* may explain its abundance in harvested seeds.

Loam soil was preferred by all *Fusarium* species. It seems that organic peat soil contains sufficient microbial antagonists to control *Fusarium* to some extent. In the present trial sand and clay soil were probably too dry for the fungi to grow abundantly. On the other hand, it has been shown that *Fusarium* fungi thrive better in dry soils than many other pathogenic fungi (FOCKE 1972). In foot and root rot the importance of soil type was less significant, although even here peat soil prevented the infection somewhat. In the seeds harvested incidence of fusarial infection could not be said to depend on the soil type.

Of the two cereals, spring wheat suffered more from seedling blight and foot and root rot. Yield reductions were also more severe in wheat than in barley. Barley's more efficient tillering capacity makes it more resistant to these fungi than wheat. In grain harvested barley, in turn, was contaminated more than wheat. This may be due to morphological differences in the structure of the head and seed.

Finally, weather conditions determine the severity of fusarial diseases. Seedling blight and foot and root rot are favoured by warm, dry weather (STOVER 1953), whereas head blight generally increases under humid conditions (COOK et al. 1972). Thus the weather in 1973 should have been almost optimum for fusarial infestation during the first part of the growing season. Dry weather during harvest prevented the severe head blight experienced in practice the previous year.

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SELOSTUS

Viiden Fusarium-lajin vaikutus kevätvehnän ja ohran kasvuun ja kehitykseen

JUHANI UOTI

Maatalouden tutkimuskeskus[1])

Tähti-kevätvehnän ja Karri-ohran siemenet inokuloitiin erikseen viiden *Fusarium*-lajin itiöillä. *Fusarium*-lajit olivat *F. avenaceum*, *F. culmorum*, *F. graminearum*, *F. poae* ja *F. tricinctum*. Inokuloidut siemenet kylvettiin ulkona oleviin puulaatikoihin, jotka oli täytetty neljällä eri maalajilla: hiekka, hietasavi, aitosavi ja turvemulta.

Viljojen kasvua ja kehitystä seurattiin tarkoin orastumisesta sadonkorjuuseen. Kaikki *Fusarium*-lajit rajoittivat orastumista jossain määrin kaikilla maalajeilla, mutta enemmän kevätvehnällä kuin ohralla. Muita selvästi voimmakkaampi vaikutus oli *F. culmorum* -lajilla, joka alensi orastumista eniten hieta- ja aitosavella.

Samoin kaikki *Fusarium*-lajit aiheuttivat sadonalennusta. *F. culmorum* -lajin vaikutus kevätvehnän satoon oli kaikilla maalajeilla erittäin haitallinen.

Sadonkorjuun jälkeen tutkituissa korsissa ja juurissa esiintyi runsaimpana jälleen *F. culmorum*. Maalajilla ei ollut suurta vaikutusta tyvitautisaastuntaan.

Eri *Fusarium*-lajien esiintymisrunsaus sadossa vaihteli enemmän maalajista kuin inokuloinnista riippuen. Yleisin laji sadossa oli *F. poae*, ja eniten sieniä esiintyi hietasavelta ja aitosavelta korjatuissa sadoissa.

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ANNALES AGRICULTURAE FENNIAE, VOL. 15: 263—266 (1976)

Seria ANIMALIA NOCENTIA N. 90 — Sarja TUHOELÄIMET N:o 90

PESTS OF CULTIVATED PLANTS IN FINLAND IN 1975

MARTTI MARKKULA

MARKKULA, M. 1976. **Pests of cultivated plants in Finland in 1975.** Ann. Agric. Fenn. 15: 263—266. (Agric. Res. Centre, Inst. Pest Inv., SF-01300 Vantaa 30, Finland).

In 1975 pests were slightly more abundant than normal, which was at least partically due to high temperatures and scarcity of rainfall in South and Middle Finland. Responses to inquiries showed that average abundance of all pests, in terms of a five-value scale, was 2,8, compared with 2,6 over the ten year period 1965—1974. Pests were particularly abundant on cruciferous vegetables.

The ladybeetles *Coccinella septempunctata* and *Adalia bipunctata* were exceptionally plentiful and prevented an increase in the numbers of aphids. The potato cyst nematode *Heterodera rostochiensis* was discovered farther north than ever before, by the Agricultural Research Centre's Lapland Experimental Station (66° 35' N).

Index words: plant pests, Finland, year 1975, severity of damage, frequency of damage.

The present survey, as the previous ones (e.g. MARKKULA 1975), is based chiefly on replies to four inquiries sent to the advisers at Agricultural Centres. Inquiries were sent to 205 advisers, and replies were received as follows:

	Replies	%	Communes	%
Spring inquiry	122	60	131	27
First summer inquiry	159	78	165	35
Second summer inquiry	148	72	156	33
Autumn inquiry	157	77	167	35

A general estimate of the abundance of pests for the whole growing season was given by 117 advisers from 123 communes. The estimate was based on a five-value scale (MARKKULA 1969). In the year under review the country was divided into 392 rural communes, 22 country towns and 63 cities, a total of 477 communes.

May was warmer than normal throughout the country. Mean temperature for May was 0,5—3,0°C above the average for the period between 1931—1960. June was also slightly warmer than normal in Southwestern Finland, but normal or slightly cooler elsewhere. In July and August, temperatures were above normal in southern parts of the country, but 0—3,5°C below normal in Middle or North Finland. The latter part of the growing season was warmer than normal throughout the country.

The growing season was clearly drier than normal in South and Middle Finland. The rainfall was generally 20—90 % that of the long term means. In North Finland rainfall was normal or even above normal.

Table 1. Results of questionnaires. Severity of damage reported, using a scale of 0—10. The frequency of damage shows the percentages of crops in which damage was observed.

	Numbers of observations 1975	Severity of damage		Frequency of damage	
		1975	1965—74	1975	1965—74
CEREALS					
Macrosiphum avenae (F.)	78	**1,4**	1,4	**28**	22
Oscinella frit (L.)	133	0,9	1,0	11	13
Rhopalosiphum padi (L.)	135	0,8	1,2	**38**	18
Phyllotreta vittula (Redtb.)	78	0,6	1,0	5	18
Elateridae	73	0,4	1,1	6	15
FORAGE PLANTS					
Amaurosoma spp.	75	1,1	1,5	13	28
Apion spp.	42	0,8	1,0	12	16
ROOT CROPS AND VEGETABLES					
Pieris brassicae (L.) etc.	96	**3,3**	1,7	**37**	29
Plutella xylostella (L.)	87	**2,3**	1,6	**23**	21
Trioza apicalis (Först.)	98	**2,0**	1,3	**31**	21
Mamestra brassicae (L.)	53	**1,7**	1,1	**21**	21
Hylemya brassicae (Bché) and *H. floralis* (Fall.)	142	1,6	2,0	22	28
Hylemya antiqua (Meig.)	82	1,4	1,9	14	21
Halticinae, crucifers	81	1,3	2,0	18	38
Brevicoryne brassicae (L.)	42	**1,2**	0,8	**16**	14
Phaedon cochleariae (F.)	54	0,8	1,1	12	19
Psila rosae (F.)	63	0,7	0,8	9	10
TURNIP RAPE					
Meligethes aeneus (F.)	56	1,6	1,8	36	40
SUGAR BEET					
Pegomya betae (Curt.)	154	1,5	1,8	44	48
Chaetocnema concinna (Marsch)	74	1,1	1,7	33	40
Lygus rugulipennis Popp. etc.	54	1,0	1,9	27	43
Silpha opaca L.	47	0,9	1,4	**38**	33
PEAS					
Cydia nigricana (F.)	59	1,8	1,9	36	37
APPLES					
Argyresthia conjugella Zell.	55	2,5	3,4	36	46
Cydia pomonella (L.)	57	2,4	2,5	30	42
Panonychus ulmi (Koch)	100	**1,8**	1,3	19	21
Aphis pomi (Deg.)	53	1,4	1,5	17	24
Hyponomeuta malinellus (Zell.)	66	1,1	1,6	12	23
Lepus europaeus Pallas and *L. timidus* L.	56	0,8	1,6	7	15
Psylla mali (Schmidbg.)	48	0,7	0,9	14	13
Arvicola terrestris (L.)	53	**0,7**	0,5	2	4
Microtus agrestis (L.)	56	0,5	1,1	3	8
Xyleporus dispar (F.)	43	0,3	0,5	**4**	4
BERRIES					
Nematus ribesii (Scop.) and *Pristiphora pallipes* Lep.	82	**2,4**	1,7	**26**	16
Aphididae, on Ribes species	105	**1,9**	1,8	**30**	26
Tarsonemus pallidus Bks	83	1,8	2,0	19	28
Cecidophyopsis ribis (Wettw.)	81	1,6	2,2	28	30
Byturus urbanus (Lindb.)	59	1,5	1,7	26	29
Incurvaria capitella Cl.	69	1,4	1,9	17	22
Anthonomus rubi (Hbst.)	66	1,1	1,6	22	26
Zophodia convolutella (Hbn.)	59	**1,1**	0,9	**12**	12
Pachynematus pumilio Knw.	66	1,0	1,3	16	21
Tetranychus urticae (Koch)	51	0,9	1,3	15	21
PESTS ON SEVERAL PLANTS					
Deroceras agreste (L.) etc.	50	**1,4**	1,3	**24**	24
Hydroecia micacea (Esp.)	44	0,9	1,2	19	21

RESULTS AND DISCUSSION

The high temperatures and scarcity of rainfall in South and Middle Finland appear to have been favourable to pests, which were slightly more abundant than normal. According to the replies received average abundance in pests was 2,8 throughout the whole growing season as opposed to 2,6 during the ten-year period 1965—1974.

In cereals, as in fodder plants, pests were less abundant than normal. On the other hand cruciferous vegetables were attacked of rather severely. Damage values for *Pieris brassicae*, *P. rapae*, *Plutella xylostella*, *Mamestra brassicae* and *Brevicoryne brassicae* were clearly higher than those during the ten-year period 1965—1974. Likewise *Trioza apicalis* was more abundant than it had been for years.

There were not noteworthy pest species problems on sugar beet, rape or pea cultivations. For the several of pests attacking apple trees, only *Panonychus ulmi* caused more damages than usual. Harm done by *Agryresthia conjugella* and *Cydia pomonella* was considerably less severe than in the previous year, when damage was heavy or than it had been during the period 1965—1974. The following table shows the percentages of apples damaged.

	1975	1974	1965 - 1974	Replies
Agryresthia conjugella	24	64	31	40
Cydia pomonella	20	35	22	41

Damage to berry plants was generally slight, although some pest species were a little more abundant than normal.

In the early part of the summer, aphids were very common on some plants, and a mass occurrence seemed very probable. However, ladybeetles, especially *Coccinella septempunctata* and *Adalia bipunctata*, reproduced plentifully and probably stopped the increase in aphid numbers. In late summer ladybeetles were extremely abundant, even in the centre of Helsinki.

Some living Colorado beetles, *Leptinotarsa decemlineata*, were found in loads of salt coming from Bulgaria through the Soviet Union. The potato cyst nematode was discovered considerably farther north than earlier, by the Agricultural Research Centre's Lapland Experimental Station (66° 35' N), which is probably the northernmost locality on record at which it has been found (SARAKOSKI 1976).

No information was obtained on pests new to Finland.

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SELOSTUS

Viljelykasvien tuhoeläimet 1975

MARTTI MARKKULA

Maatalouden tutkimuskeskus

Tuhoeläimiä oli v. 1975 hieman normaalia enemmän, mikä johtui ainakin osittain siitä, että kesä oli tavallista lämpimämpi ja vähäsateisempi Etelä- ja Keski-Suomessa. Maatalouskeskusten piiriagrologien arvioiden perusteella laskettu runsasluku oli 2,8, kymmenvuotiskautena 1965—1974 2,6.

Tuhoeläimet vioittivat erityisesti juuri- ja vihanneskasveja, mutta tehokkaan torjunnan ansiosta vahingot jäivät vähäisiksi. Alkukesällä monet kasvit olivat kirvojen pahasti saastuttamia ja odotettiin jopa kirvakesää. Leppäpirkot lisääntyivät kuitenkin runsaasti ja pysäyttivät kirvojen lisääntymisen.

Joitakin eläviä koloradonkuoriaisia löydettiin Bulgariasta Neuvostoliiton kautta tuoduista suolalasteista. Peruna-ankeroista tavattiin huomattavasti pohjoisempaa kuin aikaisemmin, maatalouden tutkimuskeskuksen Lapin koeasemalta. Esiintymispaikka on ilmeisesti pohjoisin maailmassa.

ANNALES AGRICULTURAE FENNIAE, VOL. 15: 267–271 (1976)

Seria PHYTOPATHOLOGIA N. 63 — Sarja KASVITAUDIT n:o 63

PATHOGENICITY STUDIES WITH FUSARIUM CULMORUM (W.G.SM.) SACC.

Juhani Uoti

Uoti, J. 1976. **Pathogenicity studies with Fusarium culmorum (W.G. Sm.) Sacc.** Ann. Agric. Fenn. 15: 267–271. (Agric. Res. Centre, Inst. Plant Path., SF-01300 Vantaa 30, Finland).

Spring wheat seeds inoculated with the spores of several different strains of *Fusarium culmorum* (W.G.Sm.) Sacc. were sown in small pots in the greenhouse. After three weeks of growth the plants were analyzed visually for foot rot symptoms. All strains showed pathogenicity, but the variation was quite considerable. Additional inoculation with *Trichoderma* spp. or *Penicillium* spp. prevented the harmful effect to some extent.

Index words: *Fusarium culmorum*, pathogenicity.

INTRODUCTION

In previous studies by the author (Uoti and Ylimäki 1974, Korpinen and Uoti 1974, and Uoti 1976) *Fusarium culmorum* (W.G.Sm.) Sacc. was shown to be the most important of the several *Fusarium* species occuring in cereals in Finland. Earlier reports also describe this species as a common contaminant in cereals, although its pathogenicity has not been studied thoroughly (Jamalainen 1943, Hårdh 1953, Ylimäki 1970). In other parts of the world the species has received much attention, and its pathogenicity in cereals is well known (Booth 1971).

Seed or soil inoculation with the pathogen is a common method for testing the pathogenicity of a fungus. Among earlier studies, the report of Johnston and Greaney (1942) describes the methods well. Numerous papers also describe the biocontrol of *F. culmorum* by inoculating the seeds with antagonistic fungi Nyvall and Kommedahl 1973). (Kommedahl and Mew 1975,

In the present study an endeavour was made to examine the pathogenicity of different *F. culmorum* strains by seed inoculation. Preliminary tests with the antagonistic fungi, *Trichoderma* and *Penicillium* were also carried out.

MATERIAL AND METHODS

The study was carried out at the Institute of Plant Pathology of the Agricultural Research Centre in Vantaa in 1973—1974. The spring wheat variety Tähti, earlier found to be the most resistant to *Fusarium* infection in grain harvested (Uoti and Ylimäki 1974) was selected for inoculation with 11 different *F. culmorum* strains isolated from spring wheat seed lots harvested in 1972. Isolation and inoculation were performed as previously described by Uoti and Ylimäki (1974) and Uoti (1976). Spores of *Trichoderma* spp. and *Penicillium* spp. isolated from soil grown for cereals were used for inoculation, using the same technique. The number of spores with these two fungi was diluted to more than 100 000 per milliliter. In the test in which the seeds were thus double-inoculated with *F. culmorum* and *Trichoderma* spp. or *Penicillium* spp., the suspension was mixed before inoculation. Untreated or »dry» seeds, and seeds kept in sterile water or »wet» seeds were used

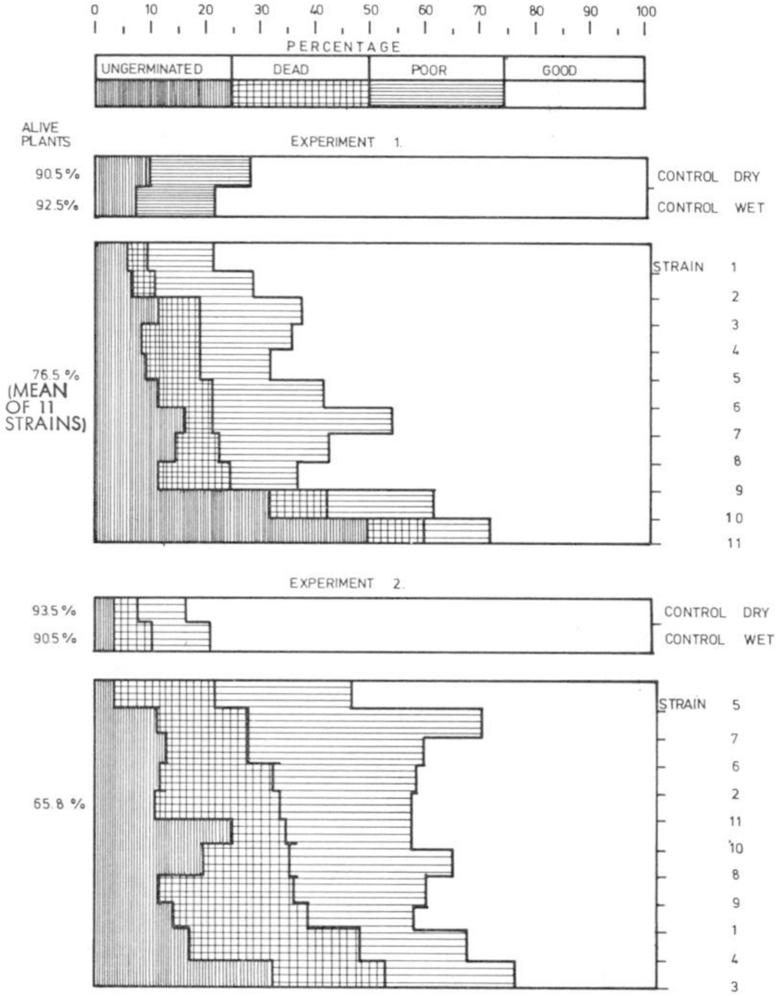

Fig. 1. The effect of 11 *F. culmorum* strains on wheat seedlings in two successive greenhouse experiments.

as control treatments.

The seeds were then sown in plastic pots 50 seeds per pot, four replicas. Soil was steam-sterilized sandy loam. Pots were kept in the greenhouse, where they were regularly, but only barely watered. Temperature varied from 15 C at night to 25 C at day. After three weeks of growth the seedlings were analyzed visually. At first they were sorted into live and dead plants. Next, the surviving plants were carefully checked for brown lesions and blackening at the foot, and then divided into »good», or plants having lesions 0—25 % and »poor», or plants having lesions 25 % or more. Finally the number of seeds which had not germinated were counted.

RESULTS

In the control pots the percentage of live plants was generally more than 90 %. »Dry» control always produced more surviving plants than »wet» control. All *F. culmorum* strains caused reduction in the number of plants surviving, also causing more lesions. The proportion of dead plants did not vary very much, but there was more variation in the number of plants which had not germinated. Measured in this way, pathogenicity did not remain stable in the two successive experiments. (Fig. 1).

In another experiment, which included some of the same strains, pathogenicity appeared much stronger. Simultaneous inoculation with *Trichoderma* spp. or *Penicillium* spp. improved the condition of the plants somewhat. *Penicillium* gave a slightly higher number of live plants. *Trichoderma* spp. or *Penicillium* spp. used alone were comparable to untreated seeds (Fig. 2).

When comparing the methods of applying *Trichodeerma* spp., best recovery from suppression by *F. culmorum* was obtained when *Trichoderma* spores were drenched into the soil one day before sowing (Table 1).

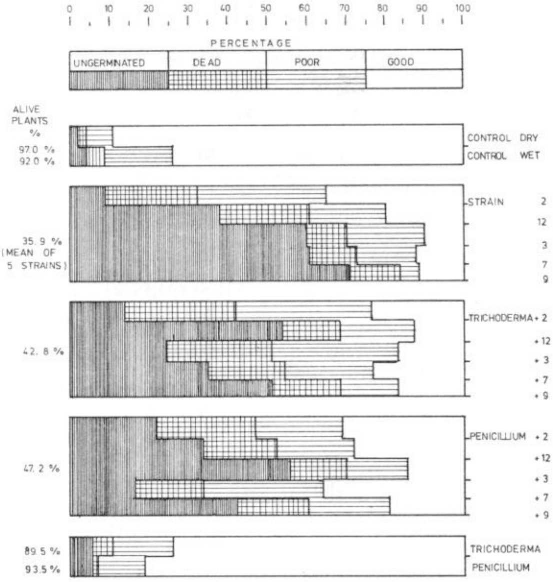

Fig. 2. The effect of 5 *F. culmorum* strains on wheat seedlings alone, mixed with *Trichoderma* spp. and mixed with *Penicillium* spp. in the greenhouse experiment.

Table 1. The effect of *F. culmorum* and *Trichoderma* spp. on wheat seedlings with different application methods.

Treatment	Alive plants %	Ungerminated %	Dead %	Poor %	Good %
Control dry	90	4	6	36	54
Control wet	87	6	7	38	49
F. culmorum alone	59	17	24	32	27
F.c. + *Trichoderma* seed inoculated	61	20	19	34	27
F.c. + *Trichoderma* soil incorporated one day earlier	74	11	15	32	42
F.c. + *Trichoderma* soil incorporated at sowing	65	13	22	18	47
F.c. + *Trichoderma* sprayed at seedlings	68	12	20	32	36
Trichoderma alone	92	3	5	38	54

DISCUSSION

Pathogenicity tests carried out under greenhouse conditions cannot be directly correlated to field conditions. Generally, pathogenic fungi can cause more damage in the greenhouse (JOFFE 1974). Also the variation in pathogenicity between the different strains of *F. culmorum* and within the same strain in successive experiments is not necessarily the same when the fungi and the crop are growing outside in the field. JOHNSTON and GREANEY (1942) concluded that isolates which proved to be distinctly pathogenic to seedlings in greenhouse tests showed only very slight virulence in the field, and vice versa.

The seed inoculation method applied in these trials does not necessarily provide the best possible conditions for infection. MISHRA (1973) showed that seedling injection was the most successful — gave the best infection, whereas seed or soil inoculation gave only moderate disease rating. Seed inoculation, however, resembles natural conditions closely. The great variation in pathogenicity between the strains makes it difficult to classify *F. culmorum* strains as pathogenic or nonpathogenic. From the practical point of view, this is actually an advantage. When *F. culmorum* is found in the seed or seedling, it should be accepted that there is a potential danger. All strains are pathogenic to some extent.

Foot rot fungi are already controlled biologically in Russia (FEDORINTSHIK 1972), where *Trichoderma lignorum* Harz is being mass-produced to treat the soil with the fungus preparation. Whether biological control would also work in practice under Finnish conditions should be studied.

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SELOSTUS

Fusarium culmorum -sienen patogeenisuudesta

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Maatalouden tutkimuskeskus[1])

Tähti-kevätvehnän siemenet inokuloitiin useilla *Fusarium culmorum* -sienen kannoilla ja kylvettiin astioihin kasvihuoneessa. Kolmen viikon kuluttua kylvöstä kasvit analysoitiin tyvessä ja juurissa näkyvien tyvitautioireiden perusteella.

Kaikki sienikannat aiheuttivat sairaita oraita ja alensivat orastumista. Vaihtelu eri kantojen välillä ja samankin kannan kohdalla perättäisissä kokeissa oli varsin merkittävä.

Kun siemenet *F. culmorum* -sienen lisäksi inokuloitiin *Penicillium-* tai *Trichoderma* -sienillä, voitiin todeta orastumisen parantumista.

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ANNALES AGRICULTURAE FENNIAE, VOL. 15: 272—293 (1976)

Seria ANIMALIA NOCENTIA N. 91 — Sarja TUHOELÄIMET n:o 91

POPULATION DYNAMICS OF CEREAL APHIDS AND METHOD OF PREDICTING POPULATION TRENDS

JORMA RAUTAPÄÄ

RAUTAPÄÄ, J. 1976. **Population dynamics of cereal aphids and method of predicting population trends.** Ann. Agric. Fenn. 15: 272—293. (Agric. Res. Centre, Inst. Pest Inv., SF-01300 Vantaa 30, Finland).

Dynamics of cereal aphids and natural enemies were studied in 40 spring-sown cereal fields in 1967—1975 in Southern Finland. *Rhopalosiphum padi* was the most dominant aphid species, *Macrosiphum avenae* occurred in most of the fields but in small numbers. *Acyrthosiphon dirhodum* was extremely rare. Aphid abundance was greatest in 1973 and 1975, maximum numbers of aphids per main shoot being in different fields 45—211 and 36—170, respectively. The warmer May was, the earlier aphids appeared on cereals.

The natural enemies of aphids were larvae and adults of *Coccinella septempunctata*, syrphid larvae, hymenopterous parasites and fungus diseases. Abundance of first generation coccinellid adults did not correlate with aphid density, but numbers of other natural enemies showed a clear dependency on aphid density.

Theoretically the numbers of aphids that could be destroyed by coccinellid larvae or second generation adults, parasites or diseases, were small, on average some percentage units a day. First generation coccinellid adults could destroy on average 15 % of first-found aphids, but the percentage value decreased later on. Syrphid larvae could destroy only a few aphids on first days aphids were found on cereals, but more than 20 % after 15th days.

To predict the abundance of aphids it is necessary to census the average number of aphids per main shoot the 3rd, 5th or 10th day after first aphids have been found on cereals. The maximum number of aphids during the summer corresponding to a certain average number of aphids on main shoot is found in a specially constructed figure.

Index words: *Rhopalosiphum padi, Macrosiphum avenae, Acyrthosiphon dirhodum,* natural enemies, phenology, prognosis, population dynamics.

INTRODUCTION

Observations on the abundance of cereal aphids *Rhopalosiphum padi* (L.), *Macrosiphum avenae* (F.) and *Acyrthosiphon dirhodum* (Wlk.) have been published since the beginning of this century (see e.g. VAPPULA 1965, STAPEL 1967). A great deal of information is based on tests where cereal aphids have been controlled by pesticides (see e.g. KOLBE 1969), but more detailed censuses have been made of the abundance of aphids in several studies (ADAMS and DREW 1964, KIECKHEFER and MILLER 1967, DEAN and LUURING 1970, LATTEUR 1971, MALYK and ROBINSON 1971, JONES 1972, WETZEL 1972, DEAN 1973 a and b). The migration and phenology of aphids have been studied by LOWE (1964), HEATHCOTE (1970), DEAN (1973 a, 1974 a and b), GEORGE (1974) and RAATIKAINEN and TINNILÄ (1961), who presented *A. dirhodum* as a new species to Finland. The distribution of aphids in fields has also been clarified (DEAN and LUURING 1970, DEAN 1973 b, WETZEL 1972, 1975, KIECKHEFER 1975).

According to DEAN (1974 b) the abundance of aphids or appearence of them on cereals did not correlate with weather, though JONES' results (1972) did support the possibility that temperatures during spring and early summer may be of importance. In fact, SPARROW (1974) found a relationship between temperature in May and aphid migration.

Later in the season, natural drying of plants (APABLAZA and TISKA 1973), heavy rains and winds (ROBINSON 1973), migration of alated females from plants (ADAMS and DREW 1964) and unfavourable weather (JONES 1972) have been observed to reduce the numbers of aphids on cereal crops.

The importance of predators, mainly coccinellids, syrphids and chrysopids, has been reported as small in several works (LOWE 1964, KIECKHEFER and MILLER 1967, LATTEUR 1971, MALYK and ROBINSON 1971, APABLAZA and TISKA 1973, SPARROW 1974, KIECKHEFER 1975), although some results also revealed that predators destroy aphids in significant numbers (TWINE 1971, JONES 1972, CARRILLO et al. 1974, DEAN 1974 a). In some cases *Entomophthora*-fungus infection (DEAN and WILDING 1971, 1973, MALYK and ROBINSON 1971, APABLAZA and TISKA 1973, LATTEUR 1973, CARRILLO et al. 1974) or hymenopterous parasites (e.g. SPARROW 1974, STARY 1976) have destroyed cereal aphids.

In Finland, notes on natural enemies of cereal aphids have been published previously (RAATIKAINEN and TINNILÄ 1961, CLAYHILLS and MARKKULA 1974). The bionomics of *Aphelinus asychis* Walker parasitizing *M. avenae* has been studied earlier by RAUTAPÄÄ (1972 b).

As far as is known, no method of forecasting the appearance and abundance of cereal aphids has been published. Several methods have been presented for estimating the yield losses caused by aphids (RAUTAPÄÄ 1966, 1968 a and b, 1972 a, 1975, BARAN and PIDANY 1973, 1975, KOLBE 1973, KOLBE and LINKE 1974) or for simple methods of counting the abundance of aphids on plants (BASEDOW 1975). A method for predicting the parasitism of *Schizaphis graminum* (Rondani), *Rhopalosiphum maidis* (Fitch) and *Sipha flava* (Forbes) by *A. asychis* has been published (RANEY et al. 1973).

The aim of this study was to explore abundance factors in cereal aphids and to develop a method of predicting their numbers on cereals. A preliminary report on the results has already been published in Finnish (RAUTAPÄÄ 1974).

MATERIAL AND METHODS

In 1967—1975 (not in 1969 and 1970) 40 fields situated in Southern Finland (N) (Table 1) were censused for the numbers of living, parasitized and diseased aphids and their predators. The size of the experiment areas varied from 150 m^2 to about 2 hectares. Growing technique and quantities of fertilizers were normal. Experiment areas were not treated with insecticides but nearly all of them were sprayed with phenoxy herbicides and some

Table 1. Fields where the numbers of aphids and their natural enemies were censused. The symbols for sites are: T = Tikkurila, V = Vihti. Aphid species found in cereals are indicated by a X.

Field	Year	Cereal crop	Site	Aphid species found		
				R. padi	*M. avenae*	*A. dirhodum*
1	1967	Wheat	T		X	
2	1967	Wheat	T		X	
3	1967	Oat	T	X		
4	1968	Wheat	T		X	
5	1968	Oat	T	X		
6	1968	Barley	T	X		
7	1971	Oat	T	X	X	X
8	1971	Oat	T	X	X	X
9	1971	Barley	T	X	X	
10	1971	Barley	T	X	X	
11	1971	Barley	T	X	X	
12	1971	Barley	V	X		
13	1972	Barley	T	X	X	X
14	1972	Barley	T	X	X	
15	1972	Barley	T	X	X	X
16	1972	Oat	T	X	X	
17	1973	Barley	V	X		
18	1973	Oat	V	X	X	
19	1973	Oat	V	X	X	
20	1973	Barley	V	X		
21	1973	Barley	T	X	X	
22	1973	Oat	T	X	X	
23	1973	Barley	T	X	X	
24	1973	Oat	T	X	X	
25	1973	Oat	T	X	X	
26	1974	Oat	T	X	X	
27	1974	Oat	T	X	X	
28	1974	Oat	T	X	X	
29	1974	Barley	T	X	X	
30	1975	Barley	T	X	X	
31	1975	Barley	T	X	X	
32	1975	Barley	T	X	X	
33	1975	Barley	T	X	X	
34	1975	Barley	V	X		
35	1975	Oat	V	X		
36	1975	Barley	V	X		
37	1975	Oat	V	X		
38	1975	Wheat	V	X		
39	1975	Wheat	V	X		
40	1975	Barley	T	X	X	

with chlormequat (CCC). Fields 17 and 20 (see Table 1) were irrigated by 30 mm of water in June 1973.

Random samples of 100 plants were picked up in a straight line through the field at 3—5 day intervals from the time the cereals sprouted until harvest. The number of living, diseased and parasitized aphids and predators other than coccinellids found on main shoots were counted. Special care was taken not to cause them to drop off the shoots during the inspection. Ten plots sized 1 m^2 were selected at random along the route for counting the number of coccinellids, both on the plants and the soil.

Mummified aphids were recorded as parasitized and aphids showing symptoms of fungus infection were classified as diseased, but neither the parasites nor the diseases were determined. Species of coccinellid adults and larvae, but not other predators, were determined in the field.

In the subsequent text the abundance of living aphids and that of natural enemies are given as follows:

Living aphids	Number of aphids on main shoot
Coccinellids	Number of specimens on 1 m²
Syrphid larvae, parasitized and diseased aphids	Number of specimens on 100 main shoots

An index was calculated for aphids and their natural enemies representing the sum of aphids or natural enemies found each day during the whole period of study on one main shoot (aphids), on 1 m² (coccinellids), or on 100 main shoots (other predators, diseased and parasitized aphids) in each field (see RAUTAPÄÄ 1975).

Tests on voracity of C. septempunctata

Because *Coccinella septempunctata* L. proved to be the dominant coccinellid in cereals, the voracity of adults and larvae were studied in the laboratory using cereal aphids as food. Ten adults, two days old, were reared five days in glass tubes (Ø 20 mm, length 10 cm), one in each. Aphids at larval stages III—IV were given each day in numbers large enough to satisfy the needs of the coccinellids. When both R. *padi* and M. *avenae* were available, one adult consumed daily on average of 23,0 R. *padi* and 25,3 *M. avenae* larvae. The average consumption was 48,2 aphid larvae per day.

When stage III—IV R. *padi* and *M. avenae* larvae were available to ten *C. septempunctata* larvae each reared one in a separate glass tube for seven days from the age of two days, the daily consumption was as follows:

Days	1	2	3	4	5	6	7	Total	$\overline{x}$
R. *padi*	10,6	32,6	23,8	47,2	65,8	44,8	20,4	245	35,0
M. avenae	20,2	33,2	22,6	47,0	66,6	43,2	23,8	257	36,7
Total	30,8	65,8	46,4	94,2	132,4	88,0	44,2	502	71,7

The feeding rate of larvae proved to be somewhat higher than that presented in HODEK et al. (1965) for R. *padi*, about 300 aphids during the total development period. According to HÄMÄLÄINEN et al. (1975) *C. septempunctata* larvae in the laboratory at 20°C consumed about 75 *Myzus persicae* per day during the larval stages.

The voracity of syrphid larvae was not clarified. However, average numbers of aphids consumed by syrphid larvae during the total larval development period have been 562 (SUNDBY 1966) and 421—844 (BOMBOSCH 1963).

When the theoretical effect of predators on aphid populations was calculated, the following generalizations were made:

C. septempunctata larva	consumes 60 aphids on a day
C. septempunctata adult	consumes 40 aphids on a day
Syrphid larva	consumes 60 aphids on a day

On the basis of the number of predators observed in the field and the number of aphids the predators were assumed to consume, the numbers of aphids destroyed were calculated for each field and for each day.

WEATHER

Daily temperatures were somewhat higher in Tikkurila than in Vihti, the difference sometimes being even more than 1°C in mean monthly temperature (ANON. 1967—1975) (Table 2). Total monthly rainfall was about the same.

The weather during the study could be described as follows: summer 1967 was cool with normal rain; 1968 was cool and rainy; 1971 was normally warm and dry; 1972 was warm and rainy; 1973 was very warm and dry; 1974 was cool and rainy; 1975 was very warm with normal rain.

Table 2. Mean monthly temperature and total monthly rainfall in Tikkurila (T) and Vihti (V).

Year		May		June		July		August	
		T	V	T	V	T	V	T	V
1967	°C	9,9		13,7		16,7		16,0	
	mm	53		19		39		107	
1968	°C	7,7		16,6		15,2		16,2	
	mm	85		37		68		52	
1971	°C	10,5		14,1		17,0		15,5	
	mm	9		21		25		90	
1972	°C	9,3	9,1	16,5	16,4	20,0	19,3	16,6	15,9
	mm	37	19	44	36	87	37	174	188
1973	°C	10,2	9,9	17,0	16,5	20,1	19,3	15,0	14,0
	mm	40	36	24	16	15	89	32	49
1974	°C	7,2	6,8	14,6	14,0	15,9	15,3	14,7	13,7
	mm	39	30	48	22	63	74	69	55
1975	°C	11,7	11,1	13,6	13,0	17,8	16,9	16,3	15,1
	mm	46	45	26	23	29	47	31	44

RESULTS

Phenology of aphids

The dates the aphids were first observed on cereal crops varied greatly (Fig. 1). In 1975 R. *padi* were found May 19, when the cereals were at the 2—3 leaf stage, but in 1974 on not until July 12, when the last sheath was open and ears were starting to appear. In 1973 the aphids were first observed at the beginning of June, in 1968, 1971 and 1972 in the middle of June. The first *M. avenae* were found somewhat later than R. *padi* in 1971, 1974 and 1975, but at about the same time as R. *padi* in 1968 and 1972.

In 1975 the abundance of aphids was at its greatest at the end of June, when the last sheath was opening and ears had started to appear (stages M—N in Keller—Baggiolini scale, Table 5). In 1974 the population peak occurred at the beginning of August, during the yellow stage of the grain (U in Keller—Baggiolini scale). In other years aphid numbers were greatest at the end of June or at the beginning of July. Aphids disappeared from the cereals before harvest, in the middle of July in 1973 and 1975, and in August during other years.

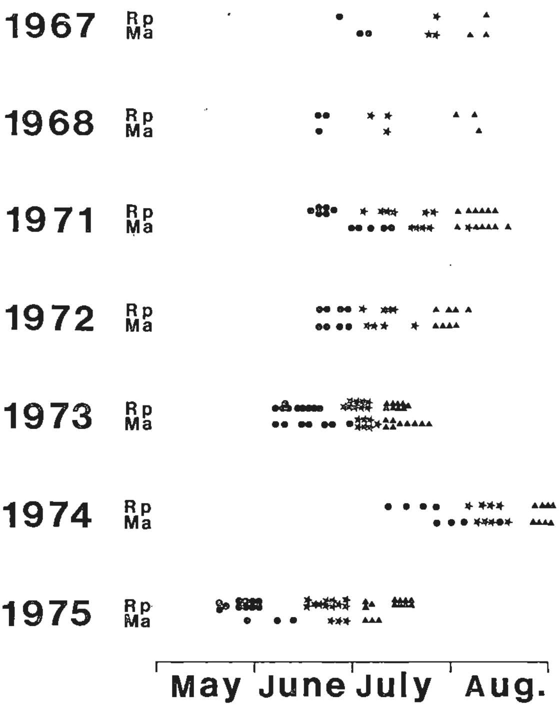

Fig. 1. Phenology of *R. padi* (Rp) and *M. avenae* (Ma). Each field is indicated by symbols as follows: date the first aphids were found = dot, maximum of aphids = star, aphids disappeared from cereals = triangle.

The difference between the two places, Tikkurila and Vihti, was small in this respect though the development of cereals was in general somewhat delayed in Vihti and the aphid maximums occurred in some cases at a slightly earlier stage of growth than in Tikkurila.

The phenology of aphids in 1975 and 1973 resembles closely that observed by RAATIKAINEN and TINNILÄ (1961) in 1959. They found the first migrating aphids at the end of May and the population maximums occurred in the middle of July. Migrating aphids were not sampled from the air in this study but according to DEAN (1974 b), GEORGE (1974) and SPARROW (1974) there was no correlation between the abundance of airborne and crop aphids though the suction traps indicated migration several days before aphids were found on cereals.

Correlation existed between the mean temperature in May and the date on which the first aphids were observed on cereals (Fig. 2). In 1975 the mean temperature in May was 11,7°C in Tikkurila and 11,1°C in Vihti, and the first aphids were observed on cereals during the last ten days of May. In 1974, when the temperature in May was lowest during the study (7,2 and 6,8°C), the aphids appeared on cereals after mid-July. No other correlation between the weather in spring or the beginning of summer and the appearence of aphids on cereals could be detected. A clear relationship was observed between the temperature and migration of R. *padi* by RAATIKAINEN and TINNILÄ (1961), too, and according to SPARROW (1974) the lower the March temperature, the later the aphids arrived on the cereals.

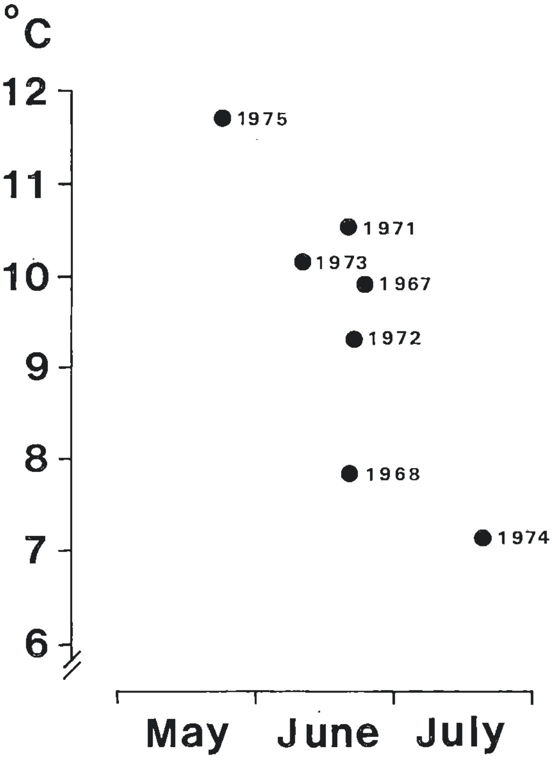

Fig. 2. The correlation between the average date first R. *padi* were found in cereal crops and the mean temperature in May.

Tabel 3. Maximum numbers of aphids and natural enemies. For explanation of the fields, see Table 1.

	Aphids on main shoot			Coccinellids per m²			Syrphid larvae	Parasitized aphids	Diseased aphids
	R. padi	*M. avenae*	Tot.	I gen.	II gen.	larvae	per 100 main shoots		
				adults					
1	0	2,6	2,6	1,0	0,2	0,2	2,0	3,0	0
2	0	2,5	2,5	1,8	0,8	2,9	2,0	3,0	3,7
3	2,8	0	2,8	1,0	1,0	3,0	3,5	2,0	5,0
4	0	1,5	1,5	0,8	1,9	0,6	2,0	2,0	19,0
5	3,3	0	3,3	0,5	0,4	0,5	3,0	0	18,0
6	8,9	0	8,9	0,8	0,3	0,7	4,0	2,0	15,0
7	19,6	2,6	21,0	0,8	1,9	11,7	2,0	2,0	4,0
8	5,8	3,8	5,8	0,9	4,6	2,6	3,0	2,0	3,0
9	3,4	1,2	3,8	0,2	2,3	4,8	2,0	0	2,0
10	1,6	1,4	2,8	0,2	1,1	3,5	1,0	2,0	4,0
11	0,7	0,6	1,2	0,3	1,1	1,3	2,0	2,0	0
12	67,6	0	67,6	0,2	12,5	6,8	15,0	0,7	45,0
13	4,8	0,9	5,5	1,1	0,5	4,7	3,0	15,0	6,0
14	2,7	1,2	3,8	0,6	0,2	0,3	4,0	8,0	10,0
15	4,4	1,5	5,5	0,5	0,4	2,8	3,0	4,0	5,0
16	2,6	1,7	3,8	0,7	2,1	4,4	3,0	5,0	3,0
17	121,5	0	121,5	0,5	4,7	11,7	10,6	18,0	601,0
18	108,7	1,2	108,9	0,1	23,7	32,5	6,0	8,0	18,0
19	157,7	1,2	157,9	0,4	17,9	21,0	6,0	4,0	6,0
20	211,0	0	211,0	0,7	10,5	14,6	10,0	14,0	20 046,0
21	134,9	1,5	136,4	2,0	12,7	35,8	13,0	2,0	23,0
22	210,6	0,5	211,1	0,1	10,9	51,6	0	10,6	9,0
23	86,8	0,3	86,8	0,5	3,8	19,2	9,0	7,0	11,0
24	77,5	0,2	77,8	0,5	2,4	8,9	6,0	4,0	8,0
25	41,0	0,1	41,1	0,2	6,9	4,0	3,3	0,3	12,0
26	2,4	0,6	2,4	0,2	0,2	0,3	10,0	2,0	6,0
27	2,2	0,2	2,4	0,5	0,4	0	0	0	2,0
28	2,5	0,3	2,8	0,2	0,5	0	0	0	6,0
29	0,4	0,4	0,7	0,1	0,8	0	0	0	0
30	18,9	0,2	19,0	0,4	0,4	3,3	2,0	0	0
31	43,0	0,1	43,0	1,3	1,3	3,0	8,0	0	0
32	105,4	0,9	105,4	0,8	0,1	5,3	0,7	0	0
33	61,6	0	61,6	0,3	0,5	15,5	4,0	4,0	8,0
34	59,7	0	59,7	0,1	0,2	5,2	1,0	0	13,2
35	43,7	0	43,7	0,2	0,2	3,8	0,2	6,7	6,7
36	75,7	0	75,7	0,1	0,2	5,4	0,8	0	0
37	37,1	0	37,1	0,2	0,4	2,6	0,8	0	6,7
38	22,3	0	22,3	0	0	3,2	0	0	0
39	27,2	0	27,2	0	0,2	2,6	0	0	0
40	14,3	0,2	14,5	0,2	0,9	2,1	0,5	0	0

Abundance of aphids

Of the three aphid species found on cereals (R. *padi*, *M. avenae* and *A. dirhodum*) R. *padi* was dominant. *M. avenae* was found in nearly all the fields but only in small numbers, and *A. dirhodum* was present only in four of the 40 fields (Table 1). Because of the extremely few specimens of *A. dirhodum*, the species is excluded from Tables 3, 4, 8 and 9.

R. *padi* was most abundant in 1973 (Tables 3 and 4, Fig. 5). The maximum number of living R. *padi* on main shoot varied from 41 to 211 and the aphid indices were 545—2 221 in different fields. In 1975 R. *padi* was numerous, too, but did not reach the numbers censused in 1973. Even on wheat fields 38 and 39 in Tables 3 and 4, the numbers of R. *padi* were about the same as on oats and on barley. In other years maximum numbers of

Table 4. Indices of aphids and natural enemies. The index represents the sum of aphids or natural enemies found each day during the whole period of study on one main shoot (aphids), on 1 m^2 (coccinellids), or on 100 main shoots (syrphid larvae, parasitized and diseased aphids). For explanation of the fields, see Table 1.

Field	*R. padi*	*M. avenae*	Total	Coccinellids			Syrphids	Parasitized aphids	Diseased aphids
				I gen. adults	II gen. adults	larvae			
1	0	35	35	17	1	2	24	34	0
2	0	36	36	25	5	47	22	43	46
3	36	0	36	12	6	47	45	22	49
4	0	25	25	5	10	5	26	12	246
5	54	0	54	5	3	7	48	0	370
6	91	0	91	7	1	8	67	31	245
7	318	34	352	6	7	159	26	22	56
8	130	57	187	13	44	25	53	34	17
9	43	15	58	2	18	64	42	0	22
10	28	19	47	2	11	26	13	15	25
11	13	7	20	5	5	9	15	33	0
12	1 037	0	1 037	2	58	112	211	7	983
13	84	19	103	16	2	38	32	115	81
14	30	21	50	12	2	3	20	106	111
15	49	21	70	7	3	29	38	45	70
16	50	22	72	9	14	57	61	91	52
17	1 100	0	1 100	2	17	73	55	109	3 502
18	1 084	2	1 086	1	82	296	59	48	121
19	2 020	1	2 021	2	70	194	37	34	61
20	2 221	0	2 221	4	29	112	111	63	15 842
21	941	6	947	9	82	326	131	11	277
22	1 865	3	1 868	1	63	430	0	128	108
23	712	2	714	4	30	141	90	90	122
24	915	4	919	9	7	89	73	29	55
25	545	1	546	2	38	44	31	5	114
26	33	12	45	1	2	44	177	27	59
27	59	4	64	0	15	0	0	0	13
28	49	7	56	0	6	0	0	0	92
29	7	5	12	0	17	0	0	0	194
30	231	2	233	3	4	32	7	0	0
31	460	1	461	12	11	36	81	0	0
32	903	7	910	8	1	71	7	0	0
33	894	0	894	5	2	206	44	72	80
34	809	0	809	1	1	48	7	0	116
35	701	0	701	3	2	36	1	98	60
36	811	0	811	1	2	57	7	60	0
37	600	0	600	3	3	21	6	126	24
38	384	0	384	0	0	33	0	0	0
39	434	0	434	0	2	38	0	0	0
40	129	2	131	2	8	14	4	0	0

R. padi were only a few aphids per main shoot with one exception, field 12 in 1971. Aphid indices in these years remained below 100, apart from field 12.

Numbers of *M. avenae* were in general smaller than those of *R. padi* except the years when *R. padi* was rare. The maximum number of *M. avenae* was 3,8 in field 8 in 1971. Indices for *M. avenae* were small, the maximum being 57 in field 8.

The greatest numbers of aphids on cereals seem to be on the same level as previously found in several studies, about 100—300 per head or plant (ADAMS and DREW 1964, SANDERSON and MULHOLLAND 1970, MALYK and ROBINSON 1971). The netting method used by Raatikainen and Tinnilä (1961), or counting aphids per foot of plant row by Dean and Luuring (1970), Dean (1973 a and b), Sparrow (1974), Kieckhefer (1975), make it difficult to compare the results.

Dispersion of aphids on fields

The infestation of plants was rapid (Fig. 3). When the first aphids were observed on field 21 on June 14, 1973, 3 % of the plants were infested. Five days later there were aphids on 73 % of plants and after two succeeding days the infestation reached 87 % of plants.

The percentage of plants infested with R. *padi* at any time during the growth period for aphid populations from the day the first aphids were found on plants until aphid maximum, correlated significantly with the number of aphids on main shoots at the same time. The regression equation (Fig. 4) was calculated by plotting the number of infested plants in percentages against the mean number of aphids on main shoots at each field inspection during the aphid population growth period. About 10 % of plants were infested when there were about 0,1 aphids on main shoot. The infestation percentage was about 25, when there was one R. *padi* on the main shoots, and all the plants were infested when the average number of aphids on main shoot was more than 18.

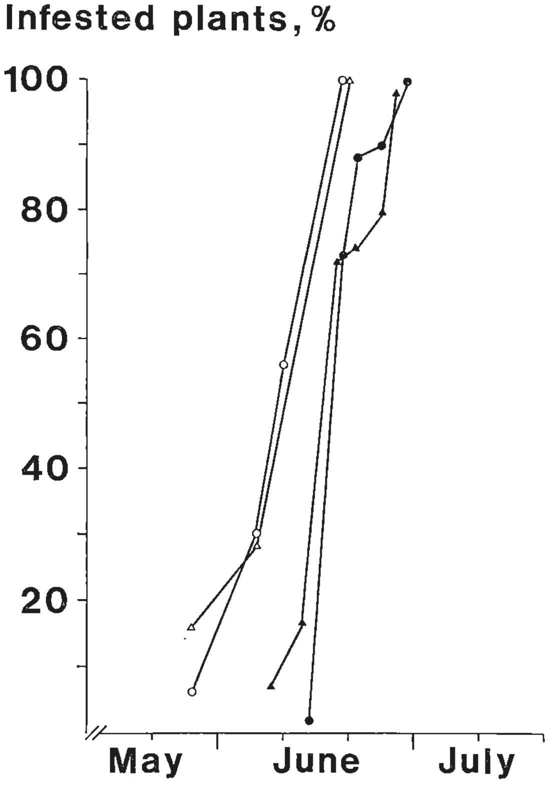

Fig. 3. Examples of the fast growth of R. *padi* infestation in fields 21 (dots), 23 (triangel), 33 (circle) and 34 (cross). For explanation of the fields, see Table 1.

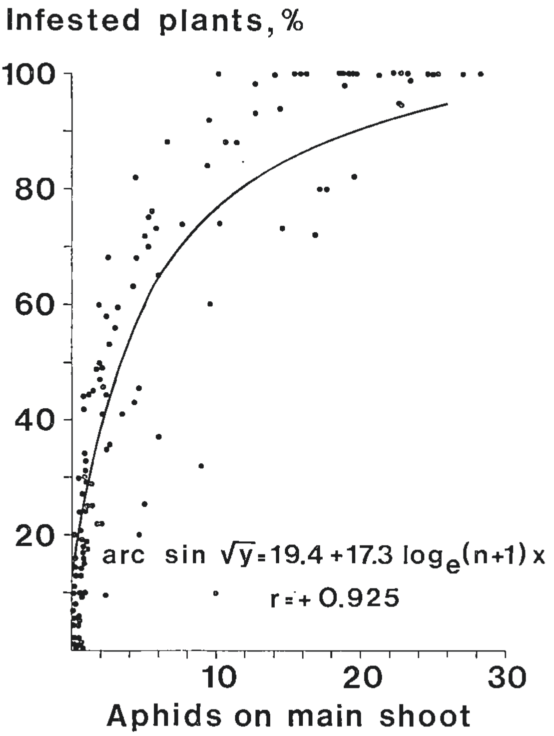

Fig. 4. Correlation between the number of R. *padi* on main shoot and percentage of plants infested. Each dot represents the situation on the day the field was inspected. Only data between the start of population existence and aphid maximum is included in regression.

Distribution of aphids in field

Distribution of aphids in different parts of field was clarified by dividing the inspection

Table 5. Stage of cereal growth at the moment when the numbers of R. *padi* were greatest. Symbols in Keller — Baggiolini scale:

K Appearance of last leaf
L Ligule stage
M Opening of the last leaf sheath
N Beginning of ear appearence
O End of ear appearence
P Beginning of flowering
Q End of flowering
S Grain-milk stage
U Grain-yellow stage

Field	Area	Year	Cereal	Stage of devel-opment	Field	Area	Year	Cereal	Stage of devel-opment
1	Tikkurila	1967	Wheat		21	Tikkurila	1973	Barley	N
2	Tikkurila	1967	Wheat		22	Tikkurila	1973	Oat	P
3	Tikkurila	1967	Wheat		23	Tikkurila	1973	Barley	O
4	Tikkurila	1968	Wheat		24	Tikkurila	1973	Oat	N
5	Tikkurila	1968	Oat	Q	25	Tikkurila	1973	Oat	Q
6	Tikkurila	1968	Barley	O	26	Tikkurila	1974	Oat	U
7	Tikkurila	1971	Oat	Q	27	Tikkurila	1974	Oat	U
8	Tikkurila	1971	Oat	N	28	Tikkurila	1974	Oat	U
9	Tikkurila	1971	Barley	U	29	Tikkurila	1974	Barley	S
10	Tikkurila	1971	Barley	U	30	Tikkurila	1975	Barley	M
11	Tikkurila	1971	Barley	Q	31	Tikkurila	1975	Barley	M
12	Vihti	1971	Barley	N	32	Tikkurila	1975	Barley	M
13	Tikkurila	1972	Barley	O	33	Vihti	1975	Barley	K
14	Tikkurila	1972	Barley	Q	34	Vihti	1975	Barley	K
15	Tikkurila	1972	Barley	Q	35	Vihti	1975	Oat	L
16	Tikkurila	1972	Oat	Q	36	Vihti	1975	Barley	K
17	Vihti	1973	Barley	O	37	Vihti	1975	Oat	L
18	Vihti	1973	Oat	M	38	Vihti	1975	Wheat	
19	Vihti	1973	Oat	N	39	Vihti	1975	Wheat	
20	Vihti	1973	Barley	N	40	Tikkurila	1975	Barley	N

Tabel 6. Distribution of R. *padi* in different parts of fields. The route used when aphids were counted was divided into ten equal parts. The figures represent the average abundance of aphids (in percentages) in ten parts at each insepection. Fields included are: 7, 8, 14, 15, 16, 17, 19, 21, 22, 23, 24, 25, 26, 31, 32, 33, 34 and 41. For explanation of fields, see Table 1.

	Ten equal parts of inspection routes									
	1	2	3	4	5	6	7	8	9	10
Average number of aphids in percentages	9,5	10,1	10,0	9,6	10,3	10,0	10,1	10,1	9,5	9,9
Range	6—22	5—23	5—12	2—14	3—23	6—13	5—17	4—16	2—14	3—20

route into ten equal parts. No evidence of aggregation or uneven distribution of aphids in fields was observed (Table 6). On the other hand, Wetzel (1972), Dean (1973 b), Dean and Luuring (1974), and Kieckhefer (1975), found clear evidence of aggregation in certain parts of fields.

Alated aphids in population

The numbers of larvae with visible wing buds and alated adults on 11 fields (Table 7) correlated positively and significantly with the maximum number of aphids on main shoots (arc sin $\sqrt{Y} = 14,7 + 0,39\ X$, r $= +0,937$,

Table 7. Numbers of R. *padi* larvae with visible wing-buds and alated females at the moment aphid abundance was greates.

Field	Maximum number of aphids on main shoot	Numbers of alated aphids (in percentages of all aphids)
2	2,5	4,0
3	2,8	5,0
12	67,6	45,0
14	5,5	6,0
15	3,8	10,0
16	5,5	5,0
17	3,7	3,0
18	121,5	98,2
19	108,7	92,7
20	157,9	98,1
21	211,0	94,1

$P < 0,01$). When the maximum number of aphids on main shoots increased by 10, the number of alated aphids increased by 18,6 percentage units. The role of alated aphids in reducing populations was previously emphasized by Adams and Drew (1964) when they observed that more than 80 % of aphids were alated and emigration of aphids resulted in an abrupt decline in the population. In other studies, however, losses due to emigration of *M. avenae* have been low, apparently because of lower population densities (e.g. Malyk and Robinson 1971).

Phenology and abundance of natural enemies

The natural enemies associated with cereal aphids were larvae and adults of *C. septempunctata*, larvae of syrphids, hymenopterous parasites and fungus diseases. Other coccinellid species as well as *Chrysopidae*- and *Itonidae*-larvae were observed, but in extremely small numbers.

In previous studies the following natural enemies have been observed in association with cereal aphids:

Hymenopterous parasites, adult coccinellids	Raatikainen and Tinnilä (1961)
Coccinellids, chrysopids, nabids	Kieckhefer and Miller (1967)
Hymenopterous parasites, fungus diseases	Malyk and Robinson (1971)
Coccinellids, syrphids, chrysopids, staphylinids, anthocorids, hymenopterous parasites	Jones (1972)
Fungus diseases	Dean and Wilding (1971, 1973), Apablaza and Tiska (1973)
Coccinellids, syrphids, parasites, fungus	Latteur (1972, 1973)
Syrphids, hymenopterous parasites	Sparrow (1974)
Hymenopterous parasites	Stary (1976)

The dominant coccinellid preying on cereal aphids in Europe seems to be *C. septempunctata* (Dunn 1949, Latteur 1973, Dean 1974 a). Other coccinellid species such as *C. rufa* (Clayhills and Markkula 1972) and *C. 14-punctata* and *Propylea*-species (Dean 1974 a) are common, too. In North-America *Hippodamia*-species as well as *Adalia bipunctata* are dominant (Ewert and Chiang 1966, Kieckhefer and Miller 1967, Malyk and Robinson 1971). In South-America *A. bipunctata* is abundant and common (Carrillo et al. 1974).

In Finland, *C. septempunctata* has been the most dominant coccinellid species (Raatikainen and Tinnilä 1961, Clayhills and Markkula 1974) but *C. quinquepunctata* and *C. rufa* have been found in cereals, too. As far as is known, there are no data on syrphids, itonids or chrysopids associated with cereal aphids in Finland, even though general faunistic data is available on these species and hymenopterous parasites of aphids, too.

In July and August 1963 several mummified cereal aphids were collected and adults were determined by Dr. Petr Stary, Czechoslovakia. The following species were found parasitizing aphids: *M. avenae* — *Ephedrus plagiator* (Nees), *Aphidius avenae* Hal., *Praon volucre* (Hal.); R. *padi* — *E. plagiator*, *Aphidius pascuorum* (Marsh.); *A. dirhodum* — *A. pascuorum*. All the species are known to parasitize cereal aphids in other countries. The material was insufficient to be used in estimating the abundance of the *Hymenoptera*-species in Finland.

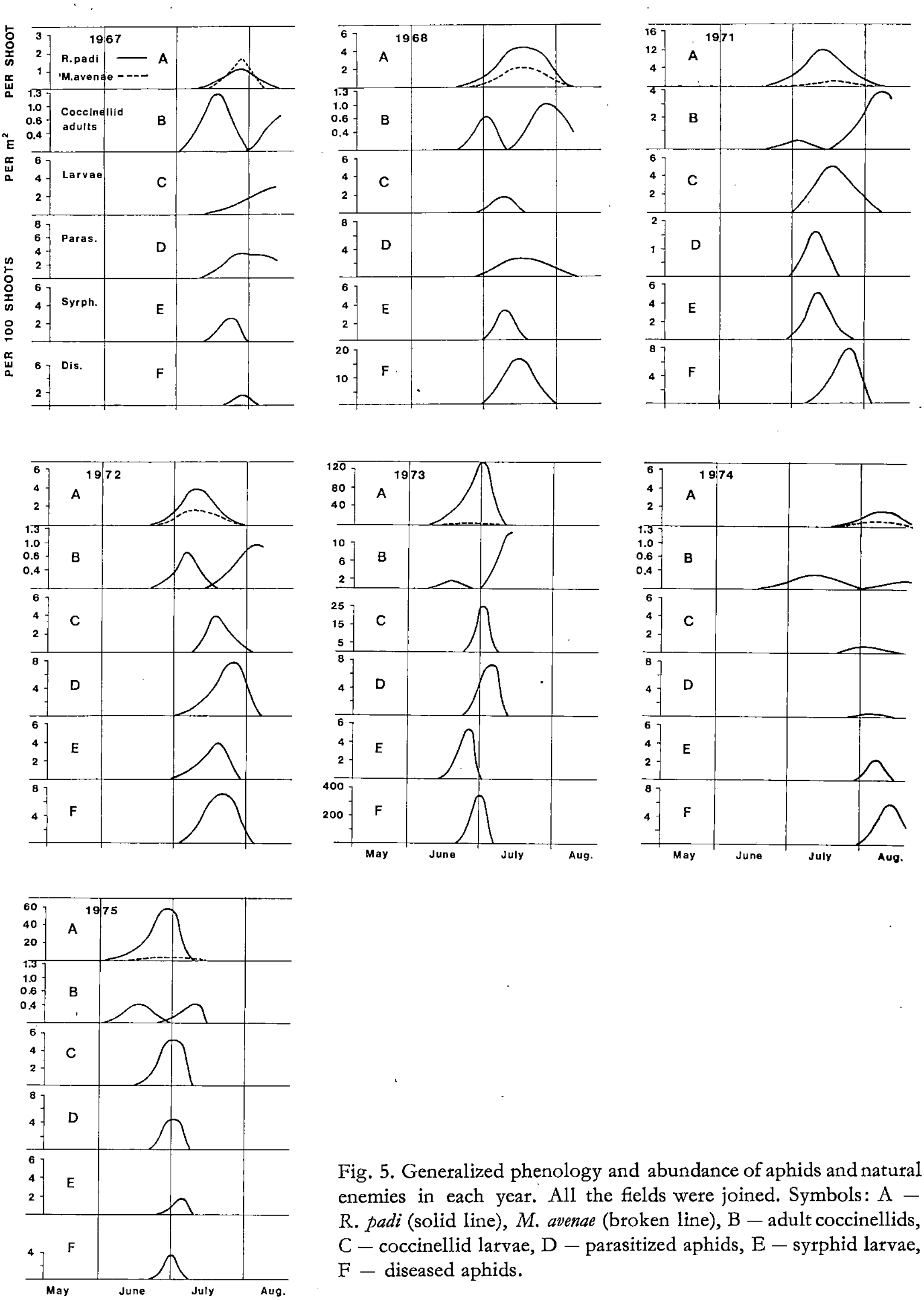

Fig. 5. Generalized phenology and abundance of aphids and natural enemies in each year. All the fields were joined. Symbols: A — R. *padi* (solid line), *M. avenae* (broken line), B — adult coccinellids, C — coccinellid larvae, D — parasitized aphids, E — syrphid larvae, F — diseased aphids.

Table 8. Days between first aphids and natural enemies were observed on fields.

	Number of fields in each category			
	First generation coccinellid adults	Coccinellid larvae	Syrphid larvae	Parasitized aphids
0 days	32	0	2	3
1—5	4	2	2	2
6—10	3	2	8	6
11—15		15	6	6
16—20		8	5	6
more than 20		10	11	5
not found	1	3	6	12
$\bar{x}$	0,9	17,0	17,1	15,7

Coccinellids. The first adults were observed on cereals on the same day as aphids (Table 8, Figs. 5 and 6). In most cases the greatest numbers of first generation adults occurred during the growth period of aphid populations and they disappeared from the fields when aphid population about reached its peak. In 1974, when aphids arrived on cereals late in July and their abundance was low, the coccinellids found in the fields at that time were the second generation.

In most of the fields the maximum numbers of first generation adults were less than one per m^2, the highest being 2,0/m^2 in field 21 in 1973 (Table 3). The indices calculated for first generation adults per m^2 varied largely, the maximum being 25 in field 2 in 1968 (Table 4).

The average number of aphids per one adult coccinellid on 1 m^2 during ten succeeding days after the first aphids were observed on cereals varied widely in different years (Table 9). The fewest aphids per one adult were in the years 1968 (46—215 per adult), and 1974 (218—635) and the most in 1973 (1 628 — over 200 000).

The first coccinellid larvae appeared on average 17 days after the first aphids were found (Table 8, Figs. 5 and 6). Larvae were not found at all on fields 27—29. The numbers of larvae were in general highest at the time aphid populations reached their peak (Figs. 5 and 6). Larvae were most abundant in 1973, when the maximum numbers were in different

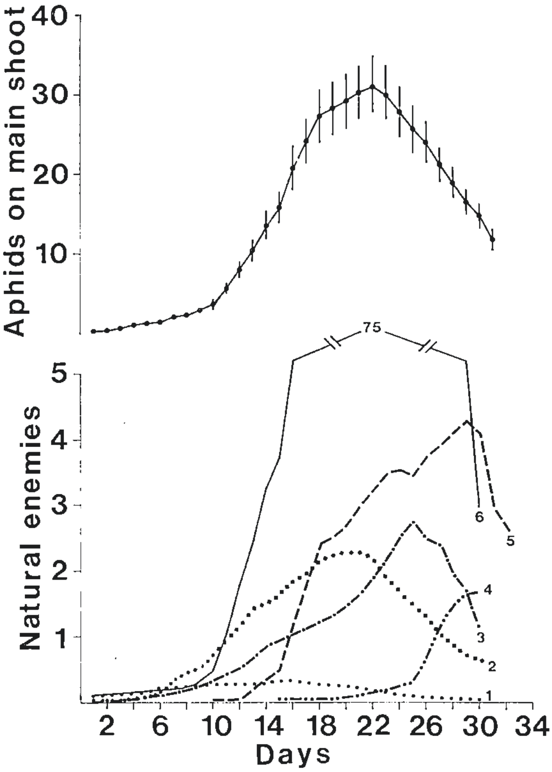

Fig. 6. Synchronization between phenologies of aphids and natural enemies. Day on which first aphids were found was marked by 1, and all the data of the fields were joined together. Aphid abundance is expressed as a mean of all the aphids per main shoot on each day. The vertical lines indicate standard error of the mean. Abundance of coccinellids is expressed as numbers of specimens per m^2, the other natural enemies as numbers of specimens per 100 main shoots. Symbols: 1 — first generation coccinellid adults, 2 — syrphid larvae, 3 — parasitized aphids, 4 — second generation coccinellid adults, 5 — coccinellid larvae, 6 — diseased aphids.

Table 9. The average number of aphids per one coccinellid adult or one syrphid larva during ten succeeding days (coccinellids) or 23 succeeding days (syrphids) after first aphids were found. The original numbers of aphids (aphids/mainshoot) and numbers of syrphid larvae (larvae/100 main shoots) were transformed to represent the abundance of aphids and syrphids on 1 m^2 by multiplying aphid numbers by 520 (mean number of plants per 1 m^2 = 400, mean number of shoots per plant = 1,3), and multiplying the syrphid numbers by 5,2. In fields with — there were no coccinellids or syrphids.

Field	Number of aphids per	
	coccinellid adult	syrphid larva
1	46	96
2	215	77
3	167	36
4	1 041	56
5	791	62
6	1 795	220
7	321	999
8	2 142	257
9	160	10
10	153	419
11	3 434	141
12	3 384	82
13	548	628
14	281	—
15	2 879	191
16	2 348	286
17	74 156	17 420
18	47 680	2 316
19	33 545	7 104
20	246 272	2 512
21	56 173	634
22	19 922	—
23	1 628	522
24	3 127	569
25	4 137	2 104
26	318	35
27	635	—
28	467	—
29	218	—
30	5 974	1 239
31	10 588	—
32	8 605	—
33	650	—
34	3 824	—
35	1 160	—
36	928	—
37	902	—
38	—	—
39	—	—
40	826	—

fields 4,0—51,6 per 1 m^2 (Table 3) and the indices were 44—430 (Table 4).

The second generation hatched after the aphid maximum had passed and, apparently, in several cases, the second generation adults were most numerous after the aphids had already disappeared from cereal crops. In several fields the second generation adults were more abundant than first generation adults, but this was not the case in all the fields (Tables 3 and 4). The second generation was especially numerous in 1973, when the maximums were 2,4—23,7 per m^2 (Table 3). The indices calculated for second generation adults were highest in 1973, varying from 7 to 82 (Table 4).

When the indices for adults and larvae in each field were correlated with each other (transformed by $\log_e (n + 1)$), the coefficients were as follows:

	Generation I adults	Larvae
Generation I adults	—	−0,163 (P > 0,05)
Generation II adults	−0,029 (P > 0,05)	+0,408 (P < 0,01)

There was no correlation between the abundance of first generation adults and larvae or between first and second generation adults. However, the more larvae found in a field, the more numerous the second generation adults.

The indices for coccinellid adults did not correlate with the indices for *R. padi* or *M. avenae*, but positive correlation was found between indices for larvae and R. *padi*. There were more larvae on fields with higher numbers of aphids. The coefficients were as follows:

	Indices for	
	R. padi	*M. avenae*
Coccinellid indices		
Generation I adults	–0,050	+0,162
Generation II adults	–0,050	–0,050
Larvae	+0,522 ($P < 0{,}01$)	+0,035

Highly significant correlations were obtained when the average number of aphids per one adult coccinellid censused in a field during the 10 days after first aphids were found (see Table 9) were plotted against aphid maximums ($Y = -133{,}8 + 55{,}3 \log_e X$, $r = +0{,}801$, $P < 0{,}01$, Fig. 7). It seems evident that the less aphids there were per adult coccinellid at the beginning of aphid population growth, the smaller aphid abundance during the summer.

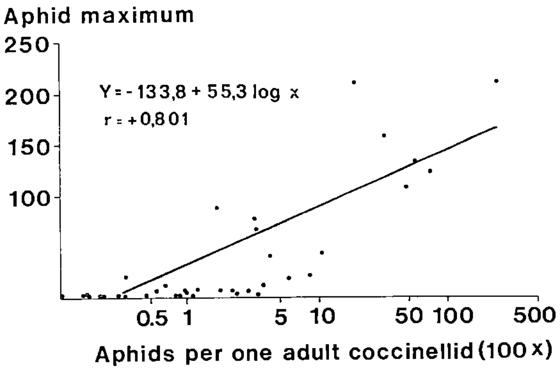

Fig. 7. Correlation between aphid maximum of the field and number of aphids per coccinellid adult on 1 m² during 10 days after first aphids were found.

Syrphid larvae were observed on average 17 days after the aphids appeared on cereals (Table 8), but the variation between fields was large. In four fields larvae were found during the first five days and before the tenth day there were larvae in 12 fields. On the other hand, on 11 fields it was more than 20 days before larvae appeared. Although the mean for the delay in the appearence of syrphid and coccinellid larvae was 17 days for both species during the first days after aphid appearence, there were syrphid larvae in fewer fields than coccinellid larvae.

The maximums, which coincided with the greatest numbers of aphids (Figs. 5 and 6), varied between 0 and 15 larvae per 100 main shoots (Table 3).

The number of aphids per one larva on 1 m² during the 23 days after first aphids were found varied between 10 and over 17 000 (Table 9). In general the figures were smaller than those calculated for coccinellid adults. When the average number of aphids per one larva was plotted against aphid index for the field, the positive correlation proved to be highly significant ($Y = -90{,}3 + 53{,}3 \log_e X$, $r = +0{,}684$, $P < 0{,}01$).

The correlation between indices for syrphid larvae and R. *padi* was positive and significant ($r = +0{,}390$, $P < 0{,}01$), but that for *M. avenae* was not ($r = +0{,}140$, $P > 0{,}05$). It seems evident that the more R. *padi* found on plants, the higher the abundance of syrphid larvae.

Parasitized aphids were found about 16 days after the first aphids were observed on plants (Table 8). On three fields the first aphids observed were parasitized and on 11 fields parasitized aphids appeared during the ten days after the first aphids were found. However, on 12 fields there were no parasitized aphids at all. The highest numbers occurred after the aphid maximums had passed (Figs. 5 and 6). Parasitized aphids were most abundant in 1973, the maximum being 18 on 100 main shoots in field 17 (Table 3).

Indices for parasitized aphids correlated significantly with the indices for R. *padi*, ($r = +0{,}332$, $P < 0{,}05$), but not with those for *M. avenae* ($r = -0{,}01$).

Diseased aphids were found about the period aphid populations reached the maximums or later (Figs. 5 and 6). On ten fields there were no diseased aphids at all. In 1973 enormous numbers were found in fields 17 and 20, after irrigating the fields with 30 mm of water. The maximums were 601 and over 20 000 per 100 main shoots. In field 20 more than 90 % of aphids were infested during the declining period of aphid populations. In general, more aphids were infested with fungus diseases than parasitized by hymenopterous parasites.

Correlation between the indices for diseased R. *padi* and R. *padi* indices was highly significant ($r = +0{,}473$, $P < 0{,}01$), indicating close dependence on aphid abundance.

Synchronization between aphids and first generation coccinellid adults seemed to be advantageous considering the role coccinellids may play in reducing aphid numbers (Table 8, Fig. 6). There were already coccinellid adults in nearly all the fields when the first aphids were found. Syrphid larvae were present in several fields from the start of aphid population growth and some of the aphids first found were parasitized. Coccinellid larvae generally appeared on cereals 17 days after first the aphids were observed and fungus infected aphids were found only when the aphid populations had reached their peak.

Abundance of first generation coccinellid adults did not depend on aphid numbers but the numbers of syrphid larvae, parasitized and diseased aphids showed a clear dependence on aphid density.

It could be concluded that coccinellid larvae, as well as second generation adults and fungus diseases were capable of affecting aphid numbers at the moment they were greatest, but they apparently were not in a position to regulate the increase of aphid populations. On the other hand, first generation coccinellid adults, syrphid larvae and perhaps parasites, too, seemed to be synchronized with the start of aphid populations on cereals and they might be able to affect the growth of aphid numbers.

Synchronization between natural enemies and their target is one of the basic problems when the role of natural enemies in regulating aphid abundance is considered. Relatively little data has been published about the sychronization of cereal aphids and their natural enemies. DEAN (1974 a) emphasized that coccinellids were abundant only in July when the aphid populations had reached their maximum. Syrphid larvae seemed to be the most common and the most important predators, even though they only appeared on cereals in late June and July. In general, parasites were more likely synchronized with the arrival of aphids on cereals than predators. However, predators, especially syrphids, became more important later in the summer.

THEORETICAL EFFECT OF NATURAL ENEMIES ON APHID POPULATIONS

On the basis of the numbers of natural enemies and on the numbers they are theoretically supposed to destroy (see chapter Methods), an average number of aphids destroyed was calculated for each day. On the first day aphids were found on cereal crops, the first generation coccinellid adults, in theory, preyed on a quantity of aphids which proved to be 15 ± 4,2 % of the living aphids found on cereals on that day (Fig. 8). The variation between fields was large, from 0 to 100 %. The average percentage value decreased steadily until 7,3 ± 3,5 was reached on the 15th day and after that it remained less than 3 %. The same percentage value calculated for aphids destroyed in theory by syrphid larvae increased slowly by some percentage units each day and reached the maximum value on the 22nd day. After 10 days from the start of aphid population growth, the percentage value estimated for syrphids was higher than that for coccinellid adults. This seeming inconsistency with the results indicating that on average syrphid larvae were observed on plants when aphids had already been living on them 17 days (see Table 8) is due to the

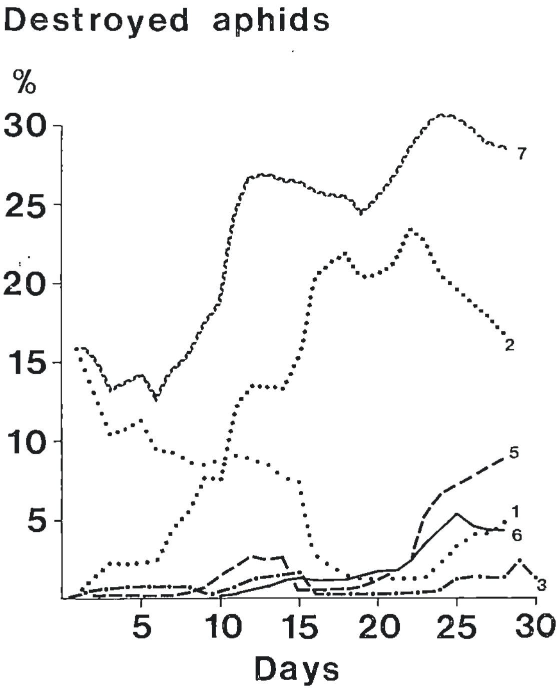

Fig. 8. The amount of aphids destroyed in theory by natural enemies expressed as percentage values of living aphids found on plants. Symbols 1—6 are the same as in Fig. 6. Symbol 7 — total sum of destroyed aphids.

fact that in several fields syrphid larvae were relatively abundant from the very beginning of aphid existence on the cereals.

The numbers of coccinellid larvae were higher than those of adults or syrphid larvae but because the abundance of larvae depended on aphid density, and because larvae were found on cereals only during the period of maximum aphid populations, the theoretical percentage figures describing the amount of aphids destroyed were very small, on average a few percentage units. The variation between the fields was not large and the highest number never exceeded 45 %.

The abundance of parasitized aphids was on average less than 2 % for all fields. The highest percentage value was 44 on field 16 on the 26th day after the first aphids were found.

On average, less than 6 % of aphids were diseased when all the fields were put together but the highest numbers reached over 90 % on fields 17 and 20.

When the effect of all natural enemies was summed up, the highest number of aphids destroyed was 37,7 ± 6,4 % of aphids found on cereals on the 29th day after the first aphids were observed (Fig. 8).

When the theoretical percentage values of aphids destroyed daily were plotted against aphid maximums and indices, the percentage values calculated for first generation coccinellid adults, syrphid larvae and hymenopterous parasites correlated significantly with indices and maximums (Fig. 9), indicating that the more these natural enemies were supposed to destroy aphids, the smaller was the aphid abundance during the summer.

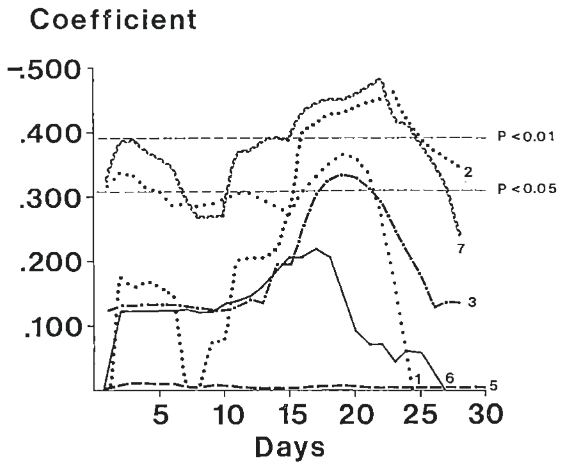

Fig. 9. Coefficients of correlation between percentage numbers of destroyed aphids and aphid indices of same fields. Symbols are the same as in Figs. 6 and 8.

PREDICTION OF TRENDS IN APHID POPULATIONS

After efforts to develop a model for population prediction on the basis of all the data collected from fields, the simple regression obtained by plotting the non-transformed numbers of aphids per main shoot on a certain day against aphid index or aphid maximum for the field, seemed to satisfy the need. The regression proved to be highly significant (Fig. 10). When the aphids on main shoots are counted on the third, seventh or tenth day after the first aphids are observed on cereals, with 99 % probability the aphid maximum will be those presented in Fig. 11. When the average number of aphids on main shoots is, for example, 2,0 on the third day, the maximum number of aphids on main shoots during the summer will be 76, and with 95 % probability higher than 59 and smaller than 93.

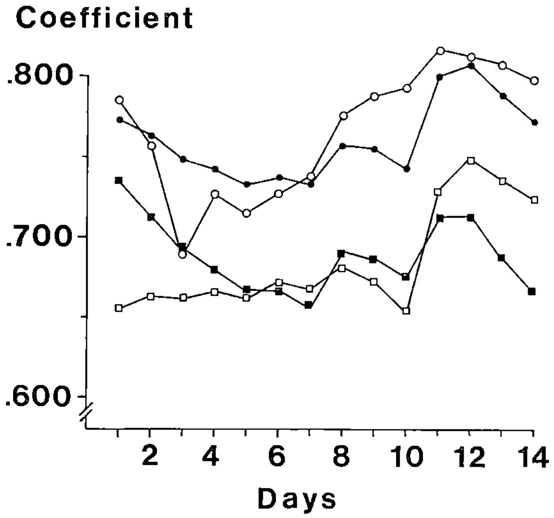

Fig. 10. Coefficients of correlation between *R. padi* found on plants on each day after first aphids were observed, and aphid index (dots), aphid maximum (circle), index before maximum (black square) and index after maximum (square).

The regression equations and coefficients proved to be as follows:

3rd day $Y = 19{,}5 + 28{,}3\ X;\ r = +0{,}734,\ P < 0{,}01$
5th day $Y = 19{,}1 + 17{,}6\ X;\ r = +0{,}709,\ P < 0{,}01$
7th day $Y = 16{,}3 + 13{,}1\ X;\ r = +0{,}732,\ P < 0{,}01$
10th day $Y = 15{,}9 + 7{,}6\ X;\ r = +0{,}798,\ P < 0{,}01$

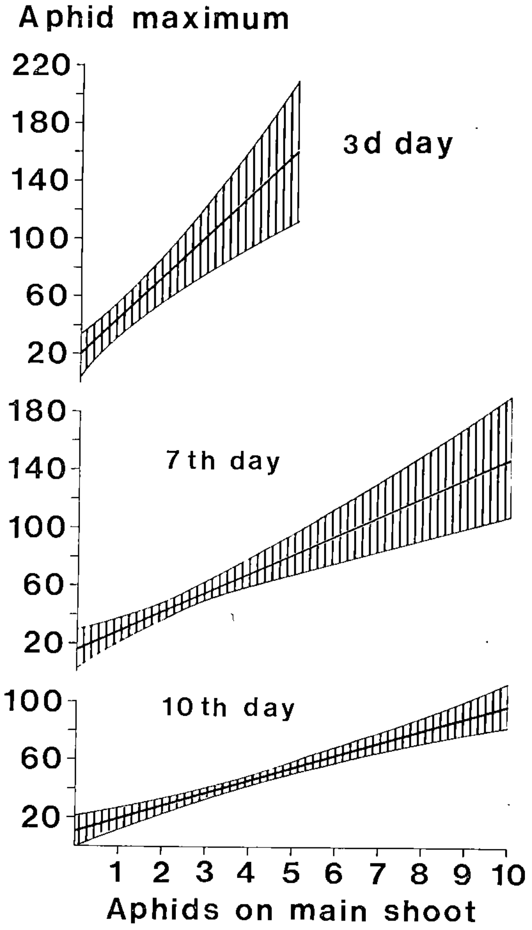

Fig. 11. Prediction of aphid maximums by means of average number of aphids per main shoot on 3rd, 7th or 10th day after first aphids were observed on cereals. Shaded area indicates the limits for 95 % probability.

DISCUSSION

The advantage of the counting method used in this study is that exact numbers of aphids and their natural enemies are obtained. However, counting insects on plants and on soil is laborious and therefore the number of fields censused during each summer remained relatively small. The counting method needs more care, accuracy and endurance on the part persons doing the work than for example sampling insects by sweeping a net. During this study the accuracy of workers was checked occasionally by comparing the results of different persons with one another on the same field. No significant differences were observed.

The most severe problem in the counting method is the possibility that some of the predators may not be included in results. The abundance of predators could be censused only once a day at intervals of some days. It is generally known that some predators, i.e. larvae of chrysopids, are extremely difficult to observe in vegetation. Those predators, which, like staphylinids, live most of the time on soil, were not included in the results. Aphids showing symptoms of *Entomophthora*-infestation were apparently easy to detect but was the fungus disease in fact the reason for death? There was no practical way of clarifying the role other diseases may have played in aphid populations. The mummified aphids are easily detected among living aphids and their numbers, even though not determined according to species, were perhaps most accurate. The reliability of the results might be summarized as follows: the data on abundance of aphids, coccinellids, syrphid larvae and parasitized aphids was relatively accurate and reliable; the information on numbers of other possible predators and causes of death is inadequate.

The method used in estimating the effect of natural enemies on aphid populations is far from adequate. The only exeptions are the numbers of parasitized and diseased aphids, which themselves indicate the numbers of aphids destroyed. The criticisms presented i.e. by KIRITANI and DEMPSTER (1973) of methods of the kind used in this study is justified. The most important source of errors is lack of knowledge on actual consumption of aphids by predators under natural conditions. Less serious is the fact that there is no possibility of distinguishing between the three aphid species as targets of predators. In works like this, all the aphids, even though they belong to three species, have to be considered as one aphid population, all equally susceptible to predators. Nevertheless, the percentage values calculated for aphids destroyed may indicate the greatest possible nummer of aphids destroyed by natural enemies in theory. In spite of the accentuated theoretical basis of the estimated percentage figures for aphids possibly destroyed, the benefit of this type of calculations is that the role of natural enemies in regulating aphid populations is more tangible than when only the original numbers of natural enemies and aphids obtained from fields are compared.

A more interesting result was that the numerical ratios of aphids and their predators were significantly correlated with aphid indices and maximums. The more aphids there were per unit first generation coccinellid adults or per unit syrphid larvae, the smaller was the aphid index and maximum. This might indicate that especially first generation coccinellid adults and syrphid larvae may affect the abundance of aphids during the summer. The numerical ratios of first generation coccinellid adults and aphids during the beginning of aphid population growth were in several fields about the same as those in cage experiments, where coccinellid larvae were shown to reduce the growth on aphid populations (RAUTAPÄÄ 1972 a, 1975).

It is a well known fact that in the laboratory coccinellid larvae consume large numbers of aphids. In cereals, however, it was concluded that the effect of larvae on aphid populations remained modest because of the apparent dependence of larvae on aphid density and the appearance of larvae late during aphid population development. The number of aphids per one larva was in all fields large and theoretically larvae destroyed only small numbers of aphids. The adults of the second generation might be important in reducing aphid numbers after the maximum has passed. However, in dense populations the most important factor reducing aphid numbers was emigration of alated aphids from overcrowded plants.

The need for predicting the abundance of aphids on cereals, which has been discussed by several authors (i.e. WAY and CAMMEL 1973, GEORGE 1974), is emphasized by the fact that control measures, either cultural, biological or chemical, have to be carried on during the very first days of aphid population growth. Not many days are left for decision-making, in most cases the aphid maximums were reached two to three weeks after the first aphids were found on cereals, and the aphid population reached the numbers that affect yield (see e.g. RAUTAPÄÄ and UOTI 1976) within a week. The method of predicting aphid abundance presented in this study is simple but accurate enough to be used in the field even by untrained persons. The correlation observed between the temperature in May and date of arrival of aphids on cereals could be used in estimating the start of aphid population growth over wider areas, i.e. in Southern Finland, and the aphid abundance on certain fields could be predicted by the method presented in this study.

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SELOSTUS

Viljan kirvojen runsauteen vaikuttavat tekijät ja menetelmä kirvojen määrän ennustamiseksi

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Maatalouden tutkimuskeskus

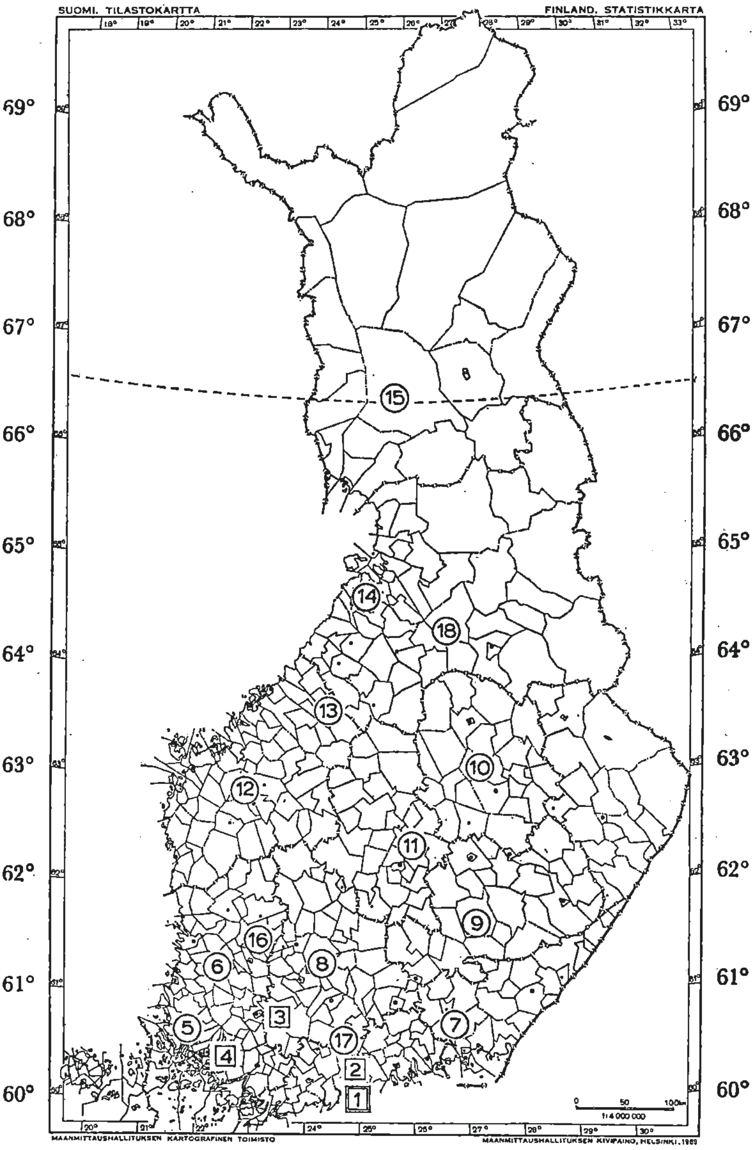
Viljan kirvojen runsautta kevätviljoissa ja siihen vaikuttavia tekijöitä selvitettiin vuosina 1967—1975 (ei 1969 ja 1970) neljälläkymmenellä koealalla Tikkurilassa ja Vihdissä. Tuomikirva oli löydetystä kolmesta kirvalajista yleisin ja runsain. Viljakirvaa oli miltei jokaisella koealalla, mutta vähän. Vain harvoja elokirvoja löydettiin.

Tuomikirvoja oli kevätviljoissa, etenkin kaurassa ja ohrassa eniten vuosina 1973 ja 1975, jolloin kirvoja laskettiin enimmillään olleen pääversossa keskimäärin 211 (1973) ja 105 (1975). Ensimmäiset tuomikirvat löydettiin viljoista aikaisimmin toukokuun lopussa (1973 ja 1975) ja myöhäisimmin heinäkuun alussa (1974). Yleensä tuomikirvat saapuivat viljoihin ennen viljakirvoja. Kirvojen määrät olivat suurimmillaan kesäkuun lopussa tai heinäkuun alussa ja ne hävisivät viljoista ennen tuleentumista tai sen aikana. Tuomikirvoja löydettiin viljoista sitä aikaisemmin mitä lämpimämpi toukokuu oli. Muutoin ei kirvojen saapuminen viljoihin tai runsaus niissä näyttänyt riippuvan säästä, joskin runsaskirvaiset kesät 1973 ja 1975 olivat lämpimiä ja kuivia tai vähäsateisia kun taas vähäkirvaiset kesät 1967, 1968 ja 1974 olivat viileitä ja sateisia.

Kirvojen luontaisia vihollisia viljoissa olivat leppäpirkkojen toukat ja aikuiset, kukkakärpästen toukat, loispistiäiset ja taudit. Kun ensimmäiset kirvat havaittiin, oli viljoissa myös aikuisia leppäpirkkoja ja joskus myös kukkakärpäsen toukkia. Jotkut ensimmäisistä kirvoista oli loisittu. Leppäpirkkojen toukat ilmaantuivat viljoihin keskimäärin 17 päivää ensimmäisten kirvojen havaitsemisesta ja leppäpirkkojen toisen sukupolven aikuiset vasta sitten, kun kirvojen määrä oli jo alkanut pienetä. Kukkakärpäsen toukat ilmaantuivat kasvustoon myös keskimäärin 17 päivän kuluttua joskin muutamilla koealoilla niitä oli jo ensimmäisten kirvojen löytyessä. Tauteihin kuolleita kirvoja löytyi vain kirvojen määrän ollessa suurimmillaan.

Ilmeisesti vain leppäpirkkoaikuiset saattoivat vaikuttaa kirvojen määrään ensimmäisten kirvojen löytymistä seuranneiden muutamien päivien aikana. Jo kirvojen löytymispäivänä ne olisivat teoriassa voineet hävittää kirvamäärän, joka oli kaikilla koealoilla keskimäärin 15 ± 4 % elävänä löytyneiden kirvojen määrästä. Leppäpirkkoaikuisten tuhoamien kirvojen määrä väheni tasaisesti ja oli 15. päivänä enää keskimäärin 3 %. Kukkakärpästoukkien arvioitiin hävittäneen ensimmäisinä päivinä vain vähän kirvoja mutta jo 10. päivän kuluttua enemmän kuin aikuisten leppäpirkkojen. Sitävastoin leppäpirkkojen toukkien ja toisen sukupolven aikuisten arvioitiin hävittäneen vain vähän kirvoja. Loispistiäisten tuhoamia tai tauteihin kuolleita kirvoja löydettiin vähän, mutta kahden koealan sadetus heinäkuussa 1973 aiheutti tuomikirvojen joukossa voimakkaan tautiepidemian.

Kirvojen saapumista viljoihin ei voida tarkoin ennustaa, mutta näyttää siltä, että mitä lämpimämpi toukokuu on, sitä aikaisemmin ne ilmaantuvat viljoihin. Kirvojen runsauden ennustamiseksi on tarpeen tehdä havainnot ensimmäisten kirvojen löytymisestä viljoissa ja laskea kolmen, viiden tai kymmenen päivän kuluttua siitä kirvojen määrä 100:ssa sattumanvaraisesti otetussa pääversossa. Ennustetta varten laaditun kuvan 11 avulla voidaan arvioida kuinka suureksi kirvamäärä tullee peltolohkolla kohoamaan.



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SISÄLLYS — CONTENTS

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